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- Script -

Industry 4.0 - Digital Transformation
TWIE23

Faculty Industrial Engineering

Prof. Dr.-Ing. Stephan Sauter

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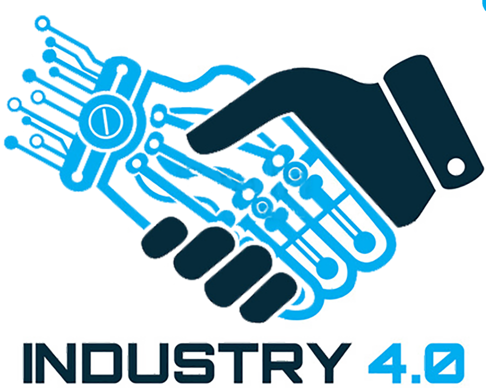

Contents

Prologue

This script is intended to help the listener to complete the lecture in self-study in addition to the online course. The exam will only contain questions on selected chapters of the script. The given literature should serve for a deeper understanding. In parallel, online knowledge quizzes offer the possibility of knowledge verification.

Lecture Content:

After attending this lecture, students should be familiar with the term Digital Transformation and be able to sort it into the context of Industry 4.0. They should be able to understand the development of digital technologies from AI to Big Data and Blockchain.

Basic Literature:

- Oswald, G. (2018): Digitale Transformation, Springer Gabler, Wiesbaden: free download https://link.springer.com/content/pdf/10.1007%2F978-3-658-22624-4.pdf

Links:

- https://www.plattform-i40.de
- www.Freiwilligschlauwerden.de

Acknowledgement:

This script was created by students from the TWIE17-22 courses on, as part of a course assignment. I would like to thank them for their commitment and familiarization with the LaTeXtypesetting program.

Please note that not all lessons are relevant for the exam!

CHAPTER 1

Digital Transformation

Learning objectives

After completing this chapter, you will know . . .

... what distinguishes digital transformation from digitalization.

... what enabler technologies are.

... how the digital transformation can be implemented in the company.

... the various levers that digital transformation uses.

... what challenges the digital transformation brings with it.

Introduction

Digital transformation describes the networking of players in the economic cycle across all stages of the value chain. The high transparency of information is changing traditional business models or gives rise to entirely new business models. This changes our understanding of the working world, and corporate hierarchies are being revolutionized. Machines are taking over tasks from people and start-ups can turn entire markets upside down. However, the impact of the digital transformation goes beyond the corporate world. It influences politics as well as our society and ultimately affects every individual.

Figure 1.1: Advancing digitalization [1].

1.1 Digital Change

The **digital change** is a phenomenon that has an impact on almost all areas of life and work. In private, digital services or products can be used everywhere: Apps make everyday life easier, and smart homes even enable people to live in complete symbiosis with the digital world. In the medical sector, treatment and diagnosis can be improved through targeted **linking** of data. In education conventional learning is being supplemented or replaced by **digital media**. In addition, the rate at which existing knowledge is replaced by new insights is increasing. This means that the acquisition of new knowledge and the competence to process **information** quickly are becoming permanently more important.

The term change describes a change process over a longer period of time. The following chapter shows that digitalization as the basis of digital change has already been going on for decades. However, this change has taken on a new dimension in the recent past and is therefore the subject of much discussion in private, but especially in the corporate environment. The reasons for this are, on the one hand, the facts described above, namely that change has impacted all areas of life and the speed of change is constantly increasing. On the other hand, the **Digital Transformation**[1] that is taking place in industry is responsible for this. It represents a fundamental change of the entire corporate world. Vast amounts of data **(Big Data)**[2] are being linked together to form **Smart Data**[3], leading to new products, services and business models. **Value Chains** can be redesigned through a networked production.

Since digital transformation also has an impact on the employment relationship and the labor market, it is often described in the entrepreneurial environment as having a **disruptive character**.

Digital transformation can be divided into three different stages in which it works from a company's perspective.

Stage 1: Digitalization of the value chain

Stage 2: Digitalization of the products

Stage 3: Introduction of new business models based on value-added data services

Smart factories are emerging with the digitalization of the value chain. In these, productivity and quality can be improved while at the same time increasing the number of variants. The digitalization of products gives rise to **smart products** in the second stage. By recording data and communicating with other smart products, they also enable an increase in productivity. Finally, the third stage leads to **smart services** based on value-added data services, which provide the user with information from processes and products and evaluate it automatically [2].

One reason why digital transformation is happening right now is because of **enabler technologies**[4]. They have emerged in the course of digitalization and represent the technical requirement for the digital transformation. In addition to the technologies of digitalization, there is a more important reason for the start of the digital transformation. The „**focus on the customer**“ trend puts the customer's expectations at the center. Technologies should increasingly adapt to people's needs and deliver high level of benefit. For industry, this means

1 **Digital Transformation** is understood as the exponential and permanent change of society and companies based on technology.
2 **Big Data** describes extensive amounts of unstructured and semi-structured data.
3 **Smart Data** is processed data that can be used to derive immediately usable knowledge.
4 **Enabler technologies** are technologies that represent a significant leap in performance and capability for a user.

that products must become increasingly individualized and the variety of variants is increased [1].

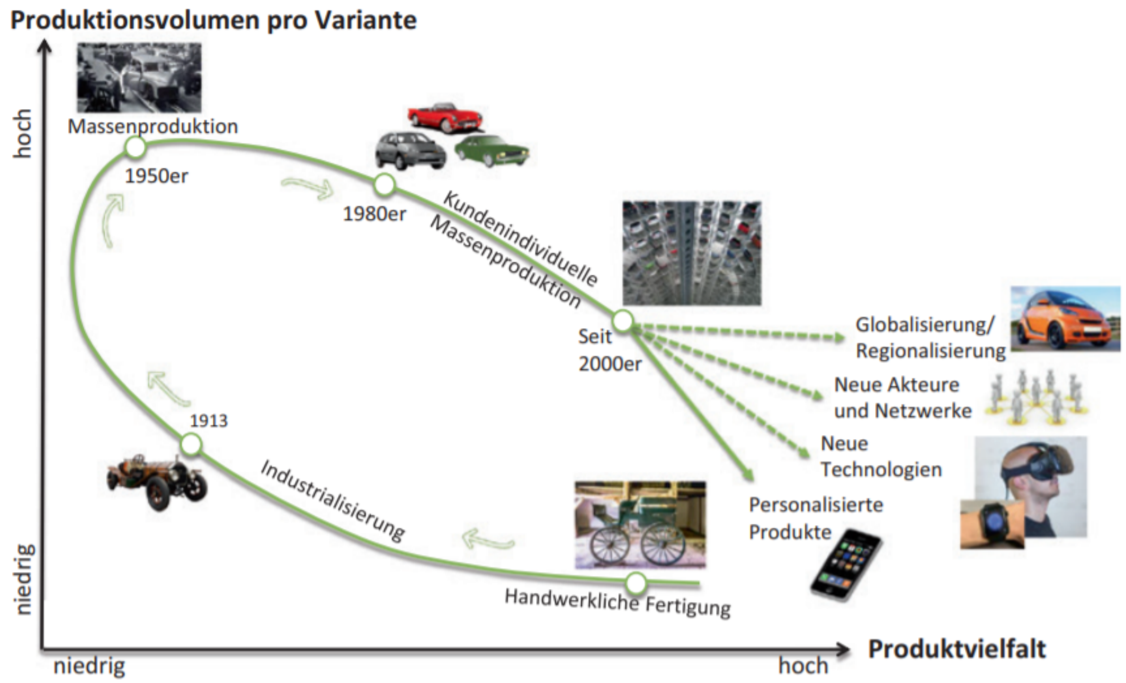

Figure 1.2: Variability at a low price [1].

1.2 Digital Transformation and Digitalization

The term **digitalization** describes the transfer of analog quantities into digital values. The background to this is that values should be able to be stored and processed which is only possible if they are available in digital form. The beginning of the digitalization already dates back decades, and the collection of digital data in its simplest form has been going on for almost 100 years [1].

The most common examples of digitalization are photos or music files, where analog content is stored in digital units.

When it comes to digitalization in the entrepreneurial environment, it is likewise only the depiction of the company with its products, processes and workflows with the aid of digital means. However, digitalization can make a valuable contribution to optimizing and automating processes or developing new technologies.

The understanding of **digital transformation** extends much further. Here, the processes are not only adapted to the new technologies, but rather also questioned as to their reason for existence. The focus is on solving problems in order to maximize the customer benefit. Even though digitalization can be described as the basis for digital transformation,the start for digital transformation is the customer-centric solution, as mentioned above.

Digital transformation stands out from the rest above all because of its more far-reaching dimensions.This is because it has an impact on our corporate culture, on politics and state institutions, and even on our society and behavioral patterns.

1.3 Enabler Technologies

The enabler technologies allow digital transformation in the course of digitalization and serve as the foundation for new digital business models.

Examples of enabler technologies are:

Internet of Things

The Internet of Things encompasses the trend in which **embedded systems**[1] support people in their work without disturbing them or restricting their actual work. The goal to be achieved with the help of the Internet of Things is to close the **information gap** between the real and the virtual world. The state of a product in the real world can be made available by the embedded systems for further processing in the network.

Ideally, in the Internet of Things, machines can communicate with machines (M2M), control each other and humans no longer have to actively intervene in production control. In addition, the information provided by the embedded systems enables early detection of maintenance work, which can be used to reduce faulty parts or for energy savings.

The growth of the Internet of Things is enormous, with the number of devices communicating with each other worldwide is growing at an almost exponential rate.

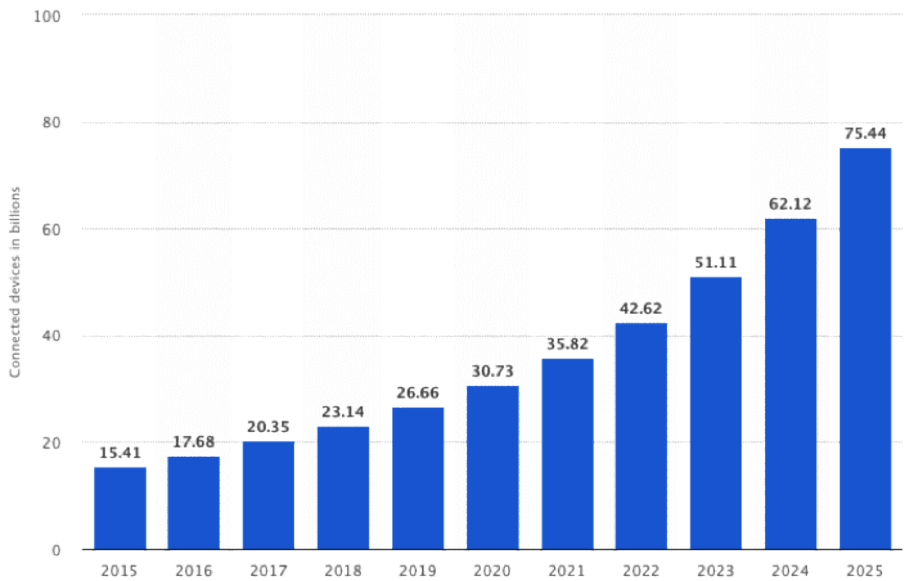

Figure 1.3: Number of devices connected to the Internet worldwide. (Statista, 2020)

1 An **embedded system** is a computer system that is integrated into and interacts with a surrounding technical system.

Internet of Values

The Internet of Values is a **logbook** for transactions of any kind. An encrypted database distributed over several computers allows transactions between companies, authorities and private individuals to be documented digitally. The transactions are registered in a forgery-proof manner and cannot be changed later. The Internet of Values thus creates **maximum transparency** for all transactions.

In the entrepreneurial environment, the Internet of Values offers, among other things, the possibility for **smart contracts**. With these, compliance with a contract is automatically ensured by the verified transactions. One application example is the rental of cars, where the user is only granted access to the inside of the vehicle once payment for the rental has been made.

Computing Power

Computing power deals with the computer performance required to process, generate and collect the enormous amount of required data. If you look at the increase in computer performance over the past decades, an exponential increase can be seen here as well. If the current development of computer performance per second is maintained the capacity of the human brain can be reached as early as 2025 [1].

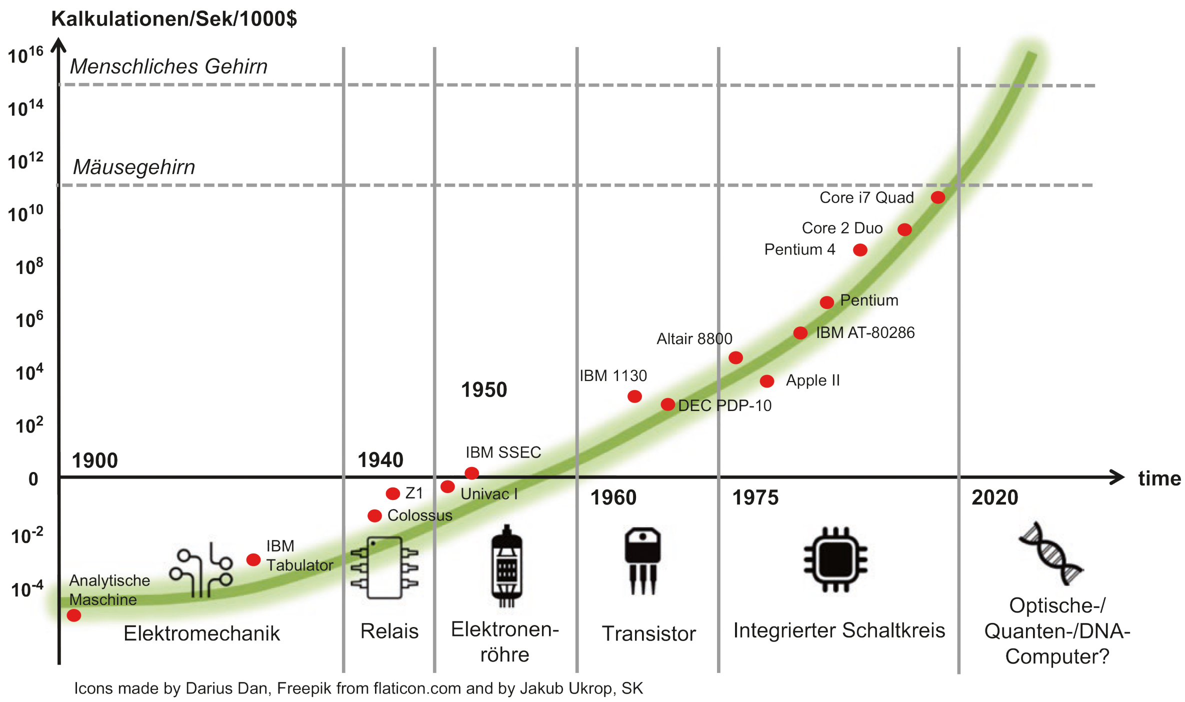

Figure 1.4: Development of computer power per 1000 US$ (Schallmo, 2018, [1]).

The enormous computer performance enables machines to learn independently and act predictively. Ultimately, powerful algorithms will lead to **artificial intelligence**, which will one day be superior to human intelligence.

1.4 Implementation of the digital transformation in the industry

In recent years, customers have gained more and more influence on market offerings. Through the digital transformation, customer demand is decisively shaping the market. This development will continue and requires providers to fully align their business model with the customer and digitalize it. A **digital business model** answers the same fundamental questions as a conventional business model, but from a different perspective. Here, the focus is on **customer benefits** and customer requirements. Information is generated in all areas of a value chain.

This information is used in digital business models by collecting and systematically analyzing it. This makes it possible to automate process steps and streamline process chains. This in turn leads to greater efficiency and increases customer benefits.

The successful implementation of digital transformation is a challenge for many companies. The main reason for this is that new paths must be taken and there is no patent remedy. Each company must develop its own **individual strategy**.

Nevertheless, there are definitely approaches for a roadmap on how to at least increase the probability of a successful implementation: The first step is to outline the **digital reality** by describing one's own business model. After all, business models can only be digitalized if there is an understanding of the previous business model [3].It is important that the analysis is not limited to looking at the company's own activities, but also looks beyond the boundaries of the company itself. By looking at the horizontal value chain and its players, the **degree of digitalization**[1] of the entire industry can be discussed.

Building on this, the next step is to formulate the **digital ambition**. For this purpose, objectives are determined which are placed on the implementation of the digital transformation. The objectives may relate to time (reduction of lead times), finances (reduction of logistics costs) or quality (improvement of the customer experience).

In the third step, the business model is examined for **digital potentials**. To do this, it is once again necessary to examine other companies in the industry and to work out the **best practices**. Decisive for the potentials are also the enabler technologies, without which it is not possible to realize new applications or services. From the insights gained into the digital potential, options for the future business model can be derived.

In the next phase of **digital fit**, suitable combinations of options are evaluated for the business model. The decisive factors in the evaluation are whether the new options fit the existing business models, whether they fulfill customer requirements, and whether they can achieve the goals formulated in the digital ambition.

The last step is the **digital implementation** of the most promising business model.

1 The **degree of digitalization** indicates the extent to which IT replaces manual work.

The basic requirement for implementation is a business model that...

... describes the future system of systems.

... defines the necessary technical infrastructure.

... determines the customer journey.

... represents the horizontal and vertical value network.

The last aspect is the most important, as it is the company that determines what role it plays in its **SOS (Systems of Systems)**[1].

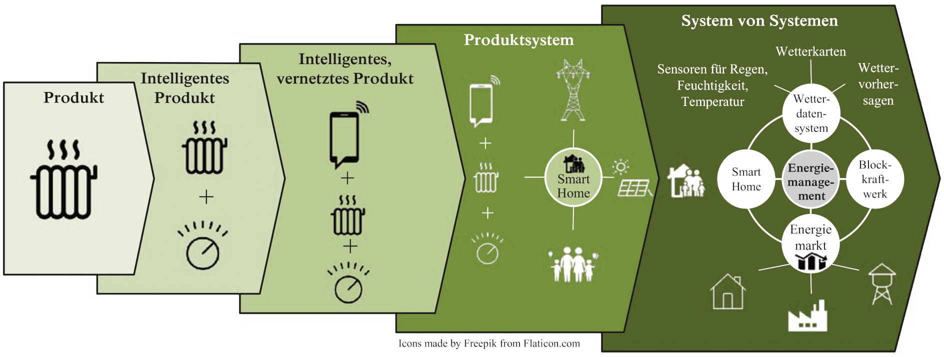

Figure 1.5: SOS, systems of systems (Schallmo,2019, [1]).

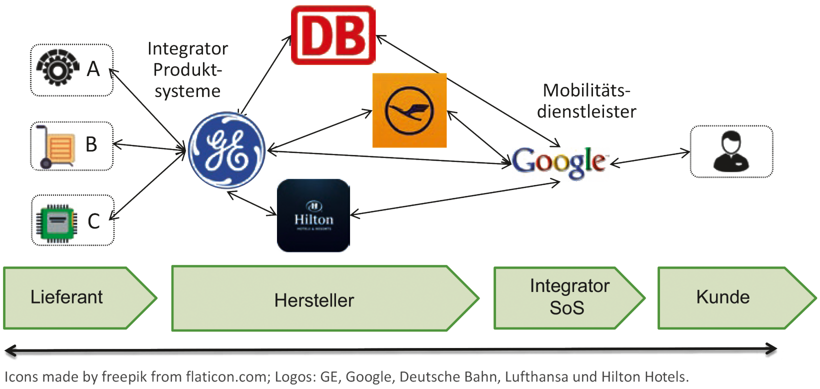

Figure 1.6: Integrated value network of systems of systems [1].

In addition to a suitable strategy for implementing digital business models, there are other factors that are crucial for a successful implementation:

- Establishing an open culture of innovation
- Providing sufficient resources
- Cooperating with suitable partners
- Tests with prototypes to minimize risks

One example of a successful digital business model is ThyssenKrupp Elevator MAX. ThyssenKrupp is a German company with various divisions, among others the company manufactures passenger and freight elevators. In addition to sales and installation, maintenance tasks are also offered. Due to the increasing number of elevators in high-rise buildings in cities, the number of maintenance work is as well increasing. However, due to intense competition in

1 **Systems of Systems** is a collection of specifically task-oriented systems that pool their resources and capabilities to create a new more complex system that provides more features and higher performance.

maintenance work, this business has turned out to be time-intensive with low margins for ThyssenKrupp.

That's why the company has introduced ThyssenKrupp MAX. An elevator monitoring system that identifies possible causes of failures in time and shortens the duration of maintenance work. For this purpose, various elevator components were equipped with sensors that provide continuous information.

This information is evaluated using **predictive analytics**[1]. This enables ThyssenKrupp to carry out predictive maintenance and significantly reduce elevator downtime. The company can thus set itself apart from the competition and has successfully revolutionized its own business model [4].

1.5 Levers of digital transformation

The effects of digital transformation can be divided into four levers that have an impact on industrial value creation. With them, disruptors are able to break down existing **value chains** into their smallest components and reassemble them through lower transaction costs. Splitting up the value chain also makes it easier for new players with little capital to enter the market, as barriers to market entry are reduced. It comes to the transformation of business models and the reorganization of entire industries. The four levers of digital transformation are:

Digital Data

By capturing, processing and evaluating digital data, **efficiency** and **effectiveness** of processes can be increased. It also enables better forecasts and decisions to be made. This is one of the reasons why digital data are now produced and traded in the economy like goods and are therefore a commercial commodity.

Automatization

Combining technologies with artificial intelligence creates autonomous, self-controlling systems. This usually makes it possible to increase **process speed** while at the same time reducing operating costs and the error rate. The decisive advantage, however, is that unit costs can be reduced and companies can approach the batch size of 1.

Networking

Fast Internet connections and modern network protocols allow an increasing number of objects to be virtually networked. With the help of these technical capabilities, entire **supply chains** can be **synchronized** with each other and are directly linked to demand. Networking therefore increases the flexibility of companies and promotes a shorter innovation cycle through the exchange of information.

Digital customer access

Through the Internet, new players are gaining direct and scalable access to the consumer, something that was previously often denied to only a few providers. Due to the **complete transparency** of consumer behavior, providers can offer an entirely new service. In order to make this possible, intermediaries are needed first and foremost to bring providers and consumers together and ensure the exchange of information. As these intermediaries increasingly gain control over customer interfaces, they themselves determine the entire market structure.

1 **Predicitve analytics** is the analysis of data that enables future outcomes and events to be predicted.

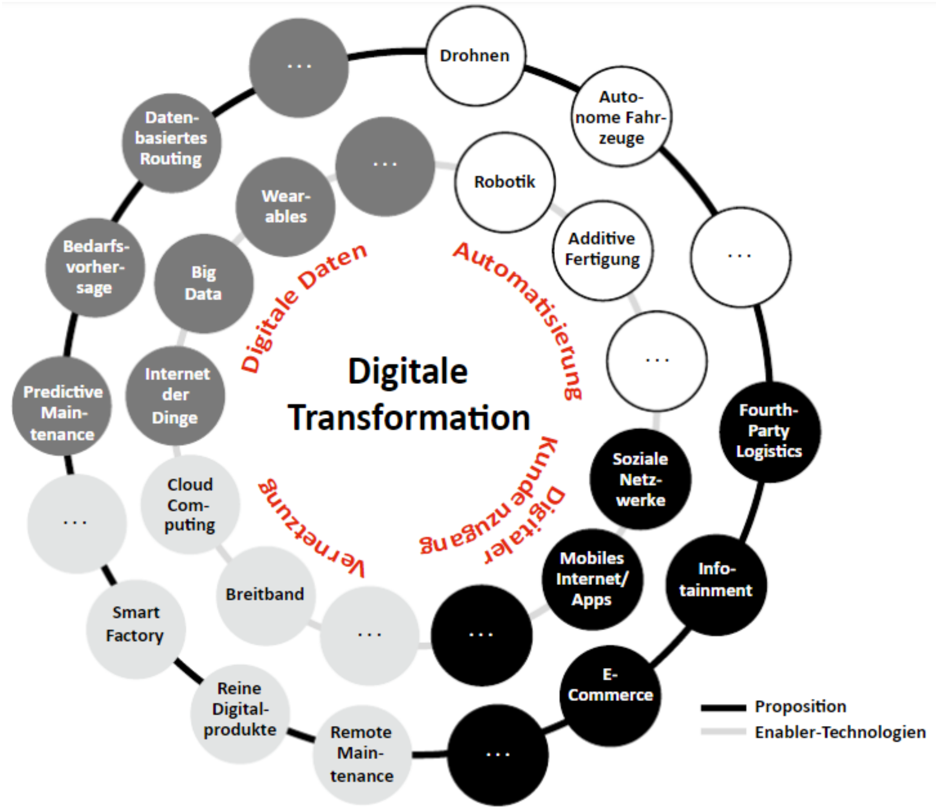

Figure 1.7: The four levers of digital transformation (Wallmüller, 2017)

These four levers can be used to explain the entire logic of digital transformation. With this understanding, it is possible for companies to assess the risk of new disruptive technologies in their own industry or to develop these technologies themselves. Hence, the four levers of the digital transformation are of enormous importance [5].

1.6 Challenges

On the one hand, The digital transformation brings progress and prosperity. On the other hand, both companies and society are faced with challenges arising from the digital transformation.

Although companies are endeavoring to incorporate the digital transformation into their corporate strategy, not even half of German companies are pursuing a cross-company strategy. This faces them with enormous challenges, especially due to the increasing variety of digital interaction channels and the focus on the customer in business models.

Many companies say that they are in danger of being overtaken by new technology leaders if they remain as innovative as they are today. This is also due to the fact that in many industries the leading company within a market now enjoys a global monopoly position, leaving little room for competition. On the other hand, even established market leaders cannot be sure of their supremacy.

In the USA, half of the 500 companies with the highest revenues have disappeared since 2000 [5].

In addition to the new competitive conditions created by the digital transformation, the industry is also faced with the challenge of ensuring that the technical requirements for the change continue to be met in the future. It must be ensured that the vast amounts of data that will be generated in the future can be stored and processed securely.

For society, digital transformation will mean that existing **inequalities in income** will be further increased. The state will be called upon above all to compensate those who lose their jobs as a result of the digital transformation. Financial support will initially be necessary for these people.

Furthermore, they must be kept up to date with the latest knowledge through **training and further education**, even without a job. Because in the rapidly changing world of work, there is a great danger that they will otherwise lose touch with current technologies [5]. In the more distant future, society will probably be faced with the challenge of developing a completely new society model. After all, when only half of the population is still employed because the most tasks are taken over by machines, the digital transformation will mean more than just a structural change.

1.7 Summary

Digitalization is a long-standing process that has been taking hold in industry and the private sector for a long time. The digital transformation is a new development that has come about as a result of the technologies (enablers) developed in the course of digitalization. However, the starting point for the digital transformation has been the fact that the customer and his benefits have increasingly moved into the focus of companies.

In order to satisfy the customer, new business models are being created, the number of variations is increasing, and products are being individualized. Digital transformation describes these processes. Due to its enormous scope and disruptive character, it represents a new dimension compared to digitalization.

There is no patent remedy for the successful implementation of the digital transformation in a company. However, there are procedures and success factors that companies should take into account in order not to be left behind in the market. An understanding of the four levers through which the digital transformation works is also elementary, as this allows to understand the entire logic of the digital transformation.

Digital transformation will decisively shape the future on many levels. Since there cannot only be winners, it will equally challenge companies and the state.

CHAPTER 2

Disruptive Technologies

Learning objectives

After completing this chapter, you will know . . .

- ... what disruptive technologies are.
- ... how they differ from other technologies.
- ... how digital transformation can be implemented in the company.
- ... how established companies should deal with disruptive technologies.
- ... what alternative model exists to disruptive technologies.

Introduction

More and more frequently, disruptive markets and disruptive technologies are being reported. The word **"disruption"** was chosen as the business word of the year 2015 by the "Frankfurter Allgemeine Zeitung" [6].

Mistakenly, the word disruption is used in any context without knowing the actual meaning. Yet an understanding of disruptive innovations is essential to ensure a long-term business success.

2.1 Definition

The term disruption has its origin in the Latin word „*disrumpere*". According to common encyclopedias, it can be translated as „*breaking*", „*bursting*" or „*tearing apart*".

This already describes what characterizes disruptive technologies:

They disrupt and change markets as well as business models..

„The electric light did not come from the continuous improvement of candles."
- Oren Harari[1]-

1 Oren Harari (Juli 30, 1949 - April 10, 2010) was Professor of Business Administration at the University of San Francisco and author of numerous books on management.

The term **disruptive technologies** can be traced back to Clayton Christensen[1], former professor at Harvard University. He first used the theory of disruptive technologies in 1997 in his work „*The innovator's dilemma: when new technologies cause great firms to fail*" and is regarded as the founder of this theory. In his further works, he takes up the theory of disruptive technologies and also uses the term **disruptive innovations** as a synonym. Both terms are therefore to be regarded as having the same meaning.

According to Christensen, disruptive technologies are triggered by resource-poor companies or start-ups (**entrants**). With their new innovation, they try to force established companies (**incumbents**) out of the market. In the process, structures in the market are broken up or completely destroyed. Disruptive technologies are therefore also referred to as **breakthrough innovations** [7].

The German Federal Ministry for Economic Affairs and Energy (BMWi) makes the assumption that projects regarding to Industrie 4.0 in particular will lead to disruptive innovations. Thus, the ministry states that Industrie 4.0 will not only revolutionize the digitalization and networking of horizontal and vertical value chains, but also the product and service offerings of companies. This will result in the implementation of new, often disruptive digital business models [8].

2.2 Clayton Christensen's Model

As mentioned at the beginning, all innovations are also incorrectly referred to as disruptive. Already at the beginning of the "Disruptive Innovation Theory" published in 1997, Clayton Christensen distinguished "common" innovations from disruptive innovations. The former usually do not change a market in a major way, but merely develop it further. Disruptive technologies, on the other hand, are characterized by **aggressive changes** in the market and its participants.

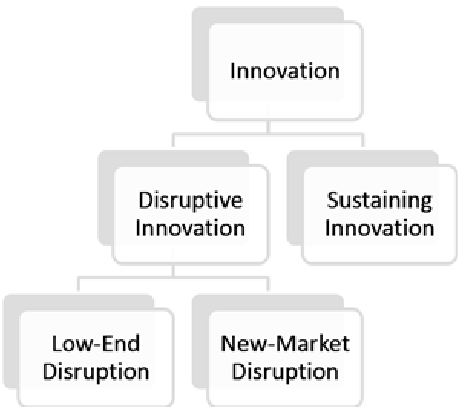

Figure 2.1: Technology types by Clayton Christensen.

1 Clayton Christensen (* 06. April 1952 in Salt Lake City, Utah; † 23. January 2020 in Boston, Massachusetts) was Professor of Business Administration at Harvard Business School and is considered the world's leading expert on innovation and growth. He is the author of many books and several hundred articles. In his first book, "The Innovator's Dilemma" (1997), he first addressed the theory of disruptive innovation. He is the founder of several companies.

- **Sustaining Innovation**

  Sustaining innovation refers to technologies which continue to follow an already existing development path. This is usually done by already established companies through internal research and development. The aim is to further develop and improve products and services that have already been accepted by the market [9].

  An example of a sustaining innovation is a new vehicle model from an established automobile manufacturer that develops a new model by improving known performance dimensions such as engine power in horsepower. However, **the existing market remains** intact when this new model is introduced. These innovations have the advantage for established companies that their previous innovations have already been tested on the market and adapted to customer requirements. Most innovations and technologies in today's market belong to the category of sustaining innovations.

  Tesla for example, currently falls into the **„Sustaining Innovation“**category because they have taken market share in the luxury segment from incumbents with electric vehicles (Model S, Model X).

  In a less formal sense, it is clear that Elon Musk is shaking the car industry to its foundations with Tesla. According to a digital manager at BMW, this is less due to the electric drive of these vehicles than to the fact that they are designed as software products from the ground up.

- **Disruptive Innovation**

  Unlike sustaining technologies, the following two types are disruptive innovations that cause **complete restructuring** or **disruption** of an existing market. Although the number of disruptive innovations is increasing in the era of digitalization, they nevertheless represent only a fraction of all new innovations. The distinction between **Low-End** and **New-Market disruption** is important because incumbents are differently alarmed about the potential threats and the uncertainty of market creation also diverges.

  - **Low-End Disruption**

    If a sustaining technology is constantly being developed and improved, the probability of low-end disruption increases. The upward trend of the sustaining technology no longer serves the customer segments with lower demands, as the performance of the constantly improving technologies exceeds the actual requirements of the low-end market segment.

    It is in this unserved low-end market environment that low-end disruption will begin, as this type of disruption is characterized by the introduction of a technology with initially lower performance. This new technology is often far inferio to previous technologies at the beginning of its introduction and does not address the mainstream market. However, these technologies have a particular benefit for customers in the low-end market[1]. If this technology is now further developed in the same way, customer groups with higher performance requirements can also be addressed [7].

    Not every low-end disruption makes the transition from lower customer segments to the main market. However, if this happens, it leads to the incumbent company

1 A **Low-End market** consists of low-priced products suitable for customers who are not willing or able to spend large amounts of money or do not need the full performance of a product.

suffering significant customer losses in the long term. An indication of this is when an established company increasingly deviates from its actual core business and focuses on other business models as a competitor with **newer technology** attacks their main business.

It is important for the established company to compensate for the loss of customers from its previous core business in the new high-end market segment and at least maintain its position there. However, the past confirms that only a few established companies were able to compensate for the loss of customers triggered by a disruptive technology.

- **New-Market Disruption**

Unlike as the low-end disruption, the new-market disruption occurs in a **completely new created market environment**. Christensen also refers to this as the introduction of an innovation into a **niche market**. Whereas low-end disruption is oriented toward and serves the customers of competitors, new-market disruption addresses previous **„nonconsumers"**. These are customers whose preferences and needs could not be met by the previous market offering and who therefore consciously decided against a purchase.[8]

However, the newly introduced innovation has a product characteristic that is of high importance for this customer group. As well as in the low-end disruption, these products are clearly inferior to the given technologies in terms of performance in their introductory phase and initially only the customer group they themselves have generated, the "nonconsumers" remains. Through constant performance improvements in "the traditionally desired characteristics of the product"[8] the new technology can also become attractive enough for customers from the established market segment.

As well as in the low-end disruption, the **lower customer segments** first become aware of the new technology before it has been further developed to attract customers from the high-end market environment. New market disruptions pose a particular threat to established companies because they are often **recognized very late**. Reasons for not recognizing new-market disruptions in time are as follows: The new technologies build their own market environment and initially grows within it. Another point that leads to this is that the established companies do not initially lose any customers, as it is the nonconsumers who first become aware of them.

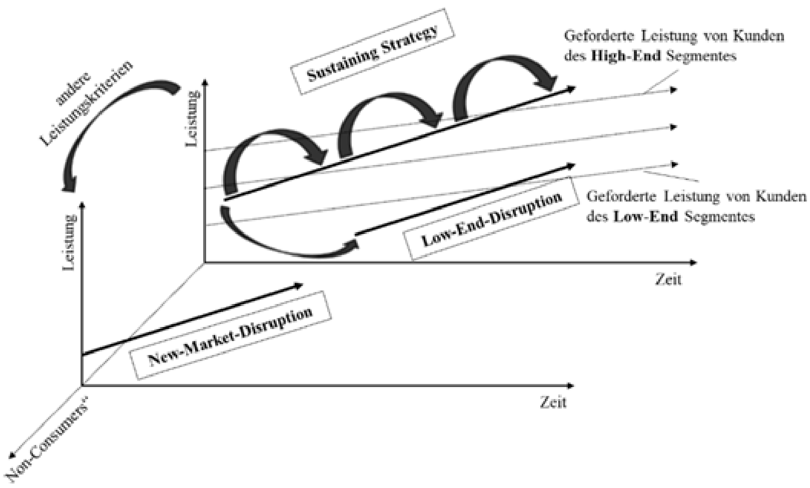

Figure 2.2: Technology types in graphical comparison.

2.3 Examples of Disruptive Innovations

Probably the best-known example of disruptive innovation is the digital camera, which meant insolvency for the **Kodak** company. This example is suitable to illustrate the low-end market disruption in practice. Kodak was the fourth most valuable brand in the world in 1996, selling cameras. Its main business was dominated by the sale of analog cameras. Kodak itself developed the first digital camera in 1975, but saw no reason to invest in it further. Instead, they continued to focus on the further development of analog cameras. The competition discovered the new technology of digital photography for themselves, although the digital camera initially offered much less performance than the analog camera.

Through ontinuous further development and investment in digital cameras, the new technology was successfully established on the market. While digital cameras still accounted for around 12 percent of all cameras sold in 2000, their share ten years later was over 99 percent. As a result, Kodak's sales also slumped enormously. Despite numerous restructuring measures and changes to its business models, Kodak was unable to compensate for the loss of analog camera sales and filed for bankruptcy in 2012. In 2013, Kodak made a new start in the printing business, but has never been able to return to its former greatness [10].

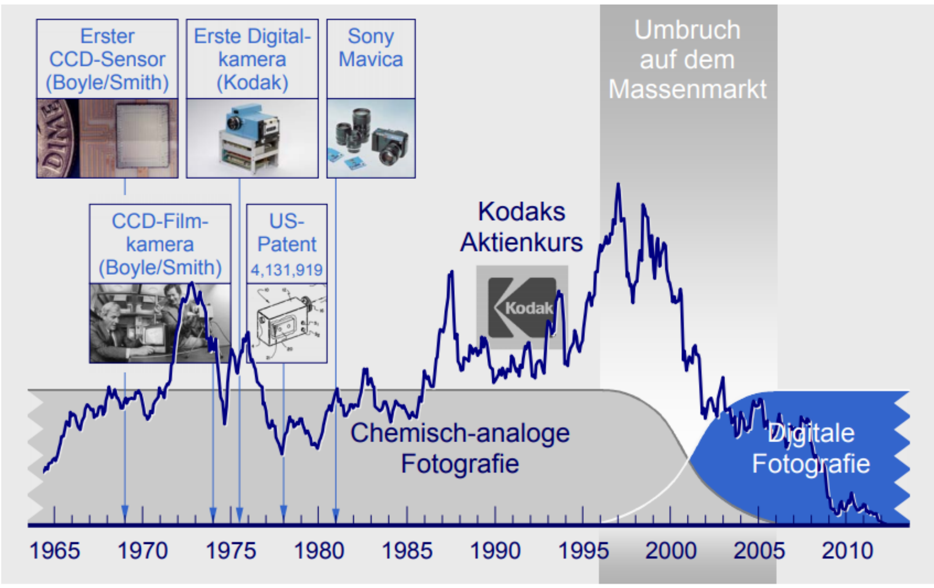

Figure 2.3: Example Kodak.

Another disruptive innovation, which does not originate in a low market, are **drones**. Here, it can be referred to as new-market disruption. Initially, drones were developed for military purposes only. The United States of America used the unmanned aerial vehicle in the 1960s for spying and surveillance purposes [11]. With the continuous development of drones in terms of their efficiency, it became possible to build small, powerful and inexpensive drones. This was an important milestone for the useage of drones, as they could now be established in the mass market.

Today's applications are diverse and disruptive. **Amazon's** former CEO Jeff Bezos, for example, plans to deliver smaller packages by drone [12].This "Prime Air" service, which he has named, will take market share from already established shipping companies such as DHL, DPD, Hermes or UPS, or even drive them out of the market completely.

A Harvard Business Review analyzed a few examples of disruptive technologies. The following table shows further examples of current disruptions in the market [13]:

Established Technology	Disruptive Technology
Local Storage	Cloud Storage
Local Shops	eCommerce
Money Transfer	Blockchain (Bitcoin)
Mechanical Watch	Smartwatch
Travel Agencies	Online Booking

Examples of known disruptors:

Figure 2.4: Examples of disruptors.

2.4 Examples of Sustaining Innovations

As already mentioned above, **Tesla**, **Uber** and **Airbnb** are not classic disruptors. They do not fulfill the conditions for low-end or new market innovations. They are undoubtedly very innovative, but not disruptive according to Christensen's definition.

Uber has changed the way cabs work. The company owns no cars and no drivers, and therefore no fixed costs. Just as Airbnb owns no hotels and no staff. Its business model is to use existing resources differently. But that's not a disruptive innovation, it's a sustaining or incremental innovation (sustaining innovation).

2.5 Dealing with Disruptive Technologies

As already illustrated in the previous chapter, many established companies do not successfully return to the market after being displaced by a disruptive technology. **439 out of the 500 companies** listed in the S&P 500 in 1955 are no longer listed in that index today [14]. Therefore, the correct handling of disruptive technologies is not neglectable for established companies. It should be noted that there is no perfect plan to protect against disruptive innovations. Nevertheless, there are various approaches that can protect established companies from them.

- **3 questions incumbents should ask themselves about new competition:**
  - Does the new idea have low-end potential?
  - Does the new idea have new-market potential?
  - Does the new idea have an impact on all incumbents?
- **„The products, not the profits, were the motivation" – Steve Jobs** [15]

  The first approach can be found in the Harvard Business Report "Steve Jobs Solved the Innovator's Dilemma by HBS Professor Clay Christensen". There, reference is made to the biography and mindset of former Apple CEO Steve Jobs. Established companies which have a monopoly anyway believe they can no longer grow through product improvements. Instead, they focus on sales and marketing areas. According to Jobs, this is a mistake, because they only focus on profit instead of innovative products.

  Visionary thinking and the importance of good products that brought them to this market monopoly are being destroyed by sales and marketing. The focus on profit instead of new innovative products increases the probability of being driven out of the market by a new technology.
- **Acquisition**

  Another method to protect against disruptive innovations is to buy up disruptive companies in their early stages. The innovation management of every established company should look for disruptive innovations in the market and identify them at an early stage. Through a steady supply of liquid funds, the aim is to act quickly and to acquire the disruptive company at an early stage. A good example of this is Alphabet Inc, of which Google is a subsidiary. In its 2019 balance sheet, Alphabet has over $117 billion in cash reserves and is known for its numerous acquisitions annually[16]. Well-known acquisitions of Alphabet are YouTube, HTC, and Fitbit [17].
- **Spin-Off**

  A very popular approach to protect oneself from disruptive technologies, but also to invent some oneself, is a spin-off. In this case, already established companies found a new independent start-up. These start-ups usually have nothing to do with the core business of the established company. They operate completely independent from their parent company and can thus react faster to market changes [14].

  Another advantage over other start-ups is the possibility to draw on the resources of the established company. The parent company usually provides liquid funds and patents freely available. As a spin-off from the **MIT** (Massachusetts Institute of Technology), Boston Dynamics managed to become a pioneer and world market leader in autonomously running robots.

  Since 2013, Boston Dynamics has continued to operate independently, but was acquired by Google. Another current example of a spin-off is also a Google subsidiary. According to the motto "*We create radical new technologies to solve some of the world´s hardest problems*", the start-up "Google X - The Moonshot Factory" pursues the goal of developing new technologies and innovative products [18].

2.6 Alternative model

In addition to the theory of disruptive technologies, Richard Foster's **S-Curve model** is another instrument of strategic innovation management. As well as Clayton Christensen's disruptive innovation theory, the S-Curve model also deals with technology leaps from old to new technologies. Similar to disruptive innovations a new technology forces the market to change, replacing the old technology from the market in the long run. This model states that each technology goes through various stages of development before it reaches its performance limit. This is followed by a technological leap, which is triggered by a new technology.

This new technology may have lower initial performance capabilities because they have hardly been tested and further developed. As a result, only a fraction of the potential performance is available in the early stages. However, through continuous development of the new technologies, significant progress can be made in terms of performance. The outdated technology, on the other hand, can produce only marginal performance improvements even with high costs in research and development and becomes obsolete for the market in the long term [19].

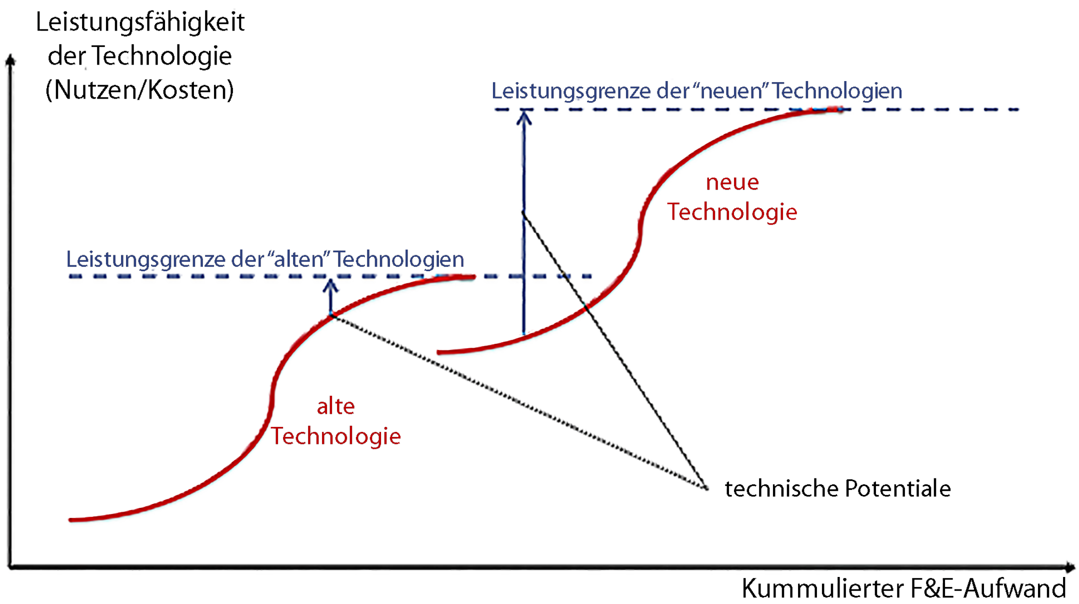

Figure 2.5: S-curve model according to Richard Foster.

A suitable example to illustrate the process of the S-Curve model is the current technology change in the **automotive industry**. Already in the 19th century, the first combustion engine was developed by Nicolaus Otto [20]. As usually in the case for such major technological developments, smaller improvements followed over a century. For example, fuel consumption was continuously improved through incremental further developments. However, the engine that is used today in the saturated market now has hardly any potential for improvement.

The technological leap to new technologies has already been initiated by the automotive industry and the first electrically powered engines are being offered on the market. Although the electric motor is currently in the early stages of its life cycle, it has already effectively caught up with the internal combustion engine in terms of energy consumption.

For example, an electric car equivalent to a 5-liter gasoline engine would have to consume 42 kWh of energy to do so. However, an equivalent electric car consumes only about 14 kWh [21]. If we now consider the long-term potential that could be achieved through further improvements, it can be assumed that the combustion engine will become obsolete in the coming years.

2.7 Summary

Disruptive technologies will cause many changes in the market, especially in the age of digitalization. Past examples such as Kodak and Jeff Bezoz's plans for drone deliveries confirm this. But it is not only from the past that a change in the market can be derived. Market processes are being accelerated by ever-shorter product life cycles and the above-mentioned digitalization. Projects of the future such as virtual reality, artificial intelligence or blockchain will cause future restructuring in the market. Nevertheless, for the purpose of targeted steering and planning of a company, a distinction should be made between sustaining innovations and disruptive innovations.

CHAPTER 3

Artificial Intelligence

After completing this chapter, you will know...

... what artificial intelligence is.

... the connection between artificial intelligence and Industry 4.0.

... which disciplines AI consists of.

... which ethical questions AI raises.

... what weak and strong AI are.

... future prospects of artificial intelligence.

Introduction

Artificial Intelligence (AI)[1] – What is it? Artificial intelligence can solve a number of tasks that require human intelligence. To do this, artificial intelligence uses a series of methods that enable a computer to solve such tasks. The use of artificial intelligence is considered a key **innovation driver** for implementing projects within the framework of Industry 4.0.

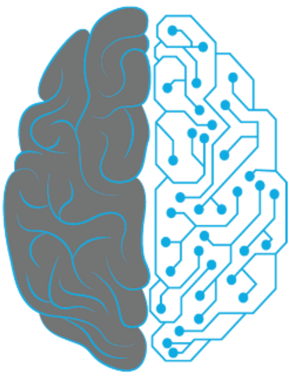

Figure 3.1: Artificial Intelligence (Abstract Representation).

1 English: **AI** = Artificial Intelligence

3.1 Definition of Artificial Intelligence

The term artificial intelligence is controversial because it is understood as the simulation of intelligent human thought and action. The problem with this definition is that it defines neither intelligent human thought nor intelligence itself. Furthermore, humans are used solely as a measure of intelligence, even though evolution has produced a multitude of organisms with varying degrees of intelligence.

Therefore, Wolfgang Ertl from Mainz proposes the following working definition of intelligence in his book „Artificial Intelligence - When Will Machines Take Over?“, which is independent of humans and of measurable system variables.

