Socio-technical information and assistance systems to increase effectiveness and efficiency in labour-intensive processes

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Foreword

This dissertation was undertaken during my professional employment at LAP GmbH Laser Applikationen in collaboration with the Institute for Production Technology and Systems of the Leuphana University Lüneburg. My special thanks go to Prof. Dr. rer. nat. Prof. h.c. Anthimos Georgiadis for his continuous support and encouragement of my endeavour. I would also like to sincerely thank Prof. Dr.-Ing. Jens Heger and Prof. Dr. Rainer Höger for taking over the co-advice and their overall support.

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Ralf Müller-Polyzou

Abstract

The requirements for the design of information and assistance systems in labour-intensive processes are interdisciplinary and have not yet been sufficiently addressed in research. This dissertation analyses, evaluates and describes possibilities for increasing the effectiveness and efficiency of labour-intensive processes through design-optimised socio-technical systems. The work thus contributes to further developing information and assistance systems for industrial applications and use in healthcare. The central dimensions of people, activity, context and technology are the focus of the scientific investigations following the Design Science Research paradigm. Design principles derived from this, a corresponding taxonomy, and a conceptual reference model for the design of socio-technical systems are the results of this dissertation.

Zusammenfassung

Die Anforderungen an das Design von Informations- und Assistenzsystemen in arbeitsintensiven Prozessen sind interdisziplinär und in der Forschung bisher nicht hinreichend thematisiert. Die vorliegende Dissertation analysiert, evaluiert und beschreibt Möglichkeiten zur Steigerung der Effektivität und Effizienz in arbeitsintensiven Prozessen durch designoptimierte sozio-technische Systeme. Die Arbeit leistet damit einen Beitrag zur Weiterentwicklung von Informations- und Assistenzsystemen für industrielle Anwendungen und den Einsatz in der Gesundheitswirtschaft. Die zentralen Dimensionen Mensch, Aktivität, Kontext und Technologie stehen im Mittelpunkt der wissenschaftlichen Untersuchungen nach dem Design Science Research Paradigma. Daraus abgeleitete Designprinzipien, eine entsprechende Taxonomie und ein konzeptionelles Referenzmodell für das Design sozio-technischer Systeme sind die Ergebnisse dieser Dissertation.

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1. Introduction

Humanity is facing extraordinary challenges. Since the Earth Summit in Rio de Janeiro in June 1992, the United Nations (UN) community has bundled its efforts to master social, economic, and environmental sustainability. The *2030 Agenda for Sustainable Development*, adopted by the UN member states in 2015, formulated 17 Sustainable Development Goals (SDGs) and 169 targets, which are an urgent call for action for peace and prosperity by all countries in a global partnership (United Nations Department of Economic and Social Affairs, 2021). Directly and indirectly, science and technology play an essential role in efforts to reach these targets. The Technology Goals 17.6, i.e. "Enhance … cooperation on and access to science, technology, and innovation and enhance knowledge sharing …", and 17.8, namely "… enhance the use of enabling technology, particularly information and communications technology", explicitly express these aspirations (United Nations General Assembly, 2019, no pagination).

The SDGs stimulate research themes for Information System (IS) scholars worldwide. Watson et al. (2021) presented IS contributions to the UN's SDGs by reviewing articles from the Association for Information Systems (AIS) Sustainability Summit at the International Conference on Information Systems ICIS 2019. Their analysis demonstrated that AIS members were engaged with 16 of the 17 SDGs, reflecting significant interest in positively impacting them (Watson et al., 2021). Thus, innovations in IS have the potential to contribute to fulfilling the SDGs and making the world better.

The COVID-19 pandemic challenges the fulfilment of the SDGs in both economic and social terms (OECD, 2021a). However, the pandemic disruption also shows the potential of Information Technology (IT) and IS as an enabler for the transformation of society. For instance, COVID-19 has accelerated research efforts in business and healthcare (Lu et al., 2021). The change is fostered by significant IS/IT developments confirmed by the 40th IT Issues and Trends Study of the Society for Information Management (SIM). The study reported cybersecurity, business-IT alignment, data analytics, digital transformation, and compliance and regulations as the major trends in the IT industry and academic research. Additionally, cloud-based services will increase while cybersecurity continues to be a concern (Kappelman et al., 2021).

In all humility before the task, this dissertation deals with socio-technical information systems for user assistance in labour-intensive processes intending to increase effectiveness and efficiency in industry and healthcare practice. It supports SDG 8 Decent Work and Economic Growth and SDG 3 *Good Health and Well-Being* in the broader context and joins the abovementioned efforts. The research was performed from 2017 to 2022 in the interplay between the COVID-19 disruption and the increasingly fast-paced digital transformation.

a. Problem area and influencing factors

Global markets and customer requirements are developing dynamically, leading to an increased number of customised products and rising product complexity. In turn, this development results in smaller batch sizes per product variant (Wang et al., 2017). In many sectors, batch size one has become a reality, including industrial and healthcare products such as individualised, patient-centred medical prostheses or drugs (Fraunhofer Institute for Production Technology IPT, 2022; IKV Institute for plastics processing RWTH-Aachen, 2022). However, producing small batch sizes often favours human work in production facilities (Brecher, 2015).

The rising cost pressure associated with these developments drives the need for production efficiency as an objective criterion to describe whether socio-technical systems are suitable to support labour-intensive processes. The same applies to the increasing product quality expectations that do not allow defective parts to result in expensive rejects or cost-intensive repairs (Dammers, 2022; Mueller et al., 2020; Müller, Vette-Steinkamp et al., 2018). Production effectiveness is an objective criterion that can describe whether socio-technical systems support doing the right things. Effectiveness and efficiency are primarily seen as the goals of socio-technical system usability, which is the fundament for user experience (UX) and a prerequisite for the acceptance of socio-technical information and assistance systems by the users in the specific field of application (Benyon, 2014, 2020; J. Brooke, 2013; Lah et al., 2020; Nielsen, 1993). In summary, system usability is linked to effectiveness, efficiency, and the overall acceptance of technology (International Organization for Standardization ISO, 2018).

Labour markets worldwide are continuously changing due to the digitalisation and automation of occupational activities. As a result, tasks are replaced or significantly changed, and new skills are required. Depending on their economy and labour market structure, countries are affected differently by job substitution and task automation. This development will continue, as even activities that require high social and cognitive intelligence are expected to be substituted by Artificial Intelligence (AI) (Ljubica Nedelkoska and Glenda Quintini, 2018). However, labour market research in Germany shows that substitution mainly affects industrial manufacturing jobs. The situation is different for healthcare occupations characterised by a high degree of patient interaction. According to the current state of knowledge, these tasks are less substitutable. Overall, task substitution is driven by technological development, with job profiles developing more slowly than technologies. However, there are indications that it is becoming increasingly difficult and costly to automate further tasks, which is likely to slow down substitution processes (Katharina Dengler and Britta Matthes, 2021). Concluding, Dengler and Gundert (2021) reported in their analysis of the German labour market that digital transformation harms the individual assessment of job loss probability, but the perceived availability of job alternatives in the market seems to compensate for this.

The world population continues to grow and is expected to reach its peak with 11 billion citizens by the end of the century. This growth is accompanied by unprecedented population ageing driven by fertility, mortality, and migration changes (United Nations et al., 2019). The demographic change impacts societies and economies as a whole, for example, the health of citizens, health care delivery and workforce capabilities (Heijdra and Prettner, 2020b). Better health care lowers mortality and secures more extended participation in the labour market. However, increased life expectancy also leads to more cases of illness. For example, in comparison to 2020, six million additional cancer deaths are expected in 2040 due to demographic change (International Agency for Research on Cancer, 2022). Economic studies have analysed the impact of demographic change on economic growth, showing that positive economic impact depends on employment increases in various sectors (Frankovic et al., 2020; Kuhn and Prettner, 2016). However, the continuous employment of an ageing workforce in labour-intensive processes demands new forms of work and workplaces (Daheim and Wintermann, 2016). Therefore, the Federal Ministry of Education and Research in Germany dedicated the Science Year 2018 to the Future of Work (Federal Ministry of Education and Research, 2019; Müller-Polyzou et al., 2018). Future work needs to consider the altered performance of cognitive and non-cognitive abilities, reduced occupational and geographical mobility, and increased life and work experience in response to the demographic change (IAB Institut für Arbeitsmarkt- und Berufsforschung, 2021). To respond to the challenges of demographic change, the *Second World Assembly on Ageing* (WAA) adopted an action plan to promote the development of a society for all ages (United Nations, 2002).

The COVID-19 pandemic disruption joins a list of major epidemic and pandemic outbreaks in human history, from the Athenian Plague in 430 B.C. to the Black Death, killing as many as 150 million people, to the Spanish Flu with an estimated death toll of 50-100 million, to HIV causing 40 million deaths, to the more recent Severe Acute Respiratory Syndrome (SARS), Swine Flu or Ebola (Huremović, 2019). In addition to the fast developments in diagnostics, contact tracing and vaccination, public health measures such as isolation, quarantine and border control remain important in managing infectious diseases (Piret and Boivin, 2020). So far, COVID-19 has caused more than six million deaths worldwide (Johns Hopkins Coronavirus Resource Center, 2022). Besides its high death toll, it is also a significant disruption to economic growth resulting in the loss of 114 million jobs worldwide. COVID-19 has also increased social divides and reinforced inequalities in labour markets. The accelerated digital transformation and automation provided opportunities for high-skilled workers. Half of the high-skilled workers could work from home, in contrast to 29% of low-paid workers. Consequently, the pandemic affected mainly low-paid workers and occupations with a high degree of manual work (Mascherini, 2022; OECD, 2021a).

The COVID-19 pandemic has also exposed the vulnerabilities of health systems worldwide, raising questions about their resilience (Sundararaman et al., 2021). Resilience is "The quality of being able to return quickly to a previous good condition after problems" (Cambridge University Press and Assessment, 2022). It has also been defined as the capacity of institutions and actors in health systems to prepare for, recover from and absorb disruptions while maintaining core functions and serving the ongoing and acute care needs (Haldane et al., 2021).

Health system resilience is conceptually linked to Business Continuity Management (BCM) and Risk Management (RM), particularly with the underlying Information Communication Technology (ICT). The health sector, especially hospitals with their care tasks, is considered a critical infrastructure that demands a high level of resilience and falls under the responsibility of the European Union (EU) member states (The Council of the European Union, 2008; World Health Organization, 2017a). In summary, the COVID-19 pandemic has fundamentally challenged businesses and health systems and accelerated digital transformation, such as teleworking and contact tracing.

The abovementioned factors significantly influence the problem area and are decisive criteria for developing and using socio-technical information and assistance systems in labour-intensive processes. The subject area of socio-technical systems and their applications are interdisciplinary due to the human-machine interaction and the considerable differences in the applications in industry and healthcare. Furthermore, the subject area is influenced by the outlined global factors in all their actuality. The subject area is thus overall complex and has not been adequately addressed in former research. This dissertation aims to increase the knowledge base in the research field by providing empirical findings and theoretical contributions.

b. Objective and research questions

The problem area and influencing factors define the broad research boundaries of this dissertation. The objective is to investigate how the effectiveness and efficiency of labour-intensive work tasks can be improved through user-oriented information and assistance systems. The hypothesis that the objective can be reached through a consistent user orientation seems plausible, but it is complex and challenging to investigate due to the interdisciplinary nature of the topic and the ever-changing technology. Figure 1 presents the formulated general hypothesis with the underlying dimensions of people, activity, context, and technology that should be considered when conducting research in socio-technical information and assistance systems (Benyon, 2020).

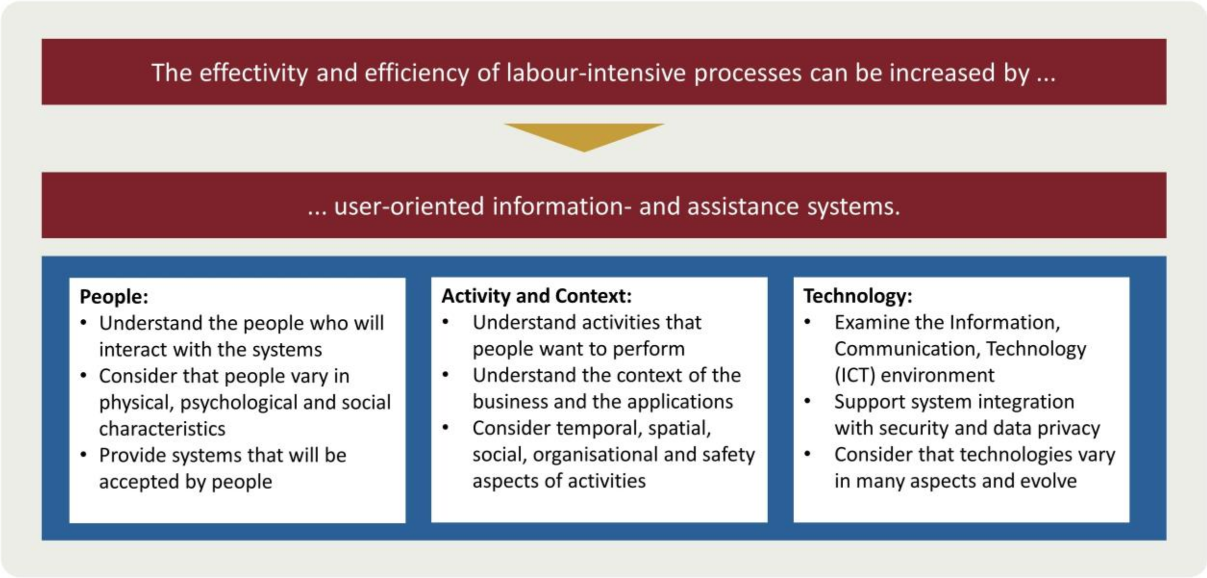

Figure 1: Hypothesis of the dissertation and underlying dimensions (own figure)

In this context, the dissertation intends to advance knowledge of socio-technical information and assistance systems for labour-intensive processes by providing new original knowledge in empiric data, bridging knowledge gaps by developing design principles for new systems and learning from the field of industrial and healthcare applications. The results form a taxonomy of design principles and technology and industry-agnostic reference model supporting the development of socio-technical systems for labour-intensive processes. Overall, the dissertation moves throughout the exchange between manufacturing industries and the healthcare sector, representing an additional complexity level. Cross-fertilisation takes place between the design cycles of the dissertation with particular emphasis on human-machine, machine-human and machine-machine aspects.

For the industrial sector, various applications were selected for investigation. These include the manual production of composite parts in individual or group work, assembly and disassembly tasks, and quality inspection applications. Labour-intensive processes characterise the applications in a variety of shop-floor environments. For the healthcare sector, radiotherapy (RT) for cancer treatment was selected as the core area of investigation. Radiotherapy is an important pillar of cancer treatment and represents an area of global healthcare characterised by a high degree of manual work and technology. Radiotherapy is patient-individual and implemented by highly educated expert staff.

Design Science Research (DSR) is selected as the surrounding research paradigm for this applied-science-oriented dissertation. DSR is pragmatic research and supports the design of artefacts for real-life problems by applying several research cycles. It is time-consuming but offers the advantage of linking the different application scenarios in healthcare and industry using single design cycles. "A significant DSR program typically encompasses many researchers over several years with any number of intermediate research results during its evolution" (Gregor and Hevner, 2013, p. 4). Therefore, this dissertation was only possible through intensive academic exchange with research partners and support from the application areas.

Dedicated research questions supporting the hypothesis analysis have been developed according to Hoang Thuan et al. (2019), who present a typology of DSR research questions as shown in Figure 2. The typology is based on analysing DSR contributions in leading IS journals according to motivation, problem statement, research question, research approach, research activities and artefact contributions combined with conceptual-to-empirical modelling. The topology is complemented by a profile of DSR research questions derived from a pattern-matching analysis (Hoang Thuan et al., 2019). Both the typology and the profiles guided the formulation of the DSR research questions of this dissertation.