> **Working definition:** A system is said to be intelligent if it can solve problems independently and efficiently. The degree of intelligence depends on the degree of independence, the degree of problem complexity, and the degree of efficiency of the problem-solving process.

The attribute „artificial“ evokes additional associations. It implies that attempts are being made to understand, model, and replicate humanity's greatest asset, intelligence. Elaine Rich, an American computer scientist, provided a fitting definition for this.

> **Definition:** Artificial Intelligence is the study of how to make computers do things at which, at the moment, people are better.

Here, Rich characterizes what scientists and researchers have been doing in AI research for about seventy years. According to Ertel, this definition of artificial intelligence will still be relevant in 50 years [22].

3.2 History of Artificial Intelligence

The history of AI began in the middle of the 20th century. The beginning of AI is dated 1950, when the British theorist Alan Turing (1912-1954) published his famous report on „Computing Machinery and Intelligence.“ Turing developed the „Turing Test,“ named after him. In this test, a machine is considered to possess artificial intelligence as soon as it is capable of preventing a human from distinguishing between a human and a machine.

For this test, a human communicates with a machine via a terminal (e.g., a monitor and keyboard). The following sample dialogue serves as an example of such a test; it uses sample questions and sample answers from various application areas. The example of the dialogue also makes it clear that even the answer to the question of writing a poem could be a typical human answer. Turing said: „**What person is creative and can write poetry?**“ [23].

> Q: Please write me a poem about the Firth of Forth Bridge.
> A: I have to pass on this one. I could never write a poem.
> Q: Add 34,957 to 70,764.
> A: (waits about 30 seconds and then answers) 105,721.
> Q: Do you play chess?
> A: Yes.
> Q: My king is on e8; otherwise, I have no more pieces. You only have a king on e6 and a rook on h1. It's your move. How do you move?
> A: (after a 15-second pause) Rh1-h8, checkmate.

In research, four phases of AI development can be distinguished.

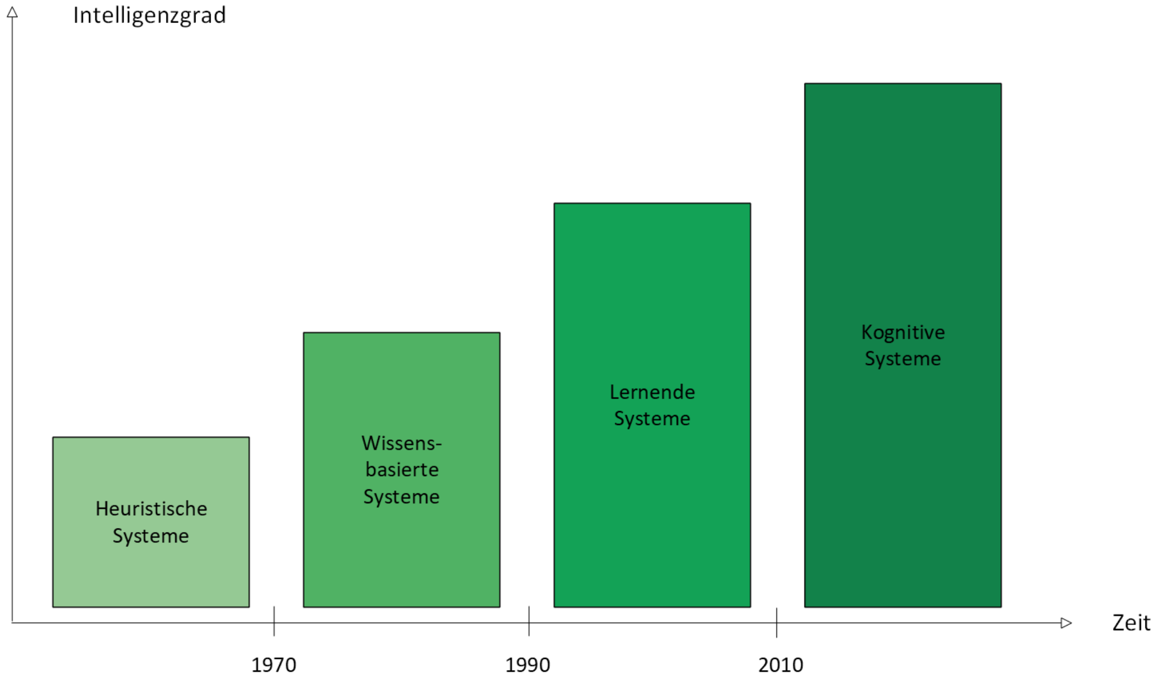

Figure 3.2: Four Phases of AI Research (based on [24])

Phase 1: Heuristic Systems (1956-1970)

In 1956, the term „Artificial Intelligence" was introduced by John McCarthy (1927-2011) at a conference at Dartmouth College. The first phase of AI research was characterized by high expectations for the new technology. The goal was to define more general problem-solving procedures for computers. However, this was unsuccessful at the time, whereas research in the area of specialized programs achieved great success. It became clear that good AI programs depended on a suitable database and a fast retrieval procedure.

These procedures are based on a heuristic approach to problem-solving, in which reasoning is also viewed as a search process.

The goal was to understand human problem-solving behavior.

An early application example was chess.

Phase 2: Knowledge-Based Systems (1971-1990)

In the second phase of AI, an increased focus on specialized programs can be observed. A widely known programming language, „MACSYMAL," which represented a collection of specialized programs in standard mathematical notation, was established. Typical tasks of the programs were integration and differentiation, which are still required today.

Knowledge-based systems process knowledge through a knowledge base and a reasoning component. They draw logical conclusions from existing information and are considered an important aspect of intelligent systems.

A well-known example is the medical expert system MYCIN, which was developed in the 1970s to diagnose bacterial infections.

Phase 3: Learning Systems (1991-2010)

Learning is considered a central feature of intelligence. Machine learning is characterized by two fundamental properties: First, it requires input data, known as training data. Second, the process consists of gaining experience from this training data and transforming it into a model. Such a model often depends on additional parameters.

In the 1990s, increased investment was made in research into artificial intelligence. In 1997, the first international RoboCup of soccer-playing robots took place there. In the same year, IBM's AI „Deep Blue“ defeated then-world chess champion Gary Kasparov 3.5 to 2.5, impressively demonstrating what AI is capable of.

Existing Go programs at the end of the 1990s had a playing strength that barely exceeded that of ambitious human beginners. Phase 4: Cognitive Systems (since 2010)

Phase 4: Cognitive Systems (since 2010)

Cognitive systems combine the learning processes from Phase 3 with the knowledge-based methods developed in Phase 2.

Service robotics is becoming a dominant field of AI research. In 2010, Google introduced the first self-driving car on a California freeway.

In October 2015, AlphaGo competed against the reigning European champion and professional Go player Fan Hui. AlphaGo won the games 5-0.

In 2018, the Google company DeepMind introduced the AI AlphaZero. It learned the games of chess, Go, and Shogi consecutively within a few hours and was then better than any software developed to date, thus achieving far superior performance.

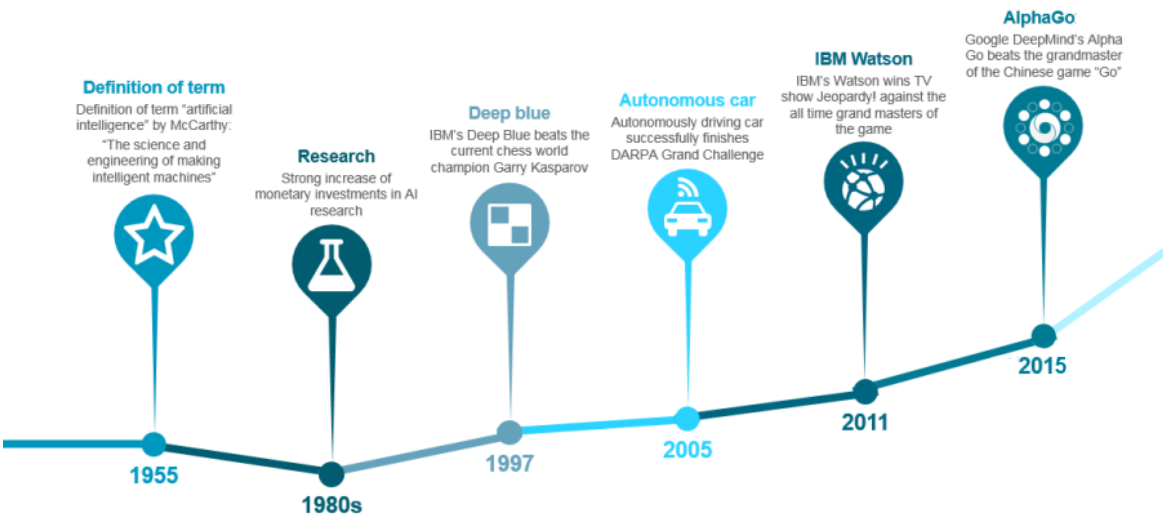

Figure 3.3: History of Artificial Intelligence

3.3 Connection between AI and Industry 4.0

Industry 4.0 stands for the fourth industrial revolution, characterized by digitalization and automation. AI plays a central role in this by analyzing large amounts of data, making machines more intelligent, and controlling processes autonomously. Applications such as predictive maintenance, intelligent robotics, and optimized supply chains enable networked, flexible, and efficient production [25].

Automation influenced by AI

AI enables systems to learn and solve problems independently within defined limits. It plays a particularly central role in the autonomous control of industrial processes, with the level of autonomy determining the degree of independent action.

The autonomy of a system depends on the task complexity and the role of the human. To achieve higher levels of autonomy, AI systems must be further developed, as their decision-making capabilities are based on experiential knowledge. AI is therefore crucial for the development of intelligent, autonomous systems.

Figure 3.4: General relationship between autonomy and AI [25]

Industrial production encompasses the entire life cycle of a plant – from planning and operation to maintenance and decommissioning, with all areas being interconnected.

A graduated model of autonomous action is important because not every system requires the same level of autonomy. Different areas such as process control, planning, and maintenance have different levels of automation. The following figure shows the gradual achievement of higher levels of autonomy.

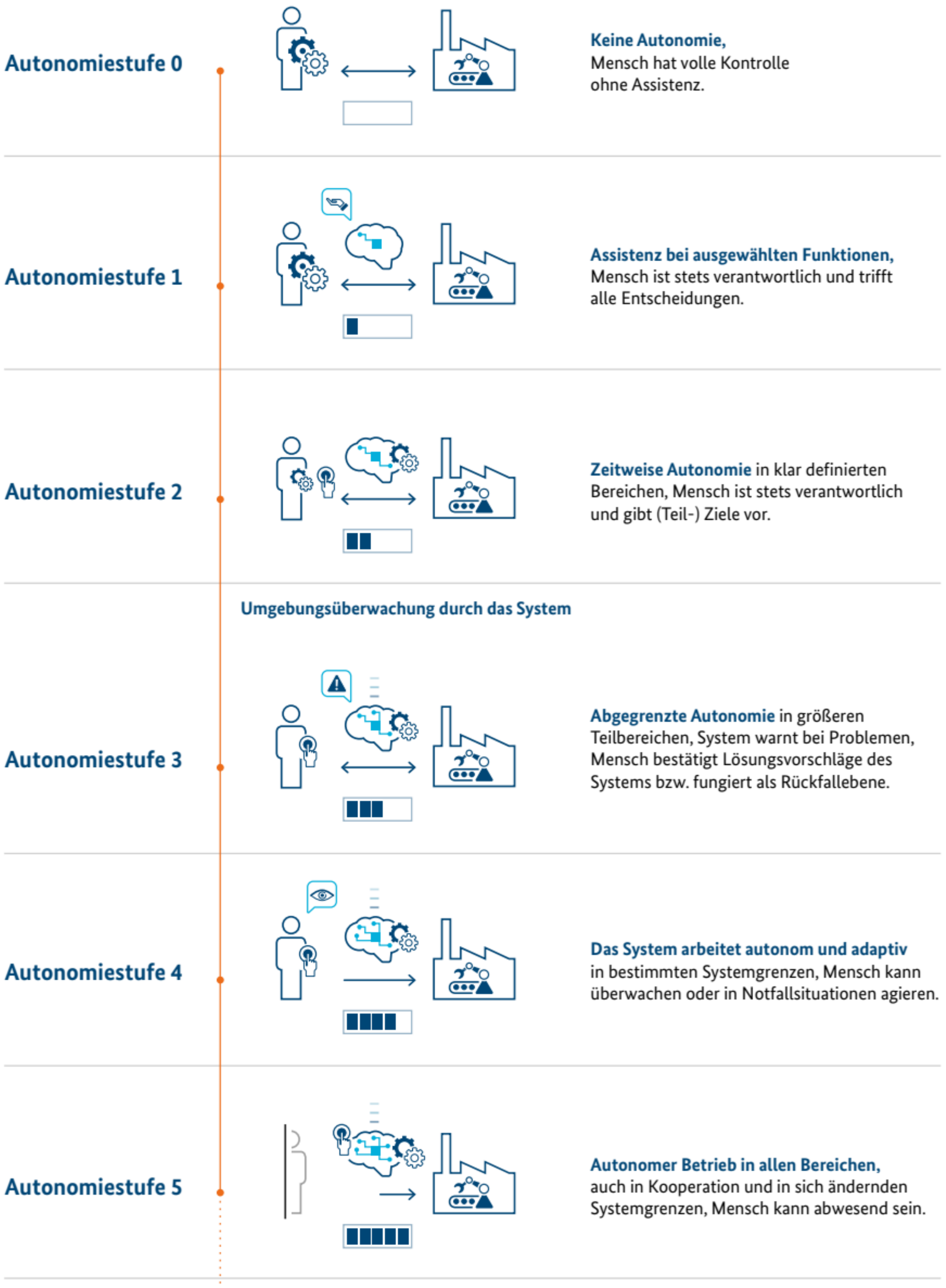

Figure 3.5: Higher-level definition of AI-influenced autonomy levels in industrial production [25]

The most important areas of artificial intelligence are machine learning, neural networks, deep learning, and data mining [26].

3.4 Machine Learning

In machine learning, an artificial system or computer learns from experience and, after a training period, is able to solve tasks for which the system was not pre-programmed [27].

The learning process is more successful the more data the system has available. During the learning process, the data is initially divided into training data, validation data, and test data. Using the training data, the system is able to recognize patterns and regularities and thus develop a model with decision rules and various parameters. The correctness of the model can be verified using validation data, and the accuracy can then be determined using the test data.

Basically, there are three different forms of machine learning:

- **Supervised Learning**
- **Unsupervised Learning**
- **Reinforcement Learning**

In **supervised learning**, training data is provided where the input and the corresponding output, or result, are known. In this type of machine learning, the correctness of the available data is particularly important, as otherwise incorrect relationships will be learned.

Unsupervised learning differs from supervised learning in that the system does not know the correct output from the training data. The data is analyzed for patterns and grouped based on different characteristics.

In the third form of machine learning, reinforcement learning, the system is confronted with problems and repeatedly receives positive or negative feedback on its chosen solution. The system thus learns strategies that maximize rewards.

Machine learning processes already have numerous applications in our everyday lives, such as facial recognition software in laptops and smartphones or personalized product recommendations. Machine learning processes can facilitate the handling of large amounts of data in many environments and industries. For example, such systems can be used in manufacturing companies in quality control to detect deviations from the norm. Predictive maintenance models enable companies to effectively utilize resources by predicting the time of failure of production systems and machines.

There are also many possible applications for the technology described in the financial sector. For example, risks can be assessed more realistically or portfolios can be optimally tailored to investor goals. Furthermore, the healthcare system, and in particular diagnostic options in the event of illness, could be revolutionized through the targeted use of machine learning. Based on the analysis of patient data, individual treatment options can also be identified and applied.

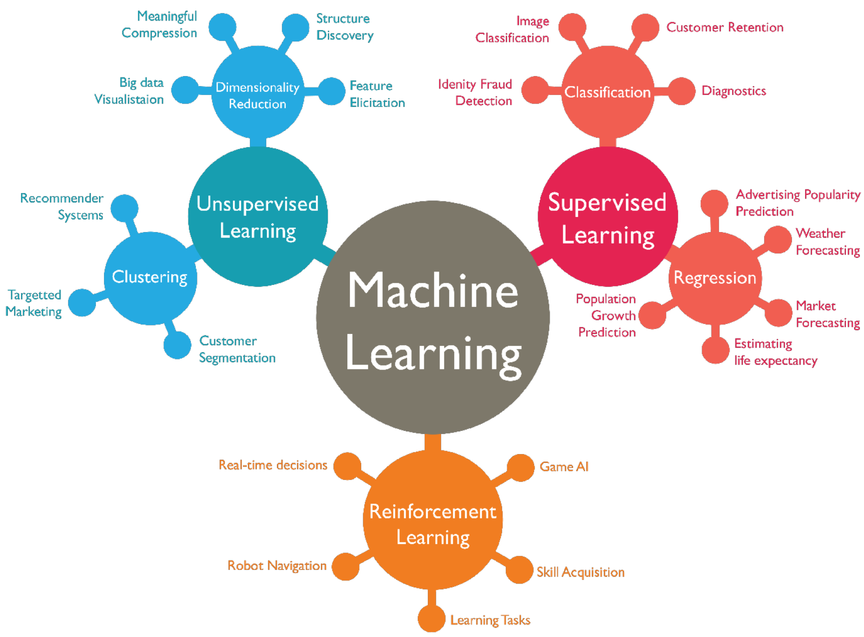

Figure 3.6: Machine Learning: Various Learning Methods.

3.5 Deep Learning

Deep learning and machine learning are two very similar methods for data analysis. Deep learning is primarily used for large, multidimensional data, whereas machine learning is more commonly used for small data sets that need to be processed quickly and efficiently. Deep learning is also based on neural networks (see chapter 3.6), which continually create new connections during the learning process, thus enabling a machine to learn. This enables a machine to improve its skills independently and without human intervention. This is achieved by evaluating existing data, recognizing, extracting, and then classifying patterns. The findings are then linked to the data to place them in a broader context. The machine is then able to make decisions based on the connections between the data.

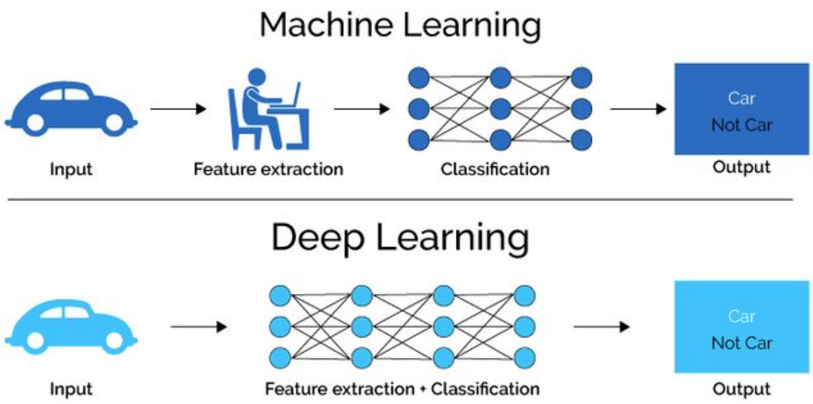

Figure 3.7: Machine Learning vs. Deep Learning

By constantly questioning decisions, certain information links receive different weightings. For example, if a decision is confirmed, the weighting of the link increases, and vice versa. This creates more and more intermediate layers and links between the input and output layers. The intermediate layers then decide on the output. (Fig. 3.8).

Deep learning requires more computing power due to the very large amounts of data. Tradi-

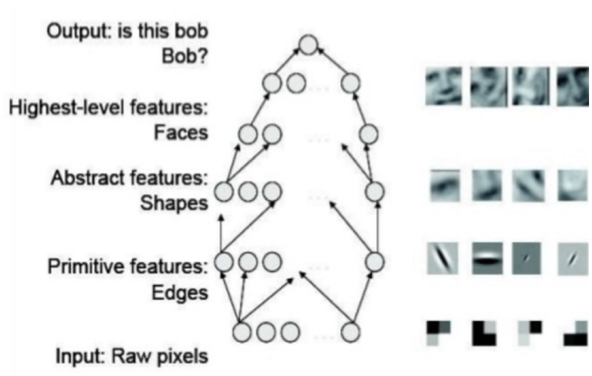

Figure 3.8: Deep Learning Feature Hierarchy in Image Processing

tional processors (CPUs) are therefore not sufficient; instead, powerful graphics processing units (GPUs) are used. This is primarily because training a deep learning model can take up to several weeks, depending on its complexity and size.

One problem with deep learning is the lack of transparency. Without additional effort, no conclusions can be drawn about the emergence of a prediction. This is because the neural network of a deep learning model learns how to make decisions from the data during training. Therefore, in the financial sector, for example, the use of deep learning models is deliberately avoided and machine learning models are deliberately used.

3.6 Neural Networks

Neural networks are networks of nerve cells in the brain of every living being. In humans, neural networks provide the complex interconnections and adaptability that enable our intelligence and a wide range of motor and intellectual abilities. The field of artificial neural networks takes nature as its model.

Figure 3.9 shows a representation of a natural neural network and an artificial neural network. A single neuron (green) has many inputs (synapses) where signals can arrive. When the neuron's synapses reach a threshold, this in turn transmits a signal via the axon. However, neurons are interwoven in a much more complex way. To apply this principle to artificial intelligence, the system is simplified and represented in several layers.

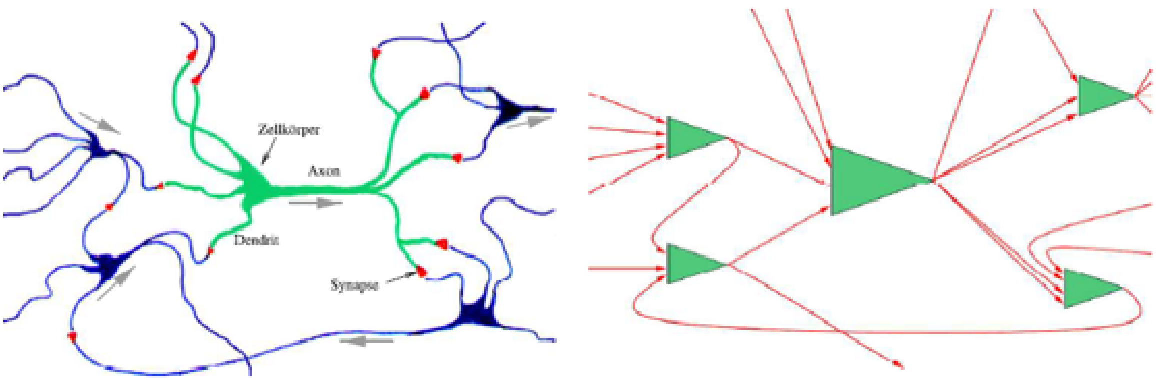

Figure 3.9: Natural Neural Network and Artificial Neural Network

A simple example of artificial neural networks is image recognition. Suppose an image with 128 pixels depicting a cat is to be classified (Fig. 3.10). In the first step, all 128 pixels are connected to the inputs of a neuron. Each neuron has four inputs, resulting in 32 neurons in the first layer of the neural network. Since each pixel actually has a numerical value, this numerical value is passed on to the neuron inputs. When a neuron's inputs reach a certain threshold, the neuron passes on an output value (Fraunhofer.2019).

The weighting of the individual pixels and neurons also plays an important role. For example, the pixels have different weights, as some are located at the edges and some more centrally. In the next step, the threshold of the neurons can also be changed. For example, one neuron will pass on an output value even with a small input value, while another will not.

It is therefore extremely important for the neurons to consider the two parameters, weight and threshold. Now, a second layer of the artificial neural network would be placed on top of the first layer, with eight neurons, each with four inputs. The image recognition process then proceeds through successive layers until it reaches the highest level of abstraction, where the output value „cat" is output. To ensure this is recognized even with as many different images as possible, the neural network can be trained. For this purpose, the individual parameters are adjusted until every cat is recognized. This is based on supervised machine learning, where the input and output values are already known.

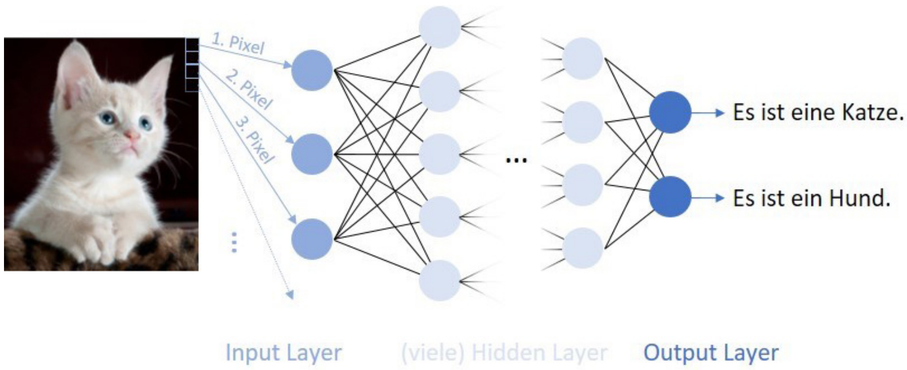

Figure 3.10: Image recognition diagram.

3.7 Data Mining

Data mining is the process of analyzing large amounts of data from various data sources to gather useful information. This is done by finding previously unknown patterns, anomalies, and correlations. All of these are later used to predict future outcomes. Data mining is based on three main models.

- **Descriptive Modeling**
- **Predictive Modeling**
- **Prescriptive Modeling**

Descriptive modeling uncovers commonalities or groupings in historical data to determine the reasons for success or failure, such as categorizing customers based on product preferences or sentiment. Examples of descriptive modeling techniques include clustering, which groups similar data sets, and association rule learning, which describes the recognition of relationships between data sets. describes [28].

Predictive modeling delves deeper to classify future events or estimate unknown outcomes—for example, using credit scoring to determine the likelihood of a person repaying a loan. Predictive modeling also helps uncover insights for issues such as customer churn, campaign response, or loan defaults. Example techniques include decision trees, where each branch represents a likely event.

Prescriptive modeling considers internal and external variables and constraints to make one or more recommendations for action—e.g., determining the best marketing offer to send to each customer. Example techniques include optimizing marketing to simulate the most advantageous media mix in real time for the highest possible return on investment (ROI), and predictive analytics, which describes the development of „if-then“ rules from patterns and predicting outcomes.

With the proliferation of unstructured data from the internet, comment boxes, books, emails, PDFs, audio, and other text sources, the relevance of text mining as a related discipline to data mining has also increased significantly.

Data mining requires the ability to successfully parse, filter, and transform unstructured data in order to incorporate it into predictive models for improved prediction accuracy. Ultimately, data mining should not be viewed as a separate, standalone entity, as preprocessing (data preparation, data exploration) and postprocessing (model validation, scoring, model performance monitoring) are equally important.

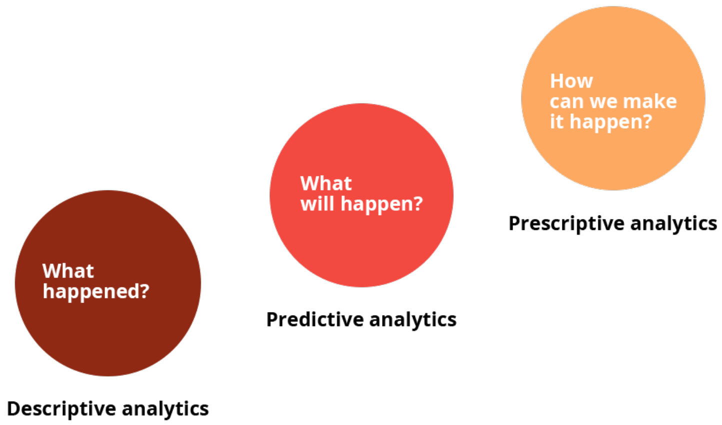

Figure 3.11: Modeling Data Mining

3.8 Ethics and the Impact of AI on the Labor Market

A controversial part of AI research is the ethical clarification. A key point of contention is the question of whether and how many jobs will be replaced or made redundant by the use of artificial intelligence. According to a study by the Federal Ministry of Labor and Social Affairs, the automation potential of jobs in Germany is 12

A study by the American investment bank Goldman Sachs from March 2023 shows that up to 300 million full-time jobs worldwide could be replaced by artificial intelligence using AI tools such as ChatGPT (Briggs/Kodnani 2023). Administrative and legal functions are among the most affected.

According to a recent McKinsey study, companies are using generative AI to significantly increase their productivity and reduce costs. This technology enables various business processes to be made more efficient, thereby achieving significant time and cost savings.

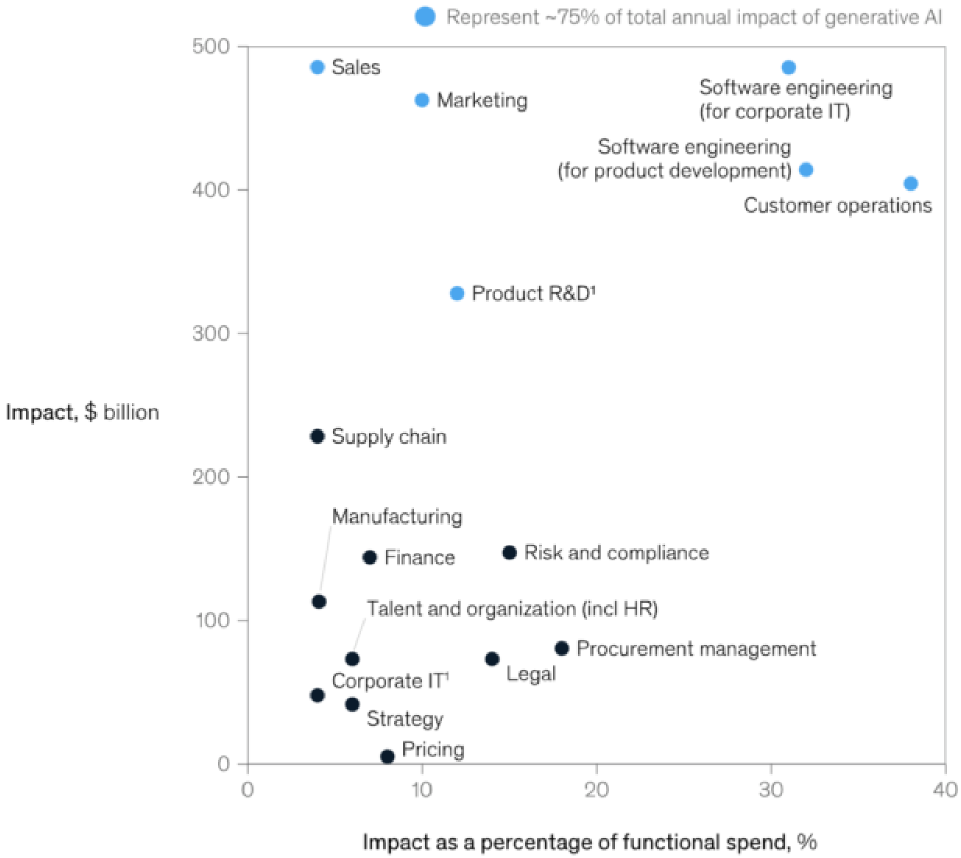

Figure 3.12: AI impact on the labor market caused by generative AI (McKinsey, 2024.

Generative AI can take over tasks that previously required human judgment, thus increasing productivity by 60-70%. Especially in the areas of software development and customer interactions, AI ensures faster processes and lower operating costs. This leads to a significant competitive advantage and better resource allocation for companies.

3.9 Ethics and Law in the Use of AI

The increasing complexity and autonomy of AI presents new challenges for ethics and law. AI systems often make difficult-to-understand decisions. Decisions, which complicates evaluation and approval. Questions also arise about the decision-making authority of machines and responsibility. A central problem is the attribution of decisions: Humans are often held responsible, even though they have difficulty defending themselves against machine suggestions. These developments require new ethical and legal debates.

AI is transforming many areas of life and brings both benefits and risks. Ethics and law must address these issues to ensure trust and prevent harm. In particular, the autonomy of modern AI, which learns and makes decisions independently, places new demands on transparency, data protection, and liability. AI decisions are often based on correlations, which is legally problematic because they are not traceable. This autonomy requires its own ethical and legal assessment, which challenges traditional concepts.

The further development of AI entails risks such as malfunctions and incorrect diagnoses. Responsibility for autonomous systems is difficult to clarify because misconduct is often unpredictable. Data protection is also a challenge, as AI often accesses and links personal data. Furthermore, AI can encourage discrimination when decisions are based on non-transparent criteria. These challenges require continuous regulation of AI [29].

Figure 3.13: Examples of possible misuse [30]

Examples of AI-generated content include the viral images of Donald Trump during a supposed arrest, Pope Francis in a white down jacket, and Emmanuel Macron as a garbage collector. These images, created using generative AI models, spread quickly. While the Pope and Macron image was received humorously, the Trump image sparked controversy because it was misunderstood as real news.

These examples demonstrate the ethical challenges of AI content, particularly with regard to transparency, fairness, and non-malice.

- **Transparency:** It must be clearly recognizable whether content was generated by AI to avoid misinformation. Companies and platforms are required to introduce appropriate labels or watermarks.
- **Fairness:** The spread of deepfakes can lead to distortions in public perception and can be deliberately used for manipulation. This becomes particularly dangerous in political and social contexts.
- **Non-malice:** The use of AI for deliberate deception or defamation can cause significant damage. Therefore, regulatory measures and technical protection mechanisms are necessary to curb misuse.

AI raises social questions, such as the fear of job loss and diminishing interpersonal interaction. This requires adjustments to legal and moral norms. Experts emphasize that concepts of guilt and responsibility must be reconsidered, especially with regard to the allocation of responsibility for AI decisions.

Ethical aspects of AI are thus becoming increasingly important, as algorithms are increasingly intervening in social contexts and are no longer limited to specific applications. Artificial intelligence is changing value creation processes, private interpersonal communication, and human interaction.

Weak and Strong AI

This influence of AI becomes particularly clear when the step is taken from weak AI (systems that act intelligently in a specific, narrowly defined context and can even exceed human capabilities) to strong AI (hypothetical AI systems that have at least human-like intelligence in all areas and not just in narrowly defined fields of application). Therefore, it is all the more important to proactively find answers to questions concerning the changes to our society brought about by this key technology.

When it comes to questions regarding responsibility, social interaction, or individual personality development, the core discourse on ethics and artificial intelligence continues. However, AI does not raise fundamentally new ethical questions. However, AI lends new weight to these fundamental debates.

Integrating ethical and legal requirements into AI systems is complex because they cannot simply be translated into algorithms.

The debate on the ethics of AI is far from exhausted; in addition to technological progress, a proactive debate on the design and regulation of AI, based on ethical discourse, is needed.

3.10 Model for AI Ethics Principles and Recommendations for Action

A model for ethical AI use combines central principles of existing approaches: beneficence, transparency, non-maleficence, autonomy, justice, and data protection.

These serve as the basis for development and application, with context-dependent emphasis.

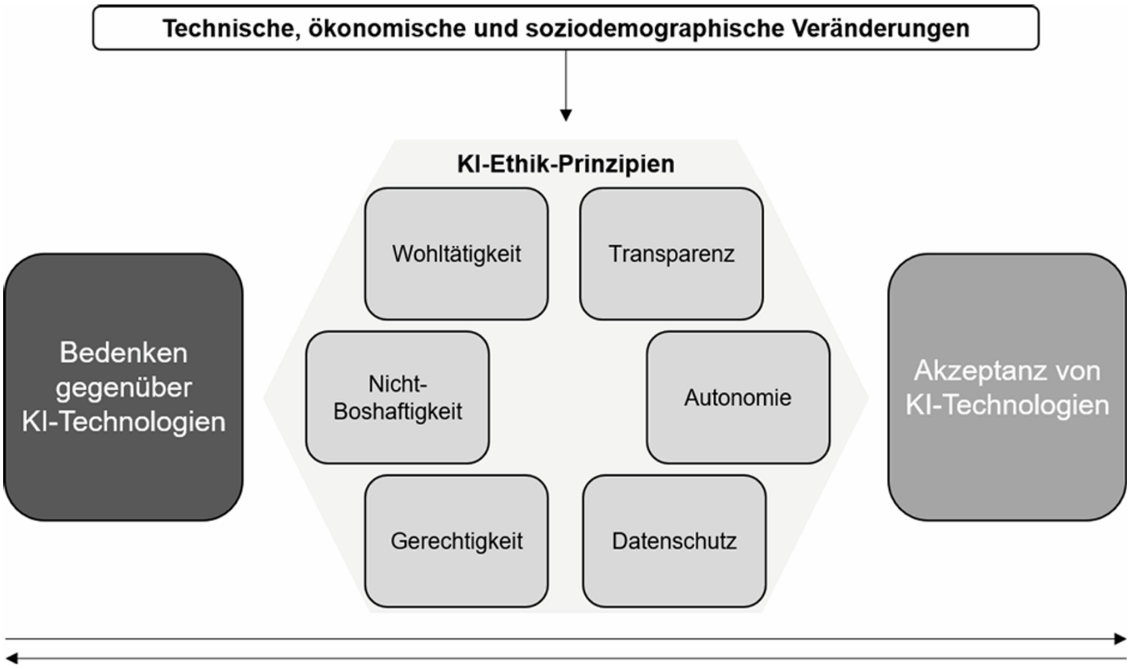

Figure 3.14: Ethics Principles in the AI Age [31]

Benevolence means using AI for the good of society, for example, to improve the quality of life. Transparency ensures accountability, and non-maleficence protects against harm. Autonomy preserves freedom of choice, justice prevents discrimination, and privacy protects personal data.

To implement these principles, measures such as aligning AI with human values, clear communication, and safeguards are necessary. Training strengthens autonomy, fairness requires diverse data sets and participation, while privacy creates trust.

The challenge is to reconcile ethics and innovation. International standards and national regulations could help to safeguard ethical principles without slowing down progress [31].

CHAPTER 4

Autonomous driving and risk ethics

Learning goals

After working through this chapter, you will know ...

... what are the levels of automation in automated driving?

... what the motivation is for researching autonomous driving

... how the human-machine interface (MMS) is changing

... how learning systems can be used in autonomous vehicles

... criticisms of the concept

... why ethical aspects need to be taken into account in development

4.1 Introduction

The invention of the first automobile, the „Benz Motorwagen“, in 1886 started a development history that is still ongoing. Over the years, the various automobiles developed into the passenger cars we know from our everyday lives. The last few years have been marked by the digitalisation of the automobile, but above all by the development of supporting technologies that assist the driver.

In the meantime, development has gone so far that self-driving cars, as „autonomous driving“, are to find their way into our everyday lives. The chapter deals with the motivation for researching autonomous driving, USE cases and the topic of risk ethics of self-driving cars.

Figure 4.1: Benz Patent Motor Car 1886 - Autonomous Driving in the Future

4.2 Definition

The term autonomy is defined in relation to „autonomous driving“ in such a way that autonomy stands for "self-determination within the framework of a superior (moral) law". In the field of autonomous driving, the human specifies this moral law by programming the behaviour of the vehicle. By programming the human, the vehicle learns to make certain behavioural decisions in traffic. [32]

Basically, autonomous or automated driving is divided into six different levels. The individual stages are illustrated and explained in Figure 4.2.

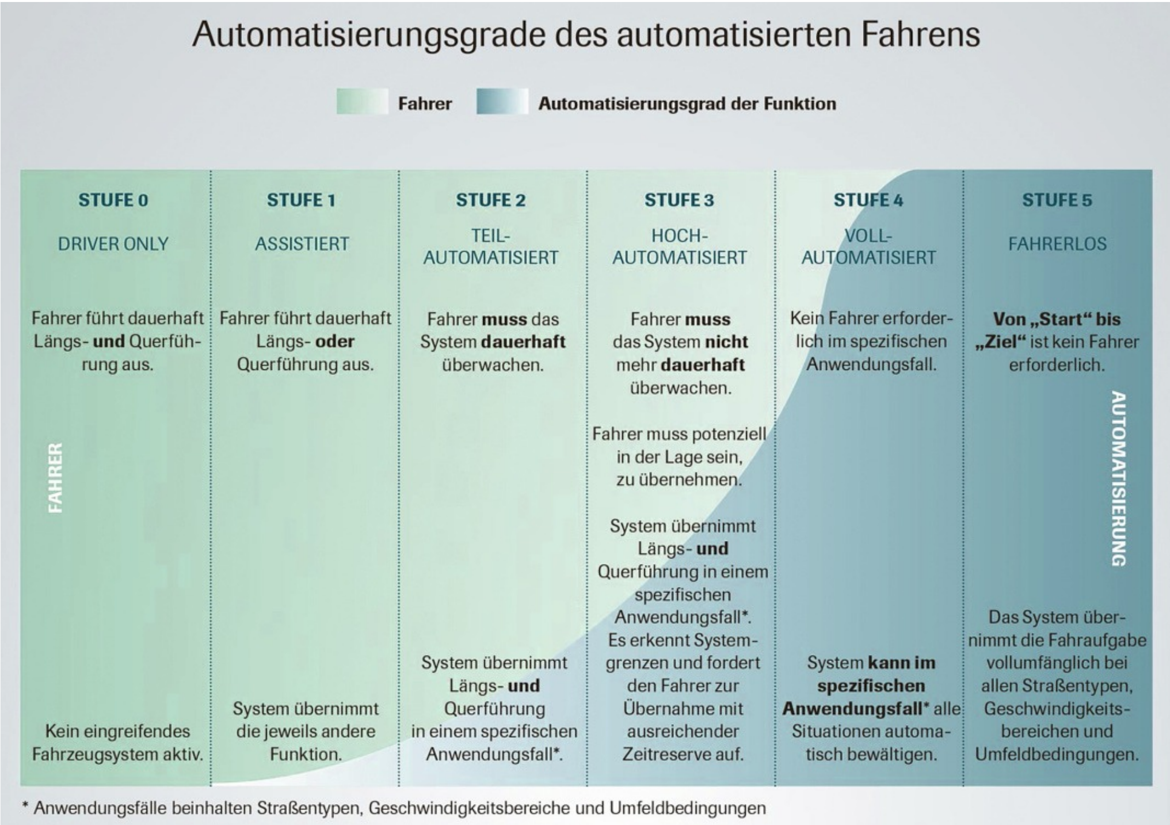

Figure 4.2: Degrees of automation of automated driving [33].

4.3 Motivation for Researching Autonomous Driving

According to the Federal Statistical Office, there were over 2.2 million police-recorded traffic accidents across Germany in 2020.

According to an article published in September 2020 by the campaign "Runter vom Gas," the cause of an accident was due to human error in 94.4 percent of cases [34].

Figure 4.3 shows the average annual number of traffic fatalities in Germany. A very clear trend can be seen, indicating that since the peak in 1970, the number of traffic fatalities has significantly decreased. The decreasing number can be attributed to the improvement of automobiles in terms of their safety. It is important to distinguish between regulations set by the road traffic regulations and individual driver assistance systems.

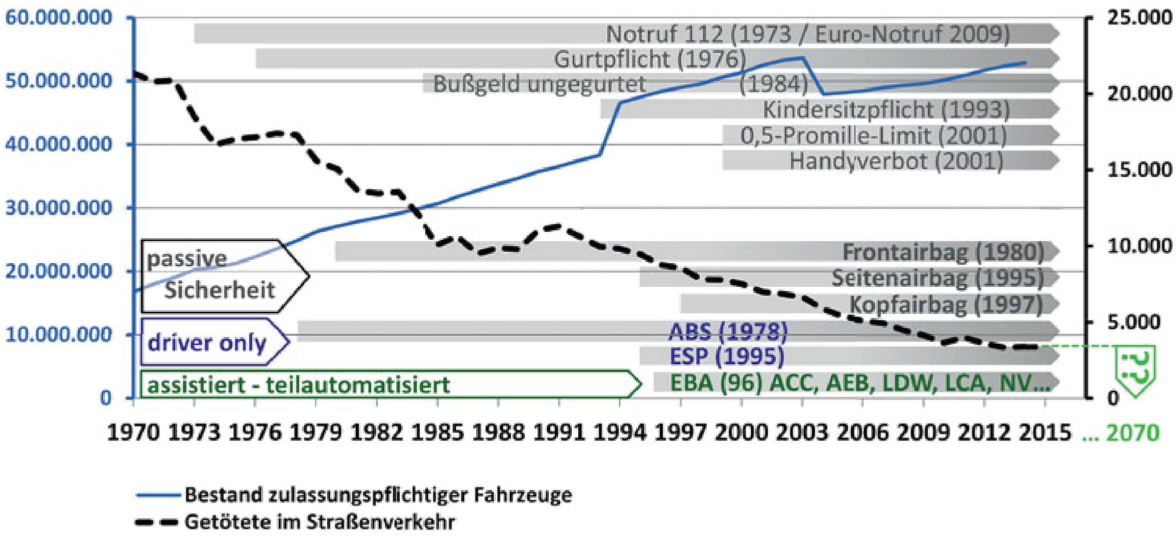

Figure 4.3: Car registrations and traffic fatalities in Germany since 1970 [35].

Guidelines for reducing traffic fatalities on the roads include, for example:

- 100 km/h speed limit on country roads
- Blood alcohol limit

  Seatbelt requirement

In addition to these regulations, there is an increase in **digital driver assistance systems** in automobiles:

- Emergency brake assistant
- Lane Keeping Assistant
- Distance assistant

The motivation for researching autonomous driving is therefore almost exclusively to make road traffic safer. The focus is on the overall accident statistics and specifically on fatal accidents. The trend of the graph from Fig. 4.3 is to be influenced by autonomous driving in such a way that it continues to decline.

4.4 USE-Cases

There are a multitude of possible applications for autonomous driving, although this chapter focuses on four different use cases.

Highway Automated Vehicle with Available Driver - Highway Pilot
This type of autonomous driving is limited to a driving robot that fully assumes the driving task exclusively on highways or similar expressways. The driver becomes a passenger in this application, still sitting at the wheel, but can take their hands off the steering wheel, take their feet off the pedals, and even perform another task.

Fully Automated Vehicle with Available Driver
This use case is very similar to the previous one, except that it can also be used outside of highways or similar roads. For the driving robot to operate, the vehicle only needs to be in an approved area. Non-approved areas could include, for example, a changed road layout or a

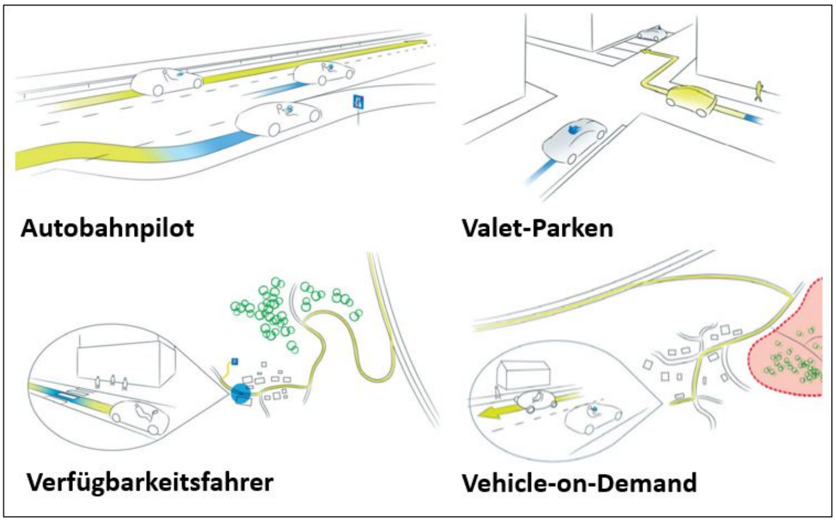

Figure 4.4: USE-Cases autonomous driving [32].

construction site. Furthermore, certain areas may generally not be available for autonomous driving, for example, if they are areas with high pedestrian traffic.

Autonomous Valet Parking
This use case is very easy to understand if you think about the situation in front of certain hotels. Here, the car is often parked and an employee parks it for the guest. Valet parking follows the same principle, except that there is no need for a human to drive the vehicle. The driving robot parks independently after the passengers disembark and is even able to repark on command, as well as leave the parking space and pick up the passengers at any boarding point.

Vehicle-on-Demand
The vehicle-on-demand system moves the vehicle completely autonomously in all scenarios, regardless of whether it is carrying passengers, goods, or cargo. The driving robot is informed of its destination (by passengers, users, or service providers), to which it then moves autonomously. Occupants are never able to take over the driving task themselves. The only option is to change the destination or to activate the so-called **Safe Exit**[1] [32].

The USE cases just described can therefore be divided into two different categories. In the first two applications, driving is only carried out autonomously in certain situations; here the driver still has the option of controlling the vehicle themselves or intervening in critical situations. The other two USE cases, however, are different. Although there are some occupants, they are passengers and only have the option of actively intervening in the driving process through instructions such as specifying the destination.