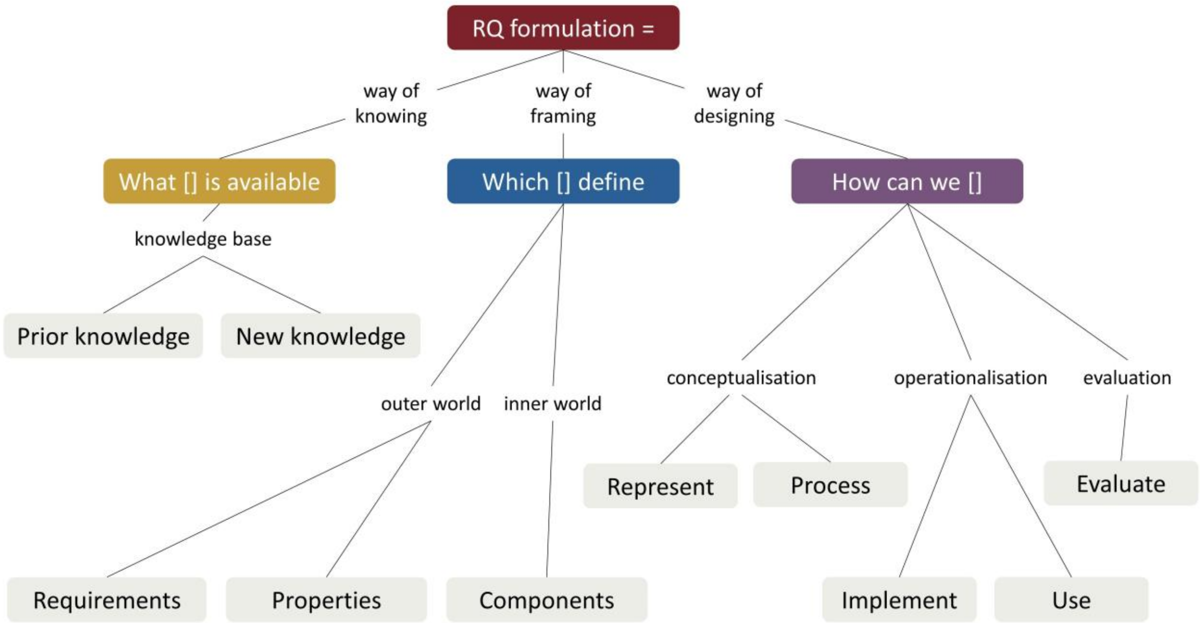

Figure 2: Topology of DSR research questions (Hoang Thuan et al., 2019)

Figure 3 presents the two research paths for industry and healthcare and twelve research questions defined following the systematic approach to support the analysis of improving the effectiveness and efficiency of labour-intensive work tasks through user-oriented information and assistance systems. The two research paths direct the research with the extension of known solutions to other industrial applications and the development of new solutions for known problems in the healthcare sector.

Different socio-technical systems are first explored in their application environment in parts production and assembly in the industrial sector. The first research question addresses the impact of semi-automation in labour-intensive processes on process speed, stability and the quality of work results while providing information on the design of quality workspaces in production. The second research question further elaborates on the design of quality workspaces in smart factories, focusing on Human-Machine-Interfaces (HMI) and the integration of CPS in the smart factory to achieve further increases in effectiveness and efficiency always considering users' acceptance of the systems. In the third and fourth research questions, answers related to work preparation and integration into production management systems should help further increase socio-technical systems' effectiveness and efficiency. Research question five examines system control improvements by applying intuitive control concepts, while question six seeks to answer further the question of how system control can be automated to increase the efficiency and quality of manual work. The industry pathway's conclusion is research question seven, which investigates how digital twins of manual assembly stations influence the flexibility and versatility of systems concerning the target variables of the hypothesis.

Further inquiries are carried out in the healthcare field with a particular focus on applications in radiotherapy. To this end, research question number eight first examines the need for socio-technical assistance in radiotherapy processes. Subsequently, research question nine analyses the transfer of the findings to the area of camera-based patient positioning. Finally, aspects of BCM are analysed in research questions ten, eleven and twelve due to the increasing importance of resilience. Based on the understanding of the influence of the COVID-19 disruption on business processes, it is examined how Decision Support Systems (DSS) and simulation can increase the resilience of socio-technical systems in labour-intensive processes. The twelve research questions build on each other and continuously increase the knowledge gained.

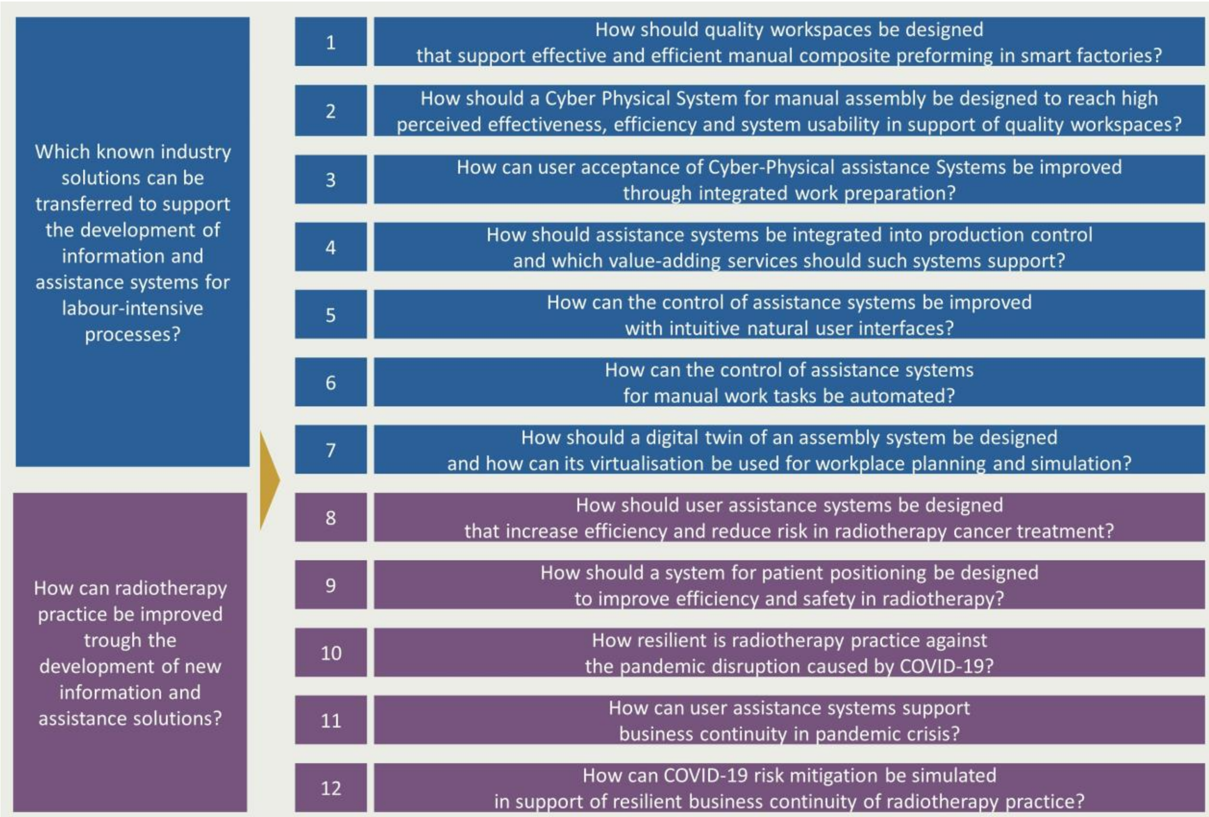

Figure 3: Distinct research questions of the dissertation (own figure)

Following the analytical framework of Hoang Thuan et al. (2019), the twelve research questions are categorised in Table 1. The analytical framework is organised according to the seven core dimensions: motivation, problem statement, research questions, research approach, research activities, theory in use and outcome artefacts. Table 1 provides a transparent view of the discourse of this dissertation that is taken in the twelve design cycles.

Dimension	Value	1	2	3	4	5	6	7	8	9	10	11	12
Motivation	Problem solving	•	•	•					•	•			
	Gab spotting				•	•	•	•					
	Problematisation										•	•	•
Problem statement	Research challenge	•	•						•	•			
	Research gap				•	•	•	•					

	Research problem												
	Requirement			•									
	Research opportunity										•	•	•
Research questions	Design process (how?)	•	•	•	•	•	•	•	•	•	•	•	•
	Design product (which?)												
	Knowledge (what is?)												
Research approach: knowledge goal	Exploratory			•	•				•		•		•
	Prescriptive	•	•	•	•	•	•	•	•	•	•	•	•
	Constructive	•	•			•	•	•		•		•	
	Confirmatory												
	Explanatory												
	Descriptive												
Research activities: mode of inquiry	Developmental			•				•		•			
	Evaluative				•				•		•		
	Mixed (developmental and evaluative)	•	•			•	•		•	•	•	•	•
Theory in use	No specific theory			•	•				•		•		
	Kernel theory	•	•			•	•	•		•		•	•
	Formal theory												
	Testable theory												
Outcome artefacts	Instantiation	•	•	•		•	•	•				•	
	Model									•			•
	Method												
	Construct								•		•		
	Design principles	•	•	•	•	•	•	•	•	•	•	•	•

Table 1: Classification of DSR projects of this dissertation (Hoang Thuan et al. (2019))

First, the design cycles one to nine targeting real-life problems are motivated by problem-solving and gap-spotting. However, the COVID-19 disruption has encouraged additional problematisation research. This fact is also reflected in the problem statement dimension, first characterised by research challenge, research gap and requirements of real-life problems. However, the research opportunity arose with the COVID-19 disruption leading to the last three design cycles. The defined research questions are related to process design, reflecting the focus on labour-intensive processes; however, some design cycles include elements of product and knowledge questions, as will be shown in the design cycle description. The knowledge goal changed between explorative and constructive research approaches and continuous prespcriptive goals using mainly mixed research modes of inquiry referring to kernel theories and experts' experiences. Primarily instantiations were created to be tested in realistic case study scenarios complemented by design recommendations and principles.

Sandberg and Alvesson (2011) unveiled in their literature review that gap-spotting is the dominant way of developing research questions. They proposed different forms of problematisation as an alternative since, in their view, challenging assumptions make theories interesting and significant. Sandberg and Alvesson (2011) presented critical confrontation, quasi-problematisation and problematisation as disruptive modes that should be applied when defining research questions. In this dissertation, gap spotting is not used unilaterally but complemented with other methods. This attempt makes this work more multifaceted. In sum, the research questions of this dissertation are formulated following a systematic approach, synthesising the application areas in industry and healthcare and elaborating on the human-machine, machine-human and machine-machine dimensions.

c. Structure of the work

The work presented in the remaining part of this dissertation is organised as follows: Section 2 outlines essential aspects of labour-intensive processes. The change of the working world and the influencing macro factors affecting the work of the future are described with their impact on socio-technical systems. Subsequently, the working worlds of industry and healthcare are examined in detail, including their similarities and differences. Section 2 concludes with a discussion of the challenges of designing socio-technical systems.

Section 3 is devoted to information and assistance systems. After reviewing research challenges, the different user assistance systems are presented, and exemplary applications in industry, crafts and healthcare are highlighted. The relation to Cyber-Physical-System (CPS) is discussed before Section 3 concludes with the state of knowledge and the need for action. Section 4 focuses on laser-based assistance systems, chosen as the object of investigation for this dissertation. Stringent industrial and healthcare applications are considered. Examples of composite manufacturing, prefabrication of parts and industrial assembly and quality inspection are presented for industrial production. The applications of interventional radiology, tumour marking, and patient positioning in radiation therapy for cancer treatment are explained in the healthcare sector. Section 4 ends with a reflection and conclusion.

Section 5 focuses entirely on the DSR paradigm as the framework of this dissertation. Following the scientific classification of design theories, the foundations are laid in knowledge contribution, kernel theories, research paradigm and methods and software tools used in the design cycles. Section 5 concludes with reflection and conclusions. Section 6 describes the design science cycles of the industry and healthcare path in detail. First, the design concept is presented. Subsequently, the design science cycles of the industry path and the healthcare path are outlined in a structured approach, including discussions of the knowledge contribution based on reflection and abstraction. Thus, in each design cycle, one of the twelve dedicated research questions is answered, supporting the overall analysis of the hypothesis. Section 6 closes with summarising reflections and conclusions.

Section 7 introduces reference models before structuring design principles into a taxonomy for transferability to other domains. Then, a reference model for the design of socio-technical systems for labour-intensive processes is developed and narratively verified in a stepwise approach. The section concludes with recommendations for action before a summary and outlook are provided in Section 8. Finally, the research institutions and companies involved are acknowledged in Section 9, followed by the Appendix in Section 10.

2. Aspects of labour-intensive processes

In describing the problem area, selected significant global factors have been briefly introduced. In the following, these global factors are scientifically outlined and discussed in the context of labour-intensive processes and socio-technological systems supporting such processes. Subsequently, scientific and governmental studies of the work of the future are presented, which form the basis for the following sections. Both fields, industry and healthcare, which are particularly important for this dissertation, are examined and compared concerning the development of work processes and related actors. Finally, the corresponding challenges to the scope of this dissertation are summarised.

a. Change of the working world

The change in the working world is a process that people experience at work and in their daily lives. The process is accelerated by globalisation and digitalisation, creating insecurity for many people about current and future jobs in terms of salaries, job stability, work conditions, required skills, and overall participation in the change process. Governmental studies show that 14% of jobs in Organisation for Economic Cooperation and Development (OECD) countries are likely to be automated, while another 32% are at high risk of being at least partially automated. Young people and low-skilled workers face the highest risk, but also, high-skilled workers are increasingly affected due to new, often AI-based technologies. Previous job models with a stable, full-time job at one employer are declining, while a shift towards service jobs occurs. The COVID-19 disruption has widened the gap between favoured and vulnerable people affecting the quality of many jobs. Internet connectivity has allowed many people to work from home during the crisis, which has benefited the platform economy. However, jobs requiring a physical presence, e.g., retail, manufacturing, and transportation, are more likely to be held by lower-skilled workers (Organisation for Economic Cooperation and Development, 2022).

i. Macro factors

The broader subject area of labour-intensive processes is interdisciplinary and complex, requiring a deeper view of the macro factors introduced initially. As shown in Figure 4, six macro factors influence socio-technical systems for labour-intensive processes from the market penetration and demand perspective. Efficiency, effectiveness and acceptance of systems are related to the penetration of systems in the market. Resilience, demographic change, and substitution impact the demand for socio-technical systems. The following includes an a priori definition of the terms used.

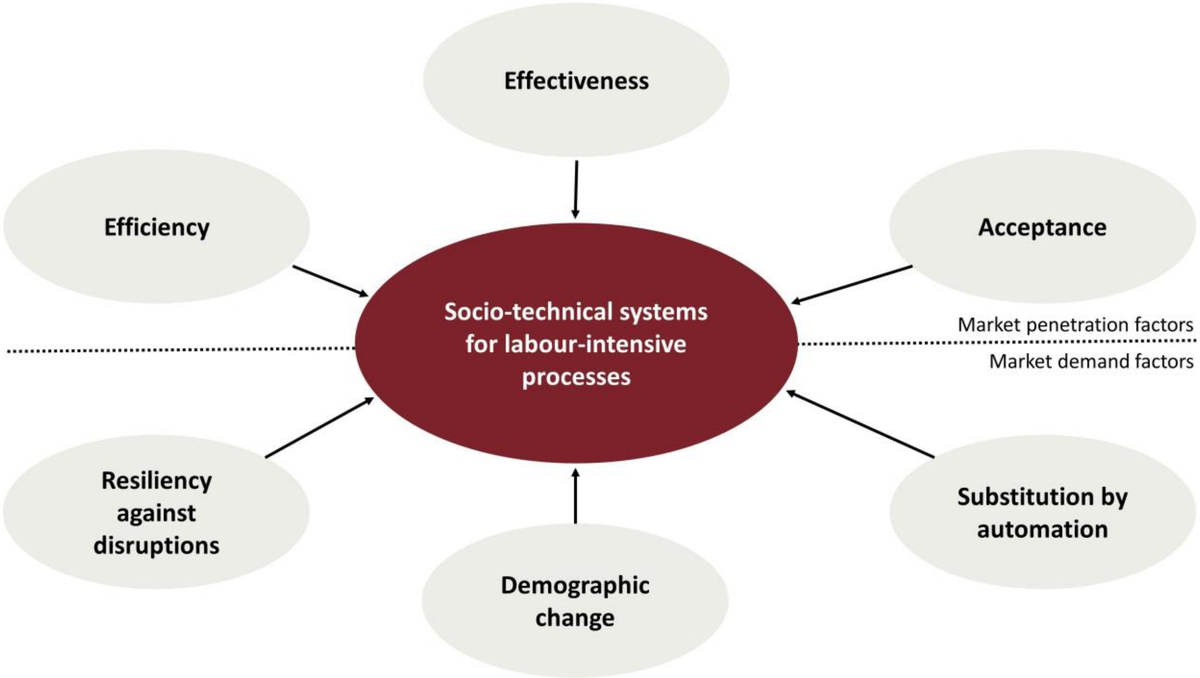

Figure 4: Macro forces on socio-technical systems for labour-intensive processes (own figure)

Efficiency is a versatile term used differently depending on the discipline or area of application. Among others, efficiency is defined as "The good use of time and energy in a way that does not waste any.", "The difference between the amount of energy that is put into a machine in the form of fuel, effort, etc. and the amount that comes out of it in the form of movement", "The condition or fact of producing the results you want without waste, or a particular way in which this is done", "A situation in which a person, company, factory, etc. uses resources such as time, materials, or labour well, without wasting any", "A situation in which a person, system, or machine works well and quickly" (Cambridge University Press and Assessment, 2022). Efficiency is calculated according to Equation 1 as the ratio of Product output to Cost as required resources and cannot reach values above 100%.

$$Efficiency = \frac{Product}{Cost}$$

Equation 1: Efficiency calculation

The continuous need to reduce costs in industry and healthcare means that socio-technical systems must increase the efficiency of labour-intensive production or treatment processes, for example, by introducing new technologies or improving existing ones.

Accordingly, effectiveness is a versatile term that is used in different ways. The definitions span from "the ability to be successful and produce the intended results" to "the quality of being successful in achieving what is wanted" to "how well a particular treatment or drug works when people are using it, as opposed to how well it works under carefully controlled scientific testing conditions" (Cambridge University Press and Assessment, 2022). The effectiveness of socio-technical systems in labour-intensive processes has two dimensions. First, customers expect high-quality products, with quality defined as "the degree to which a set of inherent characteristics of an object fulfils requirements" (International Organization for Standardization ISO, 2015b). Second, errors often result in high consequential costs. Depending on the product, faults can no longer be repaired or can only be reworked at a high price. Products that cannot be repaired are considered rejects, and additional costs are incurred for disposal (Kiran, 2017). Effectiveness is often synonymous with treatment success or patient safety in the healthcare sector. Errors in patient treatment can have significant effects, up to patient death. Consequently, the medical system suffers from high liability costs (Mello et al., 2010). The socio-technical systems' effectivity measurement depends on the application area and includes humans working with the systems. Therefore, Key Performance Indicators (KPIs) must reflect objective and subjective effectiveness perspectives.

Efficiency and effectiveness as objective measurements have found their way into concepts and performance indicators, such as in the context of Total Productive Maintenance (TPM), according to Nakajima, with the goal of a comprehensive and trouble-free production system and the Overall Equipment Effectiveness (OEE) as the multiplication of availability, performance and quality efficiency (Heller and Prasse, 2018; Nakajima, 1988). Figure 5 outlines the taxonomy of TPM and Equation 2, the calculation of the OEE. Jeong and Phillips (2001) have adapted the concept for capital-intensive industries because of their belief…" that loss classification schemes are ultimately tied to the industry type" (Jeong and Phillips, 2001, p. 1405). This statement becomes particularly clear in a direct comparison of industry and healthcare because the patient significantly influences, for instance, the loading time.

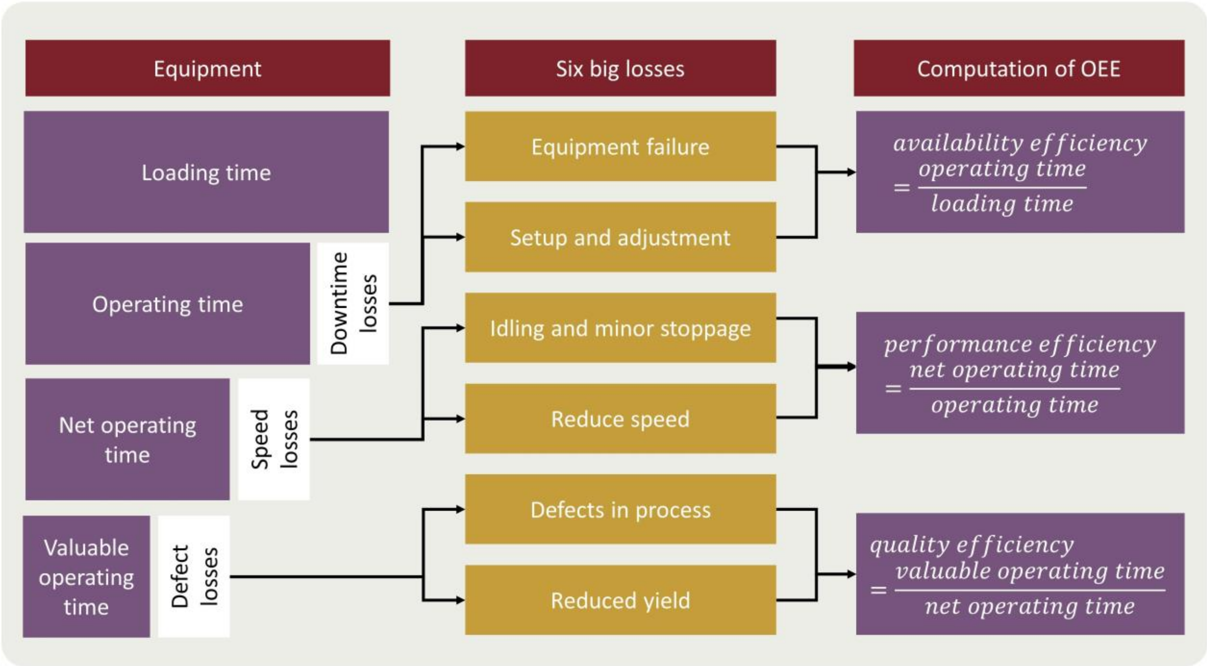

Figure 5: Taxonomy of Total Production Maintenance (Nakajima, 1988)

$$OEE = availability\ efficiency \cdot performance\ efficiency \cdot quality\ efficiency$$
$$= \frac{valuable\ operating\ time}{loading\ time}$$

Equation 2: Overall Equipment Effectiveness (Nakajima, 1988)

Sundqvist et al. (2014) analysed efficiency and effectiveness within the project management profession. They confirmed the wide variety of views on efficiency and effectiveness among academics and practitioners and the usage of the terms without clear definitions. The authors claimed that clarifying the interpretation of project efficiency and effectiveness would help project-based organisations to improve their work. Furthermore, they believed that new performance indicators beyond time and cost would increase diversity in performance measurement (Sundqvist et al., 2014).

Both efficiency and effectiveness influence the usability of socio-technical systems according to the standard for ergonomics of human-system interaction (International Organization for Standardization ISO, 2018, 2019b). The standard complements efficiency and effectiveness with the system satisfaction measure. Typical metrics for efficiency, effectiveness and satisfaction are presented in Table 2 according to Benyon (2020) in adaptation from the International Organization for Standardization ISO (2019b). The level of achievement depends on the system and application area, whereby safety-critical healthcare applications apply no-failure policies and utilise special platforms for a posteriori incident reporting (International Atomic Energy Agency, 2022). Benchmarks allow the comparison with other systems in the respective application area. Both efficiency and effectiveness support improvements in time, cost, quality and customer satisfaction (Sundqvist et al., 2014).

Usability objective	Effectiveness measure	Efficiency measure	Satisfaction measure
Overall usability	- Percentage of tasks successfully completed - Percentage of users completing tasks	- The time needed to complete a task - Time spent on non-productive actions	- A rating scale for satisfaction - Frequency of voluntary use
Meets the needs of experienced users	- Percentage of advanced tasks completed - Percentage of relevant functions used	- The time needed to complete tasks relative to the minimum time	- A rating scale for satisfaction with advanced features
Meets the needs for training and use	- Percentage of tasks completed successfully at first attempt	- The time needed on the first attempt to complete the task - Time spent on help functions	- Rate of voluntary use
Meets the needs for infrequent use	- Percentage of tasks completed successfully after a specified period of non-use	- Time spent re-learning functions - Number of persistent errors	- Frequency of reuse
Learnability	- Number of functions learned - Percentage of users who manage to learn a pre-specified criterion	- Time spent on help functions - Time to learn a criterion	- A rating scale for ease of learning

Table 2: Usability metrics according to Benyon (2020) adapted from ISO (2019)

The acceptance of socio-technical systems is important for IS researchers, system providers and users. "Acceptability is about fitting technologies and services into people's lives" (Benyon, 2020, p. 112). Acceptance can be seen from different angles, such as political acceptance, convenience, cultural and social habits, usefulness and economics. Fundamental to the analysis of system acceptance is the Theory of Reasoned Action (TRA) and the Theory of Planned Behavior (TPB), supporting the prediction of how humans behave based on their attitudes and intentions. According to the TRA, people behave rationally and utilise available information, which allows for predicting actions. The likelihood to act increases with the intent to perform the action, whereby the intention is influenced by the attitude of positive or negative thoughts concerning the behaviour and subjective norms. In turn, people's attitude is influenced by their beliefs about the consequences of the action and the social pressure, e.g. by family and friends and what they think about the behaviour. Social pressure thereby reflects the motivation to comply with the perceived expectations of the people around us (Ajzen and Fishbein, 1980; Fishbein and Ajzen, 1975). As an extension of the TRA, the TPB was developed to support the prediction of repeatable actions. The model was extended by perceived behavioural control, which reflects the degree of personal control that one perceives to have over the behaviour. Attitude and subjective norms influence behaviour by intention, whereas perceived behavioural control influences activities through the effect of intention. Both are influential predictors of behaviour (Ajzen, 1985, 1991; Fishbein and Ajzen, 1975).

Contrary to usability, socio-technical system acceptance requires understanding the context of use. Several models have been developed to describe the underlying mechanisms and evaluate the success of IS. Urbach et al. (2009) provided a literature review about the use of multidimensional IS success models. The authors analysed the theoretical foundation, the object and unit of empiric analysis, the evaluation perspective, and the data gathering and analysis. According to their findings, the acceptance model of DeLone and McLean (1992) was used in more than half of the publications. Furthermore, IS were mainly analysed by surveying users and performing Structural Equation Modelling (SEM). IS success was mainly analysed on an individual level and seldom complemented by an organisational analysis, a finding that was recently confirmed by Clarke et al. (2020).

DeLone and McLean (1992) developed an integrated view of IS success by presenting a taxonomy, and an IS success model with the six interrelated and interdependent dimensions: system quality, information quality, use, user satisfaction, individual impact and organisational impact. The model is based on usage as an appropriate measure for system success. In the model, system quality measures the accuracy and efficiency of the system that communicates information, while information quality measures the success of conveying the meaning of the information. Both influence the effect of the information on the system user. The six dimensions of the model are interrelated, which has implications for measuring and analysing IS success in empirical studies. It follows that interrelationships among the dimensions should be studied or controlled during an analysis.

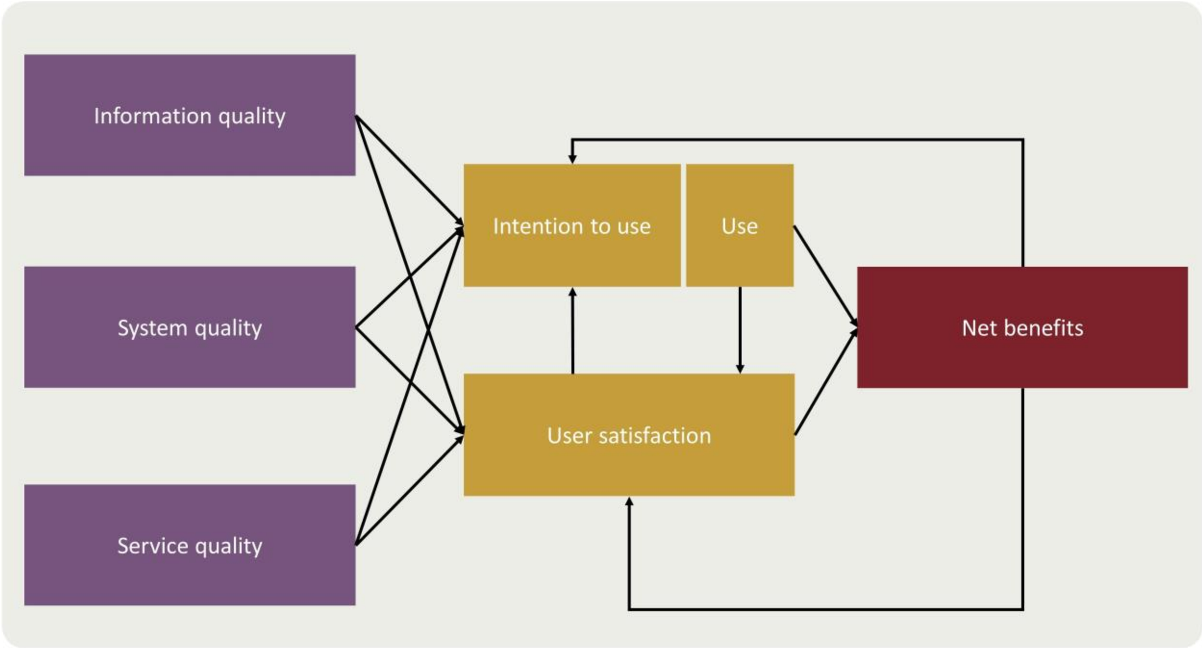

Figure 6: Updated IS success model (William H. Delone and Ephraim R. McLean, 2003)

The authors have updated their success model and adapted it to the new challenges of IS practice. The updated model is shown in Figure 6 as published by the authors in their "A Ten-Year Update" article. *Service quality* was added, reflecting that new services are continuously added to many products. Furthermore, individual and organisational impacts have been combined into *net benefits* as a common success measure. Finally, *intention to use* has been introduced to better distinguish between mandatory versus voluntary or informed versus uninformed usage. However, *intention to use* is more difficult to measure than actual usage (William H. Delone and Ephraim R. McLean, 2003).

The Technology Acceptance Model (TAM), developed by Davis (1985), is another widely used model for studying the acceptance of systems. The individual's attitude towards system usage is determined by *perceived usefulness* and *ease of use*. *Perceived usefulness* means that the user believes the system will enhance the job performance, while *ease of use* implies that the system usage will require low effort. Davis also presented evidence that the model can be used in product design. *Ease of use* is important, but the usefulness of a system is even more critical (Davis et al., 1989). The robustness of TAM as a prediction model was verified in a meta-analysis by King and He (2006). The TAM was later extended to explain *perceived usefulness* and *usage intentions* regarding social influence and cognitive processes. The extended TAM 2 was tested involving voluntary and mandatory usage before and after system implementation. Social influence processes (subjective norm, image, voluntariness) and cognitive processes (job relevance, output quality, result demonstrability, perceived ease of use) significantly influence user acceptance. The term *subjective norm* is based on the TRA and the TPB

(Ajzen, 1991; Fishbein and Ajzen, 1975). *Subjective norm* represents the social pressure which has a positive effect on the intention to use and on the image representing the status of people. Both *subjective norm* and *image* have a positive effect on perceived usefulness. The experience variable reduces the impact of *subjective norm* and *intention to use* and perceived usefulness for involuntary use cases. *Job relevance* describes the *perceived usefulness* of technology for doing the job and positively affects perceived usefulness. *Output quality* represents the effectiveness of technology in qualitative terms with a positive effect on perceived usefulness. *Result demonstrability* also positively affects *perceived usefulness* and reflects whether a user directly recognises the system's benefits (Venkatesh and Davis, 2000).