This raises a wide range of questions:

- Who is at fault in a traffic accident?
- Who is responsible for a vehicle when it is driving without passengers?
- What ethical considerations play a key role in the use of AI in automobiles?

1 The **Safe Exit** is a special driving mission. This transfers the vehicle as quickly as possible into a state that allows the occupant to leave the vehicle safely.

4.5 Human-Machine Interface: The Transformation of Autonomous Driving

In contrast to other areas, the human-machine interface (MMS) in automobiles has changed very little over time. Virtually nothing has changed here for over 100 years; the vehicle is still controlled via pedals and a steering wheel. Even the addition of assistance systems, touchscreens, or displays has not changed the actual interface.

The obvious idea, therefore, is to change the interfaces and turn humans into passive passengers. Philipp Slusallek's statement (German Research Center for Artificial Intelligence) contradicts this:

> „***We humans are not good at supervising a system that seems to function correctly all the time. It bores us, and we become inattentive.***“ [36].

There is therefore a contradiction between proponents of autonomous driving and various research institutes, which, as described above, share the finding that humans are bad at merely supervising an autonomous system.

The Fraunhofer Institute for Integrated Circuits is demonstrating what the human-machine interface in the field of autonomous driving could look like in the future. Under the name „**Semulin**“ a self-supporting concept for autonomous driving is being developed that works with multimodal input and output modalities such as facial expressions, gestures, gaze, and speech.

High user-friendliness is important to the developers here, due to the increasing complexity and, not least, the high relevance of this interface in autonomous driving. The difficulty lies in considering the limitations of existing human-machine interactions and linking them together in a meaningful way.

To implement this human-centered interface, which should also consider the overall context, established technologies are being used. AI-supported processes are used to correlate all data, and innovative approaches even aim to enable the system to learn interactively and adapt to the individual needs of each user. The following figure [37] shows an overview of this interface.

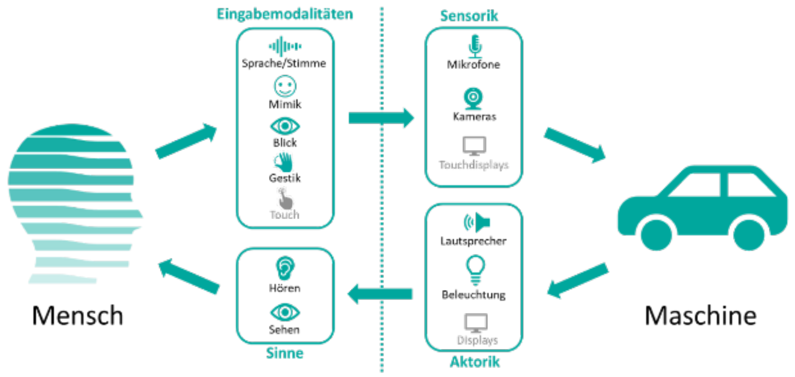

Figure 4.5: Semulin [37].

This new type of interface increasingly uses artificial intelligence, which is intended to replace humans in this system. Researcher Philip Bethge's statement therefore points to an ethical debate.

The question arises as to whether humans, as thinking beings, are even capable of functioning meaningfully and safely in such an interface. This statement can be further transformed beyond the area of autonomous driving to all areas in which artificial intelligence is used. The ethical and social question almost always arises as to whether and, above all, how humans can use artificial intelligence meaningfully and safely.

Learning Systems
A special feature of artificial intelligence, especially the Semulin interface just described, is the ability to learn. Looking at both sides of the interface, humans are fundamentally beings with the ability to learn, and their performance changes through learning. Machines, on the other hand, fundamentally do not possess this ability. Highly automated and networked machines, in this case also vehicles, can, however, acquire this ability through the use of the latest technology and thus have the opportunity to improve functions over time or learn the behavior and preferences of users.

Autonomous driving eliminates human abilities such as the ability to learn and adapt – but these would be compensated for by the use of learning systems. Furthermore, advantages would arise from individualizing vehicle control and optimizing fully automated driving.

The greatest advantage lies in the collective application of learning systems, as the exchange or copying of learned information between systems occurs significantly faster than with human processes. Due to the increased safety concerns associated with autonomous vehicles, the use of learning systems is a particularly significant challenge.

The focus is on road safety and data security. Due to the lack of a measure of road safety risk, the preliminary application must be fault-tolerant. Learning systems in autonomous vehicles must therefore first be supplemented by redundant conventional systems that can check the learning system for its safety and intervene if necessary.

4.6 Risk Ethics of Autonomous Driving

Criticism of the Concept

„In our modern society, which is undergoing transformation due to advancing digitalization, the impending changes in mobility that are to be expected from the introduction of autonomous vehicles into road traffic have increasingly come to the fore in recent years.

The criticism is based primarily on accidents that have occurred in connection with autonomous vehicles, some of which have had fatal consequences. Due to the resulting discussions in the media, autonomous driving has come under increasing criticism.

From time to time, we read headlines claiming that people have died in accidents and that a driverless car was the cause. This criticism contradicts the fundamental idea of autonomous driving: making the roads safer.

Paradoxically, the safety of autonomous vehicles is being criticized here, even though they actually aim to do precisely that. Looking at the figure, it becomes clear that currently 93.5

The criticism and concerns therefore also relate to the question of what type of errors will replace human errors. This question triggers an ethical, but also legal, dilemma, which is

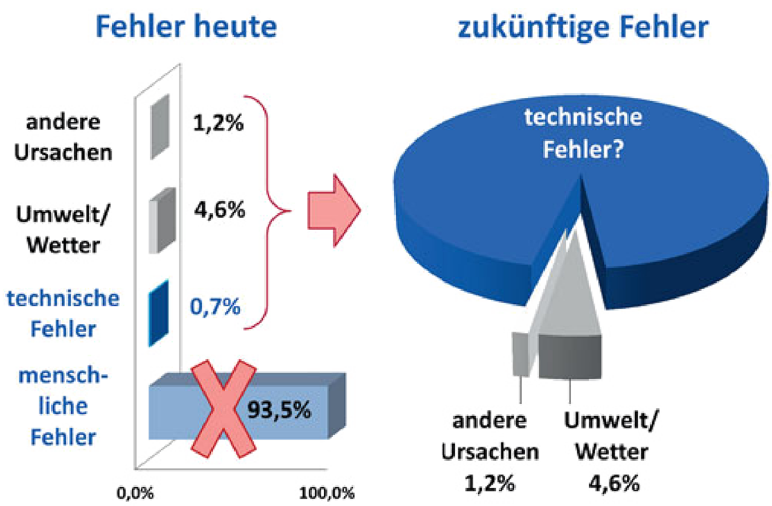

Figure 4.6: With full automation, there would be no more human errors. However, the proportion of technical errors could be perceived significantly higher in the future [32].

described and explained further below.

Ethical Aspects

There is no question that a person participating in road traffic takes a certain amount of risk and, in doing so, also poses a risk to others. These risks are socially accepted; the **risk in road traffic is therefore socially accepted**. However, an ethical conflict arises in the context of autonomous driving. The use of autonomous vehicles will change the nature of the decision, and a distinction will then be made between two different decision-making systems:

Intuitive-situational: This type of decision describes the decision, or rather the reaction, of a person in a dangerous situation.
Example: Pedestrian walks onto the road, the driver makes an emergency stop.

Considered, conscious: This decision form describes the planned, programmed decision in a dangerous situation.
Example: Pedestrian walks onto the road, the autonomous vehicle considers all parties involved in the dangerous situation and follows the decision specified by the programming. [38].

The ethical aspect refers to the second decision form, the one that comes into play in autonomous vehicles. As already described, the fully automated autonomous vehicle is controlled by artificial intelligence, which is why every action or decision of an autonomous vehicle is based on programming, or on the system's ability to learn. The ethical discussion usually takes the following or a similar scenario as its basis:

The autonomous vehicle is in a dangerous situation in which it either endangers a 10-year-old child or, through its evasive maneuver, endangers an 80-year-old person.

Assuming a serious accident, the autonomous vehicle in this case study would have to choose between two lives: a decision that is extremely difficult to justify morally. One aspect of justifying such a decision in this ethical discussion is usually the age of those affected.

In this case study, the justification could be that the child still has a whole life ahead of him, whereas the older person has already had a fulfilling life. Another aspect of justifying a decision could be the life experience of those involved. The older person could be accused of having put themselves in the dangerous situation, contrary to their experience, while the child, due to their lack of experience, got into this situation accidentally or innocently.

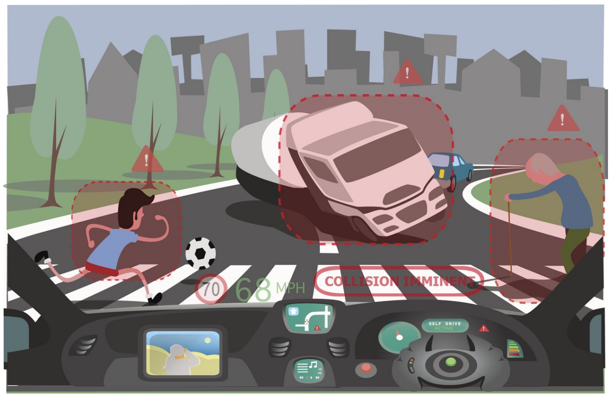

Figure 4.7: Moral Machine[1].

While the aspects just described may be acceptable to some people, if one considers the IEEE (Institute of Electrical and Electronics Engineers) Code of Conduct: To treat all persons fairly and with respect, and not to discriminate on the basis of race, religion, sex, disability, age, national origin, sexual orientation, gender identity, or gender expression, neither option would be ethically correct. According to the Code, making decisions based on someone's age would constitute discrimination. Even under German law, such a decision would be incorrect, as the first two articles of the Basic Law (Grundgesetz) already regulate a fundamental right to life and human dignity. At this point, the fundamental question arises as to how the influential German car manufacturers would even be able to bring fully automated cars onto the market. One solution to circumvent this decision would be to leave it to chance when such moral options are available. Opinions differ widely on this aspect as well, and it is repeatedly made clear:

Ethics plays a crucial role in the development of autonomous vehicles.

This and similar ethical dilemmas raise the question of whether autonomous vehicles should return control to the driver instead of having to make the decision themselves. However, this consideration only serves as a solution to the problem if control can be transferred quickly enough, or even at all. With autonomous driving systems, such as vehicle-on-demand, this solution would not be possible if the car was traveling without occupants.

Even if the presence of a driver made it possible to transfer control in a dangerous situation, this represents an unacceptable risk. Contrary to one of the advantages of autonomous driving, where the occupant can attend to other activities, they are now expected to make a decision without possibly having any knowledge of how the situation arose. Simulations and experiments were used to test and measure how long it would take to safely transfer control to a human. Depending on the so-called distracting activity, the transition time can be up to 40 seconds. However, the time required to react to a dangerous situation, as just described, requires a reaction within 1 to 2 seconds.

The comparison therefore shows that it is essential to leave the decision to the autonomous vehicle in moral dilemma situations.

So far, the ethical aspect has been considered, which involves choosing between a collision between two people. However, the collision between two vehicles (V2V) must also be considered in terms of a programmed decision by the autonomous vehicle. When making decisions

1 https://www.moralmachine.net/

regarding accidents, it plays a role whether the well-being of the occupants or other parties involved is prioritized. This is referred to as crash optimization.

For example, if the well-being of the vehicle's own occupants were the top priority, the decision would have to be made to collide with the lightest object. However, if the well-being of other road users were prioritized, the collision with the safest other road user should be chosen. Given the nature of both vehicles, an SUV should suffer less damage in a collision than a small car or motorcycle.

Important for such decisions is the autonomous vehicle's communication with other vehicles (V2V), with the infrastructure (V2I), or, in combination, communication with all parties involved (V2X).

For safe implementation, the autonomous vehicle must be able to recognize and classify all objects. For example, it must be able to distinguish a boulder from a garbage bag, because only in one of the two cases is an evasive maneuver necessary.

In addition, the autonomous vehicle for the V2V interface would have to be able to classify the other vehicle based on its design, or even have the ability to obtain the make, model, and technical specifications using sophisticated artificial intelligence.

Legal Aspects

In principle, the driver is always responsible for their vehicle in road traffic. This has been regulated since 1986 in an international treaty, the Vienna Convention on Road Traffic. A first decisive amendment followed in 2014, permitting systems to support the driver and thus including driver assistance systems and automated driving functions. This amendment came into force in Germany in March 2016 (DPMA).

For the use of assisted driving in Germany, the driver is required to be able to maintain control of the vehicle at all times. Accordingly, the driver is responsible for all traffic violations and accidents. A law regarding autonomous driving was successfully passed in May 2021, allowing autonomous vehicles to participate in public transport in Germany without a physically present driver. Until further notice, this law is currently limited to specified and pre-approved operating areas.

The law also stipulates that permanent supervision by a natural person must be guaranteed. For this reason, in addition to liability insurance for the vehicle owner, liability insurance for technical supervision is mandatory.

Criminal liability for traffic violations and accidents involving autonomous vehicles must be determined on a case-by-case basis. In addition to individual negligence on the part of the supervising party, organizational failure on the part of the manufacturer or operator can also be considered.

Currently, this law is not comprehensive enough, and more precise regulations are still needed to enable autonomous vehicles to be used in regular operation.

Summary and Outlook Autonomous driving is an important step that will contribute to road safety and also reflects the current state, particularly the further development, of technical capabilities. Although there is still a long way to go before autonomous vehicles are used in regular operation, we are already on that path. Assistance systems and functions such as automated parking have become part of our daily lives, and we know how to handle them. For this reason, the transition to autonomous vehicles should not pose a problem for humans. Only social acceptance and the resulting ethical and moral discussions remain critical of the whole thing.

A solution must therefore still be found regarding some ethical and moral views in order to maintain social, and especially moral, acceptance. Regardless of this, the final decision will be made in legislation, because in addition to responsibility and liability, risk ethics also play a role here. Only when the law can provide a comprehensive and clear solution will the path be clear for autonomous vehicles. Regardless of the law, the moral question will still remain if a machine makes a decision instead of a human and possibly learns from it.

CHAPTER 5

Extended Reality (XR)

Learning Objectives

After completing this chapter, you will know...

... what the term Extended Reality (XR) means.

... how AR, VR, and MR differ from each other.

... in which application areas XR is used in industry.

... what advantages arise from using XR in industry.

... what risks must be considered when using XR.

Extended Reality (XR) Reality means "that which actually is" or "the totality of reality" and derives from the Latin adjective "realitas" and the noun "res" for "thing, matter." Reality encompasses everything a person can see with their own eyes and interact with without additional influence from technology.

Through various technologies, collectively known as "Extended Reality (XR)," it is possible to influence reality to varying degrees. These range from an extension of reality to its complete replacement.

The term Extended Reality (XR) encompasses three levels of reality influence that can be created through technological advances between reality and virtual reality.

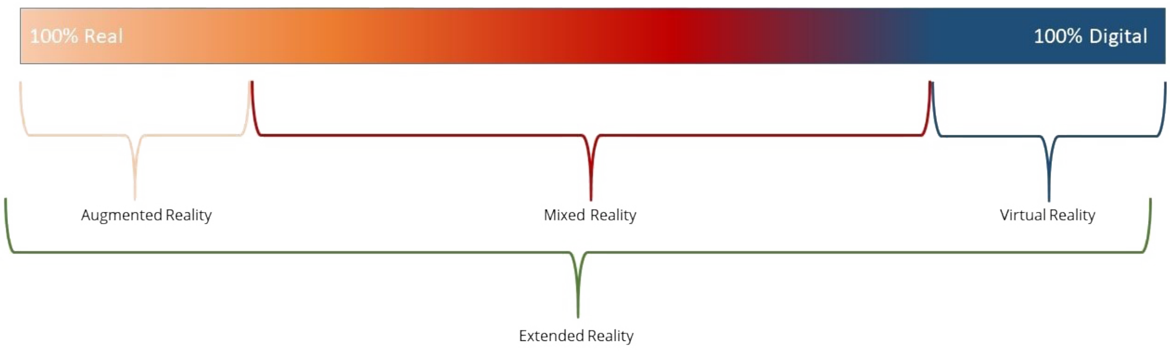

Figure 5.1: Extended Reality (XR) Spectrum

Functionality
To access the technology, the user needs various media in the form of hardware (HW) and software (SW).

VR technology uses software, databases, and a powerful VR engine to create virtual realities that are displayed to the user on a headset.

The aim is to enable the user to immerse themselves in a virtual world that is as realistic as possible. Using a connected input device (e.g., a motion-controlled controller), the user can influence the virtual world displayed via special VR headsets. This shields the user from the real world and is capable of transferring the wearer's head and even body movements to the virtual camera and thus to the virtual representation.

A VR engine calculates the necessary computer graphics and necessary adjustments in the virtual environment in real time. Photorealistic effects enable complete immersion in virtual reality, with the user perceiving the simulated reality as "real." This effect is called immersion. [39]

In contrast, AR technology aims to augment existing reality. For this purpose, the integrated cameras of an AR-capable display device are used, which capture images from the user's perspective and, based on these, continuously determine the user's position using tracking algorithms. [40]

Using this location information, virtual content, which is calculated using a real-time engine similar to VR, can be inserted into the displayed environment. The resulting augmented reality can be displayed, for example, via a smartphone, tablet, or AR data glasses.

MR technology combines these two technologies. The user looks directly through special MR glasses, which use various sensors and cameras to capture the space in three dimensions, calculate the position and orientation of objects in the space, and place the objects at the appropriate locations.

Thanks to the special features of the MR glasses, the user is able to influence the displayed information (e.g., overlays) through natural impulses such as eye movements, gestures, or speech. In addition, external influences such as objects are directly captured and immediately available for further processing.

The goal of MR is to blend the user's natural perception with virtual aspects in order to expand the perceived reality and interact simultaneously with the virtual and real environment.

Figure 5.2: Use of AR, VR and MR

5.1 Establishment of XR as an Industrial Application

The origins of XR technology lie in the field of multimedia and gaming. Continuous technological advances have made VR technology increasingly affordable compared to its beginnings in the 1990s, making it a marketable product for the consumer market. The establishment of the smartphone and the use of tablets played a significant role in this.

The first VR headset was available for purchase on the consumer goods market as early as 2014. [41]

AR technology gained worldwide recognition in the consumer market in 2016 through the game "Pokemon Go." By 2018, it had been downloaded one billion times. [42]

Figure 5.3: Pokemon Go

AR technology has been further integrated into the user behavior of private individuals over the years. It makes everyday tasks easier for users and opens up new possibilities for interaction. A popular optional feature in cars is the head-up display, which projects important data, such as speed or navigation instructions, onto the windshield. This technology, which originated in aviation, allows the driver to record important driving data without having to take their eyes off the road.

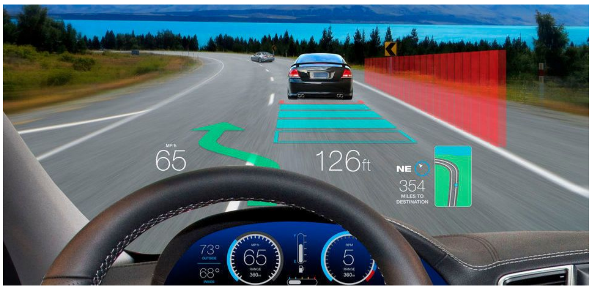

Figure 5.4: Using AR in the car: Head-up display

The possibilities of XR are now not only being used in the commercial sector, but are also being used in industry. They are considered future technologies with broad application potential. In 2018, sales of XR technology in the business-to-business (B2B) environment amounted to 521 million euros, with a projected sales increase of over 50 percent within two years.

5.2 Industrial Applications of VR

The advantage of VR technology is the creation of a parallel reality. Especially in industrial environments, non-existent objects can be represented. For the first time, this makes it possible to easily analyze and test previous designs, as the required data can be quickly compiled and displayed.

Factory Planning and Production Development
Important success factors for efficient production planning are a well-thought-out structure and coordinated processes. The approach taken during the planning phase of a new factory or machine determines how efficiently a facility can be used for its intended purpose in later operation.

The use of VR can significantly improve this planning phase, as factories and facilities can not only be drawn on paper or on a computer, but can also be virtually explored. The factory can thus be viewed in advance from all angles, allowing walking routes and machine placement to be optimized and hazardous areas to be identified.

It is also possible to simulate and evaluate various scenarios for installing storage areas in order to optimize the planning process. By using 3D objects and virtualized data, the complex processes of mechanical, electronic, and software development can be mapped during the planning phase to optimize their time and efficiency.

The quick and relatively simple trial and error process enables extensive data collection. This data can then be evaluated and used, for example, in a continuous improvement process. The use of VR technology enables the early identification of improvement opportunities. Furthermore, layout errors can be identified early and corrected before implementation. This leads to significantly more efficient use of funds, time, and labor. Furthermore, error costs during planning are reduced, potential repair costs are avoided, and production is fully operational more quickly after commissioning.

Figure 5.5: Factory planning with VR

Product Development

Using VR in product prototyping allows those involved to virtually view the current development status of a product, including existing features. A high level of data is necessary for a realistic representation of the product. The use of computer-aided design (CAD) models can help with this.

The CAD models are converted into a VR prototype using special software and integrated into a VR application. Complex and previously intangible technical drawings can now be perceived by the user with just a few glances.

This approach can support the product concept as early as the pre-design stage and prevent potential malfunctions or design errors. The engineers, designers, and constructors involved can interact with the prototype and test possible use cases in advance.

Within the framework of User-Centered Design (UCD), the customer can not only participate in the development process, but also become a part of it. In addition to the opportunity to test various ideas or gain a holistic impression of the prototype, ergonomic product modifications or overall concepts can be precisely reviewed, tested, and adapted according to the customer's wishes.

Conformity with the requirements defined in the specifications[43][1] can be verified, and functionality can be validated through tests and simulated practical applications. By using VR prototyping, physical prototyping can be partially or completely replaced. This leads to enormous savings, as a physical prototype does not have to be created in a complex and time-consuming manner. The customer benefits from early and intensive participation in their product.

Figure 5.6: VR Prototyping

Trade Fairs and Customer Presentations

The size of a medium-sized trade fair stand is approximately 25 m^2. The exhibitor usually pays for this per square meter.

In reality, the exhibitor is limited by the physical size of their stand, and consequently, the number of exhibits is limited. Therefore, it is important to carefully consider in advance which products from the portfolio will be brought to a trade fair, and how many.

The possibility of VR at least partially relieves this limitation. By designing virtual exhibition stands of any design, the company can present any product to visitors and even simulate its functionality. The virtually limitless possibilities in virtual space also allow for the selection of the setting and other sales-promoting effects. Visitors can change their perspective and viewing angle at will and are not bound by normal physics within virtual reality. This allows them to examine a product from all angles, from the inside, and even zoom in.

While a traditional trade fair stand presents a significant logistical challenge, a virtual trade fair stand requires comparatively little technology. It is easy to transport and therefore suitable for use beyond trade fairs. VR can also be used for sales events or product demonstrations, for example. This represents significant time and cost savings, especially for larger products such as production equipment, cars, or aircraft. Furthermore, an interactive product presentation

1 According to the business dictionary, the specifications are a written document containing all technical, economic, and legal details of a tender.

offers potential customers a more lifelike experience than traditional slides or brochures. [44]

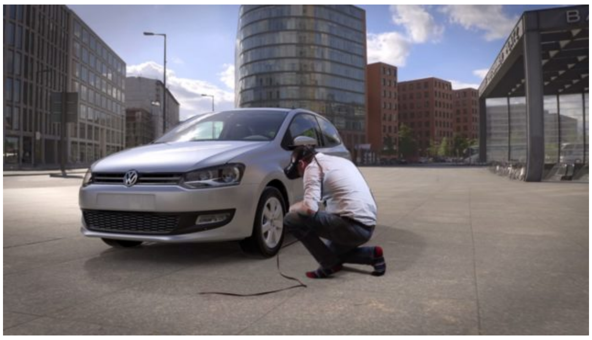

Figure 5.7: Product presentation with VR

Training
By integrating VR into training concepts, completely new, varied, and interactive training courses can be designed. By decoupling from reality, resources are not tied up for training purposes, and the trainee can operate independently of time and place. The trainee is placed in a realistic situation without the company having to create the actual framework. Critical situations with high risk potential can be trained without exposing anyone to danger. In addition to particularly critical situations, even very rare situations can be trained with a high degree of realism and little effort, without requiring extensive preparation or compromising the depth of the training.

The reduction in risk during hazard exercises enables the trainee to complete training more independently. Training for certain content no longer requires supervision, as training content is automated, reducing the risk potential. The training simulations can be repeated as often as required, allowing for adaptation to the individual learning pace. Furthermore, the trainee needn't worry about errors and their consequences, as the simulation has no impact on reality, thus ensuring ongoing company operations remain unaffected.

Finally, capacities in other areas aren't lost and can be used more efficiently through the use of AR, thus reducing personnel costs within the training area.

Figure 5.8: Training with VR

Industry Example
Bell Helicopter was the first to design the FCX-001 *(see Fig. 1.12)*, the company's first helicopter, using VR technology. It typically takes five to seven years to design a helicopter. By using VR technology, Bell Helicopter was able to design the FCX-001 in less than six months. From the very beginning of the design phase, engineers were able to work with the complete virtual model and draw on the experience and assessment of test pilots.

Test pilot feedback regarding the virtual model was collected, recorded, and implemented in the early stages of development. The use of VR technology resulted in enormous time and money savings for Bell Helicopter.

Figure 5.9: Designing with VR

5.3 Industrial Applications AR

Production and Assembly
In production and assembly, AR is used to display a virtual dashboard in the employee's field of vision, which, for example, lists the next work steps. Employee inputs are made via gesture control. This form of operation allows them to use their hands exclusively for activities within the assembly and production process. The execution of each individual step is recorded in real time and documented as completed after completion.

Reducing information to the aspects relevant at the moment prevents distractions, promotes concentration, and prevents work steps from being overlooked. The need to acknowledge warnings such as "protective clothing required" or "dangerous area" brings potential hazardous situations to the employee's attention and increases their awareness of them. The advantage arises from the fact that the assembler can see the work steps in detail, which they would not normally look up in conventional documentation. A uniform work and procedure is established within the company, leading to consistently high quality. If a new process or a change in procedure is introduced, it only needs to be implemented once and is then integrated into the "instructions" for all employees.

Figure 5.10: Produktion mit AR

Training new employees
By using AR, the training time for new employees in processes can be significantly shortened, as detailed instructions for the various procedures are available via AR. The best practices

were previously stored in the form of step-by-step instructions, taking the documentation into account. Employees with specialized knowledge regarding a particular product or project, or those changing departments or companies, can record their procedures in the form of instructions. By creating such a knowledge database, the knowledge can be made available to all employees at any time.

Figure 5.11: Einführung mit AR

Production Controlling Using AR, production employees have the opportunity to view machine status, diagnostic, or parameter data virtually and in real time. Discrepancies, discrepant production figures, and problems are brought into focus and identified more quickly. Malfunctions become visible even from a greater distance, when inspecting the system, for example, from an elevated vantage point.

In addition, the displayed information can include service information, such as upcoming maintenance and the contact details of the service partner, to enable quick and smooth interaction and reduce downtime. [45]

Industrial Example

Engineers at aircraft manufacturer Boeing use AR systems to display the circuit diagrams of aircraft wiring in their field of vision. This approach allows them to keep their hands free for wiring and focus on their task. This measure reduced working hours by 25 percent and increased productivity by 40 percent.

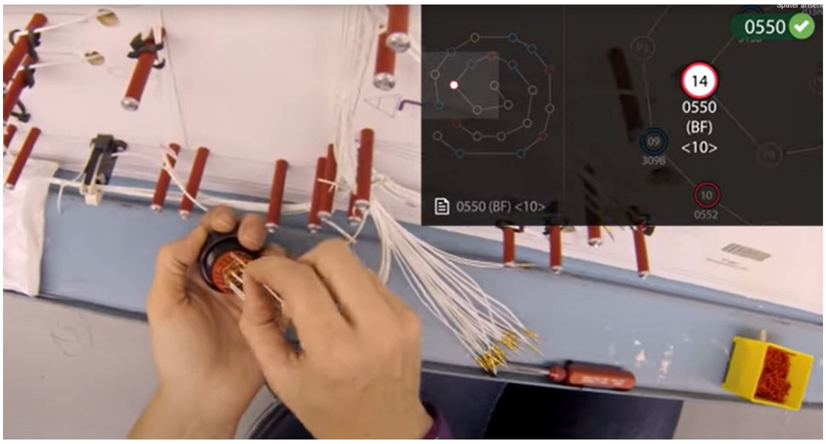

Figure 5.12: Aircraft cabling with AR

5.4 Industrial Applications of MR

Installation, Commissioning, Maintenance, and Repair

MR enables a company to pool its employees' knowledge and utilize it efficiently. During installation, commissioning, and maintenance, the company employee can connect to an expert or engineer via MR if problems or questions arise. The expert or engineer can view the situation through the employee's eyes, analyze it, and draw the necessary steps into the employee's field of vision using symbols such as arrows. The expert can guide the employee through the situation step by step until the employee resumes their work.

Handling such situations with MR either avoids the need for cumbersome explanations of the situation over the phone or prevents an inadequate view of the problem, for example, from only one camera perspective. The goal should be to obtain the highest level of information in order to initiate an efficient approach, minimize downtime, and prevent personal injury and property damage.

Furthermore, it is not necessary for the expert to travel with the employee during more complex incidents, thereby interrupting other projects and incurring additional travel costs. The experts are only involved when necessary, and staff can be deployed more efficiently.

Figure 5.13: Maintenance with MR

Logistics

If the appropriate software, hardware, and tracking system are available in the warehouse, the MR can assign the products to the respective storage location. The picker is navigated through the warehouse to the product's corresponding storage location using the most efficient route. The location, time lag, and viewing angle are recorded, and relevant, situational information is integrated into the picker's field of vision in the form of virtual objects.

Navigation arrows guide the picker along the optimal route to the storage compartment and continuously adapt to the viewer's viewing angle to continue directing them to the appropriate storage compartment. A storage compartment is highlighted, for example, by a red mark. The use of MR in logistics replaces Pick by Light technology, which requires complex implementation of the technology in the warehouse.

In der Verpackungslogistik kann durch die MR profitiert werden, da sperrige Teile, für die keine Standardverpackung existiert, von den integrierten Kameras vermessen werden können. Die Suche nach einem Behältnis wird eigenständig eingeleitet und die vorhandenen Verpackungen mit den Maßen des Objektes abgeglichen. Ist keine Verpackung kompatibel, kann der Auftrag zur Neuproduktion angestoßen werden. Der Prozess wird beschleunigt, da das umständliche manuelle Maß nehmen und dokumentieren obsolet wird.

Figure 5.14: Warehouse logistics with MR

Training
MR technology is suitable for training sessions where the trainer and trainee are located at different locations. Controlled training is possible because the trainer sees on their tablet what the trainee is currently seeing through their eyes. The trainer can give instructions to the trainee by drawing virtual objects in their field of vision, thus training them for a wide variety of actions.

This concept significantly reduces travel costs and enables comprehensive and flexible training concepts, despite possible travel restrictions.

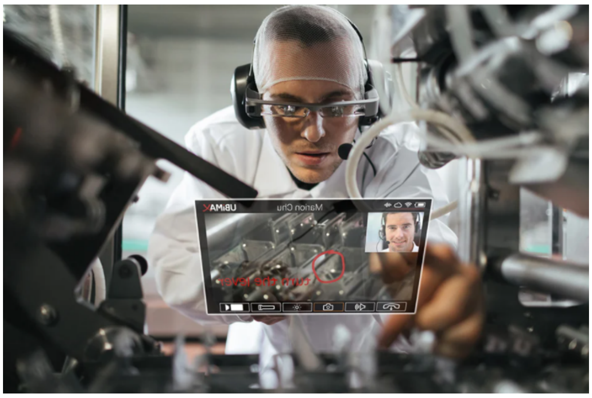

Figure 5.15: Training with MR

Industry example
Thyssenkrupp equips its elevator service technicians with MR glasses to reduce elevator maintenance time. With the help of MR, the service technicians can visualize specific characteristics of an elevator in advance. On-site, the service technicians have access to the elevator's real-time technical data and can request support from company experts via video call at any time if problems arise.

According to the company, the use of MR has led to a significant reduction in maintenance time. After successful tests, a number of buildings, such as the One World Trade Center in New York, were equipped with the technology.

Figure 5.16: Elevator Maintenance with MR

5.5 Opportunities and Risks of XR

On the one hand, the use of XR offers new opportunities:

- **Communication:** Actions that are difficult to explain can be visually presented step by step (AR). Understanding of systems and machines can be trained more quickly and in more detail.
- **Efficiency:** More sensory organs are addressed simultaneously, and data is visually presented in relation to one another (XR). Mechanical and electronic processes can be captured more quickly (AR).
- **Cost Savings:** Products and systems do not need to be physically or physically present to be viewed.
- **Quality:** A detailed representation of data, design, and interaction is possible during the planning phase. Errors can be identified early and their frequency reduced (VR). Detailed instructions for actions in the field of vision allow the installer to act with their hands free and strictly follow the instructions (AR).
- **Safety:** Warning messages displayed in the field of vision signal that caution is required directly before a dangerous situation occurs (AR).
- **Employee recruitment:** New and exciting technologies boost employer attractiveness as well as employee satisfaction and retention.[46]
- **Reduction in travel:** Many processes can be explained, demonstrated, or simulated remotely using XR. The reduced need for travel significantly reduces travel costs and enables flexible employee deployment.

However, these advantages of XR are also offset by some risks:

- **Acceptance:** Employees may have problems with the new technology, may not want change, and may reject the new possibilities. Older employees or those with little technical background are particularly affected. If acceptance of XR technology is not present among all employees, the opportunities and benefits cannot be fully exploited. Measure: Explain to employees the advantages they will gain from using the technology and involve them early on, for example, by jointly defining emerging processes. Training all employees in the use of the new technology and the new processes is essential.

- **Data protection:** Employees may develop the feeling of being monitored. Measure: Explain to employees in detail what data is recorded through the use of the technology, address concerns, and find solutions together.
- **Technical infrastructure:** The implementation of the new technology requires the appropriate Wi-Fi coverage and server infrastructure, as well as high computing power. Measure: Involve the IT department in the planning process early on to ensure timely action can be taken in the event of inadequate infrastructure.
- **Legal aspects:** Legal gray areas can arise when using XR for services, as such incidents are not specified in the contract. Measure: Before introducing XR technology into the service, the contracts must be reviewed and revised to define the procedure for incidents related to XR technology.

5.6 Summary

Extended Reality (XR) encompasses and describes all gradations between reality and virtuality. Within XR, the technologies of Virtual Reality (VR), Mixed Reality (MR), and Augmented Reality (AR) can be distinguished from one another. In VR, objects are displayed in a virtual environment. This technology can be used in industry to display, communicate, or analyze information, products, or processes that are (not yet) available or currently not available. AR technology projects virtual information onto the real world. It is used in industry when existing data needs to be communicated and analyzed compactly and in a situation-dependent manner. Mixed reality combines aspects of VR and AR and enables interaction with the real and virtual worlds simultaneously. The use of MR is suitable for optimized communication between two parties and for instructions, as it allows viewing through the user's eyes and placing virtual elements in the field of vision. All three technologies have different fields of application within industry. The opportunities offered by XR lie in the areas of rapid and targeted data acquisition, analysis, and communication, as well as cost and effort reduction. In terms of industrial use, these technologies are often referred to as "the future" and, through new types of interaction, open up new possibilities throughout the entire product development process. Risks are to be expected in the areas of acceptance within the company, technical infrastructure, and undefined procedures in the event of disagreements between the company and the customer. However, these can be counteracted through forward-looking and prudent handling.

CHAPTER 6

Blockchain Technology

Learning objectives

After completing this chapter, you will know . . .

... what blockchain, hash values and hash functions are.

... how data transactions are encrypted.

... the Proof of Work and Proof of Stake concept works.

... what are possible application fields.

... what opportunities and risks blockchain technology brings along with it

Introduction

In simplified terms, a blockchain is a database that is not located centrally on a server, but is distributed across the computers of thousands of users. This is why it is also referred to as a decentralized database. The individual data records (blocks) are linked together using cryptographic processes.

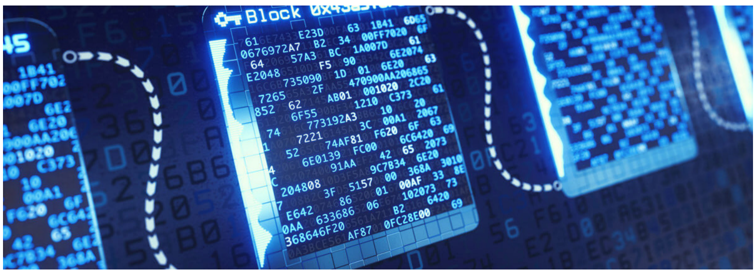

Figure 6.1: Block-Chain - eine kontinuierlich erweiterbare Liste von Datensätzen.

Blockchain technology became widely known through the cryptocurrency **Bitcoin** in 2008, when the article "*Bitcoin: A Peer to Peer Electronic Cash System*" was published by an unknown person or group named Satoshi Nakamoto.

This document contains a decentralized electronic payment system that allows financial transactions to be processed without third parties. In computing, this is understood to be a **peer to peer** network, i.e. a group of devices that store and use files together. Each participant (**Node**) acts as a single peer.

Since blockchain technology is only at the beginning of its development, no uniform definition has yet been established. Schär and Berentsen define blockchain technology as a distributed peer-to-peer network of electronic registries in which the individual data blocks are chained together [47].

Technical solutions for secure and verifiable transaction settlements between different actors are a particularly challenging area and companies should consider blockchains for their operation (Figure 6.2).

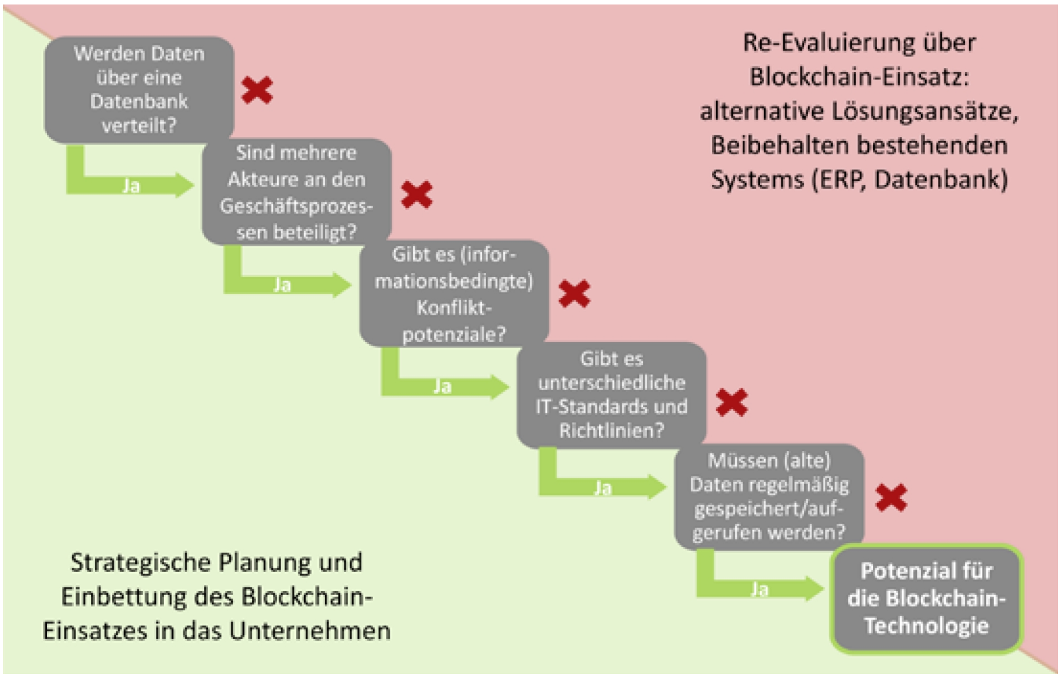

Figure 6.2: Entscheidungspfad Blockchain-Einsatz im Unternehmen [48].

6.1 Distributed Ledger (DLT)

To ensure that a chronologically ordered record of transactions is maintained, the **distributed ledger technology**[1] is applied. A **consensus mechanism** (such as proof of work) is used to decide how to add new transactions to the blockchain and how to validate existing transactions. It ensures the correctness of the result with the least amount of time and computational effort [49].

In blockchain technology, data resides in a distributed network architecture. A distributed network consists of nodes that communicate with each other and store the blockchain data **redundantly**. A node (network node) is defined as independent computers that communicate and synchronize with each other. The failure of one computer does not affect the other computers, because each node stores a status of the system. The network of the **internet** is basically **decentralized**, but it uses **linear** or **centralized** schemes through determined connection paths aswell.

In a **centralized system**, on the other hand, all participants trust a central instance. This system is often used for communication, in which the central instance controls compliance with the rules. The distinction between centralized, decentralized and distributed networks is shown in figure 6.3.

1 **Distributed ledger technology** describes a public, decentralized database that ensures participants share, read and write permissions.

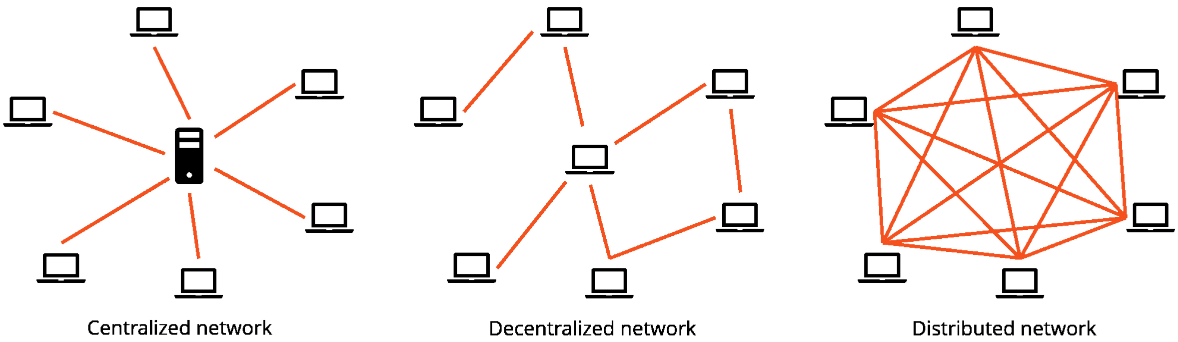

Figure 6.3: Netzwerk Topologie [50].

6.2 Hash Values and Hash Functions

The term **hash** means to chop something up or to scatter something and is used in blockchain for data storage and cryptology. Since the blockchain technology is based on **hash references**, a comprehensive knowledge of this component is important.

In general, hash-references refer to data that is stored in a different location than the reference. Here, the hash reference itself has its own hash value, which results from the combination of the stored data and information. Such a structure is useful when storing and linking data, since there is an exact and change-sensitive data reference.

A **hash function** is a function that maps a string of any length into a string of fixed length, called **hash value**. This hash value is collision-resistant, since there are no two input values for the same target value. A hash function is a kind of **digital fingerprint** that is able to uniquely identify a content.

Blockchain technology uses a variety of hashing algorithms, e.g. Bitcoin and other cryptocurrencies use the **Secure Hashing Algorithms (SHA-256)**[1]. Cryptographic hashing allows the encrypted transactions to no longer be traced back to the input data, as they are one-way functions [51].

1 **SHA-2** is the generic term for the cryptological hash functions SHA-224, SHA-256, SHA-384, SHA-512, SHA-512/224 and SHA-512/256, which have been standardized by the US National Institute of Standards and Technology (NIST) (as successor to SHA-1).

6.3 Asymmetric Encryption and Digital Signatures

In blockchain technology, **asymmetric encryption** and **digital signatures** are used to authorize transactions and identify accounts. Both proceedings work with key pairs, a non-secret **(public)** and a secret (**private**) key (**public-key method**).

Unlike a symmetric cryptosystem, the communicating parties do not need to know a common secret key. Each user generates his own key pair, which consists of a private and a public part.

The public key enables anyone to encrypt data for the owner of the private key, verify his or her digital signatures, or authenticate him or her.

The private key allows its owner to decrypt data encrypted with the public key, generate digital signatures or authenticate oneself.

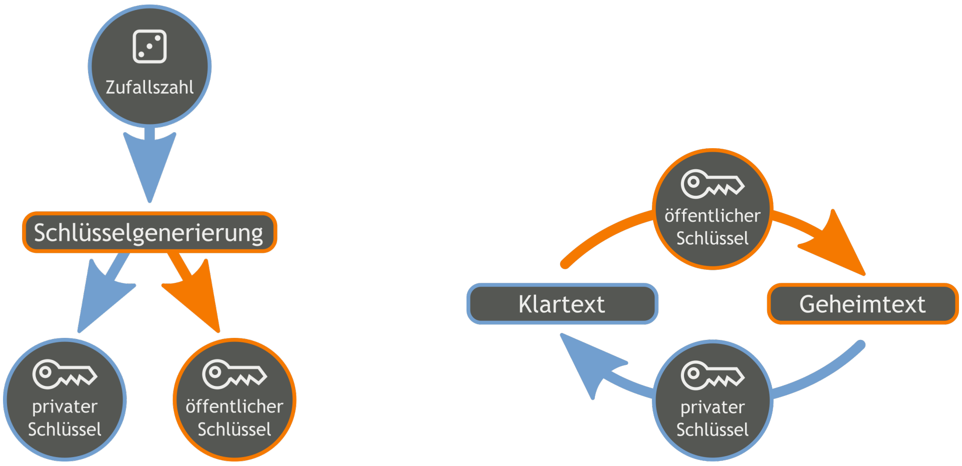

Figure 6.4: Erzeugung eines Schlüsselpaars und Verschlüsselung bzw. Entschlüsselung.

In case of the **digital signature**, the sender first generates a hash value of the data package and encrypts this hash value with his private key. This encrypted hash value is called a digital signature. The recipient receives both the data package and the digital signature. To decrypt the digital signature, the recipient can use the sender's public key and compare the resulting hash value with the hash value he calculated.

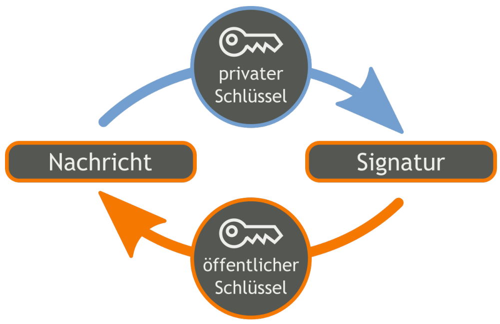

Figure 6.5: Signieren mit privatem Schlüssel und Verifikation mit öffentlichem Schlüssel.

If the two hash values match, the recipient can be sure that the message has not been manipulated. Within the Bitcoin blockchain, the digital keys are created and stored in a database called **wallet** [52].

6.4 Merkle Tree

The structure shown in figure 6.6 is called a **Hash Tree**[1] or **Merkle Tree** and stores individual transactions. The goal is to express multiple transactions by one hash value. For this purpose, the hash values are repeatedly added up until only one hash value remains. The hash values for the individual transactions are also referred to as **hash references**, which are then in turn grouped in pairs to form hash values 5 and 6.

This process is carried out with several transactions until only one hash value remains. This represents the **root** of the Merkle tree. Manipulations are quickly identified, because when the content of the transaction changes, the hash value of the transaction and all resultants change.

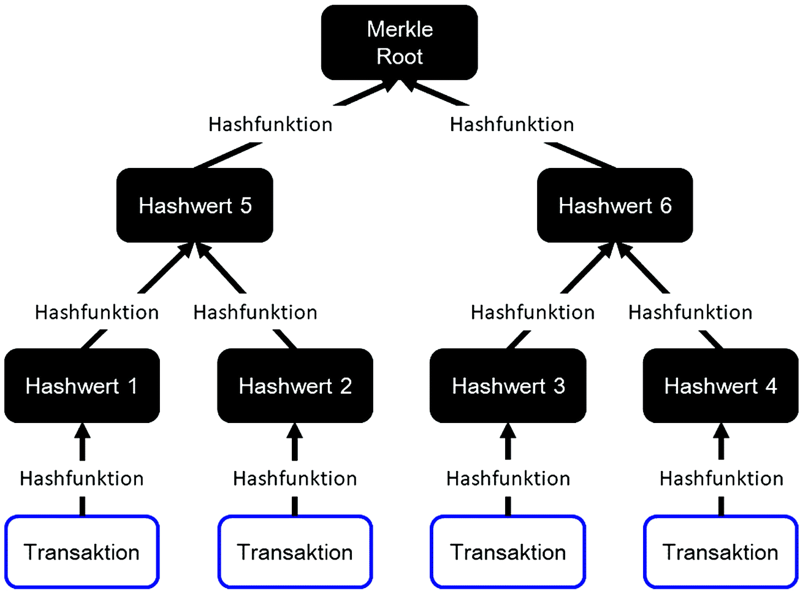

Figure 6.6: Merkle Baum

6.5 Consensus Mechanisms

Blockchain technology is based on a pure peer-to-peer network in which several computers are connected to each other and have almost equal access to the data in the blockchain. The consensus mechanisms are intended to protect the freely accessible network from forgery and manipulation.