(Venkatesh et al., 2003) recognised the need for a synthesis of several existing user acceptance models and introduced the Unified Theory of Acceptance and Use of Technology (UTAUT) based on a review and comparison of TRA, TPB, TAM, the model of PC utilisation, the diffusion of innovations theory and combinations of these models and theories. They provided a unified tool to assess the success of technology introduction, helping to understand acceptance drivers. Figure 7 shows the model with the direct determinants of *user acceptance* and *usage behaviour* and the essential moderators *gender*, *age*, *voluntariness* and *experience*. Ehrari et al. (2020) recently studied how human motivational determinants influence the trade-off between safety and privacy in technology acceptance in e-health. Consequentially, the authors extended the UTAUT model taking human motivation into account.

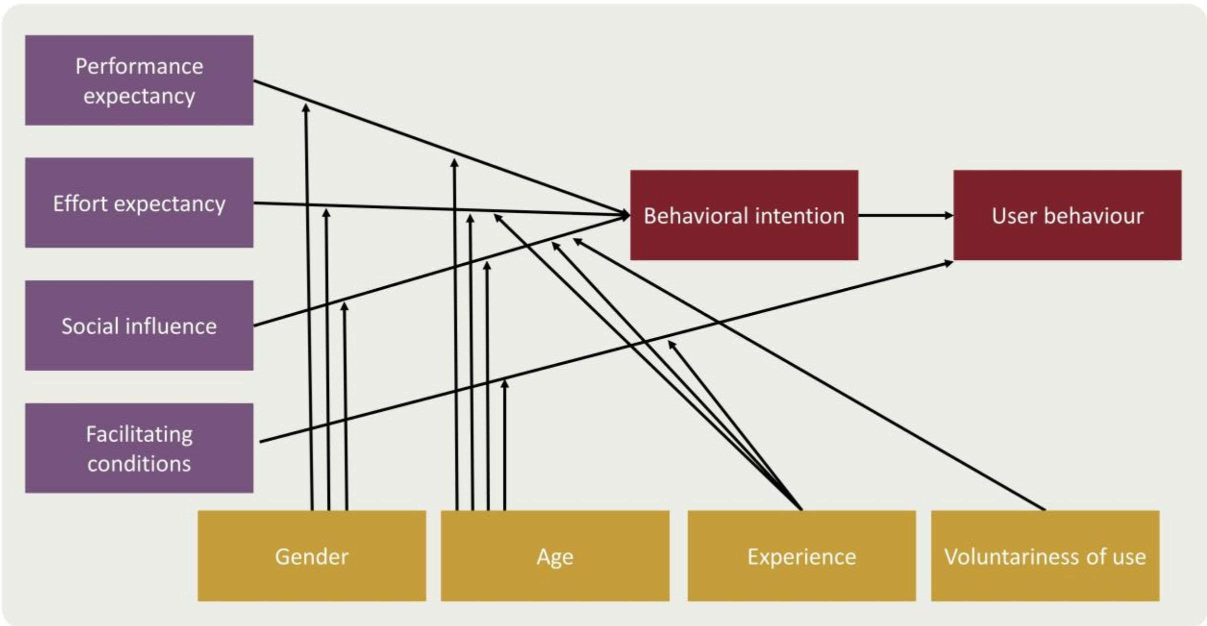

Figure 7: Unified Theory of Acceptance and Use of Technology (Venkatesh et al., 2003)

The TAM 3 model, as presented in Figure 8, depicts a network of determinants of an individual's technology adoption and use. It is more comprehensive than TAM 2 and supports actional guidance. The authors claim that the model helps managers implement interventions to minimise resistance to new technology (Viswanath Venkatesh and Hillol Bala, 2008).

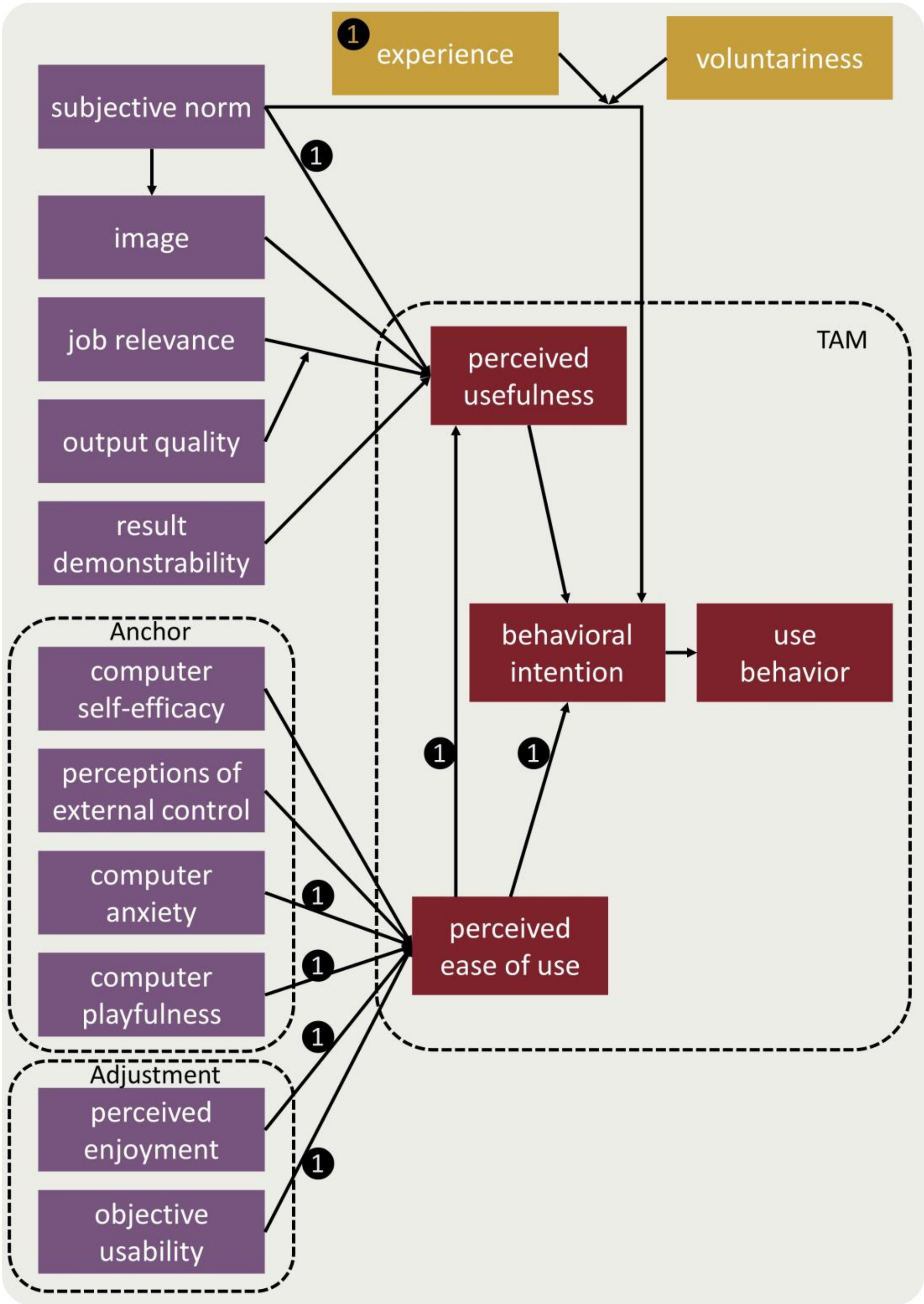

Figure 8: Technology Acceptance Model TAM 3 (Viswanath Venkatesh and Hillol Bala, 2008)

The communication of innovations also influences technology acceptance over time in social systems. Rogers (2003) described this process in his *theory of diffusion* of innovations introducing innovators, early adopters, early majority, late majority and laggards segments. The segments form the adoption curve of innovations, with the critical mass reaching the chasm point at the boundary of early adopters and the early majority (Moore, 2014).

Recent discourse criticised the use of usability, and Lah et al. (2020) investigated the relationship between *perceived usability* and *perceived usefulness/ perceived ease of use* of the TAM (Lewis, 2018a; Tractinsky, 2018). Lewis (2018a) provided evidence that *perceived ease of use* is another measure of *perceived usability*, connecting the TAM to the usability construct and providing an outlook into the future: "...I believe the construct of usability has a bright future both in usability science (theory) and usability engineering (practice), either alone or as a fundamental part of the larger assessment of user experience" (Lewis, 2018a, p. 6).

Vaezi et al. (2019) analysed user satisfaction with IS using a multi-attribute approach. They elaborated on the relationship between satisfaction with attributes, components, and the overall system to understand how users perceive system success. The model incorporates the system and service success components of William H. Delone and Ephraim R. McLean (2003) and shows that user satisfaction with IS derives from satisfaction with the single system components and the corresponding attributes. They identified the information attributes satisfaction with information currency, format and completeness, the system attributes ease of use and response time, and the service attributes accessibility and availability of support services as most important for user satisfaction. Finally, Jewer and Compeau (2021) developed a hybrid model for understanding IS success. It is based on William H. Delone and Ephraim R. McLean (2003) and their focus on system and user but elaborates on the process elements which represent developments of activities and events over time.

ii. Work of the future

The world of work is continuously changing, and Frey and Osborne (2013) described this change in their early work, *The Future of Employment*. The authors developed a labour market model to estimate the number of jobs at risk through computerisation. They analysed the probability of computerisation for several hundred occupations with the result that many jobs in transportation, logistics, office administration, production and the service sector were at risk of being replaced. Frey and Osborne (2013) also emphasised that new algorithms allow for computerising non-routine cognitive tasks. Additionally, they predicted that new developments in robotics would lead to further automation. Together they estimated that approximately 47% of United States employment could be automated within one to two decades. Their model also showed that salary and education levels were strongly linked with the occupation's probability of computerisation and that workers should acquire new creative and social skills to reallocate to tasks that are non-susceptible to computerisation (Frey and Osborne, 2013).

Their foresightedness is confirmed by the deployment of robots worldwide. The number of industrial robots in operation reached 3 million in 2020 and is expected to grow to 500,000 installed units per year in 2024. However, it should be noted that 70% of industrial robots are installed in Asia, with a high share in electronics production. According to the industry association, 43% of the industrial robots installed in 2020 perform handling and 12% assembly tasks. Most of the robots installed in 2020 were non-collaborative (94%). Advancements in cloud computing, 5G, machine vision, and AI will improve robots' performance and enable new applications. Service robots are most widely used for delivery (37%), cleaning and disinfection (29%), medical and rehabilitation (15%), social contact (13%) and automated restaurants (6%), while mobile robots are established in transportation and logistics, and medical robots are mainly used for surgeries (Ifr, 2022; Müller, 2021).

The risk of job substitution by automation was assessed by Ljubica Nedelkoska and Glenda Quintini (2018) based on Frey and Osborne (2013) and data from 32 OECD countries of the Programme for the International Assessment of Adult Competencies (PIACC) (OECD, 2021b). "Earlier discussions about digitalisation leading to massive job loss are now more nuanced, recognising that changes to task profiles within jobs may be the more important employment impact" (Eurofound, 2021, p. 2). Subsequently, the analysis considers occupational tasks and the potential of task substitution by AI, additive technologies, AR or DSS. According to their findings, 14% of jobs in OECD countries are at high risk, meaning that their substitution with existing technology has a probability of more than 70%, while an additional 32% of jobs have an automation probability of 50% to 70%. The variation in the risk of automation across OECD countries is explained by differences in economies, for example, the occupational mix within industries and the mix of tasks assigned to one occupation. In conclusion, the likelihood of job substitution is higher in East and South Europe, Germany, Chile, and Japan compared to Anglo-Saxon and Nordic countries and the Netherlands.

The figures vary between the different industries and jobs. For example, manufacturing fabricated metal products and manufacturing motor vehicles, trailers and semi-trailers have a mean automation probability of 52% and 51%, respectively, while the human health industry shows a lower automation probability of 42%. On an occupational level, assemblers face the highest risk of job substitution with 59%, compared to health professionals with 35%. Overall, the risk declines with education, PIAAC skills and salary levels. The analysis considered technological capabilities, not actual technology penetration, influenced by acceptance and adoption (Ljubica Nedelkoska and Glenda Quintini, 2018).

The Institute for Employment Research (IAB) of the Federal Employment Agency in Germany has incorporated the findings into the web-based interactive tool Job Futuromat. The tool explains the degree of automation of an occupation based on its task profile. In addition to statistical information, the technologies replacing the activities are also presented, and education opportunities are recommended (IAB Institut für Arbeitsmarkt- und Berufsforschung, 2021). The IAB has studied the scientific background at Germany's national and regional levels and described it in related publications (Dengler and Gundert, 2021; Katharina Dengler and Britta Matthes, 2021).

Additional research has been conducted on the digitalisation of industrial work with sometimes contradictory results (Hirsch-Kreinsen, 2016). Recent COVID-19 reasoned research has focused on the possibility of executing tasks remotely. The results showed that 37% of jobs in the United States could be entirely performed from home, but variations are high between cities and industries (Dingel and Neiman, 2020; Holgersen et al., 2021). In their occupation-based analysis supported by crowd-sourced data, Holgersen et al. (2021) calculated a similar figure of 38% for Norway. Digitalisation could help counteract the skilled labour shortage in many industries and provide earnings for the retired, as shown by Lorenz and Zwick (2021). The studies underline the influence of digitalisation and the expected change in the working world with occupational and geographic variations. Thus, the socio-technical system design must consider the impact of digitalisation on specific work tasks.

An additional effect with extensive impact on the future working world is the ubiquitous demographic change. "...demography plays a crucial and important role in many different economic processes" (Heijdra and Prettner, 2020a, p. 151). Understanding the influence requires a deep understanding of economic and non-market dependencies, as demanded by Heijdra and Prettner (2020b). "The relationship between automation and age is U-shaped, but the peak in automatability among youth jobs is far more pronounced than the peak among senior workers" (Ljubica Nedelkoska and Glenda Quintini, 2018, p. 8). The statement linked to the previously outlined substitution risks through automation shows the dependency between work and age in an exemplary manner. In labour-intensive processes, these dependencies are high, and the increasingly flexible, decentralised and knowledge-based work will require new skills. Overall, the demographic change will lead to new generations entering the workforce, while older generations will work longer or change their form of employment (Ulrich Walwei, Jürgen Deller, 2021). Compared to 2015, the number of 20-64 years olds will decrease by 2050 in many high-income countries. Contrary to sub-Saharan Africa, where the working-age population is projected to reach 1.3 billion simultaneously. The share of people above the age of 65 is expected to increase significantly in high-income countries. The situation in 2050 is comparatively reflected in Figure 9 in the form of population pyramids for Low-Income Countries (LIC), Lower-Middle-Income Countries (LMIC) and High-Income Countries (HIC).

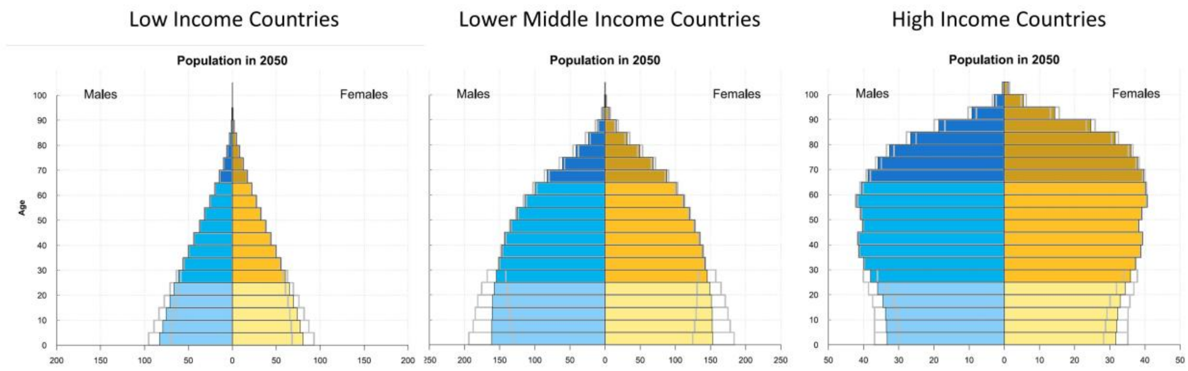

Figure 9: Population 2050 (United Nations Department of Economic and Social Affairs, 2022)

The global workforce of women is below that of men, but while the gender gap is closing in high-income countries, it continues to widen in emerging countries (International Labour Organization, 2022). Overall, international trade in the globalised world will increase the demand for highly skilled workers who fulfil cognitively more complex and collaborative tasks using technological competencies and often work remotely. The transformation of the labour market will continue with a growing platform economy employing the emerging middle class, women and the elderly, often with less economic security, health insurance or retirement plans (World Economic Forum, 2022). Permanent employment will be increasingly supplemented or substituted by project-based temporary work. At the same time, work will diversify, with workers holding several jobs and new forms of employment emerging, such as job sharing, interim management, mobile work, or crowd employment. The transition toward the circular economy is expected to create 7 to 8 million new jobs by 2030, mainly in industrial countries (European Commission Competence Centre on Foresight, 2022). The demographic change and the future of work are increasingly discussed in many countries, with a particular focus on the ageing workforce. The question that arises in this regard is how the work environments can be restructured to sustain employability of all age groups, retain people in their jobs and reintegrate the unemployed into the labour market. Maintaining work performance depends on many factors, such as willingness to engage in lifelong learning, which socio-technical systems can support.

Also, work should be organised so that employees can remain active throughout their working lives without suffering physical or mental health issues. Attention must also be paid to work circumstances because stressful and poor working conditions are responsible for performance problems as employees age (Buck et al., 2002). The Later Life Workplace Index (LLWI) has been developed to assess age-inclusive practices and working conditions for successfully managing age-diverse workforces in organisations (Wilckens et al., 2021). The effect of age on performance is characterised by a decline in physical work capacities, retaining mental work capacities, and enhancing cognitive and social skills

(Karazman 2000). The range of individual differences in performance grows wider as people grow older each year. However, age-typical changes need to be assessed in combination with individual performance ability, as visualised in the different curves in Figure 10.

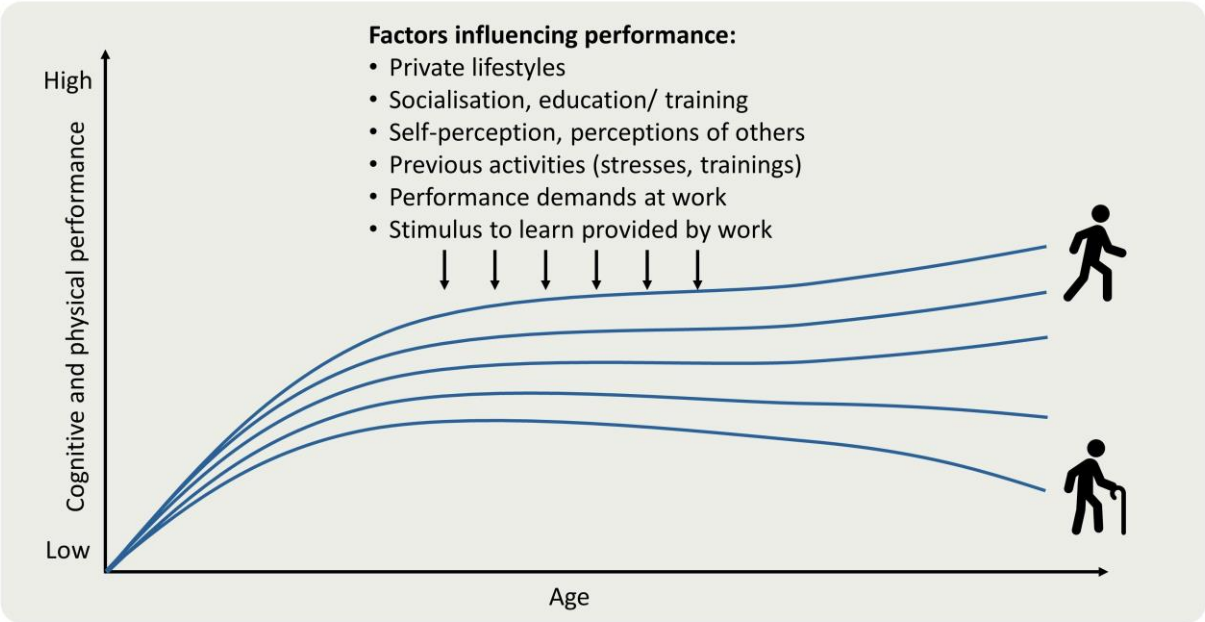

Figure 10: Individual differences in work performance with increasing age (Buck et al., 2002)

Age becomes a problem if the work demands no longer match the individual work capacities. In the future, work must be managed to prevent excessive stress on people, promote the mental and physical performance of employees, and ensure that the capacities of ageing employees are exploited to a great extent. To summarise, if workers must permanently perform work under unfavourable conditions, they will likely face health and performance problems as they age. Table 3 outlines common risks and potential counteractions that socio-technical systems can support (Buck et al., 2002).

Work risks	Actions required
- Repetitive work routines - Permanent concentration - Forced awkward postures - Night shifts - Physically demanding work - Machine-paced work - Head, noise, dust - Tight deadlines	- Ergonomic workplace design - Fostering healthy work processes - Job enrichment by changing type, content, methods of work, or mixed tasks - Reducing time pressure - Introducing flexible working-time models - Limiting deployment times

Table 3: Health risks and actions required (Buck et al., 2002)

For example, socio-technical systems can make job rotation easier, enhance jobs, and offer learning opportunities. They can also support the training of young workers with low qualifications. However, "Policy needs to ensure that digital technologies are deployed in the workplace in a human-centric way" (Eurofound, 2021, p. 22). In his comprehensive contribution, Tams (2022) analysed the lower performance levels of older users compared to younger ones in executing IT tasks. He developed a model with information processing speed of older workers as the cause of reduced IT-task capacity influenced by boundary conditions, as shown in Figure 11. According to the author, IT experience and self-efficacy mitigate the negative impacts of performance decline, while IT overload and effort cost of IT use lead to the opposite effect. He concluded his analysis with recommendations for IT designers, including consistent mapping between interface components based on pattern recognition, using tags instead of spatial elements and faceted interfaces that group results into broad categories.

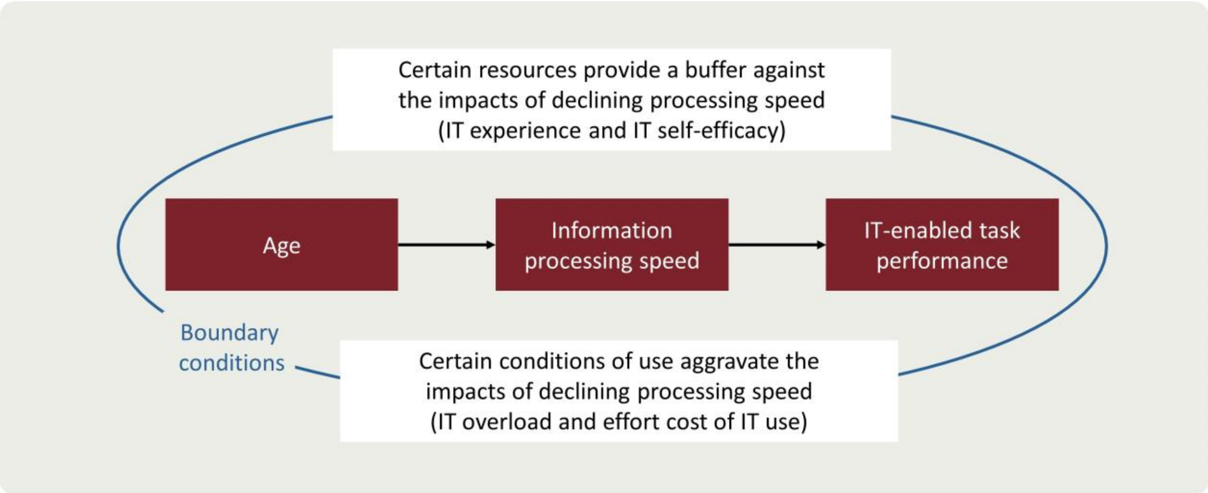

Figure 11: Extended view of ageing and IT-enabled task performance (Tams, 2022)

Socio-technical systems can secure employees' job performance if designed to compensate for age-related changes. Consequently, the demographic change and its influences must be an integral part of socio-technical systems design for labour-intensive processes.

The term resilience is often used in connection with technical systems but is more far-reaching in its overall concept. Many articles have been published on public health, epidemiological, environmental, architectural, social, psychological, organisational, energy, communication and cybersecurity resilience. It is noticeable that demographic change considerably impacts some of these topics (Souza, 2015). The National Research Council defines resilience as "... the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events" (National Research Council, 2012, p. 1) and refers to the goal of embracing a culture of resilience. Figure 12 visualises the different phases of resilience and highlights the impact of a disruption and the following absorption and recovery phases. The goal is to minimise the disruption in system performance and duration. The adaption phase should secure that systems are more resilient to future disruptions. "Building resilience does not mean abandoning efficiency, but rather maximising socio-economic systems' longterm sustainability in the face of future disruptions" (Trump et al., 2020, p. 220).

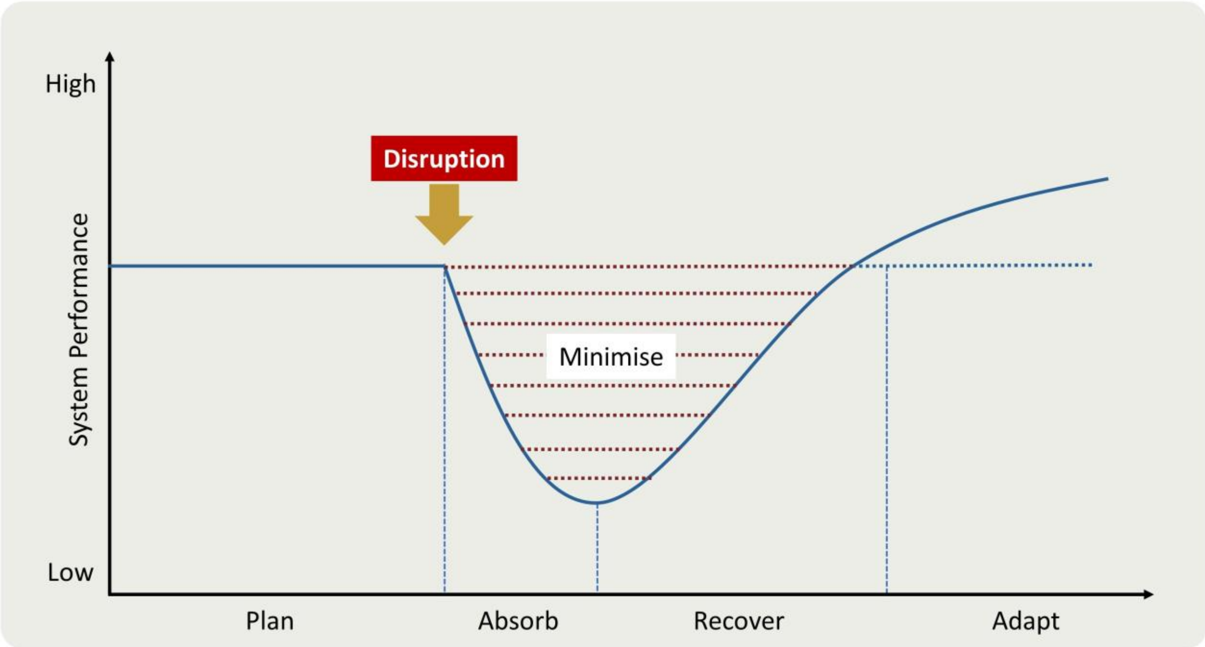

Figure 12: Stages of resilience (LINKOV and Trump, 2019; National Research Council, 2012)

This definition of resilience changes the view in which risk efforts are concentrated in the time before an incident (National Research Council, 2012). Resilience is linked to BCM and RM and is, therefore, more broadly defined in the recently revised international standard ISO 22300 as the "ability to absorb and adapt in a changing environment" (International Organization for Standardization ISO, 2021). This view on resilience improves traditional risk-based approaches, particularly for low-probability and high-impact risks such as climate disasters or cybersecurity threats (LINKOV and Trump, 2019). While supporting resilience efforts, BCM secures the uninterrupted provision of business operations and gained attention following the terrorist attacks of September 11th. The ISO 22301 standard defines the requirements to implement, maintain and improve a BCM system. It can be applied to industries and healthcare businesses regardless of location, type or organisational size. In this context, RM helps identify, analyse, evaluate, control and monitor risks, while a well-defined BCM plan supports the effective management of the identified risks. This relation is also pointed out in ISO 27001 and BS 25999 (International Organization for Standardization ISO, 2022; The British Standards Institution, 2012). For BCM, technical redundancy is essential but insufficient, a fact clearly demonstrated in the COVID-19 crisis, in which non-technical mitigation measures were widely applied. However, technical redundancy plays a critical role in many BCM projects.

Resilience can be seen from a system and network perspective, in which system designers need to understand the interconnections within the system environment. Understanding the dependencies within a system allows for identifying critical functions that can lead to cascading failures. Thus, system resilience can be increased by reducing system functioning to core services or strengthening selected functions. A resilience analysis should include physical, information, cognitive and social domains to achieve maximum impact (LINKOV and Trump, 2019). Furthermore, Zampieri (2021) proposed a method to quantify resilience from an ecological perspective as the amount of disturbance a system could take before it shifts into an alternative configuration and from the engineering point of view as the ability to restore a previous condition.

Andrea Filippetti et al. (2020) evaluated the relationship between innovation and resilience within the EU. Their work shows that more innovative regions outperformed less innovative ones following the 2008 financial crisis, concluding that innovation increases resilience during and after a crisis. Argyroudis et al. (2022) outlined how digital technologies enhance resilience by providing rapid and accurate assessments of conditions and by supporting decision-making before and during incidents. Argyroudis et al. (2022) evaluated IoT, AI/ ML, Building Information Modelling (BIM), Digital Twin (DT) approaches and agent-based modelling and their application in the different phases of a resilience plan for critical infrastructures. However, enhancing systems with technologies and adding connectivity can also increase vulnerability.

Systems theory can serve as a framework to better understand a system's functionality in the event of cascading change (LINKOV and Trump, 2019). The systems theory approach can be further complemented with a panarchy-driven approach incorporating a top-level view of systems and their interconnections (Gunderson, 2012). A resilient Digital Twin approach to preparing organisations for unexpected incidents was proposed by van der Aalst et al. (2021). The authors described creating Digital Twins of an Organisation (DTO) as a grand challenge in the IS field and proposed using hybrid or augmented intelligence as assistive AI to make DTOs more resilient to disruptions.