Since blockchains do not usually operate on a central network with a controlling entity, a **consensus** must be found among the participants. Consensus among all participants is required when new blocks are provided as additions to the existing blockchain. A variety of different consensus algorithms exist, with **Proof of Work** and **Proof of Stake** being the most commonly used concepts.

1 A **Hash Tree** (or Merkle Tree) is a data structure in cryptography and computer science.

Proof of Work

The proof of work concept is most commonly used in the blockchain and is applied, for example, to the cryptocurrencies Bitcoin and Ethereum. Changes to the blockchain chain can be manufactured by network participants called **miners**[1]. These miners are attemping to solve a complex task to find a random value that can only be found by randomly trying hash values.

If there is a match, the finder has permission to add the block. The other network participants are sent the new block with the found random number of the transaction and the block hash and check it for correctness. If there are no errors, the miner is paid a **reward**.

In general, the algorithm helps protect the network from numerous attacks, since an attack on the system requires a lot of computing capacity. The attacker would need to control more than 50 percent of the network to perform a manipulation. This is difficult to achieve on a large network.

The disadvantages, on the other hand, are that a large computing capacity of blockchain networks leads to **high energy consumption**. In addition, this computationally intensive search of the random value has limited application because costly hardware is required. A major challenge is the **scaling problem**, as increasing user transactions cause an increase in data volume and a possible delay in transaction confirmation [53].

Proof of Stake

The proof of stake algorithm wants to move away from the provision of computing power. The goal is to establish consensus among the network participants, as in the proof of work algorithm. One of the biggest differences is that there are no miners, but validators. A share system is used as the basis. Hence, the probability of participating in the formation of a block depends on the available value contribution, i.e., the **value contribute share**. This method assumes that participants must have a certain share of value deposits in order to participate in the formation of new blocks.

The deployed deposits are referred to as **stake**. The proof of stake algorithm has no direct reward as there is no competition as in proof of work. However, a **transaction fee** is required for validation and consensus building, which the validator receives. Also, unlike the proof of work, no new value deposits are created as rewards, since they are distributed in the system from the beginning.

The proof of stake concept is used, for example, for the cryptocurrencies Cardano, Algorand and, from 2020, for the second largest cryptocurrency Ethereum. General advantages are the decoupling from the computing power used and a higher throughput of transactions. A disadvantage is the tendency towards centralization, as participants with a high proportion of value deposits are preferred [54].

1 The word “mining“ refers to the collective use of a network’s computing power. Miners receive a reward based on how much computing power they provide to the network.

6.6 Chaining of Blocks using the example of Bitcoin

A block in a blockchain contains a structured record of any transactions. The computers connect to each other via a peer-to-peer network and receive all the information in the entire blockchain. When a blockchain is used for the first time, a **Genesis block**[1] is generated and all other blocks are attached to it. Table 6.1 shows the block header of a Bitcoin.

Data Volume	Block-Header
4 Byte	Version
32 Byte	HashPrev
32 Byte	Merkle Hash
4 Byte	Timestamp
4 Byte	Difficulty
4 Byte	Nonce

Table 6.1: Inhalt eines Blocks

The creation of a Bitcoin block takes place every ten minutes and is controlled by the difficulty level. In this defined time interval, a new block is created by a computer selected in the proof of work algorithm. With the help of the algorithm, the miners try to find the **nonce[2] (random number)**. The difficulty is a natural number and indicates how many leading zeros the hash value must have at least. By adjusting the difficulty (adjusting the leading zeros) to find a matching nonce, it is ensured that as the computing capacity increases, the time required to create a block remains constant.

In each new block, the hash value of the last valid block and a timestamp are included. This leads to the fact that the blocks are linked in a **chronological order** and additionally the creation time of the block is documented.

The Merkle hash is used to check the integrity of the data and transactions in a block. The Merkle tree described above combines all transactions into a hash that is stored in the block header. The Bitcoin version number indicates which block validation rules the block uses and helps to track changes in the protocol [55].

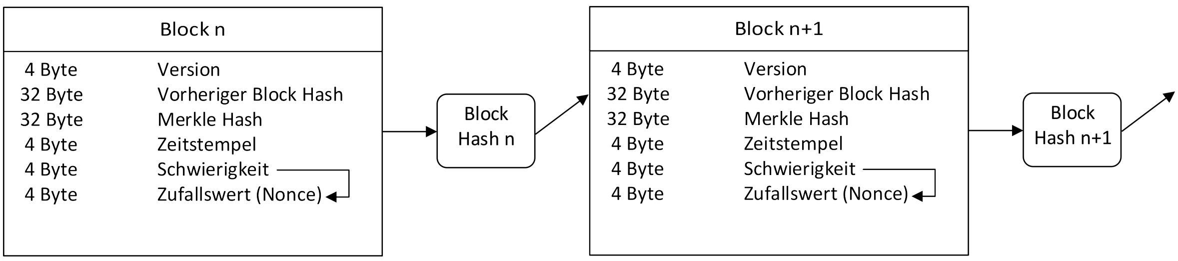

Figure 6.7: Block Kette angelehnt an [55].

1 The **Genesis block** is the very first block within the Bitcoin blockchain. Unlike all other blocks, it was not calculated by the network, but instead before Bitcoin was officially released. Furthermore, it is hardcoded into the source code.

2 A **nonce** refers to a temporary word, sequence of letters or numbers chosen for a short time with the intention of soon being replaced by something “better“.

6.7 Authorization Architecture

Generally, a distinction is made between **public** and **private** access to a blockchain system, but in some cases permission is required.

An example of public and permission restricted blockchain systems are all those, that use a proof of stake consensus process. Here, the **acquisition of value deposits** is the requirement to provide a proof of stake from a technical perspective. In the case of purely public networks, participants have full access regardless of their rights.

The private blockchain is based on the concept that not every application should be open for every user to read the records or perform validations. For example, because some systems are designed for internal company issues and are only useful for a specific group of users, the information should not be shared with others. Implementation of a network operator and a clearly defined **rights and access systems** are required.

An example of private and permission restricted blockchain systems may be confidential contracts, tax returns, or government application capabilities. In contrast, private and permission-free systems are used for licensing or supply chain traceability.

		Validierung	
		Permissionless	Permissoned
Zugriff	Public	Jeder darf lesen und validieren.	Jeder darf lesen, nur Berechtigte validieren.
	Private	Nur Berechtigte dürfen lesen, jeder darf validieren.	Nur Berechtigte dürfen lesen und validieren.

Figure 6.8: Klassifizierung der Berechtigungsarchitektur [56].

6.8 Fields of Application

Logistics
In logistics, blockchain forms an approach to unify all transactions and related information. Three important application areas within logistics are shipment tracking, risk management and self-control [57].

For example, the WHO estimates that there are 600 million cases annually of foodborne illness. One of the biggest challenges here is safety in the food chain. The automated and digital tracking of food products involves important criteria: Information regarding temperature, ripeness and quality of the goods must be retrievable, as well as data on the time of loading and unloading, and certifications and quality seals. Blockchains can provide the data at any time and prevent manipulation.

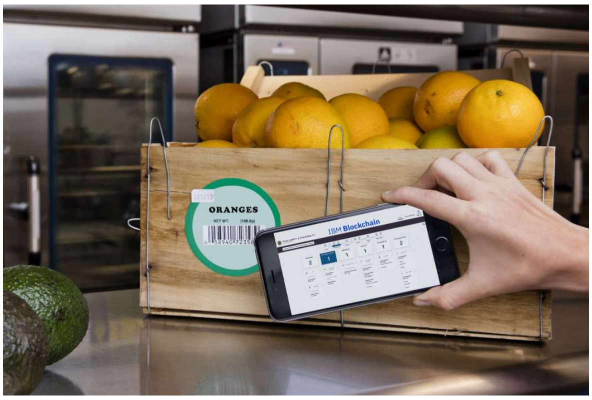

Figure 6.9: Mit Blockchain-Software kann man z. B. vertrauenswürdige Informationen über Lebensmittel verwalten. (Foto: IBM/Connie Zhou)

Smart Home
Today new-build residential units already have numerous smart home functions. However, a major risk with a smart home is security, because even a good firewall does not provide full protection. Accordingly, blockchain technologies could provide more security in this area.

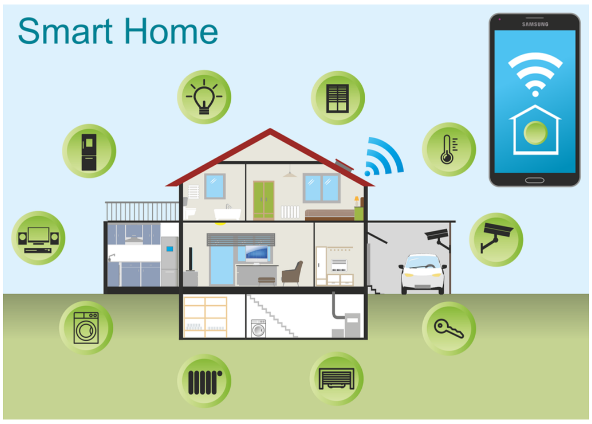

Figure 6.10: Blockchain-Technologie wird für größere Sicherheit im vernetzen Haus sorgen.

Smart Cities

Numerous major cities want to transform themselves into smart cities. This includes intelligent road layouts, adapted speed limits, automatic air measurements. New supply concepts such as smart grids for energy supply or charging stations with modern payment concepts are also part of this.

Figure 6.11: Blockchain-Technologie vernetzt die Smart City.

Digital Identities

Decentralized digital identities allow users to manage their own digital identities without depending on a central identity service provider where the data is stored. Instead, the user receives one-time digital certificates from trusted entities such as government agencies about certain personal identity characteristics, such as address or age, which they can then use for identification and authentication without further consent from the issuer.

The blockchain is used to guarantee the legitimacy of the digital certificates issued, which as such do not allow any inference to the personal data. Decentralized digital identities are of particular importance because they can be used to identify not only people but also, for example, machines or companies. Trustworthy, decentralized identities and certificates can make numerous processes more efficient, for example in risk and compliance management in the supply chain.

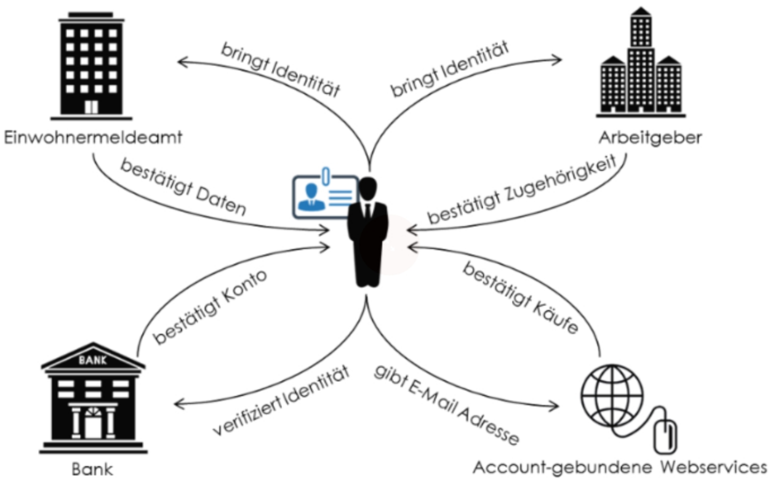

Figure 6.12: Blockchain-Technologie sichert die Identität.

E-Health

The healthcare market is considered one of the growth sectors of the future. New care concepts are already being established, and modern machines enable better diagnosis of complex clinical pictures. Digitalized health records can ensure better management of access rights.

Counterfeit drugs and their illegal trade are a major problem in the pharmaceutical industry. A secure and transparent value chain is elementary for guaranteeing drug authenticity and patient safety [58], [58].

In addition to national approaches with a central database system, such as **securPharm** in Germany, blockchain-based systems can operate without central instances.

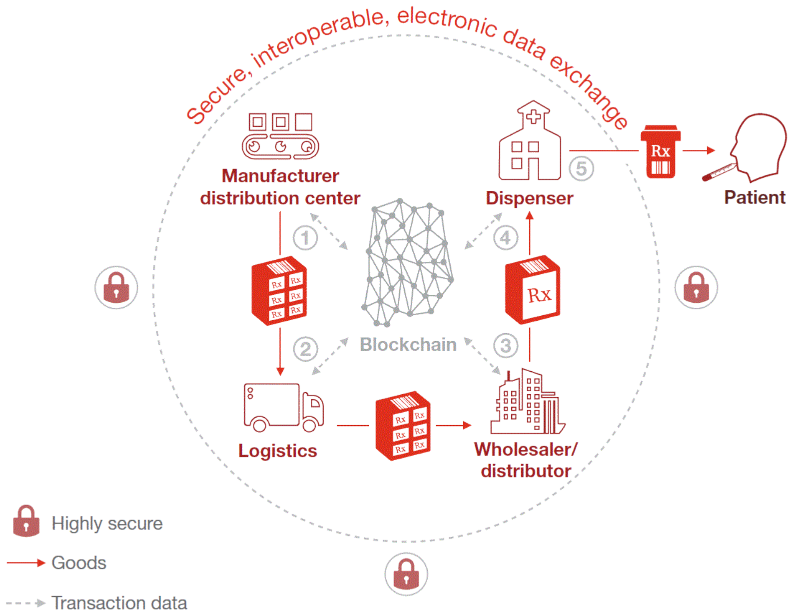

Figure 6.13: Blockchain-Technologie im Gesundheitswesen.

Smart Contracts

Smart contracts consist of software codes that represent a physical contract. The creation of smart contracts gives raise to a wide range of possible applications in finance, politics and administration, energy supply, and many other areas.

The first step describes a transaction input where a digitally verifiable result is triggered. In the next step, the program code processes the event and takes a legal action.

The testable result could be the delay of an airplane. If this is greater than two hours, the event is triggered and processed in the program code. In the case of flight delay insurance, the legal action is automatic compensation for the insured.

If smart contracts are implemented within a blockchain, the role of the **intermediary** is eliminated because trust is based on the consensus mechanism of the blockchain. Due to automation, transactions are executed significantly faster and at lower cost [59], [60].

Automotive and Mobility Industry

Our familiar mobility is on the verge of upheaval. Autonomous vehicles, new drive concepts and numerous new mobility concepts are flooding onto the market. In the future, the various vehicles will have to transact billions of times.

Smart contracts in combination with **M2M**[1] offer, e.g., the refueling of cars, which can take place autonomously and without the use of an intermediary.

In this process, the car and the gas pump recognize each other and exchange information about the payment and the gasoline demanded. The car interacts directly with the public blockchain and pays using a cryptocurrency. It has its own wallet and can use it to automatically pay for infrastructure and service.

In addition to refueling, it can be used in car sharing, parking and toll. It is a system that enables fast transactions between machines, vehicles and devices in the IoT (Internet of Things) [49].

Figure 6.14: M2M Kommunikation

Smart Grids - Decentralized Energy Supply

The energy industry offers another sector in which blockchain technology can be used in the future. Electricity is currently supplied via long routes from the energy producer to the consumer, as there are relatively few large energy suppliers. By decentralizing the supply of energy using blockchain technology, local energy producers and consumers could be connected to each other in a decentralized energy market. It can thus enable a secure and fast transaction between participants [61].

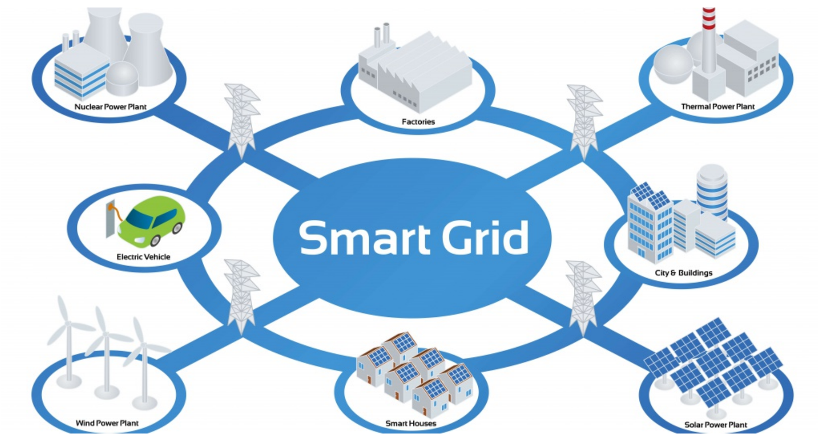

Figure 6.15: Blockchain-Technologie im Energiesektor.

1 **Machine-to-Machine (M2M)** refers to the automated exchange of information between end devices such as machines, vending machines, vehicles or containers with each other or with a central control station, increasingly using the Internet and the various access networks such as the mobile network.

6.9 Opportunities and Risks of the Technology

Even though smart contracts present tremendous opportunities, there are still risks, which are highlighted in the following list. [50].

Opportunities

- **Data availability**
  The data is stored redundantly and distributed to the nodes using a peer-to-peer network.
- **Irreversibility of the data**
  Data cannot be manipulated or deleted.
- **Decentralization**
  A consensus process ensures the trust of the participants.
- **Data integrity**
  Block chaining means that the data is logged in the time sequence in a traceable, comprehensible and secure manner.
- **Transparency**
  Each network participant has access to the database and can view transactions.
- **Automation**
  The programmability of transactions as well as the execution of a computer program (smart contracts) is possible.

Risks

- **High energy consumption**
  The proof of work consensus mechanism requires high computational power, resulting in high energy consumption.
- **Scalability**
  In a public blockchain, there is the challenge of scalability due to the large volume of data that must be exchanged between participants. Larger blocks enable higher transaction rates in the network, but increase the computational and communication overhead for the consensus mechanisms.
- **Legal Framework**
  Blockchain can operate without borders of nations, the transaction participants can be located in different legal jurisdictions.
- **Irreversibility**
  Specification or programming errors can have severe consequences, especially with smart contracts

.

6.10 Summary

Blockchain technology promises versatile fields of application, as it is a broadly applicable technology. The application examples cited from the areas of M2M, smart contracts or decentralized energy supply show that the technology has the potential to change wide areas of society. Nevertheless, there are still many challenges and open questions regarding scalability, anonymity and legal aspects that need to be clarified.

More and more research players and experts are dealing with the topic, and the Research Promotion Agency-FFG is also supporting a “Blockchain Startup Contest“ in which small companies receive financial support. Especially companies should engage in an exchange with international Blockchain experts in order to develop demand-oriented applications. Increased communication and information measures through conferences and increased media activity should also be considered.

CHAPTER 7

Cryptocurrencies

Learning Objectives:
After completing this chapter, you will know...

... what cryptocurrencies are.

... what the monetary system is and what functions it serves.

... how the technology behind cryptocurrencies works.

... which current cryptocurrencies exist.

... what application areas do cryptocurrencies have.

... what opportunities and challenges exist with cryptocurrencies.

7.1 Introduction

In recent years, a new element has become firmly established in the global financial system: cryptocurrencies. Initially conceived as a technical experiment, they have since evolved into a multibillion-dollar industry and are seen by many as the future of money.

On November 1, 2008, Satoshi Nakamoto introduced the concept of cryptocurrencies in an article titled Bitcoin: A Peer-to-Peer Electronic Cash System [62]. Two months later, on January 3, 2009, at the height of the financial crisis, Bitcoin was launched as an alternative to the traditional centralized monetary system. Today, in addition to Bitcoin, there are approximately 10,500 other cryptocurrencies (As of January 2025) [63].

But what exactly are cryptocurrencies, and what makes them so successful?

Cryptocurrencies are digital means of payment based on blockchain technology. This technology enables data to be stored immutably in decentralized networks, eliminating the need for a central authority [64]. The term cryptocurrency originates from the cryptographic encryption methods that form the foundation of this technology [65].

7.2 Origin and Functions of Money

To better understand the impact of cryptocurrencies on the existing financial system, we first examine the history of money and its fundamental functions before taking a closer look at today's monetary system.

7.2.1 History of Money

The history of money dates back approximately 10,000 years with the emergence of bartering. People tried to trade goods or services, for example, livestock for grain. However, this form of trade had a fundamental drawback: the so-called double coincidence[1] of needs.

For a transaction to take place, both parties had to have exactly what the other was seeking. To solve this problem, commodity money, also known as natural money[2], emerged.

Around 4,500 BCE, silver was first used as a form of money [67]. The first minted coins officially recognized as currency (see Figure 7.1) appeared around 700 BCE.

Figure 7.1: First minted coinage from the 7th century BCE [66]

Paying large sums with coins often proved impractical. For this reason, printed paper money was first issued as a means of payment in China in the 9th century CE. This paper currency had a physical reference to a precious metal and was therefore considered backed [67]. It could be exchanged for a tangible economic good, such as gold.
This system wcs later replaced by fiat money. Fiat money has no physical backing and thus no intrinsic value. Instead, its value is determined by the collective belief of market participants and is controlled by the government and central bank. Today, book money or giro money is widely used. These terms refer to demand deposits held in bank accounts for transaction purposes [68]. In the Eurozone, giro money accounts for approximately 80% of the circulating money supply [69].

7.2.2 Functions of Money

Economics defines money indirectly: money is whatever fulfills the functions of money [70]. The functions of money are classified into three fundamental roles [66]:

- **Medium of exchange:**
  Money facilitates the exchange of goods and services by serving as a universally accepted means of payment.
- **Store of value:**
  It allows individuals to separate buying and selling over time, enabling wealth accumulation and use for larger purchases.
- **Calculation unit:**
  Money simplifies economic transactions by providing a standardized measure of value. Instead of 4,950 possible exchange rates among 100 different goods, there are only 100 price tags [66].

1 Coincidence refers to the simultaneous occurrence of two events.
2 Natural money could include plant-based, animal-based, or mineral products with high value, long shelf life, and good storability. Popular forms included shells, snail shells, and tea [66].

7.3 Technology

Cryptocurrencies are based on blockchain technology and are stored in a decentralized peer-to-peer network[1].

For example, when a user wants to send their cryptocurrency as part of an exchange, a transaction is initiated. This transaction typically includes information about the amount of cryptocurrency and the recipient's address. These are then transformed into a hash value by a hash function, which converts any data into a fixed-length string. The hash value is then encrypted using cryptographic methods. There is a distinction between private and public keys of a user in this encryption method.

First, the hash value is encrypted with the sender's private key. This key remains secret [64]. The encrypted hash value is then attached to the transaction as a digital signature. If the data is subsequently altered, the signature and the transaction will become invalid.

The transaction is then transmitted to the network and is verified for correctness by each node using the sender's public key [71]. A node in the blockchain network represents a point that holds a copy of the blockchain, and thus maintains the network.

Once the transaction has been verified as correct, it will be added to a block in the blockchain along with other transactions. The number of transactions in a block depends on the size of the block. A new block always contains the transactions and the hash value of the previous block, thus forming a chain of blocks.
The new blocks are then verified using a consensus mechanism to ensure that all participants agree on a consistent and valid version of the block.

The two most well-known consensus mechanisms are Proof of Work(PoW) and Proof of Stake(PoS). In PoW, the so-called miners must solve complex mathematical puzzles to validate a transaction. The new block also includes a so-called nonce, which is used to validate the block [71]. In PoS, transactions are validated by validators based on the amount of cryptocurrency they own or "stake".
Once the block is appended to the blockchain, the transaction is considered complete, and the recipient can use the received cryptocurrency

Figure 7.2: Cryptocurrencies

New coins of cryptocurrencies can be created in different ways, depending on the consensus mechanism.

1 In a peer-to-peer network, equal users (peers) can communicate directly with each other or exchange resources without intermediaries.

In PoW, new coins are created through mining. Miners receive new coins as a reward for their work in the validation process.

In PoS, new coins are generated by staking. Validators stake a certain amount of their own coins as collateral to validate transactions. The more a validator stakes, the higher the chance of validating a block and receiving a reward. Therefore, PoS does not require extensive computational power.

New cryptocurrencies can also be created through Initial Coin Offerings (ICOs). In this process, the developers of the cryptocurrency offer coins to raise capital.

Cryptocurrencies fulfill the functions of money as defined in chapter 7.2 and therefore can be considered as money. As a medium of exchange or means of payment, cryptocurrencies are used as an alternative to traditional currencies and enable fast and cost-effective payments. There is no physical value backing these currencies, making them a form of fiat money. The value of a cryptocurrency unit is determined by the trust of the participants and their willingness to pay.

Cryptocurrencies also serve as an investment form with the potential for high returns and thus as a store of value. As a unit of account, stablecoins[1] are particularly suitable. For other cryptocurrencies, the high-value fluctuations present a challenge for their use as a unit of account. Unlike "regular" currencies, this is regulated by central organizations such as central banks. However, cryptocurrencies are independent of such institutions and are decentralized [64].

7.4 Current Currencies

The following table shows the five largest cryptocurrencies by total market value in US dollars available on the market in March 2026 (Mrd. ≙ US Billion, Bill. ≙ US Trillion).

ID	Bezeichnung	Gesamtmarktwert in $	Preis/Coin in $	Zirkulierende Menge an Coins
1	Bitcoin	1.44 Bill.	71.868	19.9 Mio.
2	Ethereum	225 Mrd.	2.218	120 Mio.
3	Tether	184 Mrd.	1,00	184 Mrd.
4	Binance Coin	90 Mrd.	664,12	136 Mio.
5	XRP	86 Mrd.	1,41	61 Mrd.

Table 7.1: The 5 largest cryptocurrencies in March 2026 by total market value [72]

Bitcoin:
Bitcoin was the first cryptocurrency and remains the strongest on the market worldwide. On January 3, 2009, "Block 0" , also known as the Genesis Block, was created, marking the creation of the first 50 Bitcoins. The Coinbase transaction[2] included the message: "The Times 03/Jan/2009 Chancellor on brink of second bailout of banks." This message reflected Satoshi Nakamoto's stance against the current financial system.

The exchange rate started at 1 Bitcoin = \$0.07. In April 2013, the Bitcoin price surpassed 200 USD. By the end of 2017, Bitcoin had reached approximately \$14,000. By November

1 A stablecoin is a cryptocurrency pegged to the value of another asset, usually a fiat currency.
2 The Coinbase is the first transaction recorded in a block of a blockchain.

2021, BTC continued to rise, peaking at $58,348. In 2022 and 2023, Bitcoin lost value again, dropping below the $16,000 mark. The approval of Bitcoin trading on the US stock exchange in January 2024 triggered a sharp increase to over $70,000. With the election of Donald Trump as the new US president, the increase intensified, and Bitcoin reached a new all-time high of $125,008.

Figure 7.3: Entwicklung des Bitcoin seit Beginn [73] https://www.blockchaincenter.net/bitcoin/bitcoin-kurs/

Bitcoin uses the energy-intensive Proof of Work (PoW) consensus mechanism. The current block reward[1] for miners has been 3.125 bitcoins per block since the fourth halving[2], plus mining fees.

Bitcoin initially started with a block size of 1 megabyte. With the implementation of Segregated Witness (SegWit) in 2017, a block can now be up to 4 megabytes in size [74]. Approximately every 10 minutes, a block is mined and added to the blockchain, which, given the current block reward, means that 450 new bitcoins are created each day. However, the Bitcoin blockchain can only process around seven transactions per second [75]. The number of transactions per block varies depending on their size. On average, a block contains between 2,500 and 3,000 transactions. Bitcoin transaction fees depend on network congestion and typically range between $1 and $4 [76]. The current circulating supply of Bitcoin exceeds 19.8 million[3], which accounts for more than 94% of the maximum total supply of 21 million bitcoins.

Bitcoin mining can be performed worldwide by any computer with a LAN connection. In 2024, over 40% of the global hash rate was concentrated in the United States. A significant portion of the hash rate comes from large-scale mining farms[4] and major mining pools[5].

For example, the company Riot Platforms Inc. has established one of the world's largest Bitcoin mining facilities in Rockdale, Texas, USA, with a maximum capacity of 700 megawatts [78].

1 As of March 2025
2 A Bitcoin halving automatically reduces the block reward once a predetermined number of blocks have been mined. It occurs every four years.
3 As of March 2025
4 A mining farm is a data center specifically equipped to mine Bitcoin or other cryptocurrencies [77].
5 A mining pool is a group of cryptocurrency miners who combine their computing power to contribute more effectively to transaction validation.

Figure 7.4: Mining farm in Rockdale, Texas, USA

In addition to the large Bitcoin farms, the trend towards mining pools is growing. In 2024, 38% of the US share of the Bitcoin hashrate was accounted for by the Foundry USA mining pool. This is currently also the largest pool in the world[1]. According to the Cambridge Bitcoin Electricity Consumption Index, Bitcoin mining consumed 121.13 TWh worldwide in 2023 [79]. As a reference, around 14 nuclear power plants with a capacity of one gigawatt would have to run continuously for an entire year to cover this energy demand.

According to a study, the generation of electronic waste through Bitcoin mining is estimated at around 30,700 tonnes per year [80].

Despite the negative news, Bitcoin is very popular as a currency and form of investment. It is known as the gold of modern times. Like gold, Bitcoin is hedged against inflation thanks to the quantity limit. In Germany, around 12% of the population own Bitcoin [76].

Bitcoin is the best-known cryptocurrency and currently the most valuable. However, other currencies have overtaken Bitcoin in a few factors, such as reducing environmental impact or increasing transaction speeds. However, projects such as the planned Bitcoin Lightning Network can generate improvements in the future.

Ethereum:
Ethereum is a digital platform that works with its own blockchain. The platform was published in 2015 by Vitalik Buterin, on which decentralised applications, so-called Dapps[2], can be created and offered by developers. The platform's blockchain (layer 1) currently comprises 5,962 nodes that are synchronised with each other[3] [81]. Layer 2 blockchains are separate blockchains that periodically write their data to the layer 1 blockchain to enable higher throughput and faster transaction speeds.

Within the platform, the proprietary cryptocurrency called Ether is used for transactions. As soon as a transaction is closed, a transaction fee called “Gas“ must be counted. The amount of the fee is calculated based on the size of the new block in the chain. Ether is perhaps the best known alternative to Bitcoin and therefore the largest altcoin[4].

1 As of January 2025
2 Dapps are open source software based on blockchain technology
3 As of February 2025
4 Altcoin stands for “Alternative Coins“ and describes crypto coins and tokens that were released as alternatives and successors to Bitcoin. Therefore, the term includes all cryptocurrencies other than Bitcoin.

Ethereum was introduced in 2015 by the programmer Vitalik Buterin. Like Bitcoin, Ether works within a peer-to-peer network that is completely free from state supervision and intervention. With the merge in September 2022, Ethereum switched from the PoW to the PoS consensus mechanism in order to move away from mining and become more environmentally friendly. According to an estimate by the Crypto Carbon Ratings Institute (CCRI), Ethereum's electricity consumption is more than 6 GWh, which is equivalent to approximately 2,000 tonnes of CO2 [82]. Another difference between Ethereum and Bitcoin is that the total number of Ethereum blocks is not limited. A new block is generated every 12 seconds. The ether currency was worth $1 in January 2016. Two years later, it broke the $1,000 mark and reached an all-time high of more than $4,800 in November 2021.

Tether:
Tether (USDT) is a stablecoin. A stablecoin is pegged to the US dollar so that, unlike most other cryptocurrencies, a relatively stable value can be guaranteed. This means that 1 USDT is usually always worth around one US dollar [83].

Tether was launched in October 2014 and is still controlled by the company Tether Limited. According to its own statement, Tether Ltd. covers each newly created USDT with one US dollar, but does not offer a direct exchange of USDT into US dollars. This statement can also be referred to as Proof Of Reserves. This means that at all times the reserves must be equal to or greater than the USDT in circulation.

In January 2015, the company iFinex authorised the trading of Tether on its exchange platform Bitfinex. Subsequently, the volume of Tether in the blockchain network increased rapidly. The US dollar transactions were forwarded through Taiwanese banks to Wells Fargo[1]. On 18 April 2017, such transactions were then blocked by US banks due to a lack of transparency. However, the volume of Tether issued increased to $2.8 billion [84].

In April 2019, the New York Attorney General filed a lawsuit against iFinex and Tether Limited for misappropriation of reserve funds. Two years later, iFinex and Tether Limited agreed to pay a fine of $18.5 million.
Despite these negative events, Tether is still mainly used on crypto exchanges today to quickly switch between cryptocurrencies and a stable currency.

XRP:
The cryptocurrency XRP, also known as Ripple, is the native cryptocurrency of the Ripple network. Both the network and the currency were introduced in 2012.
The Ripple network is an open-source platform from Ripple Labs that enables fast transactions of currencies, foreign exchange, and other goods. The platform was established with the aim of regulating all international transactions worldwide. Banks and other payment service providers should be able to use the software to process transactions. This means that Ripple and the cryptocurrency XRP are not in direct conflict with the current banking system, but are more of an updated version of the SWIFT transfer system currently in use[2].

The platform and therefore its cryptocurrency use a different technological approach to blockchain technology. With Ripple, transactions are processed via the so-called validation servers, which compare the data received with a decentralised database (ledger). Reaching a consensus is also different with the Ripple network. The so-called HashTree method is used, in which only a single value (hash), which serves as a summary of the data, is compared. This technology not only requires less energy and computing power than Bitcoin, for example, but also enables a high transaction speed of three to five seconds.

1 Wells Fargo is a US bank categorised as a global systemically important bank by the Financial Stability Board

2 The SWIFT transfer system has been using the Business Identifier Code (BIC) since August 2014 to uniquely identify participating banks and institutions and therefore also for all international transfers of assets.

The cryptocurrency XRP is mainly used on the platform for the transfer of values. At one point, 100 billion XRP coins were mined, of which only 58 billion are in circulation[1]. Despite the decentralised ledger, many critics accuse Ripple Labs of having too much control over XRP. Not only does Ripple Labs own over 40% of the XRP supply, but many validation servers are also owned by Ripple or close partners. However, Ripple or XRP remains an important player in the crypto sector, especially as an alternative to SWIFT transfers.

Binance Coin:
Binance Coin (BNB) is the currency of the crypto exchange Binance. The exchange was founded in June 2017 and is now the world's largest crypto exchange with more than 263 million users [86]. The spot trading volume of the last 24 hours[2] on the exchange is approximately 11.3 billion dollars, with Bitcoin accounting for more than 13% at just under USD 1.5 billion[3] [87].

The platform operates a double chain system. Two separate blockchains are linked together, reducing the load on the chain and increasing the speed and flexibility of applications. At Binance, cryptocurrencies are mainly traded on the fast BNB Beacon Chain. Smart contracts and applications from the decentralised financial system are supported on the somewhat slower BNB Smart Chain.

The currency has an upper limit of 200 million BNB. However, there are so-called quarterly BNB burning events in which BNB coins are removed from circulation in order to reduce the BNB supply to 100 million units, and thus generate an increase in value with a decreasing supply. The number of coins to be burnt is determined by a mechanism that is based on the BNB value and the number of blocks generated on the BNB chain.

BNB is used mainly to pay for different types of fees, such as trading or transaction fees on the Binance platform, as investors get a 50% discount on trading fees with BNB. As BNB is closely linked to Binance, its success depends heavily on the platform, which is also under global regulatory scrutiny.

More coins:
In addition to classic cryptocoins, there are so-called meme coins and Artificial Intelligence (AI) coins. Meme coins are cryptocurrencies that were inspired by internet memes[4] or trends, often with little or no fundamental benefit.

The first and perhaps best-known meme coin is Dogecoin (DOGE). This currency is based on the famous Doge meme with the Shiba Inu dog.

Figure 7.5: Logo Dogecoin [89]

1 As of March 2025 [85]
2 The spot trading volume refers to the total amount of cryptocurrencies traded on the spot market within a certain period of time
3 As of March 2025
4 Memes are funny photos or videos on the internet that are spread by media attention and provided with further funny comments from users [88].

DOGE was created in 2013 by Billy Markus and Jackson Palmer as a parody of Bitcoin. Unlike Bitcoin, DOGE has no upper limit, which increases inflation and price fluctuations. DOGE reached its highest value in June 2021 at €0.54/coin. The currency currently has a value of €0.16[1]. Despite the support from Tesla CEO Elon Musk, DOGE is mainly used for payments, tips, and donations, and not as an investment.

A second example of meme coins is the Trump Coin released on 17 January 2025. Three days before the inauguration of US President Donald Trump, 200 million coins of this coin were made available to the public. The current value of this coin is $10.95[2]. Other examples of meme coins are

- Shiba Inu Coin: Competitor to Dogecoin.
- Pepe Coin: Based on the "Pepe the Frog" meme.
- Floki Inu Coin: Named after Elon Musk's dog.

AI coins are cryptocurrencies that are associated with artificial intelligence (AI). They support the development of AI applications and the provision of AI services. To this end, coins are components of decentralised AI platforms that use the blockchain to process data securely and transparently. The publication of ChatGPT on 30 November 2022 has significantly increased public interest in AI, making AI coins an interesting investment opportunity. Currently, there are just over 80 currencies in the category "Artificial Intelligence" [90]. The three largest AI coins by total market capitalisation are currently NEAR Protocol, Internet Computer, and Bittensor.

7.5 Application Areas

Cryptocurrencies have long since developed beyond their original function as a digital means of payment and investment.

Decentralised Finance (DeFi):
As an alternative to the familiar financial systems, DeFi is one possible use of cryptocurrencies. DeFis are blockchain-based systems that give every user access to financial products such as cryptocurrency loans or credits without centralised institutions such as banks and are accessible anywhere in the world [91]. These systems are usually managed democratically, and each cryptocurrency holder has a vote. In DeFi applications, the Total Value Locked(TVL) is an important size indicator. TVL refers to the total value of assets deposited in the entire DeFi ecosystem.

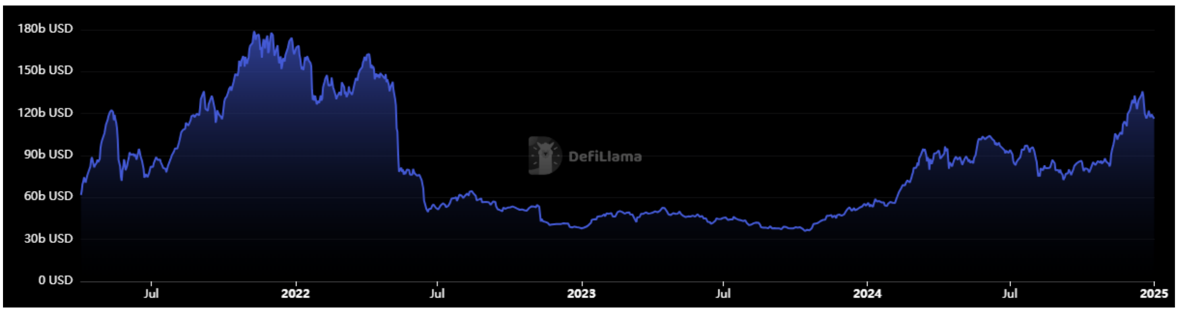

Figure 7.6: The development of TVL in DeFis since 2018 [92]

1 As of March 2025
2 As of March 2025

The maximum TVL in DeFi is currently more than $178 billion, which was reached in November 2022. In January 2025, the TVL was around $120 billion [92]. The two largest areas of DeFi are:

- **Borrowing and Lending:**
  By TVL share, borrowing and lending is the largest application of DeFi with a share of over 40% in January 2025 [92]. Users can provide their cryptocurrencies to a protocol, which then automatically lends them, and the lender then earns interest [91]. In contrast to conventional borrowing and lending, the hurdles here are significantly lower, as users only need to register with the crypto wallet[1] in order to participate in the system.
- **Decentralised Exchanges (DEXs):**
  With a TVL share of more than 15% in January 2025, DEXs are the second largest application of DeFis. DEXs enable their users to trade cryptocurrencies anonymously and, unlike traditional crypto exchanges, directly with each other.

Smart Contracts:
Smart contracts are a central field of application for cryptocurrencies. A smart contract is a program that stores codes and algorithms on a blockchain. These codes often contain simple "if-then" logic, i.e. the contracts are automatically executed when certain events occur [93]. These contracts are irrevocably saved on the blockchain and cannot be changed at a later date.

An example would be in the insurance sector. Currently, the conventional claim process often takes a long time, and the payment conditions are often complex. With smart contracts, clear conditions could be defined in the if function and the claim could be paid out automatically if it materialises. Smart contracts would increase contract security.

Non-Fungible-Tokens(NFTs):
NFTs are unique crypto tokens on a blockchain that are unique and non-exchangeable [94]. Ownership can be perfectly proven with NFTs. NFTs are used mainly in art and gaming. The most expensive NFT ever is The Merge by the artist Murat Pak. Over 312,000 pieces were purchased by 28,983 collectors at a total value of $91.8 million.

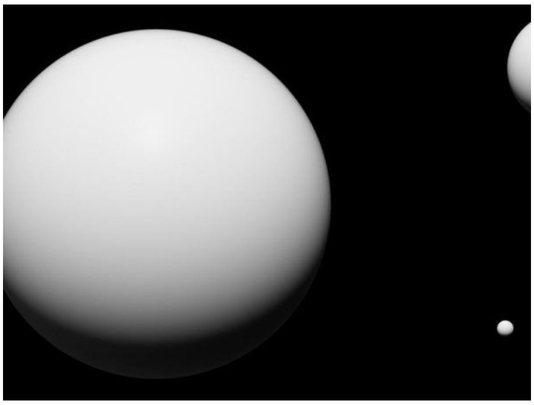

Figure 7.7: The Merge by Murat Pak

In gaming, NFTs are mainly used in blockchain gaming for unique items, avatars, or skins.

Supply chain management:
Blockchain technology and cryptocurrencies are also being used in supply chain management, where they offer significant advantages. In traditional supply chains, the lack of traceability of goods movements is a key problem that can lead to inefficiencies, fraud, and counterfeiting [95].

1 The user's private keys and thus access to the cryptocurrencies are stored in a crypto wallet

The decentralised and forgery-proof storage of transaction data on a blockchain means that every movement is fully documented and can be checked at any time.

This significantly improves traceability, for example, for the origin of raw materials or food. The use of smart contracts also enables the automation of important processes within the supply chain, while cryptocurrencies as a means of payment can reduce high transaction fees and exchange rate risks in international trade. In general, blockchain technology helps to increase the efficiency of supply chains, reduce costs, and strengthen trust between trading partners.

The various possible applications of cryptocurrencies show their enormous potential to transform traditional systems, open up new markets, and drive digitalisation in numerous industries.

7.6 Opportunities and Challenges

Cryptocurrencies offer numerous opportunities for business, technology, and cybersecurity, but they also present challenges that need to be overcome.

Opportunities:

- **Efficiency:**
  With blockchain technology, cryptocurrencies enable international transactions in seconds at low transaction costs. Transfers within the SEPA area[1] Transfers with banks can take up to four working days. Transfers outside the SEPA area take significantly longer. In addition, a fee of 5 to 10% of the transfer amount is charged [96]. With Bitcoin, the transaction fee is currently just under $1.30[2] and the average speed is around 10 minutes [97].
- **Anonymity:**
  Without the involvement of a central authority, cryptocurrencies improve data security. Financial transactions can be carried out without central monitoring.
- **Decentralisation and Transparency:**
  The decentralisation of data through the blockchain means that there is no longer a central point of attack for hackers. This data cannot be manipulated afterwards. All transactions within a cryptocurrency must be recorded on the blockchain, which greatly promotes transparency.
- **Innovation:**
  Cryptocurrencies offer a platform for new innovative technologies, such as smart contracts, that automate and optimise processes.
- **Independence:**
  Independence from central institutions means that cryptocurrencies and trading in cryptocurrencies are independent of location and opening hours. You can access and trade your cryptocurrencies around the clock from anywhere in the world and you don't have to wait for an exchange to open for trading that day.

Challenges:

1 SEPA (Single Euro Payments Area) refers to the Single Euro Payments Area.
2 As of March 2025

- **Environmental impact:**
  The biggest challenge of cryptocurrencies is the high energy requirement of PoW-based currencies. Many of the first cryptocurrencies use the PoW mechanism. Bitcoin, for example, has a higher energy consumption than some countries. However, the first currencies are already switching from Pow to PoS, which could provide a solution to the environmental impact of cryptocurrencies.

- **Blockchain trilemma:**
  The blockchain trilemma consists of scalability[1], security, and decentralisation. These three characteristics of a cryptocurrency are in conflict with each other and represent key challenges for the technology. For example, a high number of nodes in the crypto network poses a challenge to scalability. Each node has to check the transaction, which slows down the speed. However, with fewer nodes, decentralisation decreases, and with that the security of the data and cryptocurrency.

- **Volatility:**
  Cryptocurrencies are characterised by strong fluctuations in value, making them rather unsuitable as a means of payment and a challenge for many as an investment asset. During the last five years, Bitcoin has shown an average volatility[2] between 50 and 80%. The Dow Jones, on the other hand, only just under 19% [98].

- **Legal challenges:**
  There is still no standardised legal framework for cryptocurrencies. Some countries promote cryptocurrencies, others severely restrict them by law or ban them altogether. In nine countries around the world, the use and trading of cryptocurrencies is completely prohibited[3] [99].

- **Quantum computer:**
  With their revolutionary approach to data processing, quantum computers could pose a major threat to the security of blockchains and therefore also to cryptocurrencies in the future. They have the potential to solve complex mathematical problems much faster than conventional computers. Therefore, quantum computers would be able to break cryptographic encryption and use the public key to deduce the private key of a user.

7.7 Conclusion

Since the introduction of Bitcoin, cryptocurrencies have become a significant and disruptive technology. They could significantly shape the financial system of the future - whether by optimising existing structures, as with Ripple, or even by replacing the traditional system. The extent to which they establish themselves as a widespread means of payment depends largely on their social acceptance and the legal framework in the coming years. The development of quantum computers poses a growing challenge to their security and stability, which requires new solutions.

In addition, closely related technologies, such as smart contracts, offer great potential to increase efficiency and automation in various sectors, particularly financial services, industry, and insurance.

Overall, cryptocurrencies will continue to undergo an exciting and potentially revolutionary development. With technological advances and possible regulatory adjustments, they could transform the financial system in the long term and promote an increasingly digital, decentralised economy.

1 Scalability refers to the ability of a crypto network to handle an increasing number of transactions.
2 Volatility is a measure of price fluctuations.
3 As of March 2025

CHAPTER 8

The Working World of the Future - Work 4.0

Learning objectives

After completing this chapter, you will know . . .

... what Work 4.0 is.

... how Industry 4.0 will influence the working world of tomorrow.

... what challenges employers and employees must expect.

... how a socially acceptable transition to Work 4.0 can work.

... what contribution concepts such as the unconditional basic income can provide.

Introduction

In the course of technological progress and digitalization, there is a significant structural change in almost all areas of life. This also applies to the world of work, which confronts companies as well as employees with challenges in the same way, but also offers great opportunities.

8.1 The Industrial Revolutions

Due to far-reaching technical as well as social changes, several so-called industrial revolutions occurred within Europe from the second half of the 18th century onwards. Each of these phases brought with it new ways of working and therefore led to major changes in the world of work, which in turn led to a transformation and reorganization of the previously existing social and economic conditions. New and improved technologies and advances in science constantly drove development forward.

Figure 8.1: Development of work.

Figure 8.1 provides an overview[1] of the working worlds that emerged in the context of the four industrial revolutions, which are described in key words below.[2]

Work 1.0: : At the end of the 18th century, the revolution started from Western Europe and England. Mass production by machine. Wage laborers had no rights. Labor organizations emerged.

Work 2.0: At the end of the 19th century, the second industrial revolution brought electrification and mass production. Work was broken down into sub-processes (division of labor). Working conditions were improved.

Work 3.0: The third revolution in the world of work began in the middle of the 20th century. Computers and robots support human work. New forms of automation. Qualification of employees to become ”knowledge workers”. Introduction of the social market economy and increase in workers' wealth.

At the end of the 20th century, the widespread use of computers and Internet connections led to another profound change, known as Working World 4.0. This is characterized by globalization and connectivity, among other things.

8.2 Work 4.0 – an overview

The technological development of the last decades has revolutionized the industry (see Industry 4.0), in the course the working world is also affected by many changes. The resulting changes are various and are discussed under the term ”Work 4.0”. Some important aspects of the subject area are shown schematically in figure 8.2 and will be discussed in more detail in the following chapters.