Resilience is essential in natural disasters such as earthquakes, hurricanes, wildfires and flooding. The 2017 hurricane Maria, for example, revealed the vulnerability of radiotherapy healthcare services in Puerto Rico, which was affected by power outages, loss of communication and non-availability of transport services. Gay et al. (2019) shared their experience of recovering operations after the hurricane. An empirical study among medical physicists confirmed that digital process data is necessary for comprehensive RM. The study also provided a radiotherapy process map supporting BCM work (Engbert et al., 2019). Recurring human-made disasters such as war and terrorism demonstrate the need for more resilience across all domains, as shown by Kizub et al. (2022). The authors described how oncologists continued to provide cancer care to 139,000 individuals with newly diagnosed cancer and 1,200 children in active treatment during the invasion of Ukraine. In summarising, it can be said that it is increasingly important to include resilience knowledge in IS system design and to support resilience with the development of innovative IS.

b. Working environments in industry and healthcare

The working environments in industrial and healthcare are subject to constant change. A look into the past highlights these changes and supports the view into the future. The following contents are essential foundations for addressing the research questions. Developments, similarities, and differences are presented, and the role of humans is discussed.

i. Industry 4.0 and 5.0

The term Industry 4.0 was publicly used for the first time at the Hanover trade show in 2011. The Federal Government of Germany associated Industry 4.0 with the potential to create value and accelerate innovation. It was included in the 2014 high-tech strategy *Innovations for Germany* (Steinhoff, 2016). Many countries defined similar government strategies such as *Made in China 2025*, *Ubiquitous Manufacturing South Korea*, *Bring Manufacturing back to the UK*, and *Future of Manufacturing Norway*. Based on the numerous publications, Industry 4.0 can be seen as:

> "... Industry 4.0 involves value chain organisation and technology. CPSs keep track of physical processes, connect the virtual world with the physical world, and make decentralised decisions within the smart factories of Industry 4.0. Moreover, the IoT enables real-time collaboration and communication between CPS. Decision-making processes are supported by DM [Data Mining], which is able to discover knowledge from various sources. Participants can utilise both the cross-organisational and internal services via the IoT."
>
> (Wang et al., 2017, p. 315)

Wang et al. (2017) described Industry 4.0 reflecting the evolution of industrial production from *craft* to *mass production* and from *mass customised* to *mass personalised production*, as shown in Figure 13. Craft production or Industry 1.0 of the 18th century was characterised by products manufactured according to specific requirements. A limited number of products were manufactured at high costs. A paradigm change appeared with machine-based production. *Mass production* or Industry 2.0 allowed to produce products at low cost but with a limited variety using assembly lines, standardisation and division of labour. *Mass customisation production* of Industry 3.0 is driven by the developments in computer, information and automation technology, allowing a wider variety of products to be produced efficiently with flexible manufacturing systems supported by Enterprise Resource Planning (ERP) and Manufacturing Execution Systems (MESs). *Mass personalisation production* of Industry 4.0 enables smart factories to produce fully customised products at the cost of traditional mass production (Wang et al., 2016; Wang et al., 2017).

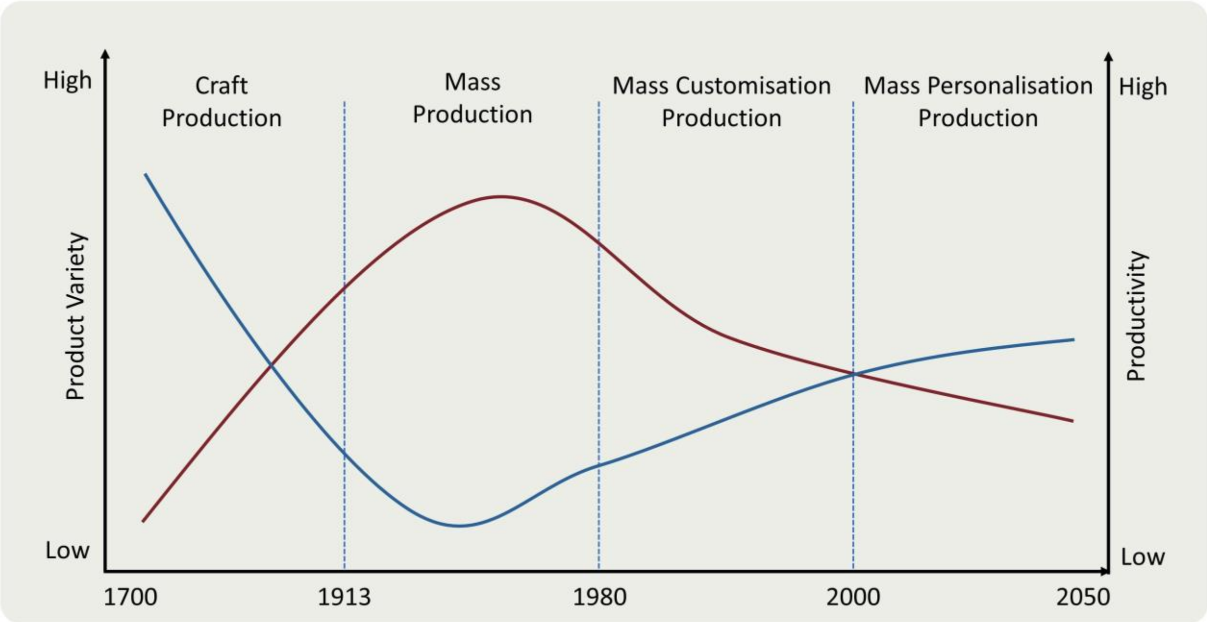

Figure 13: Evolution of production paradigm (Wang et al., 2017)

The components of Industry 4.0 have evolved with the development of technologies. CPS connect the virtual and the physical world. They are highly networked solutions equipped with intelligent sensors and actuators. The Internet of Things (IoT) is based on networked CPS and objects that collaboratively exchange information supported by new technologies. New mobile communication networks such as 5G enable machine-to-machine (m2m) communication with high bandwidth and low latencies (3GPP, 2022; Telefonaktiebolaget LM Ericsson, 2016). The advances in data handling, particularly in AI, support the storage and analysis of large amounts of distributed data, while the Internet of Service (IoS) provides services to users via multiple channels.

Many Internet 4.0 technologies and their implementations are shown in the 27 Small Medium Enterprise (SME) centres in Germany (Bundesministerium für Wirtschaft und Klimaschutz, 2022). The early framework for mass personalisation production developed by Wang et al. (2017) and shown in

Figure 14 is still valid even considering the fast development of AI, Blockchain, 5G technologies, and Digital Twins and their impact on IS (French et al., 2021). With a technology-independent view, Deuter and Pethig (2019) undertook an approach to generalise the multiple definitions of a DT and positioned it in the Reference Architecture Model Industrie 4.0 (RAMI 4.0), as described in DIN SPEC 91345 (German Institute for Standardization, 2016). The model provides a basic architecture for Industry 4.0, including an Asset Administration Shell (AAS), and allows a classification according to the life cycle of products according to IEC 62890 and the IT representation in the hierarchy according to IEC 62264 and 61512 (International Electrotechnical Commission, 1997, 2013, 2020). The importance of DTs for industrial applications has often been described, and the Industrial Digital Twin Association (IDTA) was founded to support the implementation and dissemination of DT technologies (Industrial Digital Twin Association, 2022).

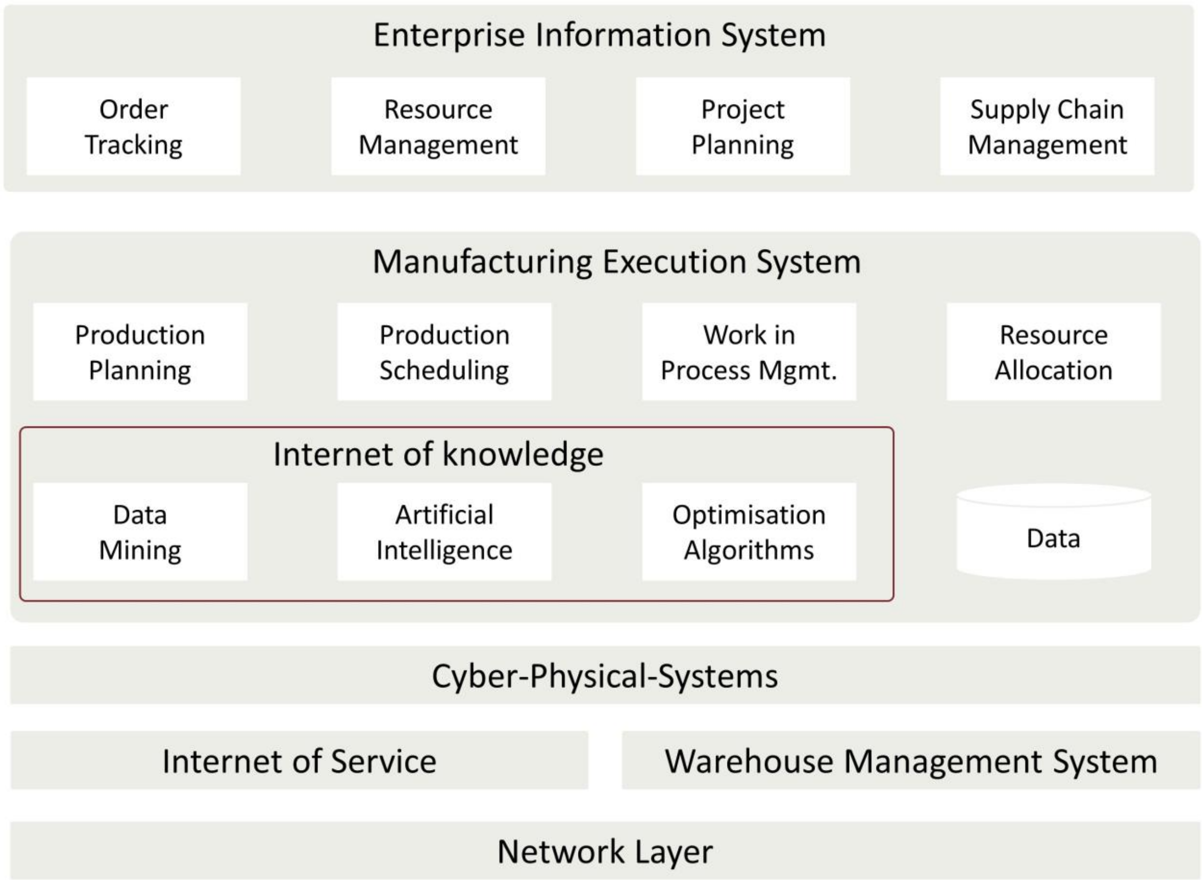

Figure 14: Mass personalisation production (Wang et al., 2017)

In addition to technological developments and the experiences from the COVID-19 crisis, there is a paradigm shift noticeable away from pure growth-orientated business toward sustainable economies. The European Commission (EC) described this shift in the Green Deal vision as Industry 5.0 and transformative for Europe based on resilience, sustainability, and regenerative and circular economic principles. The Industry 5.0 vision is proposed to supersede Industry 4.0 and is expected to deliver new forms of economic and social value as well as higher resilience against future crises. Table 4 compares Industry 4.0 and 5.0, highlighting the approach to connecting digital transformation with sustainability and climate action (European Commission, 2022; European Commission Directorate-General for Research and Innovation, 2021).

Industry 4.0	Industry 5.0
- Enhanced efficiency through digital connectivity and AI - The emergence of cyber-physical objects - Optimisation of business models for profit maximisation - No focus on the decoupling of resource and material use from negative environmental, climate and social impacts	- Combines competitiveness and sustainability - Alternative modes of technology governance for sustainability and resilience - Human-centric approach toward technology - Empowering workers with digital devices - The transition towards environmentally sustainable uses of technology - Corporate responsibility for the value chain - Indicators for the progress towards well-being, resilience, and sustainability

Table 4: Comparison of Industry 4.0 and 5.0 (European Commission Directorate-General for Research and Innovation, 2021)

While the vision of Industry 5.0 is described, the current state of digitalisation of production in countries and industries is still very different. Wagire et al. (2021) presented an overview of Industry 4.0 maturity models. They developed a technology-focused model specifically adapted for developing countries, while Zutin et al. (2022) analysed the maturity of Industry 4.0 technologies for the application in aircraft manufacturing, which needs to produce faster, cheaper and better while following the strict regulations of aviation agencies.

ii. Healthcare 4.0

"Health lags far behind other sectors in harnessing the potential of data and digital technology, missing the opportunity to save a significant number of lives and billions of dollars" (OECD, 2019, no pagination). The digitalisation of healthcare offers the opportunity for better patient care, more efficient hospitals and high-tech medical products (Kaltenbach et al., 2018). However, in many countries, healthcare systems must catch up with digitalisation and reform healthcare ecosystems through information and technology (Healthcare Information and Management Systems Society, 2019). Gastaldi and Corso (2012) proposed a two-fold approach exploring, on the one side, new and better approaches to delivering hospital healthcare while, on the other side, exploiting existing routines. Exchange of experience with adjacent areas can provide fresh ideas (Javaid and Haleem, 2019; Unterhofer et al., 2021). The term Hospital 4.0 has become established based on the digitalisation of production in Industry 4.0. Hospital 4.0 describes the digitalisation and networking of treatment and care processes in hospitals with networked and interoperable medical devices that provide digital services. These devices interact with users via intuitive human-machine interfaces and offer application opportunities (Mildner et al., 2019).

Hospitals, contrary to industries, are based on diagnosis and therapy processes, supported by logistics processes such as pharmaceuticals supply, laundry services and waste disposal. Also, instead of manufacturing products, hospitals treat patients with care activities. Communication between patients and treatment providers must be considered when digitalising processes and services. Medical cyber-physical systems (MCPS) can support physicians and nurses in decision-making and optimise the supporting processes (Dey et al., 2018). Figure 15 compares industrial production in an assembly line with Industry 4.0 production and the patient flow in a hospital. The flexible production of Industry 4.0 with the organisational principle of batch size one is similar to the patient flow in hospitals, with the patients moving individually between the diagnosis and treatment activities. Standardisation of treatment paths is applied, but patients remain individual. Hospital employees such as physicians, nursing and administrational staff must communicate and exchange information for the best treatment of patients with the given resources. Information and user assistance systems can support staff to increase their process efficiency and improve patients' individual and demand-oriented therapy (Kruse et al., 2018; Meister et al., 2019; Wibbeling et al., 2018).

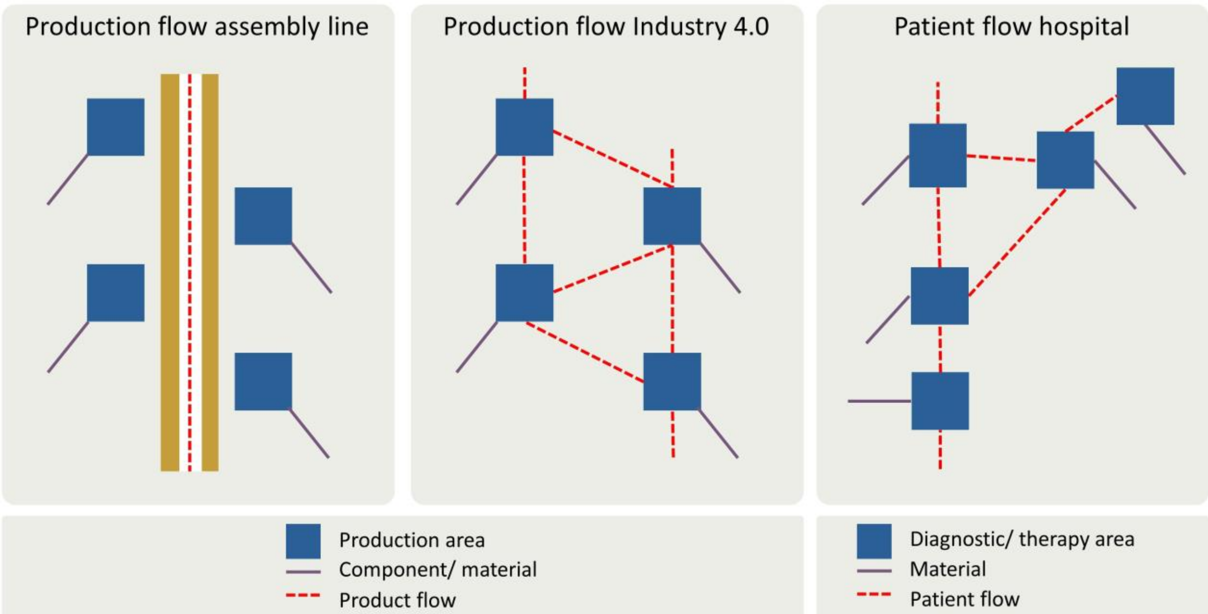

Figure 15: Comparison of industrial production and hospital operation (Wibbeling et al., 2018)

In this context, Electronic Health Records (EHRs) are particularly important and have the potential to transform the healthcare sector. These can be individual EHRs containing patient medical care data or EHRs aggregating data on an organisational or geographical level. "But while the majority of OECD countries (70%) say they are implementing ways for people to access their health data electronically, fewer than half (43%) include the ability for patients to interact with their own health records" (OECD, 2019, no pagination). Privacy, interoperability and security are limiting factors for both types of EHRs. However, IS researchers have the theoretical and technical expertise to design, develop and facilitate EHRs (Kohli and Tan, 2016; Kruse et al., 2018). During the design of EHRs, a socio-technical systems approach should be followed to secure usability and reduce clinician workload. The design should be based on a deep understanding of the work environment of clinicians and care teams. Finally, health care organisations and EHR providers should establish continuous design and learning cycles to improve system usability (Carayon and Salwei, 2021). Using AI, aggregated EHRs can also predict the likelihood of a patient's future health status, as shown by Li et al. (2020), which enables value-adding applications.

iii. Radiotherapy 4.0

Compelling application scenarios for Healthcare 4.0 arise in the technology and labour-intensive radiotherapy as an essential part of cancer treatment. More than 15 million cases of cancer are diagnosed each year. Cancer is the second leading cause of death worldwide, responsible for approximately 10 million deaths yearly. The number of cancer cases is expected to increase by 75% in the next 20 years (The International Agency for Research on Cancer IARC, 2022). The reasons for this are the growing world population and the increasing life expectancy. In addition to surgery and chemotherapy, RT is the most important form of cancer treatment. It is often combined with the aforementioned therapies for curative and palliative purposes. Studies state that the treatment benefits more than 50% of cancer patients (Atun et al., 2015). Radiotherapy is performed in hospitals and RT centres and requires high resources. Diagnostics and therapy equipment are capital-intensive, and extensive construction work is necessary for therapy rooms. Operating costs are high, as regular machine maintenance and specialised staff are necessary. Today, linear accelerators (linac) are used worldwide, and technological advances enable more precise, efficient and personalised treatment (Müller-Polyzou, Reuter-Oppermann et al., 2019).

In analogy to Industry 4.0, technical inventions have influenced the development of RT. Electrification was the prerequisite for X-ray tubes that enabled Radiotherapy 1.0, while Radiotherapy 2.0 originated with the discovery of artificial radioactivity and the understanding of radiation physics. New IT systems enabled imaging and 3D planning of treatment plans in Radiotherapy 3.0. Finally, Radiotherapy 4.0 is the extensively digitalised RT shown in Figure 16. Like Industry 4.0, it is primarily driven by advanced integrated systems and high connectivity.

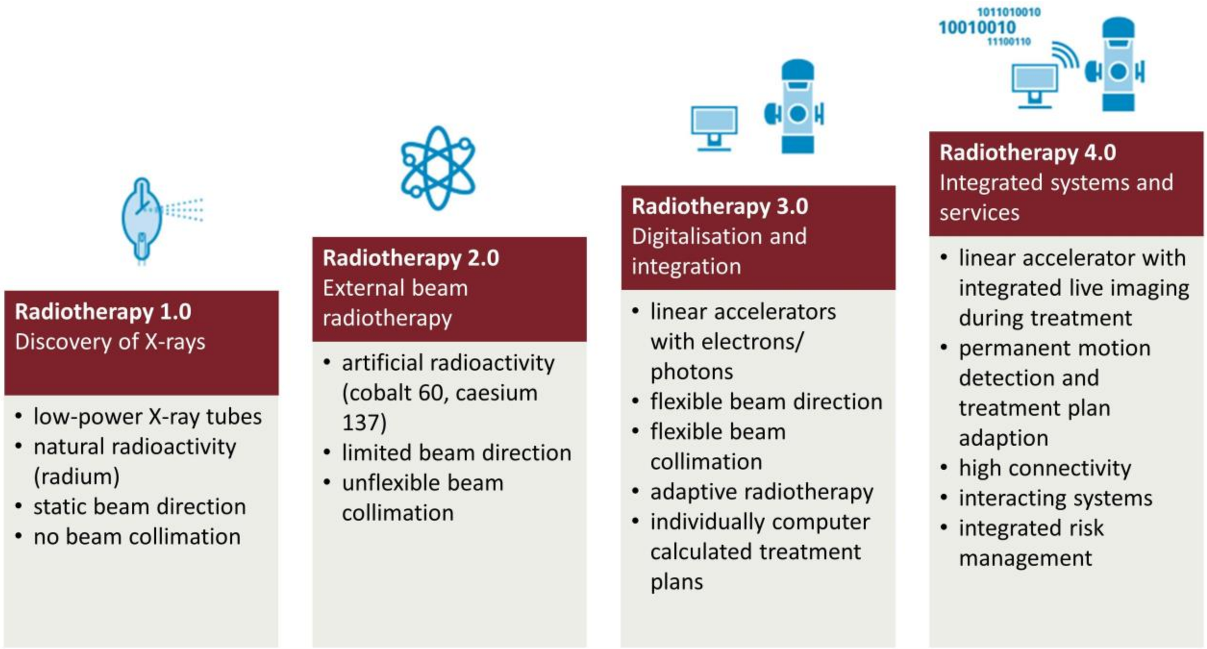

Figure 16: Development of Radiotherapy 1.0 to 4.0 (own figure)

Radiotherapy 4.0 is closely linked to Hospital 4.0. The intelligent interaction of people and technology in Radiotherapy 4.0 can reduce complexity and increase efficiency and patient safety. Radiotherapy 4.0 thus addresses the challenge of efficient, high-quality, and cost-conscious cancer treatment (Krämer and Stoffers, 2019).

"...health systems remain 'data rich but information poor'. Many opportunities to improve the health of individuals and communities remain untapped" (OECD, 2019, no pagination). Assistance systems with varying degrees of intelligence and interactivity can utilise data to provide information to users with a view to efficient and safe RT. Figure 17 presents the radiotherapy process with the underlying data sources and IT systems. The workflow is divided into diagnosis, radiotherapy treatment and after-care with sub-processes admission, imaging, planning, treatment, discharge and follow-up. Radiotherapy is data-rich, a fact pointed out in several AI publications (Parkinson et al., 2021; Thompson et al., 2018). The data used or generated in the various sub-processes is structured, semi-structured or unstructured, as in many healthcare areas (Traverso et al., 2019). It can be digital or analogue, real-time or non-real-time. Some data is exchanged automatically between the involved systems. Other data need to be processed manually by RT staff (Eder & Shekhovtsov, 2021; Mayo et al., 2018). Oncology Information Management Systems (OIMS), often integrated into Hospital

Information Systems (HIS), have evolved from linac control systems to comprehensive systems providing specific interfaces for the different occupation groups in the RT department, thus supporting patient management, staff management and linac control (Elekta, 15.01.2022). Picture Archiving and Communication Systems (PACS) support the management of extensive image data from prevailing imaging systems. Therapy Planning Systems (TPS) are central software tools that determine the exact dose distribution in defined areas within the patient's body. They communicate with OIMS and PACS via standardised DICOM file exchange. Furthermore, RT centres often use additional billing, patient management, and quality assurance solutions (Müller-Polyzou et al., 2022).

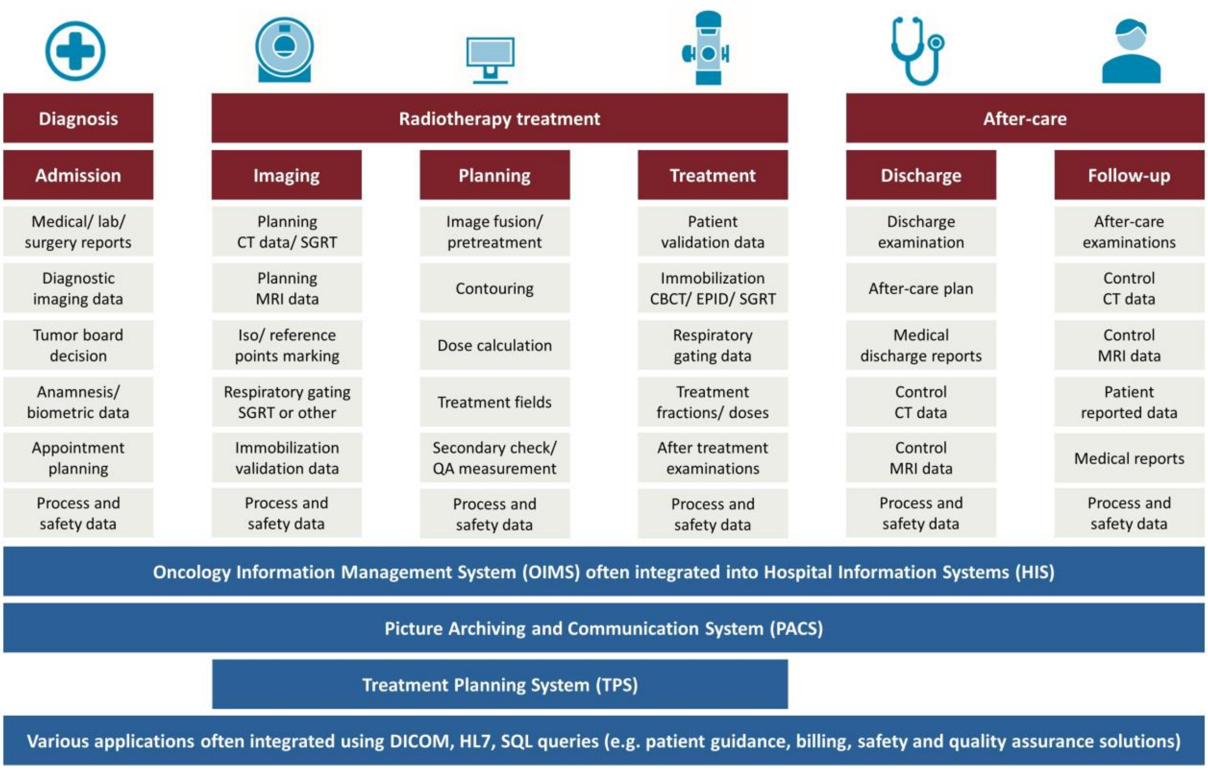

Figure 17: Radiotherapy data sources and IT systems (own figure)

Socio-technical information and user assistance systems can utilise the data in descriptive, diagnostic, predictive and prescriptive ways according to the categorisation of Gartner (2022), balancing the level of human input towards decision and action-taking.

iv. Operator 4.0

A vision for Operator 4.0 is presented by Romero et al. (2016) in the context of Human Cyber-Physical Systems (HCPS) and adaptive automation. They describe work systems for Industry 4.0, which are based on a human-automation symbiosis aiming to increase production efficiency. The systems execute a form of adaptive automation for the dynamic allocation of task control to human operators or machines. Romero et al. (2016) describe Operator 4.0 as an evolution of the interaction of operators with manufacturing systems, as shown in Figure 18. The Operator 1.0 is characterised by manual and dexterous work with limited support from mechanical tools and machines. For a long time, this was the predominant form of work. The Operator 2.0 arose with workers being assisted by computer-aided control and automation systems. The Operator 3.0 interacts with industrial robots in human-robot-collaboration scenarios, surrounded by machines and computer tools. Finally, Operator 4.0 represents the smart worker of the future who is aided by HCPSs creating adaptive production systems based on enhancing human physical, sensorial and cognitive capabilities (Romero et al., 2016).

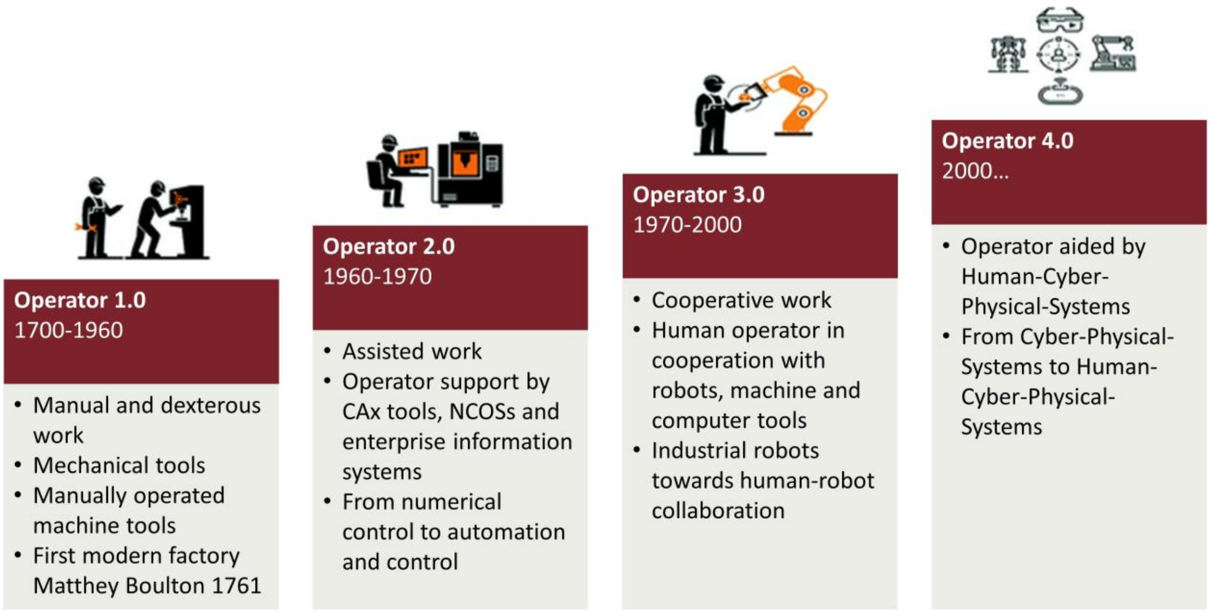

Figure 18: Evolution from Operator 1.0 to 4.0 (Romero et al., 2016)

The goal of adaptive automation is:

> "...the achievement of human-automation symbiosis by means of adaptation of automation & control across all workstations of a human-centred and adaptive production system in order to allow a dynamic and seamless transition of functions (tasks) allocation between humans and machines that optimally leverages human skills to provide inclusiveness and job satisfaction while also achieving production objectives."
>
> (Romero et al., 2016, p. 679)

Adaptive automation can be reached with human-in-the-loop supervision of the operator's performance in human-machine interaction. The supervision can be performed by the operator, by the machine or by both using a hybrid setup (Munir et al., 2013). Romero et al. (2016) describe human agents with their physical, sensorial and cognitive capabilities and artificial machine agents with their repetitive capabilities. In their vision, hybrid agents are intelligent in a symbiotic relationship between human and machine that extend the Operator’s 4.0 abilities to perform manual tasks according to the performance and quality expectations considering that the skills of the Operator 4.0 can change over time. The design of the systems shall secure operator-friendly work conditions in terms of practicability, safety, freedom from impairment, and individualisation and personalisation. Gazzaneo et al. (2020) introduced the Operator 4.0 compass, as shown in Figure 19, representing the technologies connected to the activities and capabilities of workers while highlighting the importance of interaction capabilities in addition to cognitive, sensorial and physical abilities. In this sense, the Operator 4.0 is empowered by adapting the shop floor according to workers' skills, capabilities, and needs. However, regarding workplace design, empiric analysis shows that the assessment of personal data related to well-being or performance is not welcomed among workers. Instead, workers would like to participate in their workspace and production design. Promising Operator 4.0 solutions seem to be the ones that support smooth work practices and workers' individuality (Kaasinen et al., 2020). Consequently, Value Sensitive Design (VSD) based on conceptual, empirical and technical investigation can be used to secure human values considered in system design. Value conflicts limiting the design space can arise, for instance, in trust against security or privacy against security (Gazzaneo et al., 2020). Value conflicts can also occur in the healthcare sector with the processing of patient health data. Special legislation is in force to protect patient health data (Bundesanzeiger, 2020).