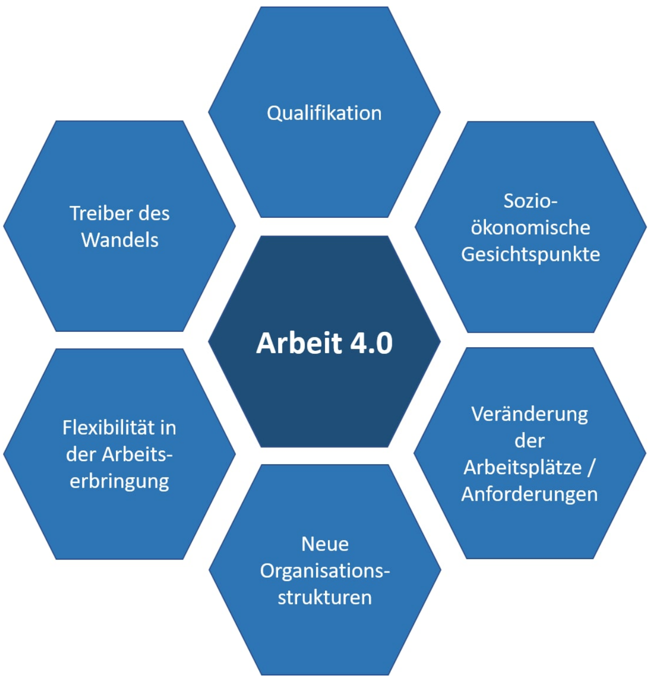

Figure 8.2: Important aspects of Work 4.0 concept (own illustration).

1 vgl. **(author?)** [101]
2 vgl. **(author?)** [102]

8.3 Drivers of Change

In addition to technological innovations such as digitalization and automation, the transformation of the working world is also being driven by employees themselves. Among other things, the generational shift is leading to a change in prevailing values and new demands on the world of work.

Technological Change/Digitalization

The technological advancements of the past decades have already found their way into today's working world. Production lines are already automated to an ever greater degree, leading to new requirement profiles, especially for skilled workers. Through the use of network-capable machines (see Internet of Things as part of the Industry 4.0 concept), machinery can already be monitored in **real time**, connected and controlled on the basis of the data collected. This is creating large volumes of data, the handling and analysis of which is giving rise to entirely new sectors of the economy, but the need for employees with specific information technology qualifications is also growing outside specialized companies.[1]

Demographic Change and Changing Values

In addition to technical advances, demographic change, which is already foreseeable today will also have a serious impact on the work design of tomorrow. In industrialized nations in particular, population figures are tending to decline and there are signs of an increasingly aging society. Against this backdrop, it is to be expected that there will be shortages of skilled workers across the board, which will pose major challenges for various sectors. While manufacturing sectors, as can already be seen today in the example of the automotive industry, rely on robots and can successfully replace human workers with them, there are other areas with less substitution potential. These include professions with an engineering background, which will certainly continue to be needed for the design, maintenance and improvement of the machines used. Also, and especially in the health and social care sector, where interpersonal interaction is irreplaceable, technical solutions offer only limited scope for compensating for the shortage of personnel.[2]

A decline in the working population will also undermine existing concepts of social security; this is particularly evident in the example of the pension system. The previously existing pyramidal age structure, in which the burden of financing pensions was shared by a broad young base, is increasingly being reversed. As a result, covering existing as well as expected pensions is becoming increasingly difficult. In order to enable a resilient working world of the future in the sense of the social market economy, new approaches must be discussed, even beyond existing concepts such as state-subsidized private pensions.[3]

It should also be noted that new generations are entering the labor market in regular waves, whose skills and requirements differ greatly from those of their predecessors. The world of work, and employers, must take these demands into account to a certain extent. Figure 8.3 provides an overview of the generations currently participating in the labor market and their prevailing mentalities.

1 vgl. **(author?)** [103]
2 vgl. **(author?)** [104]
3 vgl. **(author?)** [105]

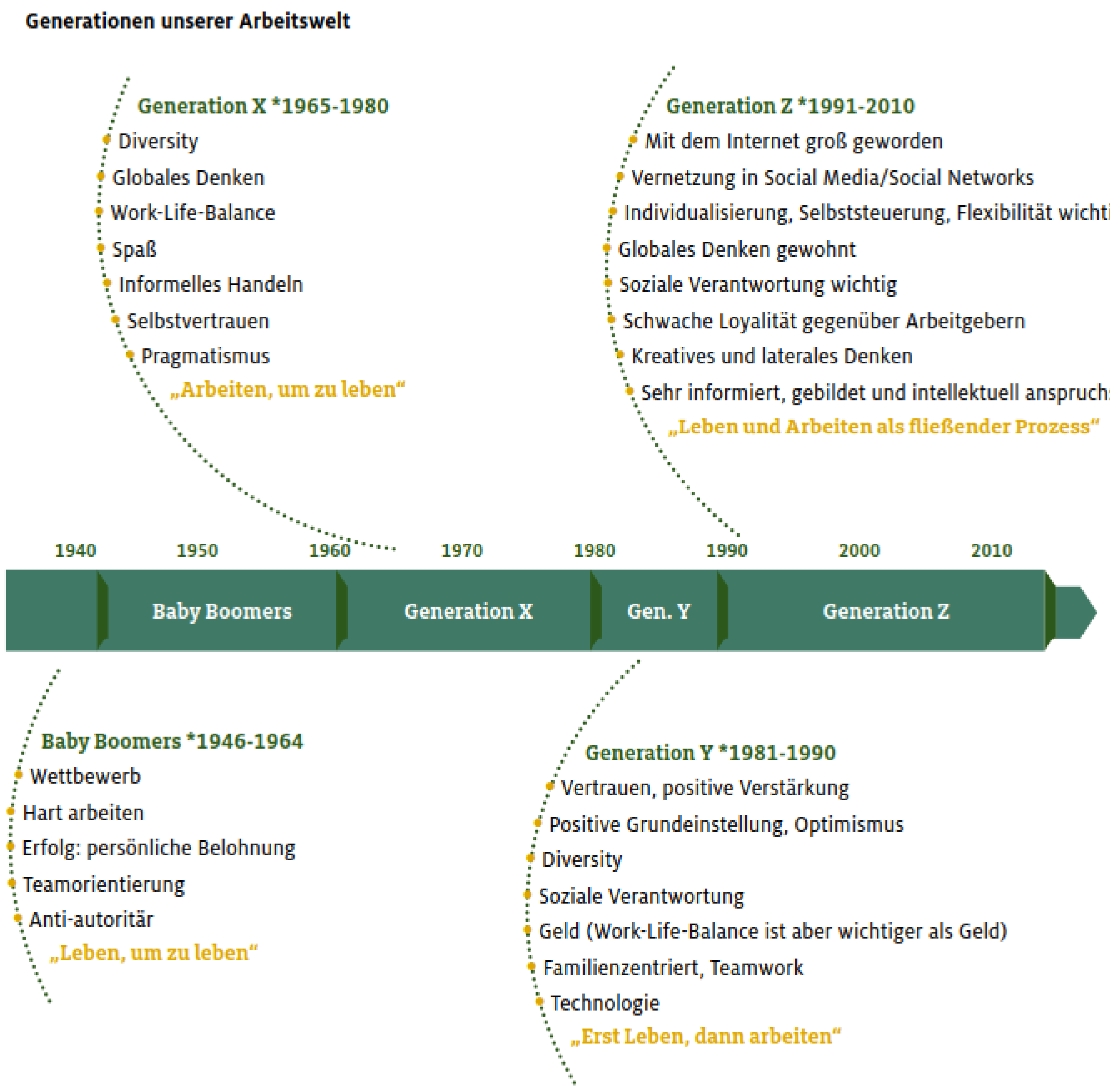

Figure 8.3: Generations of workers.[1]

Demands on Work: The Seven Value Worlds

The representative study "**Arbeiten 4.0**“ (World of Values in Work 4.0), conducted in 2016 on behalf of the German Federal Ministry of Labor and Social Affairs, looks at how employees perceive the world of work today and what they would like to see in the future.

The authors of the study identify seven differentiated value worlds that represent different perspectives on the topic of work. The value worlds focus on various aspects such as participation in a strong and intact **solidarity community**, **self-fulfillment**, a **good work-life balance** or **material security**. Membership in the respective groups can only be attributed to the usual sociodemographic factors such as income or level of education to a limited extent. Age, on which the generation concept described above is based, also seems to play only a minor role.[107]

8.4 Change of Jobs and Requirements

As the automation of workplaces advances, monotonous or physically demanding tasks in particular are increasingly being replaced. For example, this trend is already very pronounced in the automotive industry in car body construction and primarily affects production workers. In these areas, people are then mainly needed to control production processes. Here, higher qualifications will probably be necessary for future fields of activity.

Office workplaces, on the other hand, are less affected by automation, but by digitalization. Thanks to better connectivity (Internet, etc.), employees can work together independently without any geographical or time-related connection. This allows new freedom in terms of working hours and location and leads to flexible forms of work and organization.

8.5 Flexibility in the Provision of Work

Thanks to mobile devices, the availability of broadband Internet connections, and the possibility of accessing projects from different devices through cloud data storage, it is now technically possible to work in teams regardless of location and time.[108]

Already well-known solutions include mobile working or home office, which received a boost from the Corona pandemic in 2020/21. The flexible choice of workplace can offer advantages for employees, as it eases the reconciliation of work and family. At the same time, however, there are also disadvantages, in particular due to the threat of a loss of boundaries resulting from a (perceived) demand for constant availability.

For employers, the new work options bring challenges due to legal regulations. Here, a distinction must first be made between mobile work and home office. Home office refers to a fixed workplace outside the company where the work is performed and has been defined by the legislator in the Workplace Ordinance under the term „**teleworking**“ since 2016 (§2 Abs. 7 ArbStättV). The employer is responsible for setting up the fixed workplace in accordance with the applicable guidelines for workplace safety and data security.

In contrast, the term ”mobile working” has not yet been defined by law. In common usage, it is understood that employees perform their work from different locations with the help of mobile devices, which do not have to meet the requirements of a fixed workplace.

In the future, it is to be expected that such and similar flexible working models will continue to gain popularity and be used more frequently. In this context, new challenges arise in which the responsibilities, rights and duties of employees and employers must be clearly defined. In the case of permanent off-site work, issues such as health and safety and insurance must be clarified. Employees have a right to protection of their health and safety, while employers with constantly changing workplaces outside their access area (e.g. mobile working) have no realistic possibility of setting them up in accordance with occupational health and safety requirements.

Labor Minister Hubertus Heil has already advocated a general right to home office on several occasions in the past, most recently in 2020 in connection with a proposal to change the law. Since January 2021, employers have also been temporarily obligated to offer mobile working wherever possible as part of the Corona crisis.

8.6 Qualification

According to forecasts, the structural changes in the world of work caused by advancing automation and digitalization will lead to the disappearance of many jobs, for example in the production sector.[109] In this context, there is often reference to so-called technological unemployment, a term introduced by John Keynes in 1931.[110] Supporters of this theory fear that jobs will be eliminated without replacement through the increased use of machines such as computers and robots. Economists Frey and Osborne predicted as early as 2013 that 50% of jobs on the U.S. labor market would become replaceable in the following two decades due to automation and digitalization.

On the other hand, similar predictions have not come true in the past. It has been observed that technological change has also created new markets in each case, which means that, viewed on a larger scale, technological change has had a neutral or even positive effect on the labor market.

For employees directly affected by job cuts (e.g. miners/steelworkers in the Ruhr region), the new markets do not necessarily offer follow-up employment; in this case, social networks are required to provide economic support for those affected. Looking at the economy as a whole it is ultimately only relevant whether there is a macroscopic balance between labor supply and demand.

In the future, it must be expected that the newly emerging markets will demand different qualifications from employees. It is expected that there will be a shift in available jobs towards those with higher qualification requirements. Due to the increased integration of technical systems in all areas, a so-called digital literacy, the competence in dealing with technology and IT systems, will receive increased attention.

Due to the shorter innovation cycles resulting from new technologies, it is also likely that the qualifications required in each case will change ever more rapidly, which will demand flexibility and a willingness to engage in lifelong learning from employees. In the future, education systems will also have to meet this demand.

Non-substitutable occupations will continue to include those based on creativity or social interaction, as well as complex cognitive activities.

8.7 Redesigning Forms of Work – Focusing on the Human Being

While there is a general consensus that technological change will lead to an upheaval and reshaping of the world of work, there is little agreement on what the outcome will be. Everything from dystopian scenarios of mass unemployment and people under the dictates of technology to utopian notions of a human race freed from physically hard labor and able to enjoy the benefits of technological progress without existential fears has already been described [111]. Scientific studies that describe the current state of the art and seek to open up perspectives for the further development of the world of work also paint a thoroughly heterogeneous picture of the future. What becomes clear is the complexity of the situation as well as its open outcome, which can and must be shaped today.

To this purpose, it is necessary for employees, employers and political stakeholders to join forces in order to proactively set the course for a future that is desirable for all. Beyond purely profit-oriented considerations, it is important to focus on people. This opens up a multitude of possible starting points in several dimensions, which are shown schematically in figure 8.4.[112]

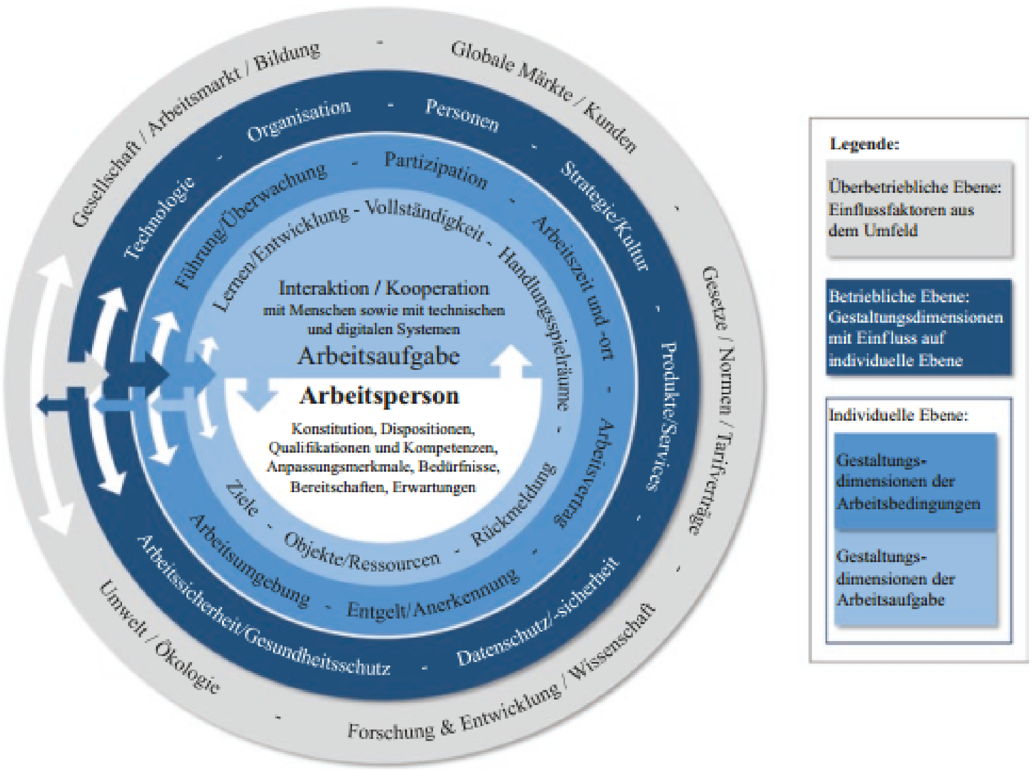

Figure 8.4: Presentation of the various influencing factors and dimensions of human-centered work design in companies.

The diagram shows that the possibilities for shaping extend from the individual position of the individual worker through the company level to the overall social environment and clearly shows that an economically as well as socially satisfactory solution can only be achieved by taking all areas into account.

8.8 Socio-Economic Aspects

The world of work 4.0 is associated with both hopes and fears. While on the one hand, advancing automation can relieve people physically, on the other hand, it is foreseeable that it will also eliminate entire fields of activity without replacement, particularly in the area of manufacturing.

As described above, there is a consensus among experts that people will lose their jobs, particularly in the context of specific conversion measures, and that it will not always be possible to find adequate continued employment within or outside the company.[1] While it may still be possible to respond to this in the short term with bridging assistance and advance payments from companies, in the long term it is to be feared that the labor market will only offer few or at least significantly different employment opportunities for low-skilled workers in the long term.

The prevailing social market economy in Germany and the associated model of social partnership, which has been established for decades, will face major challenges as a result of the impending change. In a situation in which products are manufactured to an ever greater extent by machines, fewer and fewer people are involved in the corresponding value chain. The profits generated are then distributed among a smaller group of people; in terms of society as a whole, this poses the risk that the gap between rich and poor will widen further and that this will have far-reaching social consequences.

The much quoted motto „**one must be able to live from work**“ is thus called into question within the currently existing system.

A way out of this situation is offered by approaches in which the income of the individual is no longer derived primarily from the wages paid for self-employed or dependent work; in particular, the **unconditional basic income** is the subject of much discussions. This is a sociopolitical concept in which a predefined state transfer benefit is paid out to all citizens on a regular basis and without a means test. The particular design of this concept has been under discussion for years, both nationally and internationally, and has already been tested in some pilot projects (most recently in Norway). In the general understanding of the concept, the amount of the agreed benefits should be set in such a way that they are able to cover the basic needs of the recipients, i.e. secure the existence minimum.

Opponents of an unconditional basic income often argue that the concept is not financially viable and, moreover, no longer creates an incentive for work, which would be harmful to a productive society. Low-paid activities would then possibly no longer be carried out due to a lack of financial motivation. In addition, a very small group of working people would have to pay for meeting community needs, which is perceived as unfair and undermining the principle of **subsidiarity (author?)** [114].

The financing of a basic income is indeed a challenge that requires a restructuring of the existing tax and social security systems in the medium and long term. Assuming an unconditional basic income from birth, social benefits such as parental and child benefits would be eliminated, and pensions and unemployment benefits would also become obsolete in the long run [114]. With such a greatly simplified social system, the state would already incur significantly lower administrative costs, and the surplus generated in these areas could then be used for the basic income. Other financing options include an increase in income tax, the introduction of a financial transaction tax or the introduction of new taxes on consumption or natural resources.

For supporters of the unconditional basic income, resilient financing of the model is thereby realistically achievable, and the anticipated benefits prevail. They expect, for example, that financial security for all will dampen existential fears due to actual or expected unemployment and help to level out social inequalities. Greater educational equity would be achievable thanks to basic funding that covers everyone's basic needs.[2] The choice of occupation, if

1 vgl. **(author?)** [113]
2 vgl. **(author?)** [115]

desired, could be made more freely and independently of financial incentives, which could increase subjective satisfaction in the long term [114].

Employees would be better equipped to meet the challenges of the world of work 4.0, such as the constant need for further training, and professional changes involving additional training periods would possibly be more positively accepted if they were not at the expense of their own financial security.

An unconditional basic income for all would also benefit people who perform care activities in their private lives, such as raising children or caring for relatives - activities that serve the common good, but which have so far been performed without compensation and often lead to personal losses at the latest at retirement age. Since women have been disproportionately affected by this up to now, the basic income also represents a measure for gender and equal opportunity [115].

8.9 Summary

Automation and digitalization are expected to lead to far-reaching changes in the world of work, but not every workplace will be equally affected. In order to do justice to the diverse changes, the new and increasingly complex reality of many employees must be addressed in the area of policy through adequate regulations in the form of a legal framework. In this context, it is important to find control mechanisms that protect the rights of employees and especially for the new, more flexible forms of working [111].

In addition, the concepts of the existing social market economy must be rethought in order to make room for the increasing flexibilization of professional biographies and to create basic economic security for all. Proposals such as the unconditional basic income are being discussed as potential solutions, but an immediate introduction is not yet foreseeable in Germany [114], [115].

CHAPTER 9

Big Data

Learning objectives

After completing this chapter, you will know . . .

... what is Big Data.

... which characteristics Big Data has.

... what challenges, opportunities and risks are involved in Big Data

... where Big Data is applied

Introduction

Due to the development of computers, television and the internet, the second half of the 20th century was already considered the information age. In the computing power of processors, a permanent increase can be recorded since the beginning of the development. According to **Moore's Law**, the number of transistors per unit area and thus the computing power doubles approximately every 18 months. While the first circuits available on the market in 1965 consisted of 30 transistors, the first 1-chip microprocessor 4004 from Intel a few years later already had 2300, and the Intel 8008 that followed in 1971 already had 4500.

Today's current processors such as the Intel Core i7 already have 1.5 billion, with the next processor generation then reaching 5 to 10 billion transistors. Due to the increasing computing power, the associated digitalization, artificial intelligence, technologies such as RFID (radio-frequency identification), ambient intelligence, smartphones and the ever-increasing acceptance and use of social media applications such as Facebook, Instagram, blogs and forums (see Figure 2), there has been a worldwide **explosion** in the amount and variety of data.

Every purchase, every flight, every phone call, almost every activity, whether performed by humans or machines, generates data. In 2015, each person produced between 600 and 700 megabytes of data per day; by 2020, this figure reached 1.5 gigabytes. According to a forecast from a market study financed by Seagate, the global data volume is expected to increase from **33** to **284 Zettabyte** (1 Zettabyte= 10^{21} Bytes) between 2018 and 2027 (see Figure 1). The average growth rate is around 27 percent. Video applications, metadata, Internet of Things and Social Media are responsible for one third of this growth. This enormous amount and variety of data requires new tools and algorithms to continue to extract information from the data. This phenomenon is titled "Big Data".

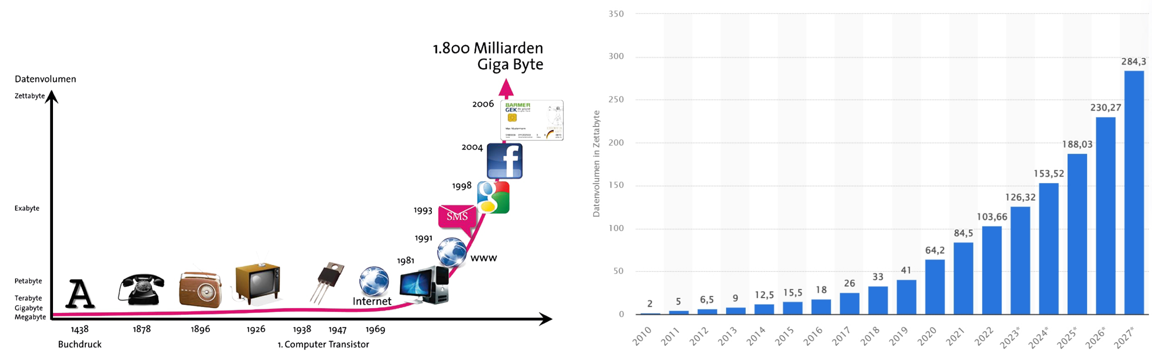

Figure 9.1: Growth of the amount of data over time.

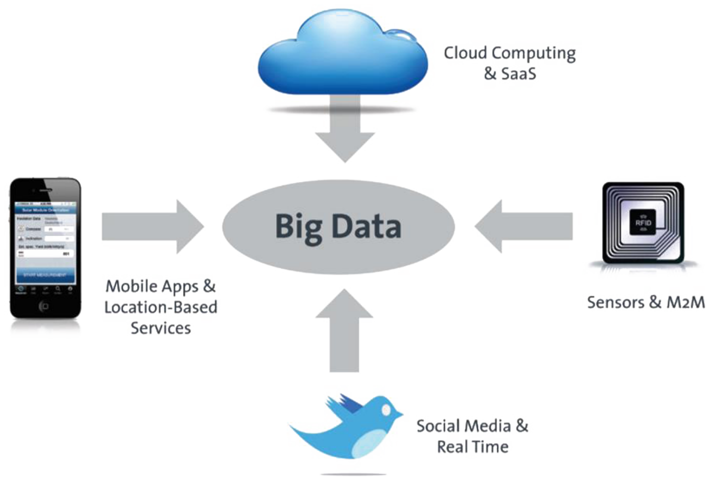

Figure 9.2: Information technologies responsible for the emergence of the Big Data phenomenon (source: BITKOM 2012, S. 11)

9.1 Definition

The term **"Big Data"** originates from the English language and is a synonym for the enormous flood of data that accumulates in private and public life today. Big data refers to all types of data and information that cannot be stored in a database or other special data structure and that cannot be analyzed using conventional data processing methods because they are too large, too complex, too fast-moving or too weakly structured. This **unstructured** data is far more heterogeneous than traditional data and can be in various forms such as e-mail messages, Power Point presentations, text files or similar. The data comes from a wide variety of sectors and applications such as the financial industry, the energy industry, healthcare, mobile communications, the Internet, credit cards, surveillance cameras, flight and driving data, social media and many more.

Big Data not only reflects complex, sometimes intangible amounts of data, but it is also often used as a collective term for digital technologies that are used to automatically collect, manage and analyze this data.

There are various definitions for Big Data. Edd Dumbill, for example, defines Big Data in terms of processing:

> *„Big Data is data that exceeds the processing capacity of conventional database systems. The data is too big, moves too fast, or doesn't fit the structures of your databases*

architectures".

Another definition from Bitkom refers to the various facets of Big Data:

"Big Data refers to the use of large amounts of data from multiple sources at a high processing speed to generate economic value".(from the German)

Gartner's definition of Big Data additionally includes the **"three Vs"** of Big Data:

*"Big data is **high-volume**, **high-velocity** and **high-variety** information assets that demand cost-effective innovative forms of information processing for enhanced insight and decision making".*

The extended five Vs describe the following characteristics of Big Data:

Volume

Volume refers to the enormous size of the data. Big Data datasets volumes are very large and range from terabytes to zettabytes. (Megabyte = 10^6 Byte, Terabyte= 10^{12} Byte, Zettabyte = 10^{21} Byte). So whether a dataset is considered Big Data depends on the **volume of data**. Due to the explosion of data volume in recent years, this is the most well-known characteristic of Big Data. Due to the large volume of data, the problem of storing this data arises. This is because the larger the volume of this data; more storage space is requiered to continue to store the data efficiently.

Velocity

The last of the three Vs Velocity refers to the **high speed** at which data is generated, produced, created or updated. Quite often, processing in real time is also required. In order to be able to process data as quickly as possible, work must be done in the RAM and not on the hard disk memory as it´s usually the case. Processing these data volumes is a challenge in terms of processing speed, as slower processing speeds result in significant performance losses. The data must also be as up-to-date as possible in order to be able to react promptly to changes. Especially for real-time decisions, processing speed plays a decisive role. The data must not be outdated and thereby allow false interpretations. In addition to the 3Vs of Big Data, some experts additionally speak of information capital or asset. For this reason, two additional characteristics are often added to the definition of Big Data:

Variety

When you deal with Big Data, you don't just come into contact with structured data. More and more data is being generated that comes from a wide variety of sources and has different structures. Variety refers to the nature of the data, in which form this data exists. **Structured** data is basically organized data. They have a defined length and a unique format. They cause no problems for database systems and can be processed efficiently in a tabular format. **Semi-structured** data can contain unstructured as well as structured data. **Unstructured** data, on the other hand, does not fit into the traditional row and column structure of relational databases. Examples include text, images, graphics, videos, etc. The more diverse the data, the more complex its storage and processing becomes. Many systems are only suitable for storing and analyzing structured data. Big data therefore requires new storage and processing options.

Veracity

Veracity is one of the less favorable properties of Big Data. While the properties mentioned so far have a positive influence, Big Data decreases the accuracy, correctness, completeness and reliability of the data. Much data is either vague or inaccurate. The quality and accuracy are sometimes difficult to control and therefore inaccurate or doubtful data must be removed from the processing in time or taken into account accordingly during the evaluation, since the quality of the data has a decisive influence on the quality of the analysis result. It is becoming increasingly difficult to check whether the data is complete and correct. For this reason **specific algorithms** must be used to evaluate the significance of the results.

Value

The last but probably most important property is **Value**. Big Data is intended to find specific answers to specific questions in order to generate **additional value**. The other characteristics are meaningless if the companies' value cannot be increased through Big Data. The use of Big Data helps to develop a **better understanding of the customer**, to focus on the customer, to optimize processes and to improve the overall performance of the company. Before a Big Data strategy can be developed, the potential of the demanding characteristics must be understood and it must be clear about the own goals, because investments should only be made where an added value can be generated. In addition to these five characteristics, Big Data is also attributed by other characteristics such as **vulnerability**, **visualization** or **volatility**. Big Data is so wide-ranging and is used in so many areas that there is no generally valid definition, which means that different characteristics are attributed to it. However, the five characteristics mentioned above - volume, veracity, variety, velocity and value - are the main characteristics of Big Data.

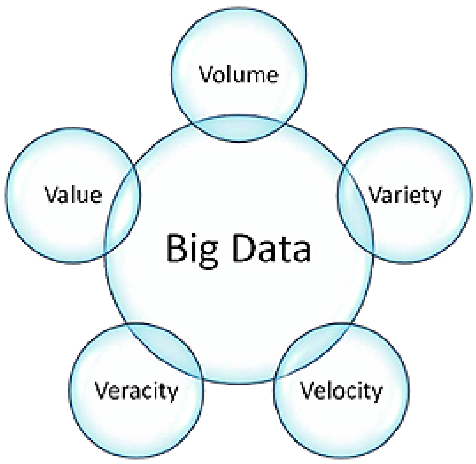

Figure 9.3: The main characteristics of Big Data (Elragal, 2014)

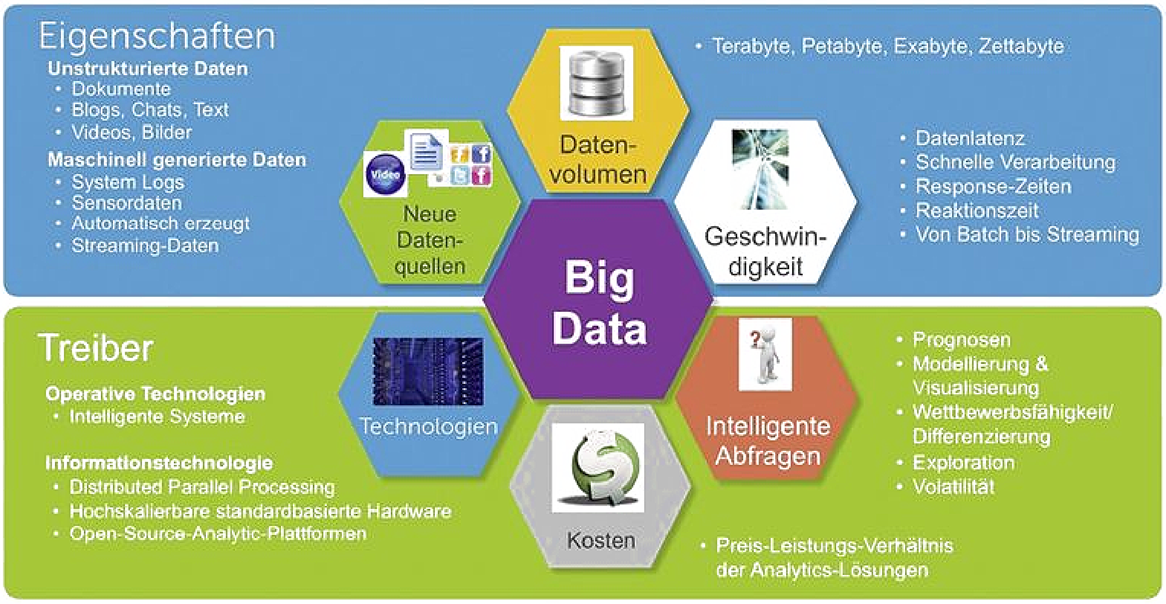

Figure 9.4: Big Data Overview (Zeman 2016)

9.2 Big Data Analytics

Data is an important component for companies today. For the rapidly increasing and ever more complex amount of data, Big Data provides concepts, technologies and methods where conventional approaches to information processing reach their limits. By collecting, managing, analyzing, validating, processing and visualizing the data, companies obtain important data material, such as information about the **purchasing behavior** of customers, information about the **performance** of machines in production, the probable **success of new marketing campaigns** and much more. This information forms the basis for making the right business decisions. It can therefore be said that big data analytics is a **management process**.

The main subfields of Big Data Analytics are:

- Using search queries to obtain data from various sources
- The evaluation and preparation of the data obtained
- The analysis of the data and visualization/presentation of the results

Figure 9.5: Big Data Analytics Process (Intellipaat, 2017)

Algorithms are needed as a basis for collecting and analyzing the data. These algorithms often work on a level that we as humans are not even consciously aware of.

Algorithms were used long before the computer age. The Egyptians already used algorithms to calculate with hieroglyphs. An algorithm is a solution prescription for the removal of a problem or for the completion of a certain task. The process should always be carried out in the same, previously defined way. The premise for the emergence of the algorithms was the enormously **increased computational performance** of devices in the last years (see introduction). Only this made it possible to process complex algorithms. The **increasing networking** of individual devices and systems also favored the development of algorithms, since these are needed for efficient and meaningful networking.

Nowadays, algorithms are used, especially on the Internet, to determine click, search and purchase behavior of users in order to then offer personalized content. Algorithms are therefore also the reason why two different people can receive two completely different search results for the same search query with Google. This is because the results are based on the previous click and search behavior of the user.

Complex algorithms are also prepared for the different scenarios that can occur. So if the circumstances change, the solution path also adapts. In the case of navigation systems, for example, the selected route changes during the journey if new traffic jams occur. Furthermore, algorithms can be **adaptive** and independently recognize new contexts. For example, based on photos of pets with corresponding names, the algorithm can learn what dogs and cats look like. After some time, the system is then able to assign new photos to the correct animal species because it has learned the distinguishing features.

Key Technologies for Big Data Analytics

There is not just one technology on which Big Data applications are based. Of course, there are advanced analytics methods that can be used to analyze Big Data. However, Big Data analytics is actually an **interplay of multiple technologies and innovations** to extract the most value from the data. The following is a list of the most significant players:

Machine Learning
Machine learning is a subfield of artificial intelligence (AI). Systems are enabled to recognize patterns and regularities based on algorithms and existing data sets and to automatically create models that analyze larger and more complex data and deliver fast and accurate results. Solutions are also developed according to the results. The advantage for companies here is the avoidance of yet unknown risks and the likelihood of identifying profitable possibilities and opportunities increases. With machine learning, **artificial knowledge** is generated from **experience**.

Data Management
Before data can be reliably analyzed, it must be of high quality, well maintained and organized. Data is constantly flowing in and out of companies. Therefore it is important to establish recurring and traceable processes to create and maintain certain standards for data quality.

Data Mining
Data mining is a methodology for **analyzing and examining large amounts of data**, to discover patterns, insights, and knowledge in the data. This information can then be used for further analysis to answer complex business questions. Data mining software can be used to search through the chaotic and repetitive tangle of data, determine the most important points, evaluate the possible outcomes, and thus speed up the decision-making process.

Hadoop
This **open source software framework** can store large amounts of data and enables parallel data processing on highly scalable cluster servers. Hadoop has become a key technology in the

business world due to the ever-increasing amount and variety of data and its computational model that can process Big Data quickly.

In-memory Analytics
By analyzing data from the **RAM** instead of hard disk, insights can be derived immediately from the data and acted upon quickly. This saves time for data preparation and data processing. In-memory analytics is not only an easy way for companies to stay agile and make **better business decisions**, it enables them to run repetitive and **interactive analytics scenarios**.

Predictive Analysis
This technology uses data, statistical algorithms and machine learning methods to determine the likelihood of future outcomes based on historical data. The idea is to get the best possible estimate of what will happen in the **future**. Companies should be able to feel confident when making decisions that they have made the best possible choice.

Text Mining
Text mining technology can be used to analyze text files from the web, comments, books, and other text-based sources to uncover previously undiscovered insights. Text mining uses machine learning or natural language processing to examine documents such as emails, blogs, Twitter posts, surveys, contest information and similar sources to analyze large amounts of information and discover **new topics** and **relationships**.

9.3 Opportunities and Benefits of Big Data

The increase in technical possibilities to process and generate large amounts of information at high speed opens up many opportunities and advantages. The most important ones are listed below:

Customer Understanding

Big Data enables companies to better understand their customers and target markets. By analyzing customer data, especially customer preferences and demand, it is possible to identify their behavior and preferences. In this way, companies can adapt to the needs of customers and offer appropriate products and services.

Furthermore, **future trends** and market movements can be predicted, which is of great importance in the area of research and development. This is because companies can react on the basis of these findings and develop new products in line with the trends, expand existing product lines, modify existing products, or even develop new marketing strategies for the existing products. Companies can act accordingly in advance instead of just reacting to changes. Overall, this shortens **Time-to-Market** and products can be brought to market faster. Big Data supports companies in providing the best possible service to their customers.

Optimization of Business Processes

The insights gained from data analysis make it possible to optimize company processes and secure advantages over competitors. Big Data accumulates in all areas of the company and powerful analysis systems can process this large amount of data, recognize hidden patterns and connect them with each other. As a result, processes in the company can be optimized and made more efficient. An example of this is the transport of goods by trucks. Many different data such as traffic data, weather data or gasoline prices play a role in the transport, most of which can be measured. Analysis systems can evaluate all this data, determine the optimal routes for the trucks and save time and costs as a result.

Decision Making

The flood of data and information that companies generate every day is enormous. New forms of data evaluation and aggregation generate information with previously unattained specificity. Based on this newly acquired information, companies can make decisions that are decisive for the further success of the company. Big Data can also help to make preventive decisions. For example, machine data can be analyzed and the intervals between machine failures can be detected. By using **additional sensor technology**, the dependency between various factors and the failures can still be determined. Based on this information, preventive measures can then be defined, such as specific maintenance intervals before a new failure occurs.

Optimal use of Resources

The optimal use of resources plays a major role for companies. Through Big Data, intelligent buildings can be combined with automated production facilities to significantly reduce resource consumption. These savings and the shortening of manufacturing times for individual parts thanks to more interconnected production processes enable companies to remain competitive worldwide. Big Data plays an important role in the Smart Factory through the processing and evaluation of large amounts of data.

9.4 Challenges associated with Big Data

In addition to the challenges posed by the five characteristics of volume, variety, veracity, velocity, and value (see chapter 9.1), Big Data poses further challenges. Companies must face these challenges and develop answers to the associated questions.

Total Cost of Ownership

Big Data projects are usually associated with high costs. Heterogeneous and complex information landscapes lead to high operating costs. Additionally to the acquisition costs, costs for new employees, software configurations, software maintenance, training, etc. are incurred.

IT-Security

Due to increasing volume, complexity and value of data, more attention must be paid to preventing fraud and manipulation. Cyber criminals can inject false data into the data pool to manipulate results. In addition, sensitive data is often not encrypted because the constant encryption and decryption of large amounts of data means a loss of processing speed. Data governance must be established, i.e., a set of rules that regulates the proper management of digital data to prevent fraud and manipulation.

Transparency

Suitable data structures are of high importance due to the large amount and variety of data. Regulated and clear data structures and processes form the basis for the interpretation of data, information flows and responsibilities. This is the only way to create an overview of the data tangle and enable transparency.

Data loss

All essential data and information must be captured and should not be lost. Storing and processing large amounts of data is the problem here, as the volume of data is constantly growing and capacities of existing technologies are reaching their limits. Data integrity, performance and availability must not be compromised.

Infrastructure

The procurement, commissioning, maintenance and operation of Big Data differ from conventional infrastructures. This is why special know-how is required.

9.5 Risks associated with Big Data

Privacy and data protection

The biggest risk of Big Data is the violation of people's privacy. Even big companies like Yahoo and Facebook have been involved in this issue. By analyzing the data collected by companies, they can gain deep insights into people's habits and character traits. When surfing the web, everyone leaves a trail of data behind them.

Cookies in particular can be used to analyze users' surfing behavior and record their movements on the web. Here it is stored which pages are visited, which products are viewed, or which products are placed in the shopping cart. People can be linked to the data by decoding and analyzing the traces, thus losing any kind of **anonymity**. People's data must be kept inaccessible to ensure their safety and anonymity.

In most cases, the persons affected do not give their consent to the use of their data. Rather, users must explicitly state their disagreement on the use of their data. It is not uncommon for users to be denied certain functions as a result of this decision. It is therefore often virtually impossible to refuse data collection.

This results in a **normalization of data collection** in society. Even if it doesn't seem so at first glance, Big Data leads to a restriction of the user behavior of people worldwide. Even if users are usually not aware of it, they no longer act according to their own personal opinion, but according to the opinion determined by society or companies.

Competitive disadvantage

Working with Big Data involves high investments for companies. Not all companies are able to cover these costs. It is easier for large companies to make these investments and benefit from Big Data, which puts smaller companies at a disadvantage. It seems that due to the high costs and the disadvantages and risks of Big Data, only the **large** and especially the **established companies** benefit from Big Data. This increases the **the competitive advantage** of large companies to the smaller companies, which do not have the same possibilities.

9.6 Application examples

- Connected cars can receive real-time data on the traffic situation and avoid traffic jams at an early stage as a result.
- Mobile devices such as smartwatches and smartphones that collect fitness and health data and automatically transmit it to the main doctor.
- The US retail chain Target analyzed the purchasing behavior of female customers. If there were specific purchase patterns that indicated pregnancy, the customers were made aware of the corresponding products with targeted advertising and coupons.
- Household electricity consumption can be optimized through smart grids (intelligently networked electricity grids and households).

- Predictive Policing - personal data is collected and analyzed to predict who is most likely to commit a crime, where and when. Crimes are to be prevented before they even take place.
- Rolls-Royce uses Big Data in the modeling of new aircraft engines. Simulations of new jet engines are carried out during the design phase, enabling the new models to be tested before they go into production.
- Caterpillar investigated how ship hull cleaning affects fleet performance for a customer. The Big Data solution analyzed data from sensors onboard ships where hulls were cleaned or not cleaned. The result was that cleaning intervals needed to be shortened and the associated investment was still profitable. Big Data helped Caterpillar get its product right and improve its corporate image.
- Big Data is also used to detect credit card fraud. Through the transactions made with the credit card, the algorithm collects information about the behavior and habits of the owner. In the event of suspicious transactions, for example a purchase in China even though transactions were made in Germany the days before, the algorithm triggers an alarm and automatically blocks the card or the card owner is immediately informed about the suspicious transaction.

9.7 Summary

Big Data - a very multifaceted phenomenon that is received very differently by people. Some are full of expectations and are enthusiastic about the infinite potential, while others feel that their privacy is threatened and see Big Data as ”surveillance”. There are many arguments for both sides, but the development continues to progress and can now no longer be stopped, because Big Data already plays a role in too many areas of life. It is probably also the right way to simply let the development progress, because Big Data offers consumers and companies many advantages and opportunities. The challenge is to accept the challenges and take advantage of the opportunities without letting the risks become too great. As a consumer, it is important to continue to be careful with your own data.

CHAPTER 10

Medicine 4.0

Learning Objectives

After completing this chapter, you will know...

... which terms are important related to Medicine 4.0

... why there is no alternative to digitizing the healthcare system

... which changes are taking place in hospitals (Clinic 4.0)

... which advances telemedicine brings

... which challenges and risks arise

10.1 Introduction

Declining birth rates and the increasing life expectancy of the population in Germany are both leading to a financial overload in the healthcare sector.

Due to medical advances, better hygiene, healthier nutrition, more suitable housing, improved working conditions, and increasing prosperity, the life expectancy of newborns is constantly increasing continues to rise. The current life expectancy in Germany for newborn boys is 78.6 years and that for girls is 83.4 years.

One way to reduce costs is to reduce medical necessity in old age by further improving the quality of the aspects already described. However, since this option is only possible to a limited extent, further alternatives must be sought.

The digitalization of the healthcare system offers the best solution in this regard. It can make services more cost-effective while simultaneously improving quality. However, it also brings with it some challenges that must be addressed.

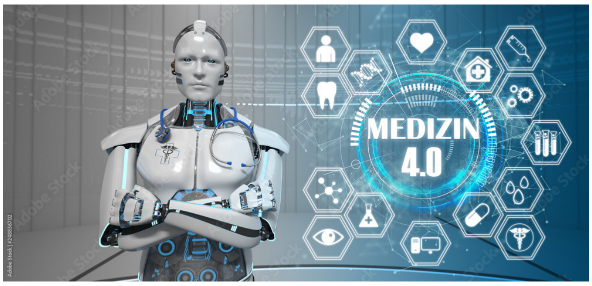

Figure 10.1: Medicine 4.0

10.2 Challenges in the Healthcare Sector

For digitalization to take place in healthcare and hospitals, many challenges must be overcome, including:

- Digital Care Network
- Interoperability and Isolated Systems
- Numerous Paper Documents and System Disruptions
- Telemedicine
- Market Consolidation and Skilled Labor Shortages
- Patient Focus and Complexity

The **digital care network** includes prescription apps and video consultations. A prescription app could, for example, be a diary app for documenting blood sugar for diabetics or a companion app for pregnant women. The **Act for Better Care through Digitalization and Innovation** has been in place for this purpose since December 19, 2019. This enables secure access to the healthcare data network around the clock. However, safety, functionality, quality, data security, and data protection pose further challenges for the Federal Institute for Drugs and Medical Devices (BfArM). Healthcare is an extremely sensitive area, and therefore, data protection and improved patient care must be fully guaranteed.

The next challenges are interoperability and isolated systems. Interoperability is the ability of a system (e.g., a medical device or software) to work together with other systems. Interoperability is currently not possible between individual devices inside or outside a hospital. However, for the digitalization of healthcare, it is fundamentally necessary to work with open standards to enable interoperability. Open standards are used to create interfaces that enable communication between devices within a hospital, as well as external communication with other parties. Currently, isolated solutions are used for hospital information systems, practice management systems (PVS), and the core systems of health insurance companies.

This brings with it the next challenges: the numerous paper documents and the system gaps between outpatient and inpatient areas must be eliminated. Medical history forms, data protection declarations, discharge letters, and other documents that must be completed by hand are often recorded in paper form. These must then be entered digitally or reprinted for the next visit. These documents also often have to be completed separately on each ward a patient visits. This process is time-consuming and therefore costly. The same problem is emerging in the system gap between inpatient and outpatient care. Care processes must therefore be optimized with the help of digital and organizational solutions.

Telemedicine is ideal for outpatient care and medical support. Routine visits, for which patients previously had to travel to the doctor's office, can now be conducted as televisits. Further advantages and possibilities of telemedicine are described in the chapter "Telemedicine" on page "Telemedicine."

The German healthcare system comprises approximately 1,900 hospitals, which are now subject to severe cost pressure. At the same time, there is a shortage of skilled workers. To remain competitive, changes must be made and new business models developed. To save costs, market consolidation is necessary. In general, consolidation in most areas refers to achieving stability or combining several parts into one whole (corporate consolidation). Hospitals, doctor's offices, health insurance companies, and all other participants in the healthcare system will need to work more closely together in the future and digitize processes to meet the challenges. The digitization of healthcare is therefore not an option that can be chosen, but a necessity that must be met.

Another challenge facing hospitals and doctors in the future is referred to as patient centricity. Due to general digitalization and networking, patients are increasingly informing themselves about the causes of their complaints. This approach must be utilized by the healthcare system, and digital medical histories must be able to be taken reliably. Patients must be able to do more independently in the future to save costs. To achieve this, the various stakeholders in the healthcare system must work together and network with each other. This will enable digital services to be offered comprehensively. At the same time, it will reduce the complexity resulting from the many stakeholders.

The first step in digitizing the healthcare system is therefore the introduction of open standards to create interfaces. This simplifies collaboration internally, externally, and with patients, allowing further digitalization steps to be initiated and further challenges to be mastered.

10.3 Digitalization in Healthcare

Digitalization in healthcare can also be summarized under the term eHealth. The term eHealth refers to the cost-effective and secure use of ICT to promote general health or health-related areas. The term eHealth can be divided into five different areas:

- **eCare** (health care - e.g., telemonitoring, teleconsultations)
- **eAdministration** (administrative processes - e.g., eGK = electronic health card, ePA = electronic patient record)
- **ePrevention** (prevention - e.g., age-appropriate assistance systems)
- **eResearch** (research - e.g., genetic research using AI)
- **eLearning** (teaching - e.g., blended learning) Blended = a didactic concept that combines online and face-to-face teaching.

There are always overlaps within the individual areas, which is why they cannot be completely separated from one another.

The basis for the interaction between the various areas is a secure **TI**[1] The first steps towards this were taken in Germany in 2015 with the eHealth Act. It is also known as the Act for Secure Digital Communication and Applications in Healthcare. It deals with the development of a secure telematics infrastructure and the introduction of digital medical applications.

Further laws, such as the TSVG, the GSAV, the DVG, and the PDSG, have subsequently further advanced the digitalization of the healthcare system. The DVPMG (German Act on the Digital Modernization of Care and Nursing), which came into force on June 9, 2021, represented a major step forward. It encompasses the further development of the TI as well as the introduction of the ePA (Electronic Patient Record) and e-prescriptions.

The telematics infrastructure connects the various stakeholders (hospitals, physicians, patients, and health insurance companies) as well as the five different areas of eHealth.

1 The telematics infrastructure (**TI**) is the data highway of the healthcare system. It is intended to enable fast and secure communication between doctors, psychotherapists, hospitals, and others.

In Germany, the foundation for a digital and modern healthcare system has been created, and the implementation, for example, within the hospital (Clinic 4.0) or the precise procedure using telemedicine can be addressed.

Savings opportunities in Germany

As early as 2018, up to €34 billion could have been saved in Germany if the healthcare system had already been digitized. This corresponds to approximately 12 percent of the total costs of the German healthcare system, which amounts to €290 billion in absolute terms.

The trend in these costs is rising due to demographic change. Costs are estimated to grow by 4.5 percent annually. A relatively new study by McKinsey (June 2022) confirms the approximately 12

There is still an urgent need to reduce costs in order to ensure the financial security of the healthcare system in the future.

A study by McKinsey identified the potential benefits of the 26 currently available digital healthcare technologies. These 26 technologies were divided into six different categories:

- Paperless Data
- Online Interaction
- Workflows/Automation
- Result Transparency/Decision Support
- Patient Self-Care
- Patient Self-Service

The results of this study can be seen in Fig. 10.2 "Potential Benefits after Digitalization Measures."

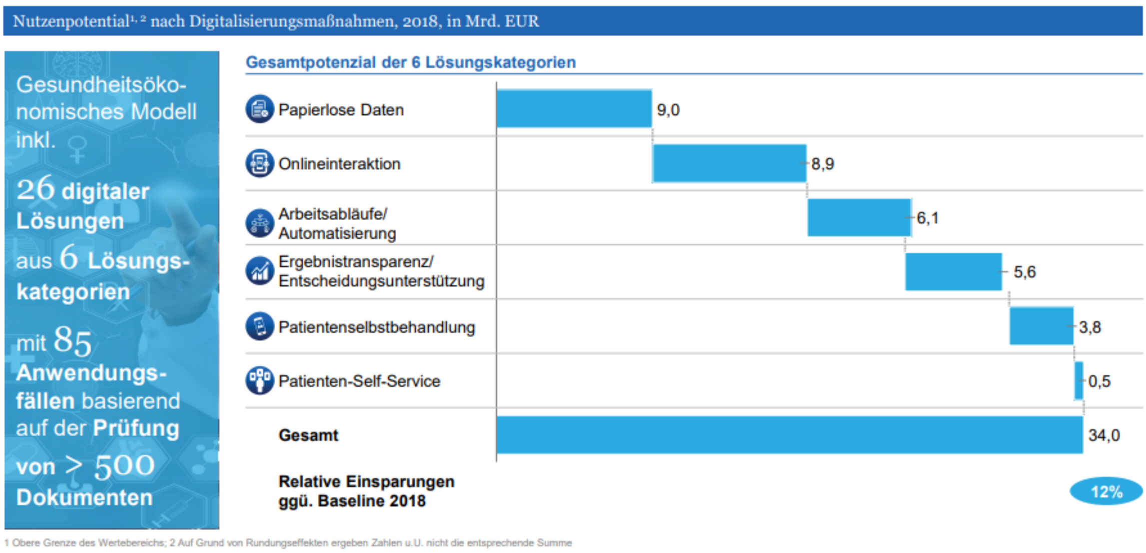

Figure 10.2: Potential Benefits after Digitalization Measures

The three areas with the greatest savings potential are paperless data, online interaction, and workflows/automation. A total of 24 billion euros can be saved here.

The area of paperless data includes electronic medical records (EHRs), e-prescriptions, internal hospital employee communication, and virtual physician assistants.

Online interaction is synonymous with telemedicine. The technologies include teleconsultation, remote monitoring of chronically ill patients, and e-triage.

Workflows/automation largely encompass the digitalization of hospitals (Clinic 4.0). This includes mobile networking of nursing staff, barcode-based medication administration, tracking via RFID, monitoring of vital signs, robots for physical therapy, the automation of simple process steps, and electronic referrals. However, parameters that can be assigned to Clinic 4.0 can also be found in the other categories. These include, for example, virtual physician assistants from the area of paperless data. Of the 24 billion euro savings potential in the three largest areas, approximately 16 billion euro can be saved through digitized hospitals alone.

Due to the enormous savings potential in the areas of Hospital 4.0 and Telemedicine, these will be examined in more detail in the following chapters and presented with concrete use cases.

10.4 Digitalization in Hospitals (Clinic 4.0)

Digitalization in hospitals, also known as **Clinic 4.0**, refers to the introduction of networked technologies and real-time communication.

A look at history shows the changes from Clinic 1.0 to Clinic 4.0:

- Clinic 1.0: Introduction of new **processes** (anesthesia)
- Clinic 2.0: Introduction of new **technologies** (X-ray)
- Clinic 3.0: Introduction of **information processing and information storage machines**
- Clinic 4.0: Introduction of **networked technologies** and **real-time communication**

The goal of networking hospitals is to provide information to the right person at the right time. This facilitates decision-making and initiates the appropriate processes in response to an event.

The **HIMSS**[1] developed the **EMRAM** to measure a hospital's level of digitalization. This model has been the global standard since 2015 and divides a hospital's level of digitalization into seven different levels. At level 0, not even the three most important systems of the ancillary departments (laboratory, pharmacy, and radiology) are installed. From level 1 to level 6, the level of digitalization increases steadily. At the seventh stage, the hospital will then run almost entirely paperless, and all areas will be automated, as far as the current state of technology allows.

Hospital areas:

Figure **??** shows the different areas of a hospital. The graphic shows a spatial separation of the individual areas. This separation is also present from a technical perspective in the currently prevailing Clinic 3.0.

In order to take the step from Clinic 3.0 to Clinic 4.0, the individual areas must be able to communicate with each other in real time. Even within the individual areas themselves, there are some approaches that are crucial for digitalization in hospitals.

1 **HIMSS** = Healthcare Information and Management Systems Society

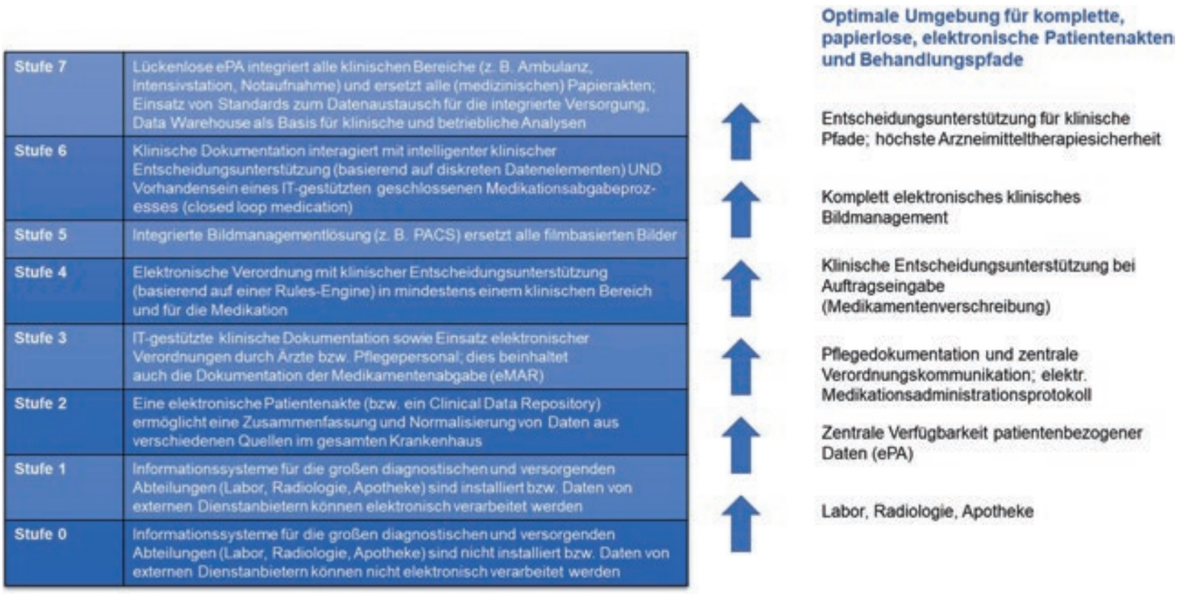

Figure 10.3: EMR Adoption Model (EMRAM), maturity model for the digitalization of hospitals

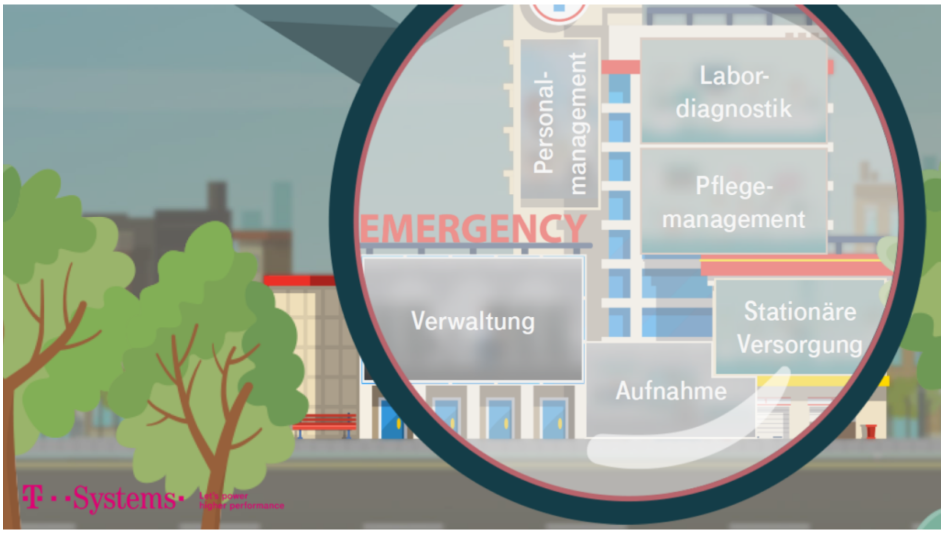

Figure 10.4: Hospital areas

With the digitalization of the hospital, the individual areas within the clinic are undergoing change. At the same time, doctors, patients, and research and teaching are evolving.

10.5 Doctor 4.0

Due to the networking of the digitalized hospital, the role of doctors is also evolving. In the future, there will be networks of numerous hospitals that cooperate with one another. Different hospitals treat different areas of specialization. Cooperation between these different specialized hospitals offers the patient the best possible service.

If a patient is admitted with complaints for which the hospital does not specialize, contact is made with the nearest specialized hospital. The patient's images, from the **MRI**[1], **CT**[2], etc., are sent to the specialized hospital. In a **video conference**, both the doctor from the current hospital and the doctor from the specialized hospital treat the patient together. Through this collaboration, physicians can assess follow-up treatment. A decision can be made as to whether the patient can continue treatment at the current hospital or whether they need to be transferred to a specialized clinic. If a transfer is not possible due to the critical condition, there is the option of calling a specialist at the current hospital.

Information about pre-existing conditions, medications, etc. will also be easier and faster to access. By networking primary care physicians, specialists, and clinics, information will be available around the clock in the future. Gaps in information, disruptions in information, and time lost due to lengthy anamnesis or searching for previous medical findings will be eliminated. The physician will have all information about the patient immediately at hand and can thus gather information about their patient even before admission. This saves valuable time and increases the chances for critical patients.

With Clinic 4.0, the role of the physician will evolve from that of a general practitioner to that of a specialist. They will become team players who work closely with other physicians. This ensures optimal patient care. The primary care physician's role will be that of team leader. They will assemble the best possible network of medical experts for their patient and dynamically develop this network.

10.6 Care 4.0

The nurses in a hospital are not only responsible for providing care, but also for a great deal of bureaucratic work. Nurses often only have 20-30 minutes for morning rounds before the first surgeries begin. During these rounds, the patient's wounds are assessed and the treatment plan for the day is determined. Due to the limited time, this information is usually not entered into the hospital information system, but rather written down on a piece of paper. If this piece of paper disappears, it is impossible to determine whether all items on the list have been completed. Mobile documentation systems can provide support here. These provide all hospital staff with an overview of the patient's most important information at all times. Furthermore, to-do lists can be created, which can then be completed throughout the day. This eliminates the risk of data loss [116] .

Patients or staff often have to be searched for for a long time because their exact location in the hospital is unknown. This can happen especially when patients have to change wards independently, for example, from the emergency room to the MRI, and get lost in the process. Other scenarios include visiting the cafeteria for visits or hair appointments, etc. Even doctors who are spontaneously called to the operating room sometimes have to be searched for for a long time. Tracking systems that use RFID chips can help here. This process is also known as tracking and tracing. The RFID chips are attached to patient wristbands, to hospital beds,

1 **MRI** = Magnetic Resonance Imaging / Magnetic Resonance Imaging → contrast agent soft tissue
2 **CT** = Computed Tomography → X-ray, 3D cross-sectional images possible

or even to hospital objects. This allows the location of missing persons to be determined at any time. This saves time and makes processes more efficient.

In addition to mobile documentation systems and tracking systems, electronic order entry systems represent an important change in care. In such a system, requests and orders, e.g., for X-rays, are recorded electronically. After the X-ray, the physician receives the X-ray images via the clinical information system. Order entry systems link a hospital's various subsystems, thus ensuring a continuous exchange of information. If they are connected to the hospital pharmacy, for example, the availability of medications can be checked and, if necessary, reordered directly and automatically. A connection with the continuing care services contributes to the faster implementation of organizational or structural measures after the hospital stay. Wheelchairs, walking aids, or the adaptation of the patient's home can be ordered or arranged before discharge, thus avoiding avoidable waiting times for the patient.

Another aspect that contributes to improving care management is referred to as hospitality entertainment. This is an entertainment station in the form of a tablet or similar device located directly at the patient's bedside. All kinds of streaming services can be used for entertainment. Non-medical services provided by the hospital can also be used. For example, hairdresser appointments can be scheduled or meal selections can be made.

Mobile Identity Access is used for access management. It is a central, digital key management system that allows access to the narcotics cabinet or other critical areas to be monitored and documented. This prevents medication misuse.

Nursing documentation via voice bots makes daily visits for nurses much easier. With the help of voice bots, documentation can be created, which is then automatically imported into the hospital information system. Furthermore, the patient can use this voice bot as an assistant. Similar to Alexa, this voice bot offers the patient entertainment options and controls smart devices.

The final area of nursing management is hygiene management. Sensors can be used to monitor the fill level of disinfection stations. Furthermore, hygiene measures are precisely documented. IoT sensors help keep the hospital consistently clean, thus further relieving the burden on hospital staff.

10.7 Hospital Administration 4.0

In addition to the value-adding core processes, the supporting processes must also be digitized. These also benefit from intelligent networking within the hospital.

Applications, which are now submitted almost exclusively online, can be forwarded to the correct department within seconds. **Absence planning** is made much easier thanks to electronic vacation requests, training requests, or sick notes. These requests are also forwarded to the appropriate departments fully automatically after approval by the supervisor.

Currently, a lot of sensitive data is transmitted via inadequately protected channels, such as WhatsApp. An **employee app** can help here. This simplifies communication within a hospital, ensures compliance with data protection regulations, and ensures IT security.

10.8 Patient 4.0

The development of Hospital 4.0 is not only changing hospital processes and the role of the doctor, but also the role and responsibilities of the patient. The focus of digitalization should not only be on financial opportunities, but rather on optimal patient care.

The distinction between inpatient and outpatient care is increasingly disappearing. Telemedicine methods offer patients the opportunity to access expert knowledge from home or the nearest hospital. Home monitoring and wearables may spare patients the need for inpatient treatment. The necessary data can be collected remotely, and further treatments can be planned based on this.

The ePA stores all data and information in a central location. For example, X-rays no longer need to be sent from doctor to doctor; they can be accessed at any time. This gives the patient full control over who can view their medical data.

With Hospitality Entertainment, the patient can access information about their upcoming appointments and the treating physicians, or schedule follow-up appointments online.

The role of the patient is changing, and the patient becomes the master of their own destiny. They are actively involved in treatment and can help shape and manage their own course of treatment. While this gives them responsibilities they didn't have before, it also offers them all the benefits of a digitalized healthcare system described above.

Research and Teaching 4.0

The further development of medicine is an enormously beneficial side effect of the digitalization of hospitals. The training of new physicians is also facilitated.

By using hospital-wide video conferencing systems, students can participate in surgeries virtually. VR and AR offer the opportunity for aspiring physicians to practice their first surgeries in a simulation. This allows them to gain experience without putting patients at risk. Even experienced physicians can use these techniques to train for complex operations or rare incidents.

Algorithms based on AI or machine learning are advancing medical research. Gaining new knowledge about certain diseases requires large amounts of data (Big Data). While the data required for such algorithms is often available in individual hospitals, it cannot be easily combined. Networking hospitals could solve this problem. With the help of Big Data Analytics, this data can be evaluated and new insights gained. This information not only serves medical research but also supports physicians in making decisions regarding individual treatments for tumors, for example. For such diseases, there are numerous treatment options, which is why selecting the best option is a major challenge for physicians.

Risk Assessment

Now that the opportunities presented by digitalization in all areas of a hospital have been explained, the associated risks must also be considered.

The greatest risk is computer viruses, which manipulate data, render it inaccessible, or publish it. A ransomware virus, for example, encrypts data on a hard drive, and access can only be restored after entering a password. Hackers usually demand a ransom for this password. The hospital has the option of restoring a backup, but this takes a considerable amount of time. Such a situation can have extreme consequences. Damage amounting to millions of euros is incurred because information exchange is no longer possible throughout the entire hospital. Furthermore, in such an incident, no operations can take place in a digitized hospital, which, in the worst case, can cost lives. IT security therefore plays a crucial role in Hospital 4.0. If this cannot be guaranteed, the foundation for digitalization is missing.

A similar issue is data protection. Patient-related information must not be disclosed to unauthorized persons under any circumstances. Patients must have full access to their own data at all times and be assured that the data actually only reaches those they have authorized.

This leads to the next risk: liability risk. If a system fails due to a cyberattack or artificial intelligence makes an incorrect decision regarding further treatment and a human life is lost, disagreements arise about blame and liability. Who is liable in such a case must be clarified before the most modern technologies are deployed.

In summary, it must be said that the risks posed by Hospital 4.0 represent a major threat. All new risks are primarily based on software solutions. Therefore, no expense or effort must be spared in development to make every piece of software as secure and reliable as possible. If this hurdle is overcome, Hospital 4.0 offers more advantages than disadvantages. Time and costs are saved, and above all, patient care is improved. Research and teaching will be advanced, which will lead to new medical discoveries and further reduce mortality.

10.9 Telemedicine

Telemedicine can be defined as medical consultations across a geographical distance. In the context of eHealth, it can be classified as eCare. Medical support is provided in the areas of diagnostics, therapy, and rehabilitation. This is achieved through the use of information and communication technologies.

Telemedicine offers several possible applications, both for the exchange of information between physicians (doc2doc) and for communication between physician and patient (doc2patient). However, such care cannot replace a physician, but rather complements treatment to improve the quality of care. The various scenarios can be divided into three areas:

- Teleconsultations
- Telemonitoring
- Teletherapy, Teleconsultation, and e-Triage

During teleconsultations, several doctors come together and discuss the further treatment of patients with tumors, for example. The structure of such a teleconsultation is a collaboration between equal participants. Thanks to the intelligent networking of hospitals, the X-ray images are available to each doctor, and the best possible treatment option can be defined together, or ideally even with the support of artificial intelligence.

Such a scenario is illustrated in Figure **??** ”Teleconsultation”. The nurse taking the patient’s vital signs is connected directly to the doctor and a specialist via video conference. They can see each other or live parameters. In this case, the best treatment strategy can be developed together. All information discussed can be printed centrally for the patient and nurse and stored on the ePA.

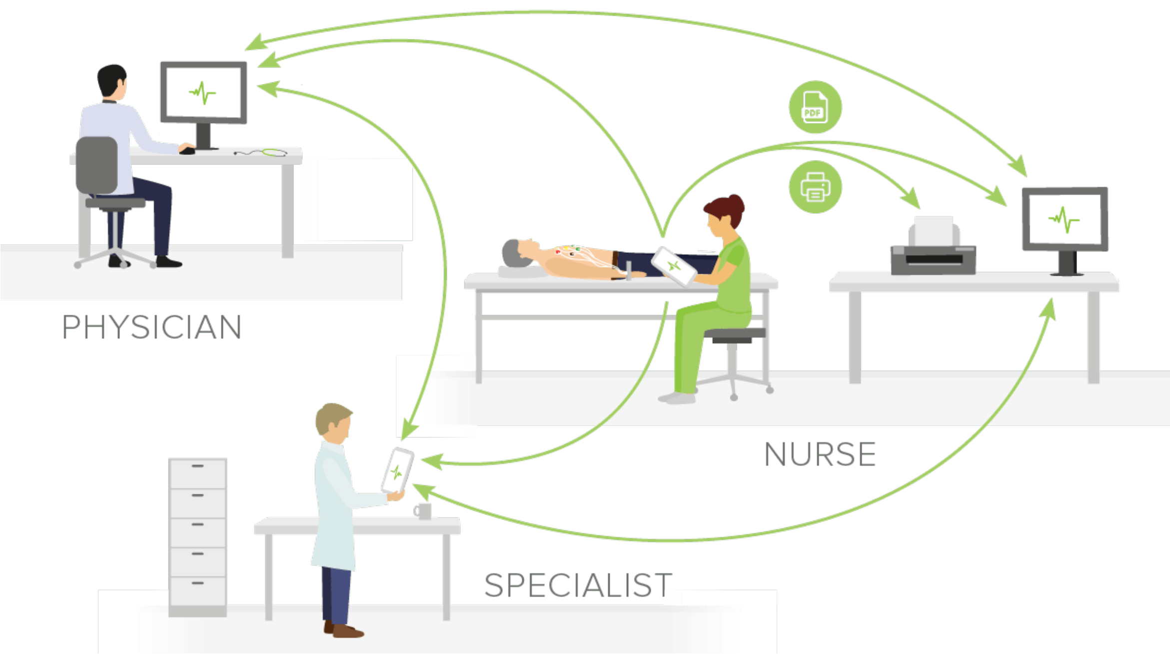

Figure 10.5: Telekonsil

Telemonitoring is used to continuously monitor certain patient health parameters. Remote monitoring of chronically ill patients, in particular, can make their lives easier or, in some cases, even save them. Wearables and home monitoring support the timely detection of changes in the stage of the disease or emergency situations and the initiation of appropriate measures [**?**].

Teletherapy can be used for mental illnesses. Consultations with a psychiatrist can be held online. For physical concerns, **teleconsulting** offers good opportunities to save time and money. Teleconsulting involves a doctor-to-patient interaction. This option is used primarily for uncomplicated issues and for follow-up examinations. E-Triage is an online tool or telephone service that helps patients assess whether a hospital visit is truly necessary. Often, complaints can be clarified remotely, thus reducing the burden on the hospital.

Tele-Intensive Care Medicine

Tele-Intensive Care Medicine, with its combination of teleconsultations and telemonitoring, represents a distinct area of telemedicine. The unique feature of tele-intensive care medicine is that a teleconsultation can be convened around the clock if necessary.

The process is the same as described in Figure **??** "Teleconsultation." The structure of a teleconsultation in intensive care medicine can be implemented either as a hub-and-spoke structure or as a cooperation between equal intensive care units.

The most common type is the hub-and-spoke structure. Figure 10.6 "Hub-and-Spoke Structure" illustrates a schematic of such a setup. The core of the hub-and-spoke structure is the tele-intensive care center. It acts as a video conferencing unit and establishes a secure data connection, for example, via a VPN server. It is also responsible for the data transmission of laboratory values, images, and monitoring. Furthermore, it is responsible for electronic documentation. The participants in this area are specially trained tele-intensive care physicians and other experts. The tele-intensive care center connects to a wide variety of hospitals and partner intensive care units.

Each partner intensive care unit must have a mobile video conferencing unit so that it can connect to the tele-intensive care center at any time. The partner intensive care units are the locations where patients are admitted and treated. A treatment team consisting of physicians and nursing staff is indispensable here. This results in a two-person principle for treatment, which allows decisions to be made more easily and precisely. If necessary, additional specialists can also participate in such a visit.

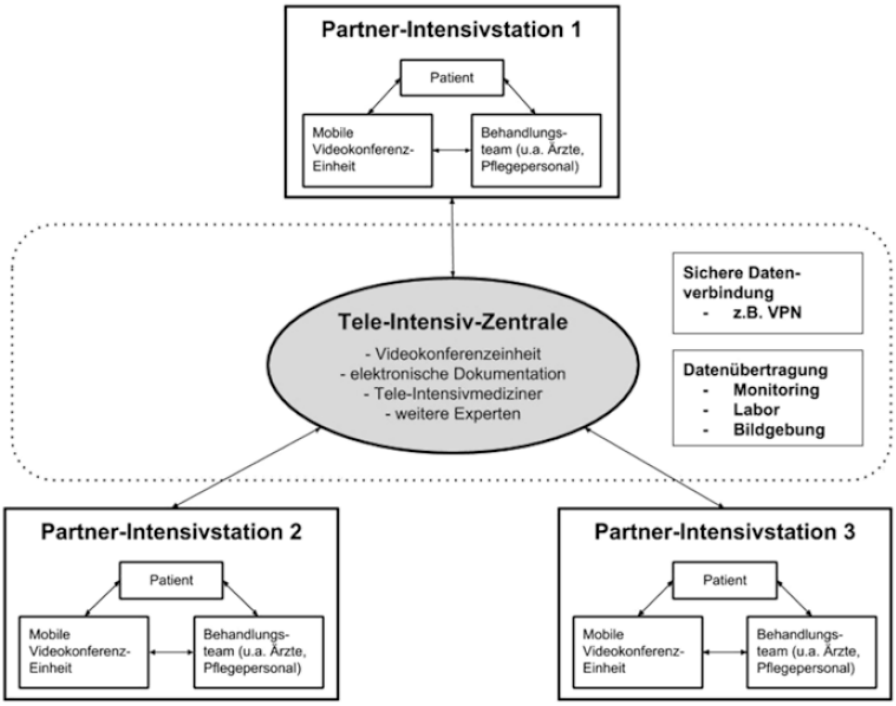

Figure 10.6: Hub-and-Spoke-Structure

Effects of Telemedicine

Telemedicine offers numerous advantages and influences the following aspects:

- Impact on mortality and length of stay
- Impact on the implementation of treatment guidelines
- Impact on sepsis mortality
- Algorithms and early warning systems
- Tele-emergency medicine
- Tele-stroke care
- Smartphone applications

Telemedicine or tele-intensive care medicine has a positive impact on **mortality and length of stay**. Due to:

- More frequent meetings
- Earlier analysis of clinical metrics
- Higher treatment adherence
- Faster response in emergencies

mortality and length of stay are reduced. Furthermore, patients need to be transferred less frequently. This saves time and costs that would otherwise be incurred through transport, and the chance of recovery is increased.

The implementation of treatment guidelines is also positively influenced. Telemedicine allows specialists to be consulted from other locations. A pharmacologist is often involved in treatment and can quickly identify medication violations.

Approximately eleven percent of the approximately 2 million people who end up in intensive care units in Germany each year suffer from severe sepsis (blood poisoning). If sepsis occurs, there are precise guidelines as to when and which measures must be taken. If these measures are not initiated, the patient's chances of survival are relatively low. The implementation of these measures is currently very unreliable. Televisits allow the measures to be implemented more effectively, and the patient's chances of survival increase enormously.

Algorithm-based monitoring systems can detect organ dysfunctions early on. Immediate initiation of appropriate measures significantly increases the patient's chances of survival. Telemedical early warning systems are primarily used in outpatient settings and enable patients to continue their normal lives. Non-invasively measured vital signs are continuously monitored in a telemedicine center. Changes or abnormalities in these data are detected early, and medical care can begin.

In the event of a rescue operation, tele-emergency medicine can play a crucial role. All data collected by the rescue team on site is forwarded via a mobile communication and transmission unit to a telemedicine center. A telemedicine center is located there and can be connected to the scene of the accident in real time. They receive all vital signs as well as a live video transmission. In non-life-threatening situations, the telemedicine center can delegate the emergency personnel.

In life-threatening situations, the time until the emergency doctor arrives can be used effectively. This leads to an overall reduction in emergency medical calls and relieves the burden on the healthcare system.

Especially in rural areas, too much time passes between the time a stroke occurs and the time it takes to receive the correct treatment. Tele-stroke care provides a solution. Immediately after a stroke patient is admitted, a stroke expert is consulted using a telemedicine method. Based on their expertise, they can then initiate the appropriate treatment steps and therapy without having to be on-site.

Ultimately, smartphone applications can also make the lives of sick people easier. While follow-up examinations should be a matter of course after treatment, they are far too often neglected. Using smartphone applications, patients can electronically document symptoms following treatment. These can then be monitored by the treatment team and specialists. By incorporating an audio-video conference, contact can be maintained and the overall quality of treatment can be improved.

In summary, telemedicine offers comprehensive support both in the outpatient care of chronically ill patients and in emergencies. The quality of treatment is improved, and the chances of survival in particularly urgent cases increase enormously. Therefore, telemedicine applications must be focused on and expanded in the future. However, this must first be achieved through the networking of the healthcare system within the framework of a Clinic 4.0.

10.10 Summary

Based on all the aspects presented above, the digitalization of the healthcare system is an integral part of the future of medicine. Demographic change and increasing life expectancy are forcing change and presenting the healthcare system with numerous challenges. A digital healthcare network must be developed, and interoperability must be ensured. Paper documents must be eliminated and system gaps eliminated. All stakeholders in the healthcare system must work together on a common platform (telematics infrastructure) in the future. This is the only way to overcome the shortage of skilled workers, keep healthcare costs within limits, and ensure improved patient care.

In Germany, approximately 34 billion euros can be saved annually through a digitized healthcare system. Most of the cost savings can be achieved through a modernized or digitized Hospital 4.0 and through telemedicine.

In Hospital 4.0, networked technologies are being introduced and real-time communication is being enabled. This will enable all areas to evolve. Doctors will lose their role as general practitioners and assume a role as specialists within a team. Patients will be required to assume more responsibility and independence, but in return, they will also gain more influence over their treatment process. Nursing care will be greatly reduced through mobile documentation systems, tracking systems, electronic order entry systems, hospitality entertainment, and other systems. Administration will flow more smoothly between individual departments. Research and teaching can utilize VR and AR to help them rehearse surgeries and rare situations. Using algorithms, machine learning, and big data analyses, new insights will be gained, and previously incurable diseases will be brought under control.

Telemedicine, through teleconsultations, telemonitoring, teletherapy, teleconsultation, and e-triage, is having a positive impact on many areas of life. For example, mortality and length of stay are being positively impacted. People in rural areas can receive care more quickly, and early warning systems improve the chances of receiving high-risk patients.

Computer viruses, data protection, and liability risks represent new risks that must be addressed. However, once these barriers have been eliminated, a promising future for a better life will flourish with Clinic 4.0 in

CHAPTER 11

Digital Administration

Learning Objectives

After completing this chapter, you will know...

... what digital administration is meant to be

... what the advantages and disadvantages of digital administration are

... what challenges must be overcome in Germany

... what technologies can help and how they can be used

... what a fully digital administration could look like.

11.1 Introduction

The public's desire for digital processes is growing, extending beyond the private sector to include digital processes in the public sector. Driving this affinity for digitalization in the private sector are the major tech companies, which have sparked people's enthusiasm for digitalization with their simple, affordable, and user-friendly applications and products, be it through smartphones, smartwatches, or numerous other useful inventions such as Apple Pay.

The coronavirus crisis also impressively demonstrated the state of digital networking among German government agencies and how much work still needs to be done regarding digital administration in Germany. Good examples of this are the numerous coronavirus mishaps that were previously unknown to the broader German population. This includes, for example, the contact tracing of individuals infected with the coronavirus. Health authorities attempted to trace chains of infection by telephone contact. Furthermore, there is the persistent problem that the German authorities have not managed to create an interface through which coronavirus case numbers can be reported digitally to one location without having to resort to the fax, the emblematic technological standard of German authorities.

11.2 Definition

Digital administration, also known as e-government, refers to the simplification of internal and external workflows in government institutions. This simplification is achieved with the help of ICT (information and communication technology). The use of these modern ICT technologies is intended to enable digital access to services in the future. Four different relationships can be distinguished between internal and external workflows. These are: [117]

Government to Government = G2G

Government to Citizen = G2C

Government to Business = G2B

Government to Employees = G2E

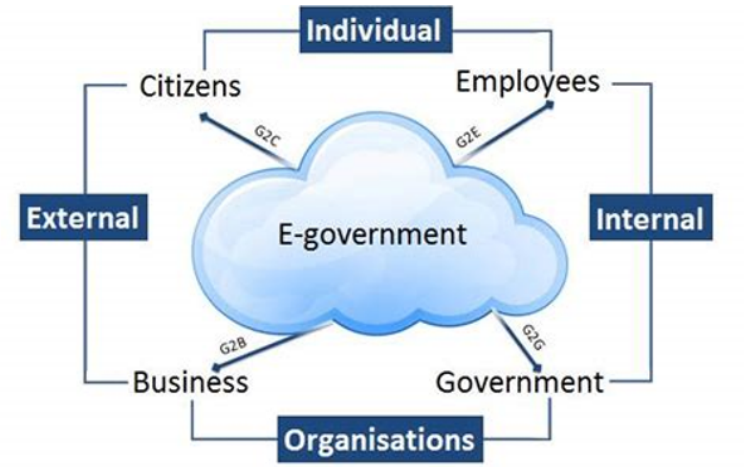

Figure 11.1: The various relationships in e-government.[118]

The relationships mentioned above show that digital transformation in the various government institutions offers a multitude of new opportunities for a wide variety of interest groups, such as cities, municipalities, communities, businesses, and citizens. Administrative procedures will thus become simpler, more flexible, and more transparent for various interest groups.

11.3 Reasons for Digitalization and Advantages and Disadvantages

Due to private-sector digitalization and its demands on Germany as a business location, it is in Germany's own interest to advance the digitalization of processes, in order to maintain Germany's attractiveness as an international industrial location. Only in this way can a digitalization process across society succeed, from which all stakeholders can mutually benefit. This results in the need to utilize freely available options provided by private companies in order to fulfill tasks better, more economically, and more efficiently.

The major advantages of e-government arise, on the one hand, from the constant availability of services, which can thus be accessed regardless of time constraints, and, on the other hand, from the advantage that in the future, government offices will no longer have to be visited in person, but applications can be processed online, in many cases in real time.

These advantages are not limited to the needs of citizens but also offer numerous positive effects for government offices, as they eliminate the need for specialized staff for many routine tasks, allowing these specialists to devote themselves to more challenging activities. Furthermore, electronic data is much easier to handle and store, resulting in efficiency gains that could benefit other municipal projects in the future. Another key aspect is the resulting flexibility. Documents can be accessed from anywhere, making home office work possible in administration, which plays an important role in making the workplace more attractive, as public authorities compete with private companies for qualified employees. Overall, it can be said that a streamlined, accelerated process is emerging.

The disadvantages of e-government mainly lie in data protection issues, which arise from the transmission of citizens' information over the internet. Well-thought-out IT security measures can effectively address data protection issues. Another disadvantage is that it is not fully accessible, as certain knowledge is required to access online services.

11.4 Laws

E-Government Act
The E-Government Act was enacted on July 25, 2013, and entered into force on August 1, 2013. The law is intended to promote electronic administration.

"The core points of the law are as follows: Article 1 is the E-Government Act. The key provisions are:

- Obligation of the administration to open an electronic channel and, in addition, the federal administration to open De-Mail access,
- Principles of electronic file management and substitute scanning,
- Facilitation of the provision of electronic evidence and electronic payment in administrative procedures,
- Fulfillment of publication obligations through electronic official journals and announcements,
- Obligation to document and analyze processes,
- Regulation on the provision of machine-readable data sets by the administration ("open data")" [119]

Government Program "Digital Administration 2020"
The government program "Digital Administration 2020" was adopted by the Federal Cabinet on September 17, 2014, and represents a kind of **action guide** for the implementation of the E-Government Act.[**?**]

Online Access Act
The Online Access Act, or OZG for short, is the second important law in Germany that enables digitalization in public authorities.

The OZG is a law passed on August 18, 2017, which is intended to guarantee access to all administrative services until the end of 2022.

The law obliges those involved in public authorities to make all administrative services accessible electronically via the government portal.

There are only exceptions for a few administrative services that cannot be made available digitally for special reasons. These exceptions are the following: [**?**]

- "the factual impossibility (e.g., emptying a garbage can),

- the legal impossibility (e.g., issuing a new identity card, which legally requires the applicant to inspect it in person), and
- the economic impossibility based on a cost-benefit analysis (e.g., applying to operate a new nuclear power plant)."

The **Federal Portal** is a portal in which all administrative services of the German authorities will be displayed in the future. Furthermore, after entering a search term in the search box, a status can be retrieved regarding the digitization progress of the respective service. This provides information on whether the service can be fully, partially, or not at all digitized.

Figure 11.2: Federal Portal homepage [120]

The following is an example of the process for a fully automated administrative service.

Figure 11.3: Process of a digital service

As shown in the figure, the federal portal must first be accessed. The desired administrative service can then be entered into the search box. If this service is available digitally, registration must be completed using the ID card that has activated the e-ID function. The corresponding application can then be completed and submitted.

11.5 Application of existing technologies in the government apparatus

As digitalization continues to advance and the world is in a constant state of change, there are constantly new opportunities and technologies in the area of digitalization in administration that can be implemented in the future.

Science is already exploring further additions to the further development of digital administration. Among other things, the term **Smart Government** is being used, which is considered appropriate for the future embedding of technologies in digital administration. Technologies such as **blockchain, artificial intelligence, and big data** are being used here.

The following graphic illustrates and names the technologies available today and shows examples of how they can be used in the government apparatus.

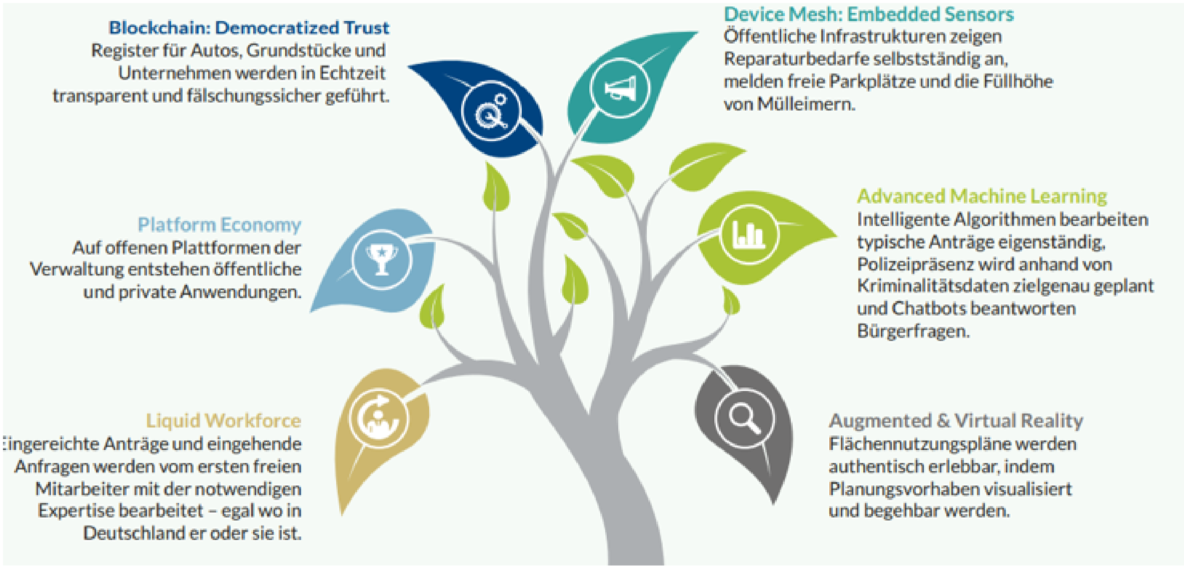

Figure 11.4: Technologies and their areas of application [121]

These technologies are presented below along with their fields of application in government institutions. The aim is, on the one hand, to highlight possibilities that are currently not considered, and, on the other hand, to actively address fields of application that are already being implemented.

One of the technologies that the administration could utilize is blockchain technology. With regard to the tasks of the administration, two major themes can be identified. On the one hand, the issue of notarization and the various register management processes play an extremely important role in the administration's process landscape. This involves maintaining both citizen data and vehicle and property data, all of which make the organization of communal living possible. On the other hand, the administration plays the role of a fair, objective, and neutral intermediary, whose presence enables certain processes in which trustworthiness plays a central role. For this purpose, the administration has developed a variety of tools over the centuries, such as deeds, seals, stamps, certificates, and others, to ensure legal certainty for everyone.

This is where blockchain technology can intervene and redefine the role of the administration, as blockchain technology is predestined to keep data neutral, immutable, and decentralized. This makes it possible to replace existing registers and certifications. Blockchain data storage, such as identity cards, weapons or vehicle data, patient data, birth certificates, and land registry entries, will become possible. [122]

Argumented Reality can be used in the future to initially inspect planning projects virtually. This allows for a variety of perspectives that incorporate the natural environment. Another option is the measurement of objects, which, with the help of VR headsets, displays the dimensions directly to the user.[123]

Within the context of machine learning and artificial intelligence, there are a multitude of use cases that can be addressed with the new technology.

Various possibilities are shown in the following figure.

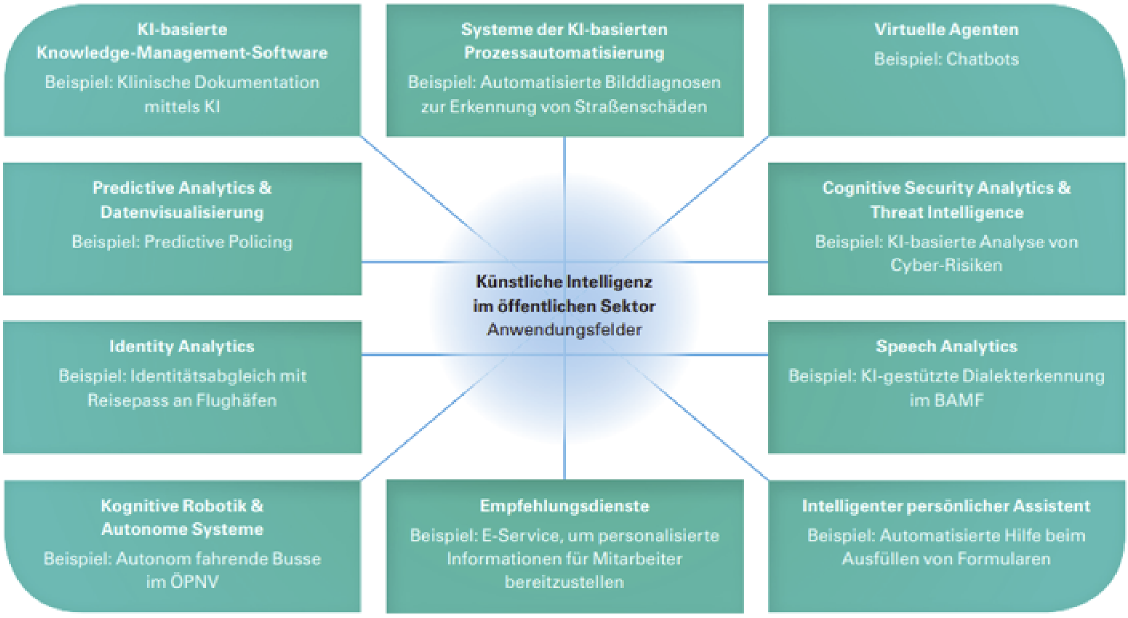

Figure 11.5: Application areas of artificial intelligence [?]

The Internet of Things technology will make smart city concepts feasible, which aim for an efficient, technologically sustainable, socially responsible, and equitable city. Embedded sensors will play a central role in this, contributing to the intelligent control of the city with their data from the environment. To do this, the sensors collect various data from the streets, such as air quality or the condition of empty streets, which then trigger the streetlights to switch off to save energy. Furthermore, sensors are already being used to detect water and wind hazards early on so that appropriate measures can be initiated. Traffic monitoring on highways is also already a reality today, attempting to prevent hazards and emerging traffic jams at an early stage.[124]

11.6 Challenges

In order to harness the transformational potential offered by digitalization in German administration, decisions are needed that release the brakes.

A major **challenge** here is our **federal system**, according to which Germany is organized. Innovations often only succeed on a small scale, and the overall system shows little capacity for innovation.

"Joint action is made more difficult by the fact that political opinion-forming processes are largely decoupled and run in staggered cycles, that the actors in the ministries and IT departments, in municipalities, states, and the federal government, pursuing different goals, and that past IT investment decisions continue to have an impact because different paths were taken, which can only be abandoned with difficulty due to lock-in effects." [1]

These challenges are graphically illustrated again in the following diagram and demonstrate the **inertia** with which **the expansion of digitalization in public administration in Germany is taking place.**

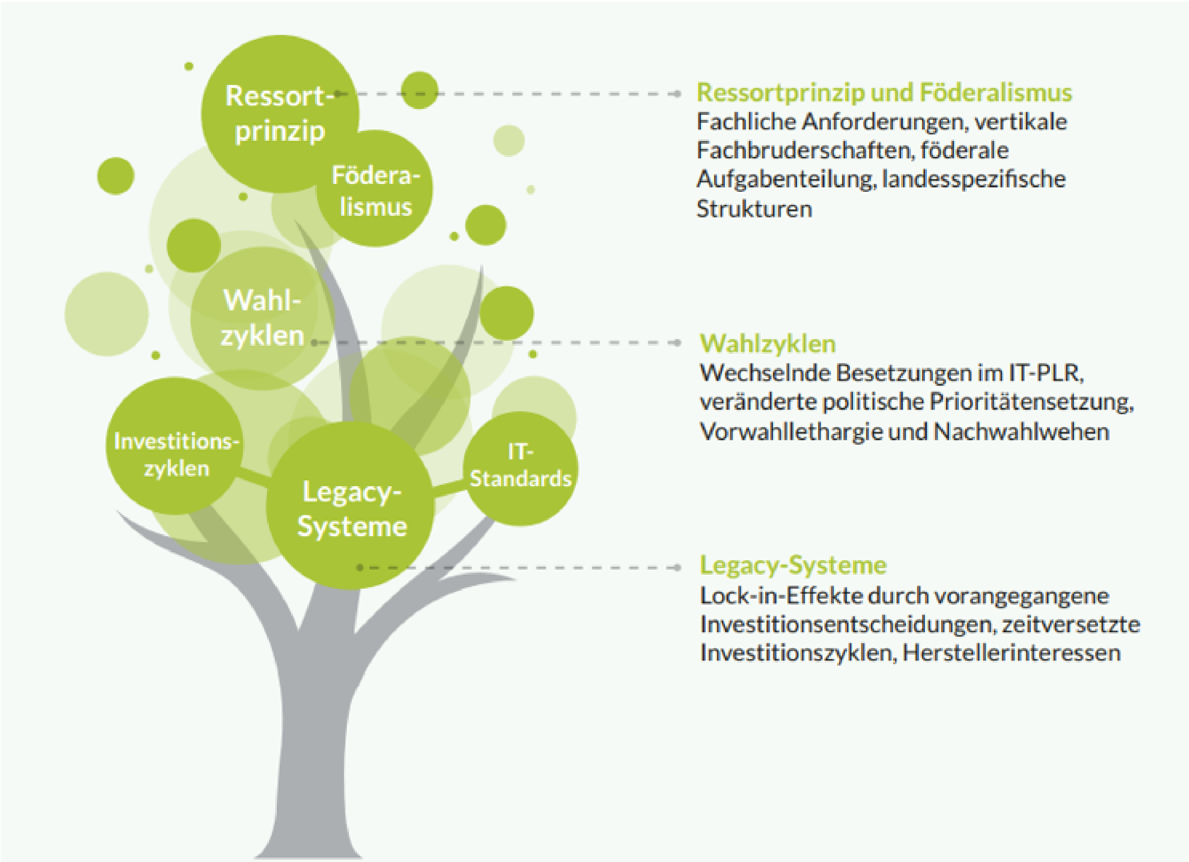

Figure 11.6: Challenges of the federal system [121]

In order to consistently and successfully advance digitalization in public authorities, a strategy must be followed. First, a **common consensus** must be found that provides orientation and alignment for all parties. Furthermore, a common mission statement must be formulated. Once this first hurdle has been overcome, the second step of the recommendation pyramid (figure below) can be applied. This involves ensuring that the administration is open to innovation, incorporates stakeholders' ideas, and increases the speed of implementation. Furthermore, the processes must be usable across existing organizational boundaries. For this, uniform interfaces and standards must be created. Building on this, it is necessary to ensure secure administration so that citizens' data is handled responsibly. Furthermore, the collected data must be intelligently incorporated into decision-making. The foundation of the systematic digitalization process is a legal framework that must be designed. The laws passed within this legal framework are needed to guide digitalization in a pioneering manner.

1 [121, Beck p. 21]

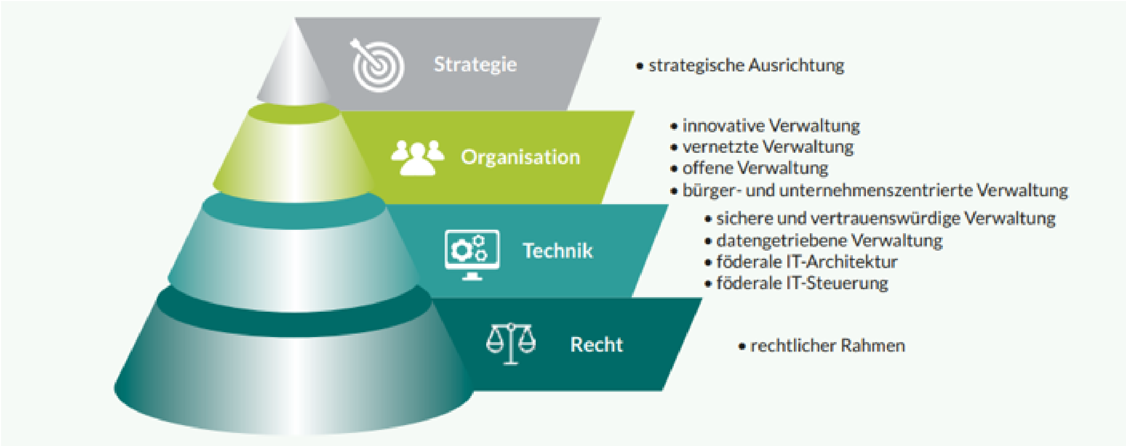

Figure 11.7: Recommendation pyramid for the implementation of digital administration

11.7 Example of a Complete Digital State

The following example illustrates one possibility for digital administration, using Estonia as an example.

In Estonia, digital proof of identity has long been standard. Unlike in Germany, the Estonian identity card also replaces other functions, such as a driver's license or the points card in supermarkets. Estonia has created a way to make a digital signature legally binding. All that is required is an identity card and a PIN, which can be used to create a digital signature. Therefore, documents no longer need to be signed by hand. The system behind it is called **X-Road**. In Estonia, all data only needs to be made available to one authority once. These authorities, in turn, can then access the data of the other authority if this complies with data protection regulations. This means that all authorities only have access to the data of the citizens they need to work with. The advantage for the citizen is the **once only principle**. Any data only needs to be submitted once, so if you change your address, this only needs to be done once. To promote trust in the state apparatus, Estonia has created a gateway through which citizens can see who accessed which data and for what reasons, and when. Furthermore, this allows information about the data the state holds about you to be read. Data that the Estonian registration office needs to know after the birth of a child is transmitted directly from the hospital. Furthermore, you receive a personal ID card immediately after the birth, which you can use to identify yourself. This means that state benefits such as child benefit do not need to be applied for; they are transferred automatically. By comparison: in Germany, the birth certificate must be sent by mail to different authorities at least three times. According to the Estonian government, 99 percent of administrative procedures can be done digitally. Only marriages, divorces, and buying a house are not yet possible digitally. For these, you still have to appear in person, even in Estonia. Beck p. 16 ff.]Bertelsmann

Finally, the following figure impressively illustrates which topics and areas of action must be considered and addressed in the transformation to digital administration in Germany.

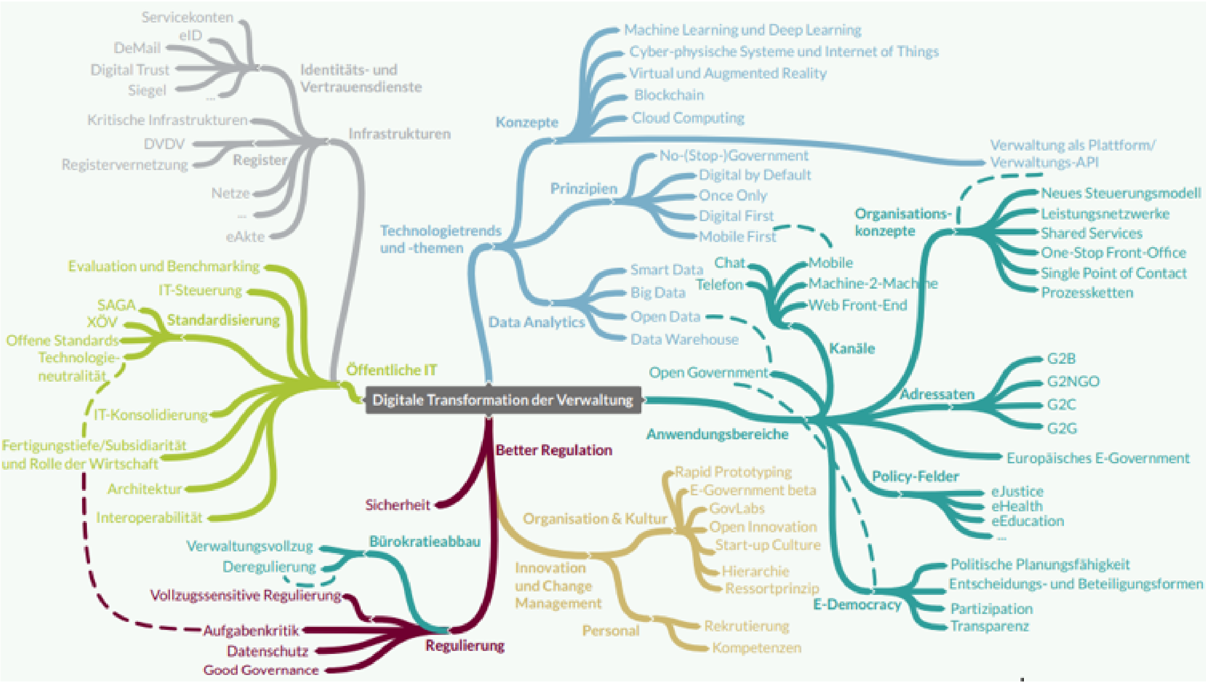

Figure 11.8: Areas of Action of Digital Transformation

11.8 Summary

Digital administration is already being used today, as demonstrated using the example of Estonia. Digital administration will sooner or later also become established in Germany, although it became clear that some fundamental conflicts still need to be resolved in Germany before the same administrative processes can be found here as in Estonia. Nevertheless, the potential that digital administration can unlock in Germany and how it secures Germany as an industrial location was demonstrated.

Digital administrative processes promise a much faster, more efficient, and more cost-effective alternative for Germany. Not only will they save a significant number of jobs in the future, but they also offer the advantage that citizens gain from e-government: They can avoid future visits to the authorities and complete them at a time of their choosing.

CHAPTER 12

Cultural Digitization

Learning Objectives

After completing this chapter, you will know...

... what digitization means in art.

... what cultural digitization projects can look like.

... what digital art can look like.

... what the Digital Fund is.

Introduction

Cultural digitization describes the approach of digitizing culture in as many areas as possible, such as music, theater, and works of art. Since this encompasses all aspects of culture, it is also a very broad topic. It ranges from the digitization of works of art to new possibilities in concepts for cultural institutions and even digitally created art. A large number of projects dealing with all aspects of digitalization are currently underway, and new ones are being added daily. This chapter provides an initial insight into cultural digitalization and some of the projects that have emerged in the process. It begins by introducing previously implemented projects and art forms, followed by a brief description of the Federal Cultural Foundation and why it is so important for promoting digital culture. The whole process concludes with the KulturDigital funding program. This describes how projects will be funded and implemented in the future.

12.1 Projects

This chapter presents various projects to make the topic of cultural digitalization more tangible and to once again highlight the various aspects and possibilities of digitalization. The projects can generally be divided into three artistic areas:

1. Digitization of art institutions
2. Digitized works of art
3. Digitization of music and theater productions

12.1.1 Digitization of Art Institutions

The **Museum as Co-Laboratory** falls under the category of "Digitization of Cultural Institutions." In the Museum as Co-Laboratory, the project partners are committed to conveying archaeological practice and expertise in a new way through the creation of digital applications. Museums are supported by an advisory board in the conception of **digital serious games**[1] and the development of digital installations for the various institutions. In game jams and workshops, participants co-develop and test digital and interactive formats.During testing, we are experimenting with techniques such as:

- Augmented Reality (AR)
- Mixed Reality Glasses
- LiDAR Scanning [2]
- Photogrammetry

The focus is on collaborative, process-oriented, and co-creative work. The stated goal of this project, "Museum as a Co-Laboratory," is to implement digital applications into exhibition practice in the long term and thereby sustainably shape the transformation of museums into co-laboratories. The institutions are supported by experts from digital, marketing, and consulting agencies who not only provide technical expertise but also train in working with agile and digital methods. The younger generation will be responsible for preserving and disseminating history and culture in the future, but the question arises: how can this work if history and culture are not addressed?

The **Museum as a Co-Laboratory** addresses precisely these questions, as participants have long been aware of this:

Digitization is no longer the future, but already the present!

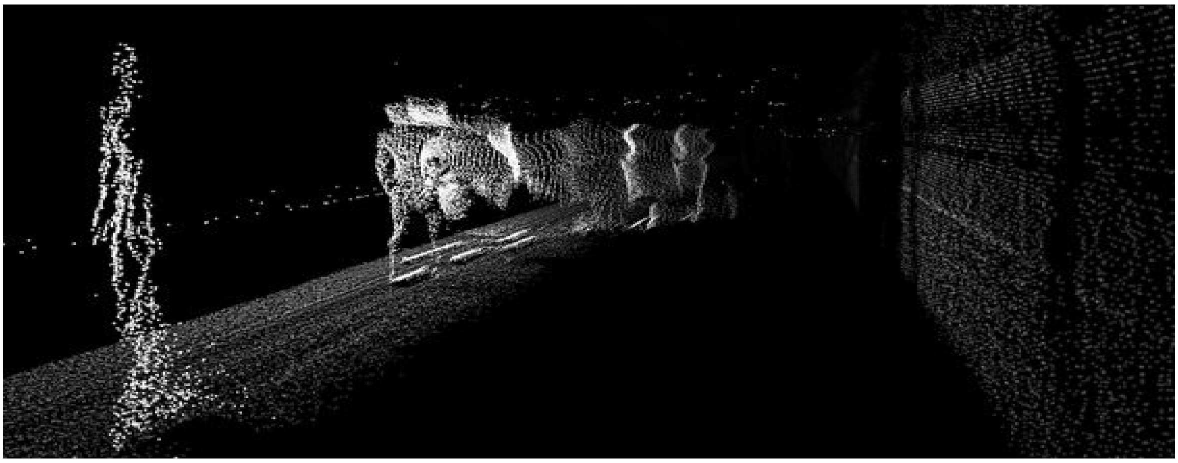

Figure 12.1: Museum interior scanned using LiDar technology

1 These are games that take place in a hardware- and software-based virtual environment and are intended to stimulate the learning of specific and desired content.

2 A form of three-dimensional laser scanning for optical distance and speed measurement, as well as for remote measurement of atmospheric parameters

12.1.2 Digital Art

Digital art can be viewed from various perspectives. These can be categorized into the following five points:

1. historical perspective
2. art genre
3. computer science
4. video games
5. computer as a tool

When looking at digital art from a **historical perspective**, one explores the history of computers and, beyond that, the history of machines in the service of art.
From the perspective of the **art genre**, digital art can be found in all areas. It can be found in the visual arts, performing arts, as well as in literature and music.
From the perspective of the scientific discipline **computer science**, digital art spans many fields, ranging from the spectrum of digitization to digital humanities and data archiving.
A special case of digital art from a computer science perspective is video games. Entire worlds and landscapes are created here, depicted in a variety of designs and representational possibilities.

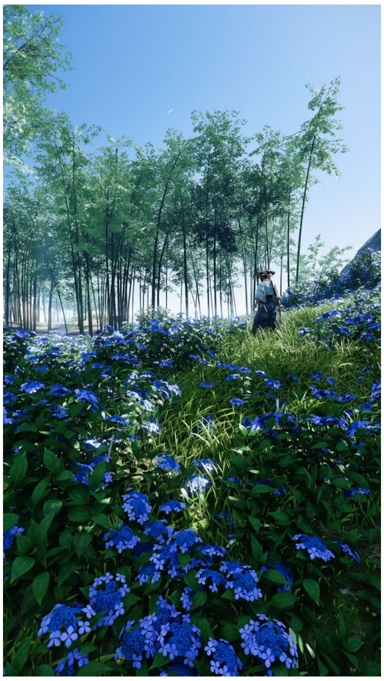

Figure 12.2: Here you can see an excerpt from the game Ghost of Tsushima, which won the Game Developer Choice Award in the visual design category.

The last perspective is the computer as a tool. The diverse possible uses in art are particularly striking here. The machine is also an adequate means of making art contemporary.
With digital art, it is striking that it receives surprisingly little visibility in museums, archives, and artistic discussions.

NFT Art

So-called **NFTs** (non-fungible tokens) are non-fungible tokens. This means that an NFT cannot be sold for the same price after its purchase. It behaves like an investment whose value rises or falls depending on the market situation.
An NFT is a purely **digital asset** that exists only in the digital universe. For the buyer, this means that they can only own an NFT. NFTs can be any digital file. They range from works of art, articles, music, to memes. [1]
The NFT art boom began around April/May 2021. Since then, search terms related to NFTs have been trending on platforms like TikTok, Twitter, and Instagram. This justifiably raises the question: "What impact will the digital form of art sales have on creatives and the industry?" What can already be said is that NFTs are no longer just a hype, but rather a long-lasting trend.

With NFTs, there is, for the first time, the opportunity to own digital content. Before, people simply downloaded digital content like songs or sent pictures without becoming owners of that content. This has fundamentally changed with NFTs. Artists can now freely decide whether they want to lend, sell, or even exhibit their NFTs. An environment is developing in the digital space that is increasingly aligned with reality.

In order to legally own NFTs, they must first be mined using a blockchain, or turned into a token. The advantage of the blockchain is in that it is very well protected against hacker attacks. This can be particularly important when tracing copyright, as it is very difficult to introduce false information.

In simple terms, a digital work of art belongs exclusively to the artist, provided they have mined it.

However, the legal situation regarding the ownership of digital artwork is currently being reviewed again.
Trading digital art offers artists a new way to categorize artwork and also earn money from their work. The goal of this type of art distribution is, from the artist's perspective, a very **quick and easy** way to produce works and reap their rewards. The big advantage is that you no longer have to wait for payments from customers, prepare files for printing, or wait for feedback from customers regarding adjustments.
In addition, there are **royalty fees** charged by the creator on NFTs. These are usually **8-10 percent** if the work is resold in the future. The general danger with trading digital art is that its value is based solely on cryptocurrencies. So, if cryptocurrencies decline over a long period of time, the value of NFTs and crypto artworks will also decline at the same time.

The cryptocurrency in which it is traded is called **Ethereum**[2].
To better understand the dimensions of NFT trading, here are a few examples of the currently most expensive NFTs:

- 1st place: **Everyday the First 5000 Days**
- 2nd place: **CryptoPunk #7523**
- 3rd place: **CryptoPunk #3100**
- 4th place: **Crossroad**

1 This is creative content, usually images or short videos, that spread primarily online. The content is usually humorous and uplifting, sometimes also socially critical and satirical.
2 It is an open source distributed system that offers the creation, management, and execution of decentralized programs or contracts in its own blockchain. It is thus a counter-design to the classic client-server architecture

- 5th place: **first Twitter message**

At the end of 2021, the **40 billion US dollar** mark was broken on the NFT market. In March 2021, the most expensive NFT artwork to date was sold for $69.3 million. It was titled "Everyday: the First 5000 Days." The artwork features a compilation of Beeple's first 5,000 digital artworks. What's special about this artwork is that the artist Beeple began creating digital artworks back in 2007. Since then, he has created a new artwork every day and compiled them into the work "Everyday: the first 5000 Days." The compilation includes various styles, content, and media. The first artworks were definitely not cutting-edge, but the overall concept allowed the artwork's value to rise rapidly.

Figure 12.3: In this image of the artwork "Everyday the first 5000 Days", the individual 5000 elements of the entire work are clearly visible

The second most expensive NFT is the **"CryptoPunk #7523"**. It depicts a pixelated portrait of a fictional character. In keeping with the pandemic, he wears a surgical mask and further increases the hype surrounding blockchain products.

Figure 12.4: CryptoPunk #7523 with his surgical mask

Third place also goes to a CryptoPunk. This artwork is titled **"CryptoPunk #3100"**. Whether this will become the most expensive of its kind in the future remains unclear. The current owner hopes to resell his Punk for **91 million USD**. This would make it not only the most expensive of its kind, but even the **most expensive NFT ever**.

Figure 12.5: CryptoPunk 3100, which is expected to fetch record sums one day

The video **"Crossroad"** was acquired for **6.66 million USD**, making it the fourth most expensive NFT. A closer look reveals a clear **sideswipe** against former American President **Donald Trump**. In the video, pedestrians walk past an oversized, fallen Donald Trump, who has been insulted. What's special about this NFT is that it's based on the American election campaign. If the election had gone in Trump's favor, the NFT would have a figure depicting Trump with a crown, going through hell.

Figure 12.6: The image is an excerpt from the 10-second video "Crossroad"

The fifth and final NFT on this list is the **first Twitter message ever written**. It consists of just the words "I'm setting up Twitter." Twitter CEO Jack Dorsey sold these words for $2.9 million. He donated the proceeds from the auction to poor people in East Africa. The response from the corporate world was immediate. Sina Estavi, CEO of Bridge Oracle, a startup focused on blockchain technologies, commented: "I think years later, people will realize the true value of this tweet, like the Mona Lisa painting."

Figure 12.7: Jack Dorsey, founder of Twitter with the first-ever tweet

12.1.3 Digitization of Music and Theater Productions

Theater has always seen itself as a place for reflection on politics and society. But what does this look like in the digital age? Can cyberspace now also be used as a space for theater? Are the forms developed by the Internet even usable for the institution of theater? Since 2013, the **Conference Theater and the Internet** has been discussing and investigating the consequences of digitalization for theater. Topics of the annual discussions include:

- Platform or Player? Political Art and New Activism
- Digital Stages of Extremism
- Assertion Machines: Fake, Facts, and Fiction
- From Audience to Community
- The Innovation Screw

The 14th edition of Netztheater describes how the coronavirus pandemic is dissolving hierarchies, creating new workflows, and connecting employees through data streams. At the time, it seemed as if theater in its traditional form would be suspended until the coronavirus pandemic was over. According to some theater professionals, this was a better solution than offering "bad television" on its own website. However, for the Burgtheater in Austria, suspension was not an option. The desire to maintain contact with their audience gave rise to the series MyHomeIsMyBurgtheater. In this series, members of the ensemble filmed themselves reading self-selected texts that had become important at some point in their lives or had accompanied them for a long time. This series quickly reached 50,000 people on Facebook alone. The Burgtheater's goal was to use the alternative program to maintain customer loyalty and service. The great danger was that at this point the internet would be drowned by aesthetically undemanding self-filmed statements. To counteract this, the series "Wiener Stimmung" (Vienna Mood) was created. It significantly increased the artistic ambition by awarding 22 prize-winning commissions to Austrian artists. Each artist delivered 10-minute monologues, which were filmed via video conference with a small team (usually just a sound engineer and cameraman) due to the crisis. This led to the Burgtheater's performance schedules being replaced by online calendars. The program was also expanded. The formats offered included streams, readings, performance instructions, and Zoom workshops. Everything was under the motto "Theater without Theater." This gave rise to the Twitter appeal "#vorstellungsänderung" (change of performance). The idea behind it is that people narrate a performance that exists only in their imagination. Within a very short time, 3,000 tweets were written under this hashtag about a collective narrative of a theater evening. What's special about this hashtag is that the theater neither dictates themes nor intervenes in the events. With the help of the Twitter algorithm, the hashtag ends up trending in Germany and Austria. The announcement of the fictional theater meets the conventional minimum requirements:

1. Title
2. Genre
3. Personal Setting

Because theater is a very complex art form, #vorstellungsänderung follows a very simplified and extremely reduced approach: collaborative performance, shared imagination and creation, as well as traditional mechanisms. All participants recognize the conventional arrangement of an evening visit. The freedom granted by the theater leads the series participants to explore the following aspects:

- Plot
- Play
- Implications
- Reconciliation with the stage feel
- Demands for entertainment and meaning
- Emotional involvement

The **#vorstellungsänderung** series is a unique experiment in the tension between art and creativity versus the possibilities of quantification and commercialization.

The goal is not only to have theatrical performances on a stage in the classical sense, but rather to explore new forms of theatricality in spaces other than traditional ones with social constraints. This raises the question:
"Is the idea that theater takes place in separate rooms already passé?"

12.2 Federal Cultural Foundation

In order to better understand the **Digital Culture** funding program in the remainder of this chapter, the importance of the Federal Cultural Foundation must first be emphasized. This foundation is dedicated to supporting innovative programs and projects in an international context. It has an annual budget of €35 million for this purpose. Since 2002, the Federal Cultural Foundation has used this to support around 4,000 projects in the field of contemporary culture.
In addition to supporting the arts, the project also focuses on cultural exchange and cross-border cooperation. This can be divided into the following three areas:

1. general project funding
2. program funding
3. cultural lighthouses

In **general project funding**, projects are funded with up to €10 million, regardless of the genre (art, music, theater, etc.). Cultural workers can apply for this funding for their projects twice a year and, ideally, receive it. The funding and financial support usually relates to large international and innovative projects, such as DOMiDLabs, Jupiter - Performing Arts for Young Audiences, and Kultur Digital.

Program funding runs parallel to general project funding. The difference is that program funding sets its own priorities. These can come from the following areas, for example:

- Climate
- Digitalization
- Structural Change
- Diversity

The program funding category also includes the funding program Kultur Digital, which will be discussed in more detail in the following chapter.
The last item supported by the Federal Cultural Foundation is the so-called cultural lighthouses. Selected cultural institutions and internationally renowned festivals receive multi-year funding. This funding primarily provides them with multi-year planning security. This funding includes, for example, the following:

- the documenta in Kassel
- the Donaueschinger Musiktage
- the Berlin Theatertreffen
- the World Cinema Fund
- the Dance Congress
- ...

12.3 Digital Culture

Digital Culture is a funding program that supports cultural institutions in shaping digital opportunities and challenges in a self-determined and public-interest-oriented manner. However, to date, only a few institutions have developed digital concepts and offerings and further developed them in this direction. The reasons for this are the lack of specialist know-how to assess and utilize these highly dynamic technologies. The Digital Culture funding program primarily refers to projects that have not yet been implemented or are in the initial phase. Thus, the projects presented here differ from those in the previous chapter.

The three-part program **Kultur Digital** fundamentally pursues an **open access, open source, and open content** approach.
Components of this program are:

- Fonds Digital
- Kultur Hackathon Coding da Vinci
- Academy for Theater and Digitality

12.3.1 Digital Fund

The Digital Fund is an association of cultural institutions from all artistic disciplines. It is aimed at public cultural institutions that have already developed digital strategies and tested digital offerings. The Digital Fund is intended to enable cultural institutions to expand their transformation processes and advance their institutions with the help of new digital aesthetics and profiling.

Funded projects come from the fields of digital curating, digital artistic production, digital mediation, and communication. The project-related network always consists of two cultural institutions and a digital partner, who is responsible for supporting the implementation of the concepts already developed. The partner helps to acquire new digital skills, which the cultural institutions share along with new content and publish on public networks. To support these institutions and alliances, regular Digital Labs academies, organized by the Federal Cultural Foundation to provide professional support to institutions and promote mutual exchange, are planned, as well as colloquia, international excursions, and training courses. A total of €15.8 million is available for the Digital Fund. Projects excluded from the Digital Fund are those that focus exclusively on digitizing collection holdings.

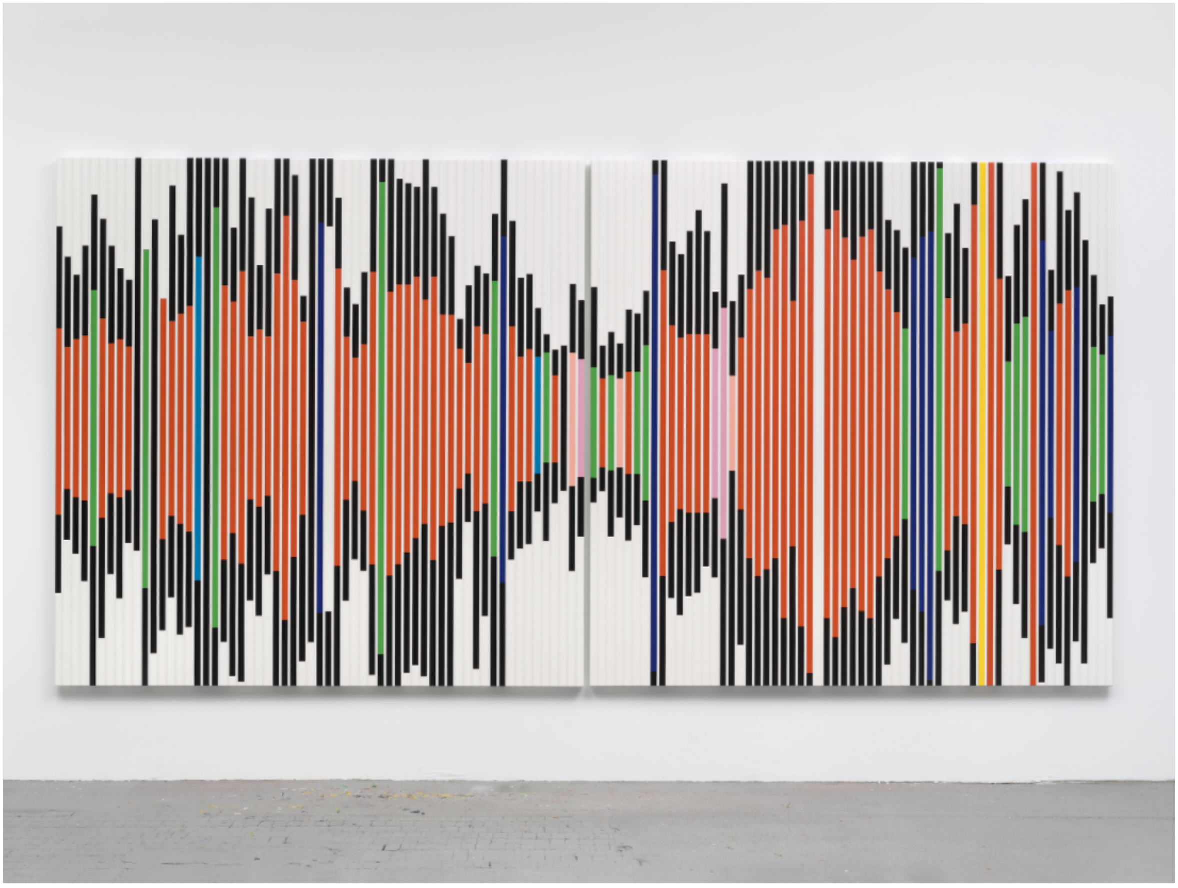

Figure 12.8: The Soundgraph 3.0 emerged from one of the Digital Fund's projects; it visualizes a digitally composed piece

12.3.2 Culture Hackathon Coding da Vinci

The **Culture Hackathon Coding da Vinci** aims to motivate institutions to prepare cultural data for the public using the possibilities of digital technologies. This is an event format that aims to further expand the availability of open and freely accessible cultural data.

Coding da Vinci not only supports **digital transformation** but also creates attractive opportunities for the online community to creatively engage with culture (and cultural data).

The Cultural Foundation supports eight editions of the Culture Hackathon and cooperates with the founding institutions of Coding da Vinci.
Furthermore, there are scholarships available to support participants in the ideas generated during the hackathon. These scholarships include €1,250 per month and participation in coaching sessions and workshops to learn new skills related to their projects and, where appropriate, to pass them on.
Generally, the hackathon is a joint project of the German Digital Library, the Research and Competence Center for Digitalization, the Open Knowledge Foundation Germany, and Wikimedia Germany.

12.3.3 Theater and Digitality

This is the third program within Kultur Digital. Between 2019 and 2022, 54 artist grants will be awarded, each for five months at the Academy for Theater and Digitality at the Theater in Dortmund.
This will create, for the first time, a place for digital artistic research, collaboration, and the training and continuing education of artistic and technical staff in theaters in Germany.
Individual research grants will receive up to €1 million in funding. A total budget of €18 million is available.
Two project examples for theater and digitality are:

1. **Das House - Reinventing the Real**
2. **UnBoxing Stages - Digital Practice in Theater**

Das House - Reinventing the Real

This is a virtual reality theater project that addresses the questions: "If and how digital spaces can be used by theaters?" and "How do theatrical storytelling and co-presence function in virtual landscapes?" "Das House" invites you into atmospheric and enigmatic in-between worlds constructed from new and existing 3D scans. There are also 3D-scanned avatars of participants. There are already two episodes of this project: "Das House 0.1" and "Das House 0.2”.

Whether this type of theater production will prevail, however, remains to be seen.

UnBoxing Stages - Digital Practice in Theater

This is a collaboration between the Theatertreffen, the Academy for Theater and Digitality, and the Digital Dramaturgy Initiative within the framework of Theater virtual. The coronavirus pandemic has forced theaters to deviate from their typical working routine. "Theater online" was initially a stopgap measure, but it has become clear that it harbors enormous potential and opportunities. With the help of new aesthetics and new narrative styles, a new audience can be inspired. However, important questions for the future also arise here:

- How can one engage meaningfully with theater online?
- What risks and potential lie behind this initiative?
- How can a sustainable engagement with theater online and digital technologies be achieved?

- Which aesthetics, forms of interaction, and presentation modes are on the rise? What technical know-how is necessary for a sustainably successful production?

The research project "Unboxing Stages - Digital Practice in Theater" addresses all these and other questions and invites participants to exchange ideas about theater forms on and via the internet. This will be conducted through three panel discussions, in which all relevant parties are represented. There will also be the "Long Night of Tutorials" in which experts will give a series of 60-minute hands-on presentations and share their technical knowledge of combining the internet and theater.

This question will continue to be with us for some time to come.

12.4 Summary

At the end of this chapter, we provide a brief overview of the most important information on the topic of cultural digitization. Regarding concrete projects related to cultural digitization, there is, for example, "Museum as a Co-Laboratory," which uses new methods to convey archaeological practice and expertise through the creation of digital applications. New technologies such as LiDAR scanning are used. In the area of digital art, the whole topic of NFTs cannot be ignored. These are purely digital assets that can only be owned through mining using the blockchain. NFTs are very popular with artists because they offer a quick and easy way to monetize their art. The currency for NFTs is called Ethereum.

The conference "Theater and the Internet" has been running since 2013 on the digitization of music and theater productions. It addresses the topic of how to digitalize theater in the future. Successful attempts have already been made under the hashtags "#MyHomeIsMyBurgtheater" and "#vorstellungsänderung." In the long term, the question arises: **Is the idea of theater performances taking place in separate spaces already a thing of the past?**
There are only a few institutions in the Kultur Digital funding program. This is due, among other things, to the fact that there are still very few concepts and offerings in this direction. The situation is further complicated by the fact that the institutions are not sufficiently developed in this direction.

Kultur Digital pursues three approaches: open source, open access, and open content. The basic components of the program are: "Kultur Digital," "Kultur Hackathon Coding da Vinci," and "Akademie für Theater und Digitalität." The Digital Fund is an association of museums, theaters, opera houses, and memorial sites. The Digital Fund's project teams consist of two cultural institutions, each with a digital partner. Funded projects come from areas such as digital curating, digital artistic production, digital mediation, and communication. Regular digital labs, colloquia, international excursions, and training courses are held to support these projects. The Coding da Vinci cultural hackathon aims to encourage the public to use digital technologies to prepare cultural data. In addition to digital transformation, it aims to create attractive opportunities for the online community to engage creatively with cultural (data). The Theater and Digitality program offers 54 artist grants at the Academy for Theater and Digitality. This creates, for the first time, a space for digital artistic research, collaboration, and training and continuing education for German theaters.

CHAPTER 13

Cloud-Computing

Learning objectives

After completing this chapter, you will know ...

... how cloud computing fundamentally works.

... what models of cloud computing are available on the market.

... how cloud computing is technically realized.

... the advantages and disadvantages of cloud computing.

13.1 Basic Concept of Cloud Computing

The steadily growing need for IT infrastructure of industrial companies, brought along by digitalization, has given rise to the solution approach of cloud computing. This is an infrastructure that offers companies the opportunity to obtain software, storage capacity and computing power on a customer-specific, location-independent and on-demand basis via the Internet. The scope of functions, the duration of use and the number of users are charged for. The importance of a flexible and scalable hardware and software infrastructure has become particularly apparent in the last decade. According to a representative survey by Bitkom Research, two out of three companies in Germany now use this technology [125].

However, the use of cloud services requires a broadband connection so fast that it is no longer any difference whether the data is stored locally or in the cloud. In the private sector, the usage is therefore also linked to the market supply with DSL or LTE connections. In general, the bandwidth requirements depend on the respective service model, which will be discussed in more detail later [126].

Cloud computing is essentially defined by five technology characteristics (see figure 13.1). These were defined by the National Institute of Standards and Technology (NIST) as follows [127]:

- **On-Demand self-service:** When needed, computing capacity such as server time and network storage can be automatically accessed without further interaction with the provider.
- **Broad network access:** Cloud computing functions are made available over the network and are accessible via standard mechanisms (e.g., Internet browser).
- **Shared resource pool:** resources such as storage capacity, computing power and network, are dynamically allocated according to consumer demand.

- **Fast elasticity:** virtual resources are scaled quickly and elastically according to demand. From a user perspective, this scaling appears almost unlimited.
- **Measured performance:** Includes monitoring and control of resource usage. This provides transparency for both providers and consumers. This can also be used for automatic scaling and billing.

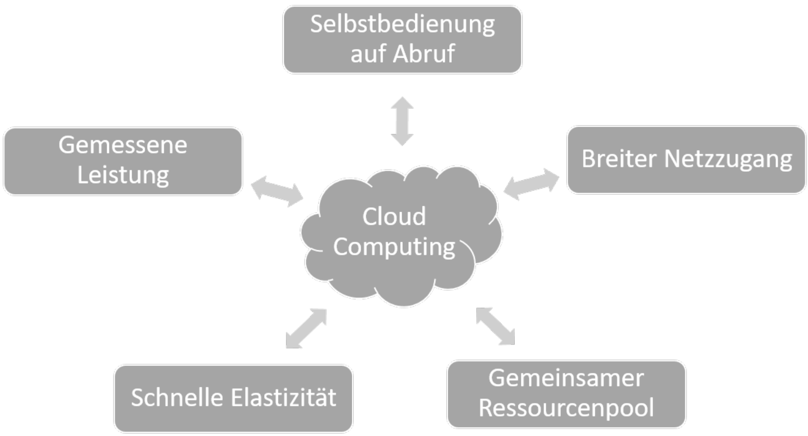

Figure 13.1: Technologie Merkmale.

A significant opportunity offered by the use of cloud computing is the increase in efficiency through the optimal availability and utilization of IT resources. The performance-based payment of services in combination with the elimination of cost-intensive investments in the area of IT infrastructure can also lead to a cost advantage, which benefits young companies (start-ups) in particular [128].

On the other hand, there is the inevitable need for a fast Internet connection to enable optimum use. In addition, there is a certain risk with regard to data protection, since the servers of the cloud providers are mainly located in foreign countries outside the EU. The data protection laws of the respective country therefore apply, which are usually less strict than EU directives.

13.2 Cloud-Computing Models

In addition to the characteristics mentioned above, cloud computing is also defined by service and provision models. The available service models are based on the three levels of IT infrastructure (hardware, operating system, software). The provision models, on the other hand, are differentiated according to the use of public network structures. The form of the respective model can range from open (public) to completely closed (private).

Service models [127]

- Software as a Service (**SaaS**): Software and application programs are made available to the user via the cloud. Access is usually via the web browser or a separate program interface.
- Platform as a Service (**PaaS**): PaaS is primarily aimed at application developers and system architects. In this service model, the developer is provided with a programming or runtime environment with dynamic computing and data capacity. This offers users the opportunity to program their own software and also to have it executed on the cloud.
- Infrastructure as a Service (**IaaS**): Describes the provision of virtual computer hardware such as storage, network and computing capacity. The user is able to design his own virtual computer cluster. The user has control over the operating system, memory and applications and can manage them independently.

Provisioning Models

- **Private Cloud:** Use is exclusively by a single organization, which enables easier integration of other business units (e.g., company locations) into the cloud. The cloud platform can be managed (hosted) both in-house and via third parties. A high degree of individuality is achieved through the organization's exclusive access. This offers advantages in the areas of data security and legal conformity (compliance).

- **Public Cloud:** In the public cloud, the provider and the user belong to different organizational units. In order to achieve the greatest possible economies of scale, the IT infrastructure is made available to the general public, which is why a high number of users is characteristic of this model. Payment is made here according to actual use (pay-as-you-go).
- **Community Cloud:** This is an association of organizations with similar interests that can access a shared cloud infrastructure. The user group is rather small and distributed locally. In this model, the usage costs are distributed among all participating organizations. Examples of this would be: several public authorities, universities, cooperatives.
- **Hybrid Cloud:** Is a combination of public and private cloud, in which certain functions and services are outsourced to a public cloud, which can be accessed in the event of peak load or failure. In this way, both the cost advantage of a public cloud and the advantage of data security from the private cloud are used.

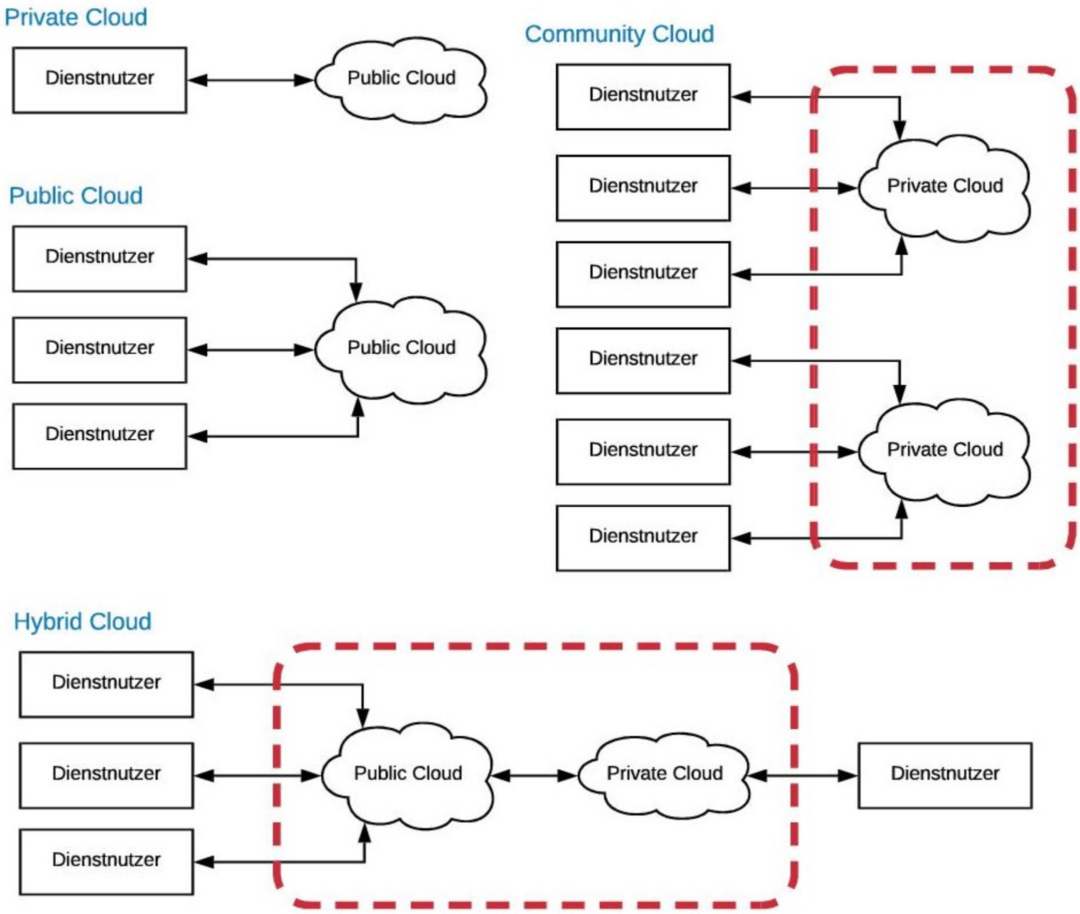

Figure 13.2: Cloud Computing Deployment Models.

13.3 Architecture and Technical Realization

The architecture of cloud computing can best be compared to the structure of a computer. Processor cores, main memory, hard disk and programs are components that can be found in a similar form in a cloud, but with the possibility of enormous scaling. As already explained in chapter 13.2, there are different models (types) in cloud computing. One way of dividing the cloud is to divide it into three layers, with each layer representing a level of abstraction.

- **Application**
- **Platform**
- **Infrastructure**

The layers of the cloud can be used to classify the different models of cloud computing.

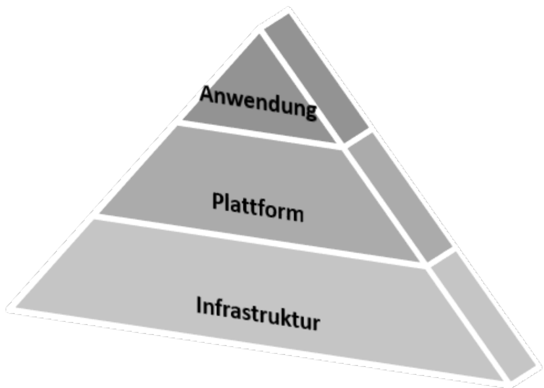

Figure 13.3: Layered model cloud computing.

Application (SaaS)

The Software as a Service model serves the application layer, which is the most abstract layer of the cloud services. The user accesses an application offered to him by the cloud. The use case already includes the two underlying layers, but without the user coming into contact with them. This means that scalability and data management are managed by the cloud service, so the user does not come into contact with them.

Typically, an upload speed of 128 Kbit per second is sufficient in this area, since only the information of the current work step is transferred, instead of the entire process or the complete document [126].

Characteristics of SaaS applications:

- Modular and service-oriented design
- Load is unpredictable as usage intensity and number of users is unknown
- Dynamics and multi-client capability of the application

The area of application of SaaS ranges from online backup and long-term data archiving to the provision of teamwork documents and network drives. Well-known examples of SaaS applications are Apple iCloud, Google Drive or Microsoft OneDrive.

Platform (PaaS)

At the platform level, the developer is offered platforms, tools and interface for programming or operating applications. The cloud itself serves as a programming interface for the developer, via which he exclusively introduces his program logic. The cloud platform then independently controls the allocation of the data to be transfered to the processing units (resources). The user therefore has no access to the computing instances in this model. The abstraction of the technical components is desired here, since the user primarily wants to process data and not manage the system. Companies normally use PaaS in three central areas:

- Development framework
- Business intelligence or analysis of enterprise data
- Internet of Things (IoT)

Since the PaaS layer performs the computationally intensive operations and a lot of throughput is generated due to the large exchange of information, a data transfer rate of 10 GBit/s is required. Examples of such cloud products are Windows Azure or App Engine from Google.

Infrastructure (IaaS)

The infrastructure represents the lowest layer of the architecture. In this service model, the user has access to the computing instances and can manage them himself to a large extent. The IaaS concept includes storage and messaging services, which are designed to be highly scalable. However, this does not apply to the programs brought in by the user. The IaaS model offers the advantage of scalability over the traditional data center. This means that the computing instances can be expanded or reduced as required. Infrastructure as a Service is therefore particularly suitable for highly fluctuating demand for server, network and storage capacity, as is the case, for example, when carrying out tests during application development or for higher capacity utilization of an online store during peak sales periods [129].

Since the largest amount of data is moved and stored on the IaaS layer, the bandwidth requirement is also greatest here at around 100 Gbit/s [126].
The best-known examples in the IaaS area are Amazon Web Services and the Open Telekom Cloud. The limits of the scalability of the IT resources (main memory, number of processor cores, storage memory) depend on the respective provider.

RAM	between 100 und 240 GB
Processor cores	16 - 32
Storage Memory	1 - 2 TB

Table 13.1: Typische Skalierungsgrenzen IaaS

13.4 Differentiation from other Technologies

The desire to share IT resources and thereby make better use of them has given rise to other technologies in addition to cloud computing.

Grid-Computing

A term closely related to cloud computing is grid computing. This technology, developed in the mid-1990s, is the predecessor to the cloud. The technology focuses on the controlled, shared use of decentralized IT resources. In contrast to cloud technology. Grid computing does not consider economic criteria such as business and pricing models. As a result, centralization of IT resources (data centers, management, etc.), which offers precisely the economic advantages, is not pursued [130], [131].

Edge-Computing

The aim of edge computing is to process the data streams largely on site (in a resource-conserving manner), but at the same time to benefit from the advantages of the cloud. By placing the resources (storage, computing power, software) closer to the end devices and with the help of an optimal distribution, higher efficiency and lower latency times are to be achieved. Only the relevant data is then compressed and forwarded to the central systems.

Fog-Computing

This term is sometimes used as a synonym for edge computing. This is primarily due to the large overlaps that exist between Fog and Edge Computing. In fact, Fog computing focuses less on the end devices and more on bringing the cloud resources closer to the applications. This is realized by smaller data centers, which perform a partial evaluation of the data before it is transmitted to the cloud.

<table>
<tr><th>Comparison of alternative technologies</th><th>Grid-Computing</th><th>Edge-Computing</th><th>Fog Computing</th></tr>
<tr><td>Goal</td><td>Controlled, shared use of IT resources</td><td>Data streams are processed by end devices (on site). Only relevant data is forwarded to cloud</td><td>Similarity to Edge Computing. Difference: approximation of cloud resources to the application.</td></tr>
<tr><td>Advantages</td><td>Flexible capacity for peak loads</td><td colspan="2">Reduction of the data volume to be transmitted, leading to lower transmission costs and waiting times and at the same time to higher service quality</td></tr>
<tr><td>Disadvantages</td><td>Lack of encryption of data. Dependence on the cloud provider</td><td colspan="2">Irregular computing or storage requirements and capacity bottlenecks when processing large amounts of data.</td></tr>
</table>

Table 13.2: Überblick: alternative Techniken

13.5 Data security and data protection

The main challenge in cloud computing is to ensure the security of stored information. This involves protecting not only corporate information, but also all customer, partner and employee data. Because centralized storage of large amounts of data creates a wide attack surface for cybercriminals, the effort required to protect data from misuse, loss or theft by third parties or even the cloud provider is correspondingly higher. The EU Data Protection Directive 95/46/EG of the European Parliament is the authoritative standard for the protection of personal data.

Insecure interfaces and a shared system environment in particular are potential points of attack. It must be taken into account that data security here is determined by the technology and applications used by the provider. Larger cloud providers in particular benefit from the economies of scale, as the costs for technical, financial, and human resources are shared among a larger number of customers.

Requirements for the cloud provider

According to the German Federal Data Protection Act (§ 3 Abs. 7 BDSG), the user of the cloud is still responsible for the security of the data in the external relationship. Therefore, according to § 11 BDSG, a contract for commissioned data processing (ADV = Auftragsdatenverarbeitung) must be concluded with the cloud provider.
In particular, the following points must be taken into account [132]:

- Commissioning of subcontractors: All subcontractors commissioned by the cloud provider must be named conclusively. In addition, the user must be granted a right of objection with regard to future subcontractors, which enables him to terminate the contract in such cases.
- Control rights: The cloud user has the right to carry out a control at the provider. Since on-site control is difficult to implement, the cloud provider can also meet the requirement by providing evidence of certificates.
- Possibility of a change of provider: including transfer of the data to the new provider.
- Deletion of data after completion of the order
- Ownership rights to data

Data transfer to countries outside the EU

A large proportion of cloud providers store their data outside the EU. Since the respective data protection laws of the location apply and the regulations outside of the EU are comparably loose, this often means that the conclusion of an ADV agreement is no longer sufficient. However, the transfer of data requires a legal basis, so an adequate level of data protection must be established here.
There are two ways to do this:

- Privacy Shield certification (= informal agreement between the EU and USA in the field of data protection law, which regulates the protection of personal data)
- EU standard contractual clauses

However, in both cases, an additional ADV agreement is often required by the regulatory authorities. This additional ADV agreement is not negotiable with every provider. In these cases, the only remaining option is to choose a cloud provider that has data centers in the EU [131].

CHAPTER 14

Robotics in the Smart Factory

Learning goals
After working through this chapter, you will know...

... The significance of robotics in industry and the smart factory.

... How industrial robots are structured and how they move.

... The different types of robots and their applications.

... How networked robots collaborate and optimize processes.

... How robotics enables flexible and customized production

14.1 Introduction

Increasing digitalization and automation have shaped industrial production for years and form the basis of the smart factory concept. In this context, robotics plays a central role. Robots are considered a key technology to make production processes more efficient, flexible, and high-quality.

14.2 Development and Definition

The development of robotics has a long history; the first industrial robots were introduced as early as the 1960s. These were modeled after the human arm and designed as universal machines with the aim of automating repetitive manufacturing processes without human labor.

The main objectives of using robots remain economic rationalization and ensuring consistently high product quality, regardless of human performance. This is particularly evident in car body manufacturing, which has become nearly fully automated and serves as a benchmark for many other industries. In addition to the automotive and supplier sectors, industrial robots are widely used in the electrical, metal, chemical, and food industries. While their use was traditionally pronounced in high-wage countries, China is now considered the largest robot market worldwide, followed by South Korea, Japan, the USA, and Germany.

There is no universal definition of the term “robot,” mainly due to the diversity of robot types and their application environments. ISO 8373:2021 defines an industrial robot as “an automatically controlled, reprogrammable, multipurpose manipulator, programmable in three or more axes, which can be fixed or mobile for use in industrial automation applications.”

Robots are increasingly becoming an integral part of everyday life and are crucial for the development of intelligent, networked production systems. In the smart factory, they enable close collaboration between humans, machines, and digital systems a key step toward Industry 4.0.

14.3 Fundamentals of Robotics

The structure and operation of an industrial robot can be exemplified by a six-axis articulated robot, as it represents the most widely used type in industry. The articulated robot is modeled on the human musculoskeletal system. Its structure resembles the human arm. The rotating main axes provide the robot with high mobility and enable free positioning and orientation in three-dimensional space.

With six degrees of freedom, the articulated robot can reach nearly any point within its workspace. This allows it to perform complex movements precisely and repeatedly. Its motions include translations and rotations in all spatial directions, making it extremely versatile. This flexibility is a key reason for its widespread industrial use.

An articulated robot consists of several basic components that together ensure its mobility and functionality. These include the robot arm, the central hand, as well as the swing and carousel, which are responsible for the robot's movements in space.

The base frame forms the stable foundation, while weight compensation balances loads during movements and supports precision. The robot controller coordinates the axes and movement sequences, controlled via the programming device. Finally, the mounting flange connects the end effector or additional tools to the central hand.

These components together form the functional unit of an articulated robot, enabling precise execution of complex movements in industrial applications.

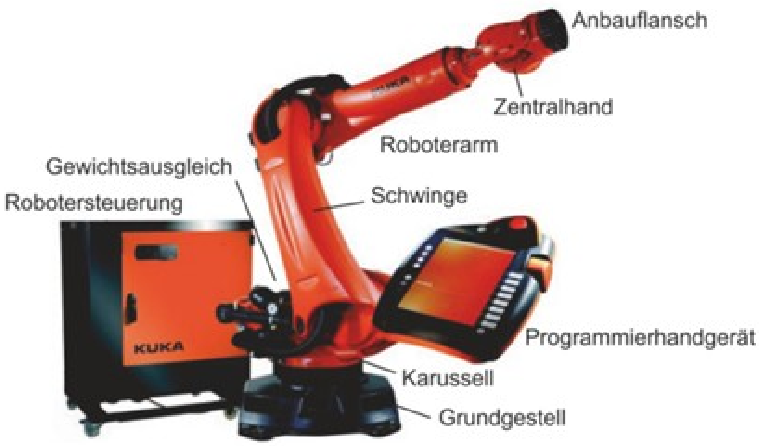

Figure 14.1: Construction of a six-armed articulated robot

The movements of an industrial robot are realized by main and secondary axes. The main axes (A1–A3), also called large axes, are used for positioning the end effector and determine the workspace. Their movements are linear or rotational, enabling the robot's macro-movements.

Secondary axes (A4–A6), also known as small axes or wrist axes, handle fine positioning and orientation within the gripping area. They are almost always rotational and allow precise fine positioning.

Axis numbering starts at the robot base. Axis 1 is the first movement axis at the mounting surface. Counting continues along the kinematic chain to the end effector, i.e., the mounting flange. This numbering also applies to overhead-mounted robots.

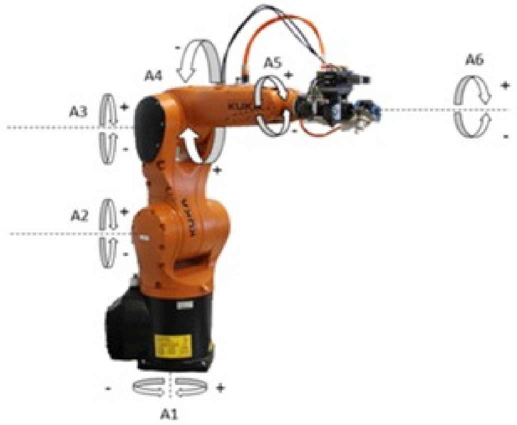

Figure 14.2: Illustration of the axes of a six-axis articulated robot

The degree of freedom (f) describes the independent movement possibilities of a body. In three-dimensional space, a rigid body has six degrees of freedom—three translations along the x, y, and z axes, and three rotations around these axes. Industrial robots typically have six axes, allowing them to reach any position and orientation in space. A higher number of axes enables greater freedom of movement and more flexible path control but requires more mechanical and electrical complexity in construction and control. Robots with fewer than six degrees of freedom are considered globally degenerate. They have a limited range of motion and allow only a restricted orientation of the tool. Standard industrial robots, on the other hand, have six degrees of freedom, which gives them full mobility in three-dimensional space and allows precise positioning and orientation of tools. Robots with more than six degrees of freedom are called redundant or overdetermined. They offer more movement possibilities than are strictly necessary for the task, making them particularly flexible in avoiding obstacles and performing complex motion sequences.

14.4 Applications of Robots in Industry

Industrial robots have become indispensable in industrial production, especially where precise, fast, and repeatable tasks are required. Robots can move heavy loads and perform tasks that are unpleasant, dangerous, or monotonous for humans. Today, industrial robots are primarily used in fully automated mass production. A central application is the automotive industry. In body manufacturing, robots perform almost all repetitive and physically demanding tasks, while humans continue to handle most work in final assembly, with robots assisting. Beyond the automotive sector, industrial robots are also widely used in consumer goods production and electronics manufacturing. Other tasks include welding, lifting, transporting, painting, palletizing, machine loading, deburring, and gluing. Here, robots handle assembly-line work, physically demanding tasks, as well as measurement and inspection applications. Tasks such as gluing or measuring and testing significantly increase productivity, safety, and quality in modern manufacturing. A current trend shows growing use of assembly and inspection robots, further improving efficiency and precision in production processes. In some automotive areas, the automation level already exceeds 95 percent.

14.5 Types of Robots in Industry

Industrial robots differ not only in their tasks but primarily in their kinematics, construction, and degrees of freedom. Depending on the application, different robot types are used, each with specific strengths and limitations. Below is a detailed overview of the most significant robot types in industrial production, their construction differences, and their ideal applications. **Gantry robot**s are kinematically underdetermined systems with three to four degrees of freedom. Their movements occur along linear axes, allowing precise coverage of large workspaces while keeping the floor area free. Due to high load capacities and precise positioning, they are particularly suitable for machine loading, multi-machine operation, assembly of large components (e.g., engines), and material flow integration in production lines. Variants such as linear, cantilever, or planar gantries allow flexible adaptation to production requirements.

Figure 14.3: Gantry robot

Figure 14.4: Gantry robot

Palletizing robots specialize in stacking pallets, boxes, or packages and typically have four degrees of freedom. Thanks to parallelogram kinematics, the tool remains parallel to the floor, enabling precise handling of heavy loads at high cycle speeds. Typical applications include automatic pallet loading in industries such as beverages or packaging.

Figure 14.5: Palletizing robot

SCARA robots (Selective Compliance Assembly Robot Arm) are compact, occupy little space, and move quickly. They have four degrees of freedom—three horizontal rotations and one vertical lift—and can be installed on the floor, walls, or ceiling. Their high repeatability and short cycle times make them ideal for small parts assembly, pick-and-place tasks, PCB assembly, as well as sorting and packaging processes.

Figure 14.6: SCARA robot

Delta robots are based on parallel kinematics, where multiple arms connect the base to a movable platform. They have three to four degrees of freedom and are very light, fast, and precise. Their stationary main drives allow highly dynamic movements, but they are suitable only for low payloads and small workspaces. Typical applications include high-speed pick-and-place, packaging, sorting, and assembly, especially in the food and pharmaceutical industries. With camera systems, delta robots can flexibly recognize and handle objects.

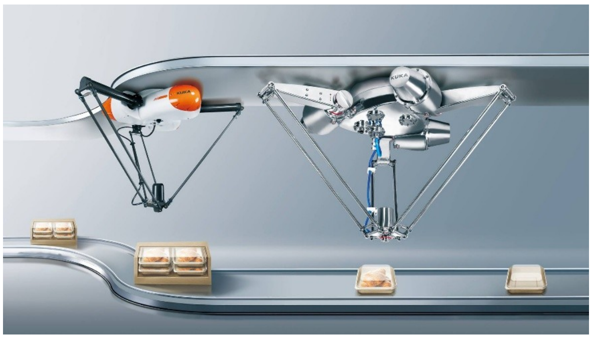

Figure 14.7: Delta robot

Mobile robot platforms differ fundamentally from fixed systems, as they can move independently. They are used primarily in intralogistics, warehouse logistics, and material transport. Mobile robots provide high flexibility, support workers directly at production lines, and do not require a fixed workstation. Modern developments increasingly lead to collaborative systems ("cobots"), which operate without protective fences and interact directly with humans, becoming true cooperation partners in manufacturing. Each robot type is tailored to specific tasks, allowing companies to optimize production processes and significantly increase efficiency, precision, and safety.

Figure 14.8: Mobile Roboterplattformen

14.6 Humanoid Robots

Humanoid robots are machines modeled in shape, movement, and sometimes behavior after humans. They are designed to perform tasks normally done by humans, particularly in dangerous, monotonous, or physically demanding areas. A current example is Tesla Optimus, also known as the Tesla Bot, developed to support industry and everyday life. Tesla Optimus is designed as a fully humanoid robot. Its structure follows the human body to ensure flexibility and versatility. It is approximately 173cm tall, weighs 55–60kg, and has two arms with multiple degrees of freedom, two legs for walking and balancing, and a head with cameras, microphones, and sensors for environmental perception. Its hands are designed to grasp and manipulate objects precisely, while its body is made of lightweight materials like aluminum and composites for mobility and energy efficiency. Its energy comes from an internal battery, though exact capacity is not publicly disclosed.

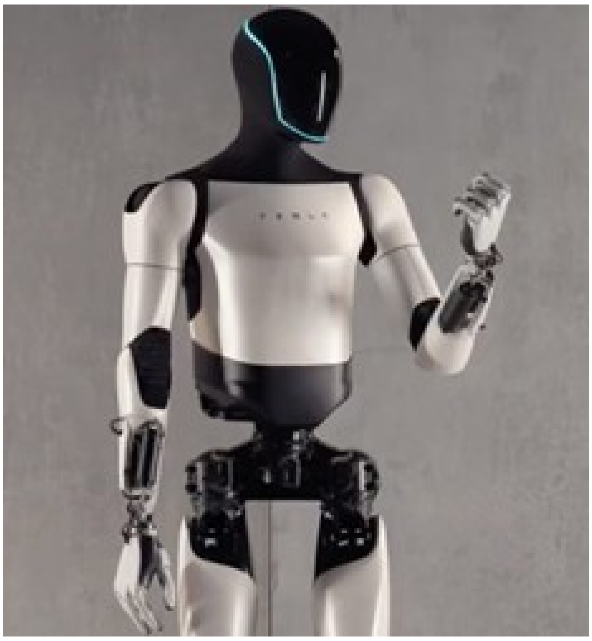

Figure 14.9: Tesla Optimus

Optimus operates through a combination of hardware, software, and artificial intelligence. Cameras and sensors capture the environment in real time, while the robot's "brain" is based on Tesla's Full-Self-Driving chip and neural networks. This chip, originally developed for autonomous driving, is highly powerful. It enables Optimus to recognize objects, plan movements, and make autonomous decisions. Forty electric actuators control the arms, legs, and hands, allowing fine motor movements. Sensory feedback continuously adjusts position, force, and balance to execute movements precisely. Technically, Optimus has numerous functions qualifying it for industrial tasks. It can walk up to 8km/h and carry loads of 9–68kg depending on body and arm posture.

Figure 14.10: Tesla Optimus erledigt Aufgabe

In industry, humanoid robots like Optimus could be used in assembly and manufacturing, where they install, screw, or handle smaller components. They could also transport materials in logistics, load and unload items, or handle goods. Additionally, they could perform quality control to check products for defects or deviations and operate in hazardous environments, e.g., in hot, toxic, or radiation-prone areas. Pioneers in industrial humanoid robot deployment include Mercedes, which is testing the “Apollo” robot in a factory in Hungary in assembly, intralogistics, and direct human collaboration.

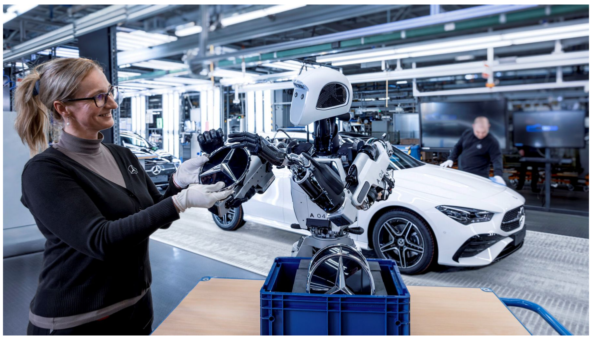

Figure 14.11: Apollo at Mercedes with human

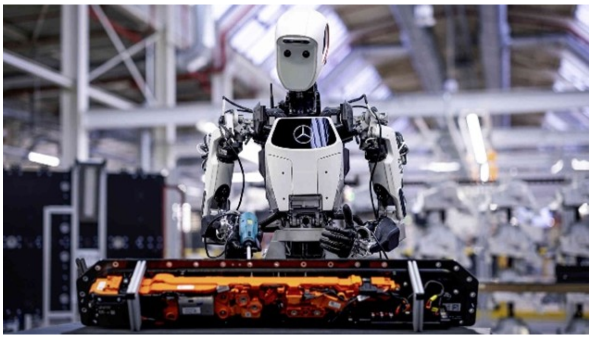

Figure 14.12: Apollo at Mercedes during assembly task

The advantages of humanoid robots include flexibility, relieving humans from dangerous or monotonous tasks, and easy integration into existing workflows due to human-like design. Disadvantages include high cost, technical complexity, and incomplete autonomy in complex assembly tasks. Overall, Tesla and Mercedes demonstrate how humanoid robots can bridge the gap between human flexibility and robotic precision. The combination of AI, sensory perception, and humanoid design makes them especially relevant for industrial applications. Even though the technology is still emerging and full autonomy in complex manufacturing is not yet achieved, Optimus illustrates the potential to complement and facilitate human labor across many industrial sectors.

14.7 Internet of Robotic Things

The Internet of Robotic Things (IoRT) extends the Internet of Things (IoT) by integrating robots that not only exchange data but also act in their environment. While IoT connects physical devices like sensors, machines, or autonomous vehicles and allows data exchange, IoRT systems incorporate robots that use this data to autonomously and adaptively control their actions. The goal is to form networked robot teams that perform tasks efficiently, learn from each other, and detect errors. IoRT systems connect smart spaces—such as smart rooms, factories, buildings, or cities—with autonomous robots. While smart spaces monitor states and perform simple actions, robots handle complex tasks such as moving objects or interacting with humans.

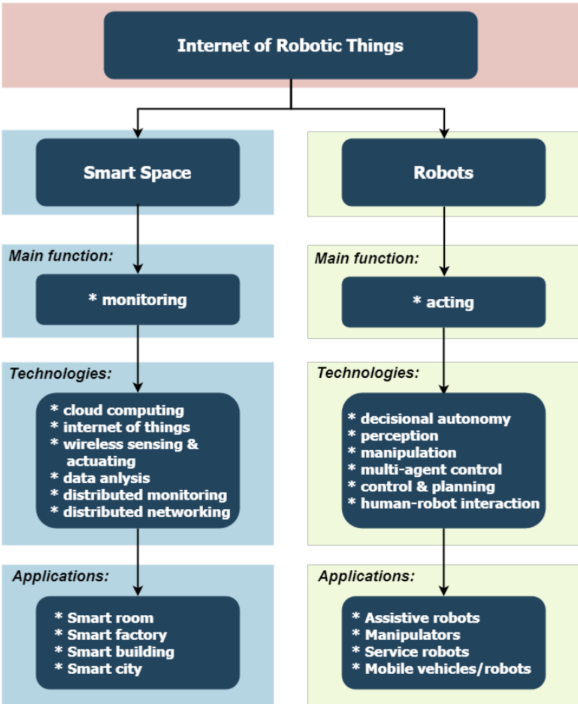

Figure 14.13: Scheme IoRT

The main advantage of IoRT is that robots do not have to develop every cognitive ability themselves but can rely on information available in the IoT. This enables local and distributed process optimization, evolving traditional machine-to-machine workflows into robot-to-robot interactions. Robots in an IoRT network can share data, learn from errors, and identify optimization potentials, particularly improving efficiency in collaborative robot production environments. Practical examples, such as Amazon Fulfillment Centers, illustrate these benefits.

Figure 14.14: Multi-Robot-System at Amazon

Here, robots autonomously move goods to workers, detect obstacles using cameras and infrared sensors, navigate via QR codes on the floor, and are coordinated through a central Wi-Fi connection. The result is shorter walking distances, faster order processing, and flexible handling of various product types and sizes.

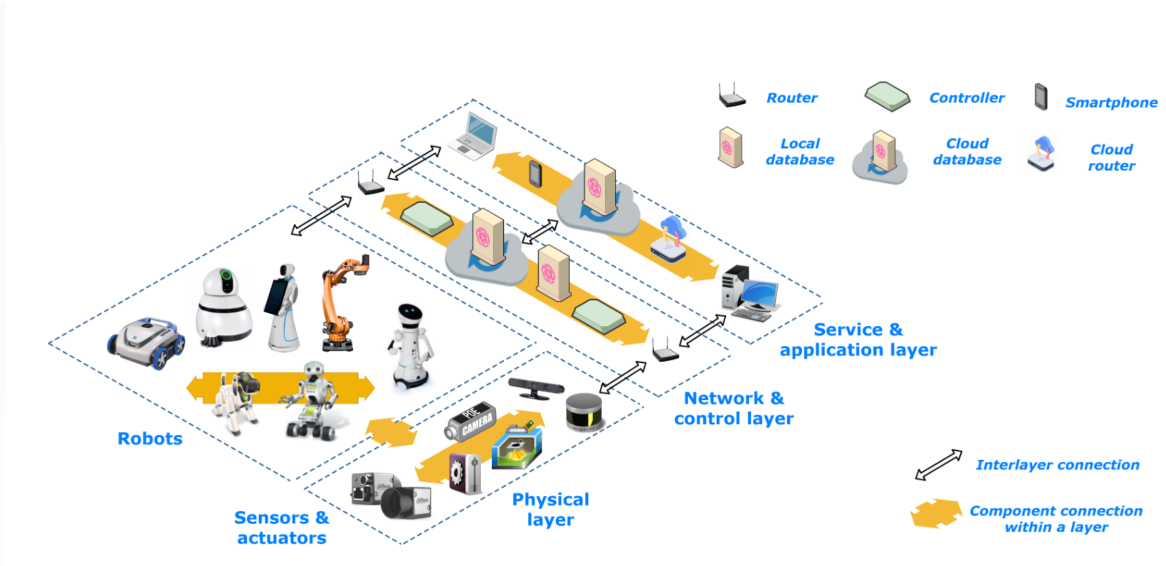

Figure 14.15: IoRT system architecture

The IoRT architecture can be divided into three layers. In the physical layer, robots act as intelligent agents, communicate with each other, and form multi-robot systems supported by cameras, motion sensors, and actuators such as machine tools or 3D printers. The network and control layer includes routers, controllers, local and cloud databases, and communication and control protocols that ensure coordination between robots, sensors, and actuators. In the service and application layer, software monitors, processes, and controls operations, optimizing them with AI and machine learning. Networking and communication often use wireless mesh networks to enable data exchange among robots, sensors, actuators, and smart spaces.

IoRT particularly supports multi-robot systems (MRS), where several robots collaborate in the same environment. Objectives include higher efficiency, distributed task execution, extended functionality, and fault tolerance through redundancy. Challenges include coordination, potential interference, costs, and robustness. Multi-robot systems can be classified by cooperation level, knowledge, coordination type, team organization, communication mechanisms, team composition, architecture, and team size. IoRT naturally supports these networking and communication requirements efficiently.

Public perception of networked robots is often influenced by fears from science fiction scenarios where robots act against humans. In reality, fully autonomous, human-hostile robots are pure fiction. However, IoRT raises societal questions, such as potential job losses or the creation of new jobs via AI-driven robotics. At the same time, IoRT enables flexible human-robot collaboration, with robots handling routine tasks and humans contributing cognitive skills, flexibility, and problem-solving. Overall, IoRT represents the next evolution of robotics. It combines physical robotics with data-driven intelligence, enables networked, autonomous, and learning robot teams, and optimizes processes in smart spaces. Real-world examples, such as Amazon Fulfillment Centers, show that IoRT increases efficiency, conserves resources, and lays the foundation for a new flexible form of production in which robotics and human labor are effectively combined.

14.8 Batch Size 1 in Industry 4.0

Lot size 1 refers to manufacturing a product as a single unit, i.e., a batch of size 1, aiming to meet individual customer requirements while maintaining economic production. Unlike traditional production, which aims for an optimal batch size greater than 1 to minimize setup costs and handle large quantities efficiently, lot-size-1 production places special demands on industrial value creation. Traditional production systems were only partially able to economically produce a high variety of products due to long setup times and limited flexibility.

Implementing lot size 1 is greatly facilitated by combining modern robotics, the Internet of Robotic Things (IoRT), and autonomous transport systems. Industrial robots enable precise, fast, and repeatable steps necessary for single-piece production. Flexible robot systems allow different production orders to be executed without long changeover times, while humanoid robots and cobots enable direct human-robot collaboration in assembly and physically demanding tasks.

IoRT extends these possibilities by allowing networked robots to exchange information in real time, adapt actions autonomously, and learn from each other. Integration into smart spaces enables flexible process control, prevents bottlenecks, and coordinates multiple robots efficiently. IoRT data also supports continuous process optimization and reduces programming effort for individual machines. Autonomous transport systems contribute by flexibly managing material flows and logistics within production. Goods, workpieces, or components can be transported between stations as needed without human intervention, minimizing waiting times and reducing order lead times.

Together, these technologies create the conditions for economical, flexible, and individualized production. Automation, networking, and adaptive control make lot-size-1 production possible without losing efficiency or quality. The smart factory thus forms the basis for quickly, precisely, and resource-efficiently responding to customer needs.

14.9 Summary

Robotics forms the backbone of the smart factory, enabling automation of industrial production through flexible, precise, and repeatable steps. Different robot types—from articulated robots to SCARA and delta robots, mobile platforms, and humanoid robots—cover a wide range of tasks, from small part assembly to palletizing and direct human collaboration. Humanoid robots like Tesla Optimus and Apollo demonstrate how human-like flexibility can be combined with robotic precision to handle complex and physically demanding tasks.

The Internet of Robotic Things (IoRT) expands these capabilities by allowing robots to work networked in real time, exchange data, and learn from one another. Integration into smart spaces enables adaptive control, optimizes multi-robot systems, and reduces programming effort for individual robots. Practical examples like Amazon Fulfillment Centers demonstrate that networked robots can increase efficiency, optimize processes, and improve resource use.

These technologies lay the foundation for lot-size-1 production in Industry 4.0. By combining robotics, IoRT, and autonomous transport systems, economical and flexible production of individualized single products is possible. The smart factory allows fast, precise, and resource-efficient production where customer requirements are directly integrated into the production process without sacrificing efficiency or quality.

CHAPTER 15

Additive Manufacturing in Industry 4.0

Learning goals
After working through this chapter, you will know ...

... . . .what additive manufacturing is.

... . . .which process steps are required from the file to the finished component.

... . . .which manufacturing methods and materials are available for additive manufacturing.

... . . .the role of additive manufacturing in Industry 4.0.

... . . .the opportunities and limitations of this technology in industry and development.

15.1 Introduction

Additive manufacturing, also known as 3D printing, is becoming increasingly important as it opens up new possibilities in production. It enables the creation of complex shapes and customized products in an efficient manner. With growing demand for flexibility, rapid implementation, and resource efficiency, this technology is gaining significance across many areas.

15.2 Fundamentals of Additive Manufacturing

In a subtractive manufacturing process, material is removed from a block until the workpiece has the desired geometry. This principle has been known for thousands of years and was already used by sculptors, for example in the creation of marble statues or wood carvings. Modern manufacturing methods such as CNC milling and CNC lathes are also based on the same principle, where tools or workpieces are shaped from metals through machining. Additive Manufacturing (AM), also called 3D printing, describes a process for producing three-dimensional objects layer by layer. Unlike traditional manufacturing methods, where material is removed or shaped by milling, drilling, or casting, additive manufacturing builds the workpiece by depositing material precisely where it is needed. This principle allows for particularly resource-efficient, flexible, and individualized production. Since the 1970s, additive manufacturing has complemented traditional production methods and has become a key technology of modern industry. The term “3D printing” gained widespread use around 2012 and attracted significant public and media attention. The resulting global hype made the technology known beyond industry and contributed substantially to its development and application in various fields. The core idea of additive manufacturing lies in the direct conversion of digital models into physical products. This allows even complex geometries and individual units to be produced efficiently, making the technology an important component of modern, flexible production systems and Industry.

15.3 Principle of Operation and Process Chain

Additive manufacturing goes through several coordinated process steps, from digital modeling to post-processing of the physical component. Each of these steps has a decisive influence on the quality, precision, and reproducibility of the final product. The basis for additive manufacturing is a digital STL file (Standard Tessellation Language), which describes the object to be manufactured as a polygon mesh, usually composed of triangles. This file can either be created from a CAD program or generated using 3D scanners and other digitization methods. The STL file thus forms the bridge between design and manufacturing. In the next step, the STL file is processed in slicing software. This converts the digital 3D model into machine code (G-code) that controls the additive manufacturing system. The model is divided into many horizontal layers, a process called "slicing." In the slicing software, various parameters can be configured, such as print and movement speed, temperature, infill pattern, or the positioning of the component on the build platform.

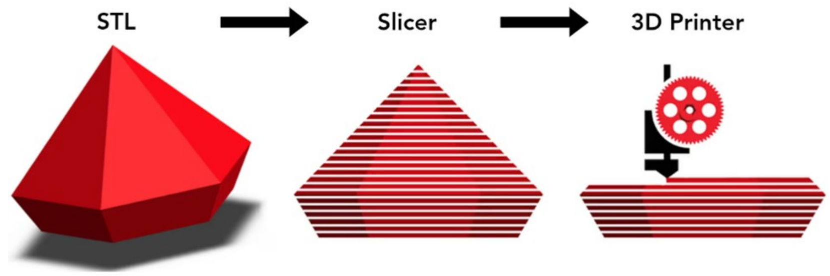

Figure 15.1: 3D printing process

Before the actual manufacturing starts, the software allows a simulation of the build process to detect potential errors or collisions and optimize material and time usage. The finished G-code is transferred to the manufacturing system in various ways, typically via memory card, cable connection, or network (Wi-Fi/Ethernet). The memory card offers advantages such as lower error susceptibility and energy savings, whereas the cable connection allows real-time process monitoring. During printing, the physical object is built layer by layer. Overhangs with an angle greater than 45° require support structures. These can be made either from the same material as the component and removed mechanically or from a soluble foreign material that is chemically dissolved after printing.

The level of detail and surface quality depends largely on the chosen layer thickness (Z-resolution) and nozzle diameter (X/Y-resolution). Thinner layers result in a smoother surface but also increase production time.

After additive manufacturing is complete, post-processing is carried out to improve the optical and functional quality of the surface. Especially in FDM/FLM processes, mechanical post-processing is required because surfaces often show visible layer lines. Usually, a multi-step finishing process is applied. Mechanical processing removes excess powder, stair-step effects, and support contours. Optional heat treatments can also be performed.

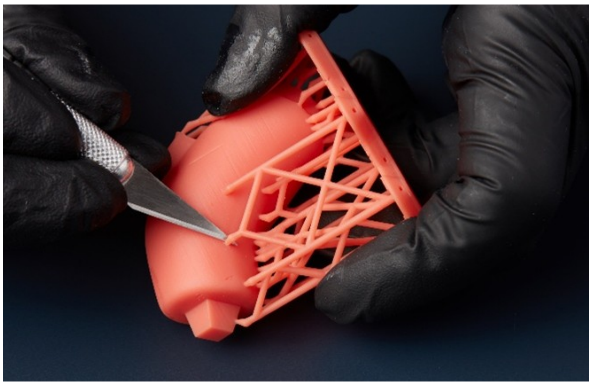

Figure 15.2: Removing the support contour

15.4 Additive Manufacturing Processes and Materials

Additive manufacturing encompasses a wide variety of processes, which mainly differ in the method of material deposition and energy supply. In principle, components are built layer by layer, using different materials (solid, liquid). The choice of the suitable process depends crucially on the desired material properties, the geometry of the component, and the application area. One of the most important additive manufacturing processes is **Binder Jetting**. This method is characterized by a particularly wide material compatibility, as a wide range of materials such as metals, plastics, ceramics, plaster, or sand can be processed. It is therefore used both in prototyping and for functional end components.

The printing process starts by applying a thin layer of powder onto a build platform. This platform lowers slightly while a roller spreads the powder evenly. A print head, similar in function to a conventional 2D printer, then precisely deposits the liquid binder in tiny droplets (about 80 µm), exactly where the material is to be solidified.

After each layer, the build platform lowers again, and a new powder layer is applied. This process repeats layer by layer until the component is fully built. After printing, excess powder that did not come into contact with the binder is removed. This unbound powder can be partially recycled and reused for future prints, improving cost-effectiveness and sustainability. A major advantage of Binder Jetting is that no additional support structures are required. The powder bed itself acts as a natural support during the entire build process, allowing greater design freedom and more complex geometries.

The strength and robustness of the objects produced depend heavily on the binder used and the subsequent post-processing steps. Untreated parts generally have lower mechanical stability than metal or ceramic components. Subsequent sintering, i.e., thermal densification of the material, can significantly increase strength.

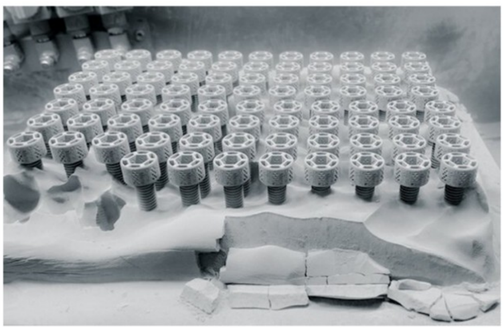

Figure 15.3: Binder jetting

Material Jetting applies the build or support material to the build platform layer by layer in tiny droplets through print heads. The droplets cure immediately, either by UV

light or cooling, as with wax materials. After each layer, the platform lowers slightly to allow the next layer to be deposited. Overhangs and complex structures are stabilized using support material, also applied in droplet form, which is removed after printing by melting or dissolving.
Material Jetting offers high precision in droplet placement and layer thickness, resulting in very smooth surfaces and finely detailed structures. It also allows flexible combinations of colors, transparency levels, and material properties such as hardness or elasticity. These features make Material Jetting particularly suitable for prototypes, design models, and applications with high aesthetic requirements, e.g., in medical technology or investment casting.
Limitations arise from the limited strength of the polymers used, which usually do not match the durability of conventional thermoplastics. High acquisition and operating costs also apply, as both print heads and curing systems require special environmental conditions and regular maintenance. Furthermore, the build volume of many machines is limited because the highly precise print heads are difficult to enlarge. For this reason, Material Jetting is rarely used for mass production.

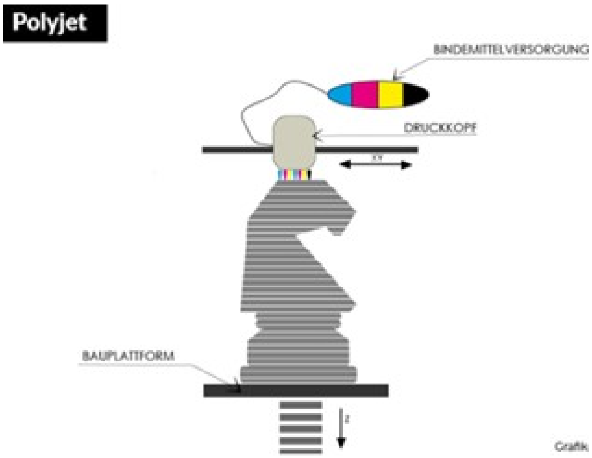

Figure 15.4: Material jetting

Das Material Jetting überzeugt durch eine hohe Präzision bei der Platzierung der Tropfen und der Schichtdicke. Dadurch entstehen sehr glatte Oberflächen und fein detaillierte Strukturen. Zudem ermöglicht das Verfahren eine flexible Kombination von Farben, Transparenzgraden und Materialeigenschaften wie Härte oder Elastizität. Diese Eigenschaften machen das Material Jetting besonders geeignet für Prototypen, Designmodelle und Anwendungen mit hohen ästhetischen Anforderungen, etwa in der Medizintechnik oder beim Feinguss.
Einschränkungen ergeben sich durch die begrenzte Festigkeit der verwendeten Polymere, die meist nicht die Beständigkeit klassischer Thermoplaste erreichen. Hinzu kommen hohe Anschaffungs- und Betriebskosten, da sowohl die Druckköpfe als auch das Aushärtesystem spezielle Umgebungsbedingungen und eine regelmäßige Wartung erfordern. Zudem ist das Bauvolumen vieler Maschinen begrenzt, da sich die hochpräzisen Druckköpfe nur schwer vergrößern lassen. Aus diesem Grund findet das Material Jetting in der Großserienfertigung nur selten Anwendung.

Material Extrusion feeds a thermoplastic filament or a pasty material through a feed mechanism into a heated nozzle. The material melts or softens strongly and is then deposited on the build platform through the nozzle. The print head (or alternatively the build platform) moves precisely in the X and Y directions to create the first layer according to the 3D CAD data. Once a layer is complete, the build platform lowers or the print head rises to make room for the next layer. The extruded material solidifies quickly, building a three-dimensional object layer by layer.

For a stable bond between layers, precise coordination of key process parameters is essential. These include extrusion speed, nozzle temperature, layer height, and feed rate. Only with optimal tuning is a consistent, strong bond between paths achieved. A characteristic of this technique is the visible layer lines on the components.
A major advantage of material extrusion is its simple technical implementation and low investment cost. The systems are usually compact, easy to operate, and suitable for a wide range of materials, from inexpensive PLA for simple prototypes to high-performance plastics such as PEEK for industrial applications.
Compared to more precise processes like Material Jetting, Material Extrusion has lower surface quality and detail resolution. Visible layer lines often remain, and shrinkage or warping during cooling can cause cracks or adhesion problems between layers. The mechanical properties of the components are strongly dependent on print parameters, material choice, and build chamber temperature. Post-processing steps such as sanding, polishing, or heat treatments may be necessary to improve component quality.

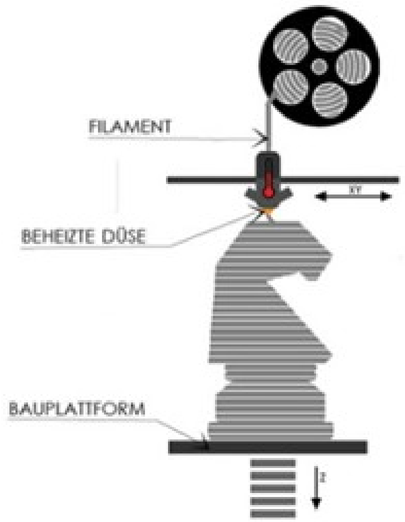

Figure 15.5: Material extrusion

Vat Photopolymerization involves filling a usually transparent container (e.g., glass or specialized plastic) with liquid resin. A light source, such as a laser, projector, or LCD panel, selectively cures the layer of the component. Then either the build platform or the optical system moves to make a new resin layer available. This process repeats layer by layer until the component reaches the desired height. After completion, the object is removed from the resin bath and often post-cured under UV light to ensure final strength.
This method offers very high surface quality and precise dimensional accuracy. The components often appear almost injection-molded, and with specialized resins, applications in medical and dental technology, jewelry manufacturing, and design prototyping are possible. Very fine details can be represented, and transparent or colored resins allow a variety of aesthetic and functional properties.
Limitations arise from the mechanical properties of photopolymers, which are often brittle and have limited heat or chemical resistance. The resins can be expensive and require careful handling (e.g., protective clothing, UV protection). Compared to Powder Bed Fusion or Material Extrusion, build sizes are often limited, and UV post-curing is usually required to achieve final material properties.

Figure 15.6: Vat-Photopolymerization

Powder Bed Fusion (PBF) spreads a thin powder layer evenly on the build platform. Then an energy source, usually a laser or electron beam, selectively melts or sinters the powder particles at the locations where the component will form. After each layer, the platform lowers slightly, and a new powder layer is spread. This cycle repeats until the workpiece is built layer by layer.
Excess powder supports the component during the printing process, often making separate support structures unnecessary. In polymer PBF processes, it is usually sufficient to remove the finished part from the powder bed and brush or vacuum off excess powder. In metal PBF processes, support structures may sometimes be needed for heat management or part fixation and can be removed afterward. The process allows almost unlimited design freedom because the loose powder provides natural support. Fine details, high resolutions, thin walls, and high density for metal parts are possible. Complex internal structures and function-integrated designs, e.g., for lightweight applications, can be realized that would be difficult with conventional methods.
Disadvantages include high investment costs for machines and powder materials and elaborate powder handling, especially for reactive or hazardous metals. Build speed can be limited for very delicate or very large parts. Metal PBF components often require post-processing, e.g., removal of support structures, surface finishing, or heat treatment to achieve desired final material properties.

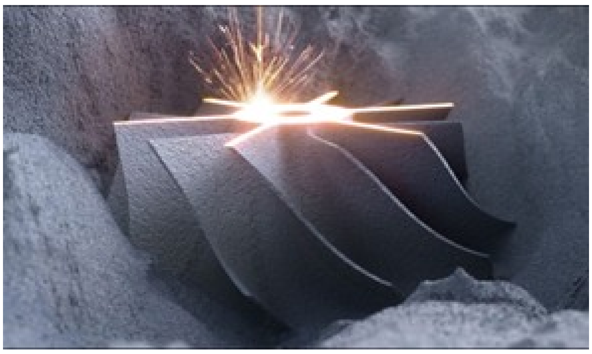

Figure 15.7: Powder Bed Fusion

Directed Energy Deposition (DED) uses a focused energy source to create a small melt pool into which powder or wire is fed simultaneously. The new material fuses with the surface of the base material, building the component layer by layer. Control is based on 3D data that determine the deposition path and layer thickness. A key feature of DED is that only the area required for adhesion of the new layer is melted, reducing thermal stress and warping.
DED offers advantages for repairs and large-volume components. Damaged areas can be repaired selectively without exposing the entire workpiece to high temperatures. The process allows high deposition rates and large build flexibility, as it is not necessarily bound to a fixed chamber. Some systems use industrial robots to apply complex contours or curved surfaces

precisely.
Disadvantages include often relatively rough surfaces and contours, requiring mechanical post-processing if tight tolerances are needed. Powder-based DED systems provide finer layers but require more expensive raw material. Coordination of energy source and material feed requires precise process monitoring and complex machine control.

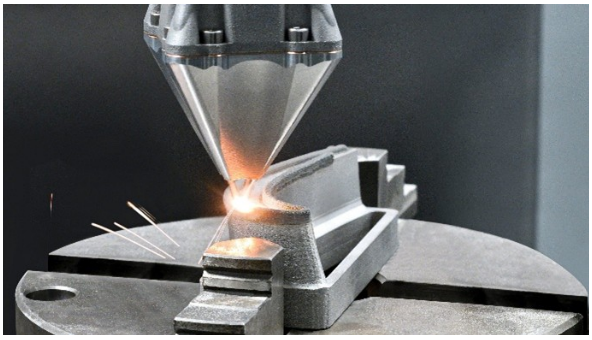

Figure 15.8: Directed Energy Deposition

The following outlines the most important materials used in additive manufacturing. For solid materials, such as powders or granules, large-scale components can be produced, for example in mechanical engineering or aerospace. Processes using liquid materials are suitable for small to medium-sized components, for instance in medical technology.

Figure 15.9: Materials for 3D printing

The main materials used in additive manufacturing can be divided into four groups. Metals (e.g., steel, aluminum, titanium) are used for high-load components. Polymers such as ABS, PA, or PEEK are used for prototypes and functional plastic parts. Ceramics are used for high-temperature or wear-resistant components. Biomaterials, such as hydrogels or collagen, are applied in medical technology and tissue engineering.
Material forms also vary depending on the process. Powder enables precise parts with high accuracy, while granules are more cost-effective but less precise. Filaments (thread-like plastics) are easy to handle. Liquid resins provide very smooth surfaces. Thus, additive manufacturing offers a broad spectrum of processes and materials, ranging from fine prototypes to robust metal structures. By selecting the appropriate process and material, tailor-made solutions for diverse industrial requirements can be realized.

15.5 Additive Manufacturing in Industry 4.0

The ongoing digitalization is fundamentally transforming industrial manufacturing, making production processes significantly more flexible and efficient. Through data integration across the entire process chain from product development to manufacturing and logistics high transparency and efficiency are achieved. Additive manufacturing processes, in particular, help to shorten the so-called time-to-market, significantly reducing the period between product development and market launch.

Thanks to modern data transmission capabilities, additive manufacturing can be seamlessly integrated into digital production chains, a crucial step toward fully connected and self-regulating manufacturing systems. Another important aspect of digitalization is the concept of digital warehousing. In this approach, spare parts are stored not physically but digitally, for example in 3D databases. When needed, these parts can be produced additively on demand, eliminating storage costs and ensuring long-term availability of spare parts.
Additive manufacturing is also characterized by a high degree of automation. Through digital process chains, all machine control data is provided automatically, allowing the printing process to start at the push of a button and operate largely autonomously. This human-independent production enables continuous 24/7 manufacturing, consistent production rates, and stable product quality. Nevertheless, manual steps are still required, such as loading the printing systems, post-processing the components, or performing quality inspections. In the long term, additive manufacturing will become a central component of digitized industrial production. It combines flexibility, customization, and cost-efficiency, thereby enhancing competitiveness compared to conventional mass production.

15.6 Application areas of additive manufacturing

Additive, tool-free manufacturing is particularly suitable for producing products in small quantities. It enables a high degree of customization, as modifications can be made directly in the CAD file and transferred to the final product with minimal effort. A major advantage is that part complexity has little impact on the manufacturing process— even complex geometries can be realized efficiently and precisely. From an economic perspective, additive manufacturing is especially advantageous when low production volumes and high product variety are required. It allows for on-demand production, reducing inventory and tied-up capital.
Additive manufacturing can be categorized according to its purpose, reflecting the technological maturity and intended use of the produced components. Essentially, three main terms are distinguished: Rapid Prototyping (RP), Rapid Tooling (RT), and Additive Manufacturing (AM).
Rapid Prototyping (RP) refers to the fast and cost-effective production of sample or prototype parts. The goal is to enable design and functional testing in the early development stages without relying on complex or expensive tools. RP processes thus allow cross-departmental testing and significantly shorten development time.

Figure 15.10: Prototype made from 3D printing and original part

Figure 15.11: 3D-printed prototype

Rapid Tooling (RT) goes a step further and involves the production of tools or tool components that are subsequently used in formative or shaping processes, such as injection molding or deep drawing. This approach allows efficient production of molds, fixtures, or casting forms and helps shorten production preparation.

Figure 15.12: 3D printed mold

Additive Manufacturing (AM), finally, describes the industrial use of additive processes for the serial production of market-ready end products. Unlike Rapid Prototyping or Rapid Tooling, the focus here is no longer on model-making or tool production but on the direct manufacturing of functional parts or small series.

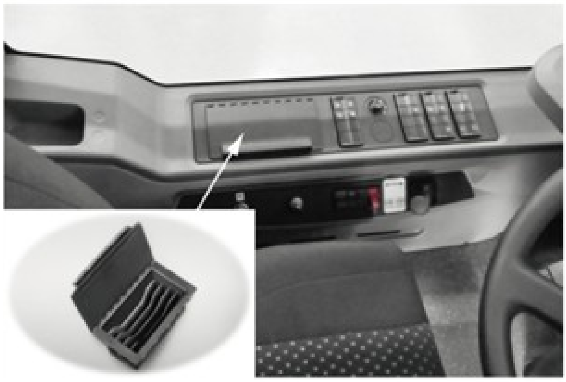

Figure 15.13: Money tray: Additively manufactured by Daimler

This classification makes it clear that additive manufacturing has evolved from a pure prototyping technology into a fully-fledged production method. It thus makes a central contribution to the flexibilization of modern manufacturing processes and the realization of customized products in line with Industry 4.0.

15.7 Advantages and Challenges

A major advantage of additive manufacturing is its flexibility. It allows individual product customization, often more cost-effectively than many conventional methods. Development times can be significantly reduced, as results are often available within hours rather than days or weeks. It also allows the production of small batches or complex geometries without high costs. Clear benefits also arise during development and testing. Design concepts can be evaluated before producing physical prototypes, allowing ergonomic, visual, and tactile properties to be assessed early. Functional tests of mechanical, electrical, or aerodynamic properties are also possible. This accelerates development cycles and helps detect design errors early.

Another positive aspect is sustainability. Layer-by-layer building uses only the material required, significantly reducing waste. CO2 emissions are reduced through shorter transport routes and local production in the target market. Eco-friendly filaments from renewable resources, such as PLA from corn starch or sugarcane, add to environmental sustainability. Thermoplastics such as HDPE or PET can be reused multiple times, enabling recycled materials from bottles, filament remnants, or even ocean plastics to be used.

Challenges remain, however. Surface quality is often limited due to the layer-based structure, requiring extensive post-processing, especially for metal components. Mass production is currently another limitation. The printing process is comparatively slow, and production costs for large volumes are still too high to compete economically with conventional methods.

Despite these limitations, additive manufacturing offers significant potential for industrial production. It is individual, resource-efficient, and allows designs that are not feasible with conventional methods. It is thus a key technology for flexible, sustainable, and forward-looking production processes.

15.8 Summary

Additive manufacturing has developed from a technology primarily used for prototypes to a central part of modern production. It combines the ability to efficiently produce complex geometries and individual components with the flexibility of digitally controlled manufacturing processes. By directly converting CAD data into physical objects, material is saved and development time drastically reduced.

Different processes, such as Binder Jetting, Material Jetting, Material Extrusion, Vat Photopolymerization, Powder Bed Fusion, and Directed Energy Deposition, each offer specific advantages regarding material variety, detail accuracy, mechanical strength, and build volume, covering a wide range of applications, from prototypes and design models to functional plastic and metal parts, and highly precise medical or industrial components.

Additive manufacturing plays a crucial role in Industry 4.0, as high automation, digital networking, and flexible production planning increase manufacturing efficiency and responsiveness. Concepts such as Digital Warehousing and on-demand production reduce inventory and provide quick spare part availability, while integration into the digital process chain enhances transparency and control. At the same time, the technology opens new possibilities for customization, functional integration, and lightweight construction, which are difficult to achieve with conventional methods. Despite challenges such as surface quality, production speed for large series, investment costs, and post-processing, the potentials outweigh the limitations. Additive manufacturing enables resource-efficient production, reduces material waste, and offers flexibility rarely achievable with traditional methods.

It is not just a supplement to conventional production but has the potential to fundamentally transform production processes and enable new business models. As a key technology of modern industry, additive manufacturing contributes sustainably to customization, efficiency, and innovation across various sectors and will continue to grow in importance.

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