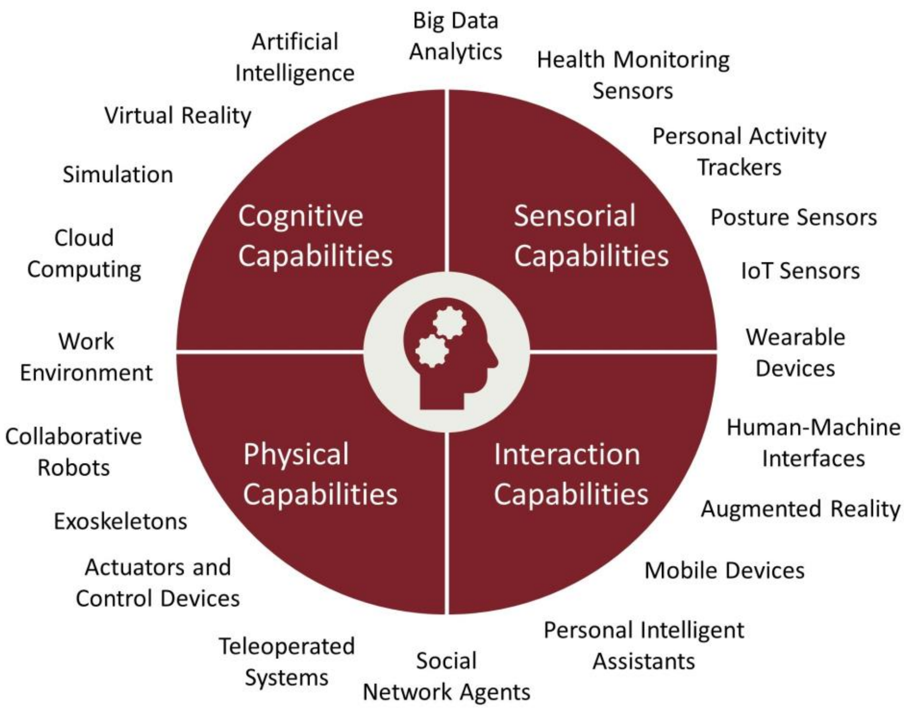

Figure 19: Operator 4.0 compass (Gazzaneo et al., 2020)

Depending on the IS application, several operators can exist. In RT, for instance, medical physicists operate and supervise complex technical devices. They apply physical methods in medical diagnostics and therapy and are responsible for the quality and safety of the technical equipment and processes. Their responsibilities increase in clinical practice with the move toward more specialised treatment courses and modalities (Samei, 2022; Samei and Grist, 2018). Medical technical assistants for nuclear medicine or radiotherapy technologists (RTT) support the RT processes during imaging examinations and at the linac and work directly with the patients (BERUFENET 2019).

In summarising, the Operator 4.0 concept recognises the human-centric role of the operator in HCPS and urges the consideration of human factors in industrial and healthcare socio-technical system design. Consequently, Gazzaneo et al. (2020) stated, "...Industrial Revolution is inevitably changing not only what the human operators do and how they do it, but also who they are, their identity and all the ethical issues associated with their practice" (Gazzaneo et al., 2020, p. 219).

v. Patient 4.0

The concept of Patient 4.0 is closely linked to the digital life journey, which describes the data spaces created around people from birth to death. These include personal data categorised into volunteered, observed, and inferred data. Individuals' volunteer data is shared by themselves, while external sensors record observed data. On the other hand, inferred data is derived from volunteered and observed data (World Economic Forum, 2011). Personal data storage, Digital Twin, usage control, sovereignty, and ethics are often discussed in connection with personal data. Personal data storage addresses safeguarding personal data, which can be implemented centrally or in federated systems. The machine readability of the data is essential for AI applications (Panesar, 2019). The Digital Twin as a virtual patient is derived from Industry 4.0 and offers advantages from a healthcare perspective, such as personalised medicine (Bruynseels et al., 2018). Determining who is allowed to use personal data is already incomprehensible for many people, a fact that will become even more difficult with the progressing digitalisation. Meta-consent concepts build on defined data, and user classes can provide a solution to this problem. Ploug and Holm (2016) presented such a concept for the healthcare sector. Decision-making power over personal data is closely linked to data sovereignty, including the guiding principles of freedom of choice, self-determination, self-control and security. Data sovereignty requires both digital competencies and regulation. Data ethics describes fundamental issues of moral and societal handling of personal data. In this context, the aim is to create more transparency, decentralise data, and enable data donations (Palmetshofer et al., 2017).

Meister and Otto (2019) presented a framework for a self-determined life in an increasingly digitalised world. The framework is illustrated in Figure 20 and covers the three evolutionary steps Digital Shadow, Digital Me and Digital Twin. The Digital Shadow is characterised by data stored in data silos of different providers and only available to selected applications. The user has only minimal influence on the usage of the data. The Digital Me secures a holistic view of the available data as it works across provider boundaries. The data becomes transparent to users, and users can control their data. Finally, the Digital Twin interacts with the ecosystem while learning and performing new skills. Overall, the framework ensures that citizens can make sovereign decisions about using their data. Personal Data Storage is a central element in the framework and consists of all data of the Digital Me. The Digital Business Model reflects that the individuals and their data become part of a business model, with a value assigned to the personal data. Digital Literacy, Digital Rights and Regulations, Digital Ethics, Digital Governance and Corporate Digital Responsibility describe the individual's technical capabilities and the legal, regulatory and ethical framework for data usage. The Digital Business and Data ecosystem connects producers, suppliers, buyers and other market participants (Meister and Otto, 2019). Hadzic and Chang (2010) show an application in the healthcare sector with their Digital Health Ecosystem (DHES) that incorporates the use of the EHR within the DHES.

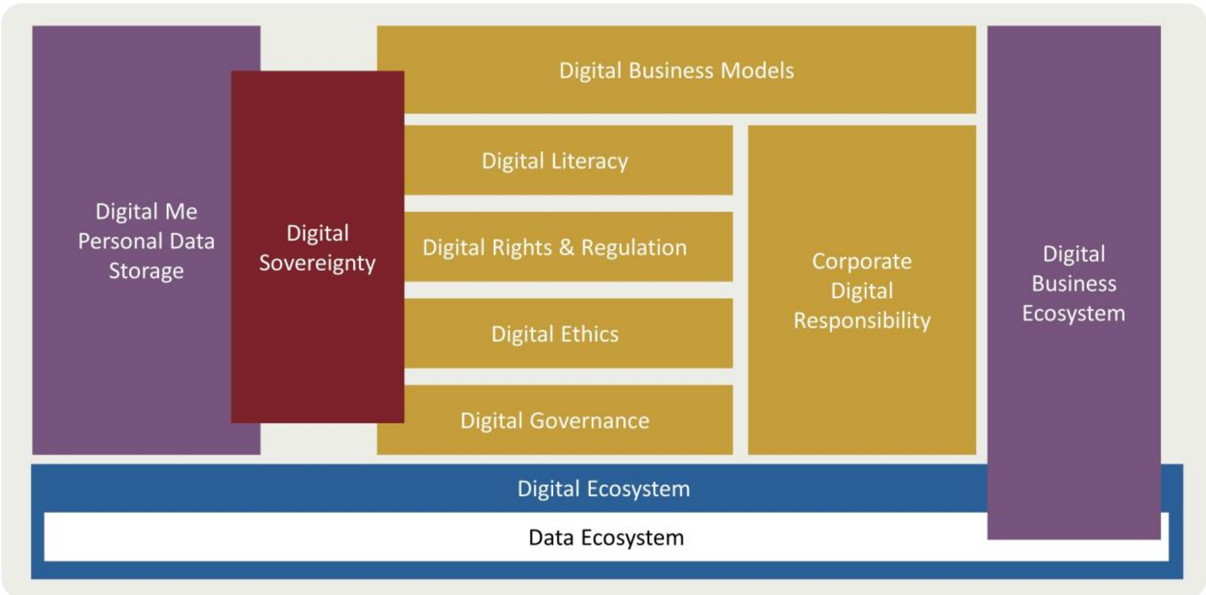

Figure 20: Digital Life Journey Framework (Meister et al., 2019)

Jannes et al. (2019) provided a profound overview of algorithms for digital healthcare, showed how they can contribute to improving care and discussed issues of misuse and liabilities for algorithm-based decisions. "Not everything that is technically feasible is necessarily societally desirable" (Jannes et al., 2019, p. 6). And remembering that "Digitalization is more than technology; it is a process of transformation. Especially in healthcare, the human-to-human interaction like patient-to-physician plays an important role" (Meister et al., 2019, p. 330). For example, shared decision-making between patients and physicians can be supported by Patient-Reported Outcome Measures (PROMs), which objectively measure the perceived health status of patients with standardised questionnaires. PROM data supplement clinical and health system process data. "The fundamental idea is that what really matters is the health-related quality of life: every medical intervention should ultimately contribute to improving or maintaining the patient's quality of life or to mitigating an impending deterioration" (Steinbeck et al., 2021, p. 4). PROM data collected, for example, with mobile applications, provide feedback for continuous improvement. Identified success factors for PROM implementation are patient focus, the definition of clinical champions, standardisation, IT infrastructure, incentives and political will (Steinbeck et al., 2021). The approach is supported by the extended chronic-care model developed by S. Y. Ho et al. (2019), which introduced the informed activated patient taking an active role in healthcare services:

> "People want to take greater control of their health. In 2017, 3.7 billion health-related smartphone apps were downloaded globally, up from 1.7 billion in 2013. The proportion of adults seeking health information online more than doubled between 2007 and 2017."
>
> (OECD, 2019, no pagination)

vi. Similarities and differences

"Industry 4.0 and digitalization. Both of them address the lack of skilled workers at the one hand and the need for increased productivity at the other hand" (Meister et al., 2019, p. 330). Unlike industry, hospitals work with patients, which adds further complexity. However, in terms of process flows, the principle of Industry 4.0 can be transferred to the patient in the hospital. The treatment path, resources requirements and flow of materials are similar in Hospital 4.0 and the Smart Factory, with patients moving individually between the therapy steps. Hospital 4.0 is defined by high agility focusing on the diagnosis and therapy processes. It is personnel-intensive, and hospital staff are crucial to the success of the therapy. The support provided by socio-technical information and assistance systems provides context-sensitive information, leading to more efficient processes and needs-based care for patients (Wibbeling 2018). The potential for improvements is high. "...a fifth of health care expenditure in OECD countries (around USD 1.3 trillion annually) is not used to generate better health, and sometimes even harms health" (OECD, 2019). Therefore, there is a considerable need for optimisation in the healthcare sector.

c. Challenges

In 2007, a TV station pointed out the lack of digitalisation in the Australian healthcare system. "One of the major killers of patients is the Australian medical systems' own chronic inability to share vital information" (ABC News, 2007; Hadzic and Chang, 2010). This drastic statement is understandable even in today's world. A survey among doctors in German practices in 2021 showed that 53% of medical practices still communicated by telephone, 19% by mail and 22% by fax (BITKOM and Hartmannbund, 2021). In contrast, opportunities can arise from the digital transformation in the health sector:

> "A digital transformation can help meet the changing needs of patients and the public. It can serve as a catalyst for a team-based approach to deliver quality and co-ordinated health services. This is particularly important with ageing populations, a growing chronic disease burden and rising expenditure."
>
> (OECD, 2019, no pagination)

In contrast, industries have made considerable progress in digitalising and automating processes and activities. Transferring learning from industry to the healthcare sector can help overcome the digitalisation challenge while creating research opportunities for the Business and Information Systems Engineering (BISE) community (Legner et al., 2017).

3. Information and assistance systems

The research field of IS comprises a wide range of interdisciplinary aspects within the IS lifecycle from development to application in organisations. Technological innovations have stimulated research activities in IS and related scientific areas leading to a rich knowledge base. "...the major strength of the field is its responsiveness to a large variety of issues emerging in organisations as they learn to exploit the new technological potential" (Avgerou, 2000, p. 2). The scientific field of IS is interdisciplinary, but it is strongly linked to engineering and social sciences. It is often challenged by both disciplines and must continuously prove its value. Nevertheless, it is also argued that the complex nature of IS requires interdisciplinary theories and methodologies. Being oriented on improving real-life aspects of organisations, IS research is responsive and produces knowledge directly impacting practice. This fact is perceived as a significant strength of IS research compared to traditional academics (Avgerou, 2000; March and Smith, 1995).

IS research originated from applied computer science and has developed with IT innovation and organisational impact. Today IS studies are often hosted in business and economic schools rather than in computer science and engineering. Major academic journals and conferences have evolved, such as the Management Information Systems (MIS) Quarterly, Information Systems Research, Scandinavian Journal of Information Systems, the European Journal of Information Systems, the Journal of Information Systems, and the International Conference of Information Systems (ICIS) (Avgerou, 2000). Furthermore, the creation of the Association of Information Systems (AIS) in 1995, with its regional structure for America, EMEA and Australasia, was a significant milestone for the academic field of IS (Association for Information Systems, 2022). According to Avgerou (2000), the field of IS includes five thematic areas, as depicted in Table 5. The topics differ in their application areas and the underlying supporting research fields.

Thematic area	Characteristics
Applications to support the functioning of an organisation	- Application areas such as database technology, transaction processing systems, DSS, expert systems, electronic data interchange, multimedia systems, computer-supported cooperative work systems - Understanding the domains of application and developing models for forming applications - Based on decision theory, psychology, organisational theory and operational research
The process of system development	- Develop reliable and effective systems in a cost-efficient way - Introduction of system analysis and life-cycle management

	- Shift from system construction to system implementation and management issues
IS management	- Evolution of IT and learning processes within organisations - Centralised and decentralised management of IS - Comprises IS strategy development, using IT to manage change, applying IT in multinational set-ups - Informed by strategic management, quality management and business process engineering
The organisational value of IS	- Cost-benefit analysis, profitability, and competitiveness - IT as an enabler of organisational transformation - Adoption of social sciences to understand the impact on organisations
The societal impact of IS	- Impact on wealth creation, working life and social life - Aspects of socio-economic development, work, privacy, identity, democracy, and ethics

Table 5: Main thematic areas of information technology (Avgerou, 2000)

The work described in this dissertation is classified as designing applications to support the functioning of industry and healthcare organisations. However, it is also influenced by the themes *organisational value of IS* and *societal impact of IS*, as it impacts the working life of users and the social life of patients.

"From a conventional academic perspective IS has serious limitations. It lacks the distinctiveness of theory and method that is usually associated with scientific disciplines" (Avgerou, 2000, p. 22). Therefore, IS scholars have spent effort establishing theories, paradigms, and methodologies. Multiple theories inform the five thematic areas and reference disciplines, such as system modelling and development, knowledge-based systems and DSS, individual and organisational behaviour, problem-solving and decision making, business, economics and sociology. Most influential, however, are systems theory and the organisational rationalism and structuration theory, as presented in Table 6 (Avgerou, 2000).

Thematic area	**Characteristics**
System theory (P. Hanika, 1977)	- Breakdown of problems into parts and discovery of causality between the elementary unit or variables of these parts - Valid across conventional disciplines

	- Generalisation to general system theory and specialisation, e.g. soft systems theory for unstructured problems
Organisational rationalism (Becker and Potter, 2002)	- Study of organisations in society with a focus on improving organisational efficiency - Includes decision-making theory, administration science, industrial and organisational psychology - Dominant approach in management research
Structuration theory (Giddens, 1986)	- Socio-technical tradition of IS research, which conceptualises the association of technology and organisations - Reconciliation of the technical and the social - The critical theory showed that most IS development approaches support an interest in technical control

Table 6: Important influential theories (Avgerou, 2000)

In his map of science, shown in Figure 21, Hieronymi (2013) positions system science and system design in the sciences field. In his view, System Science and System Design create a bridge between formal sciences and normative sciences. In line with Avgerou (2000), cognitive, social and technological systems aspects are particularly interesting for this dissertation, and with it the scientific fields of psychology and cognitive sciences, sociology, economy and engineering.

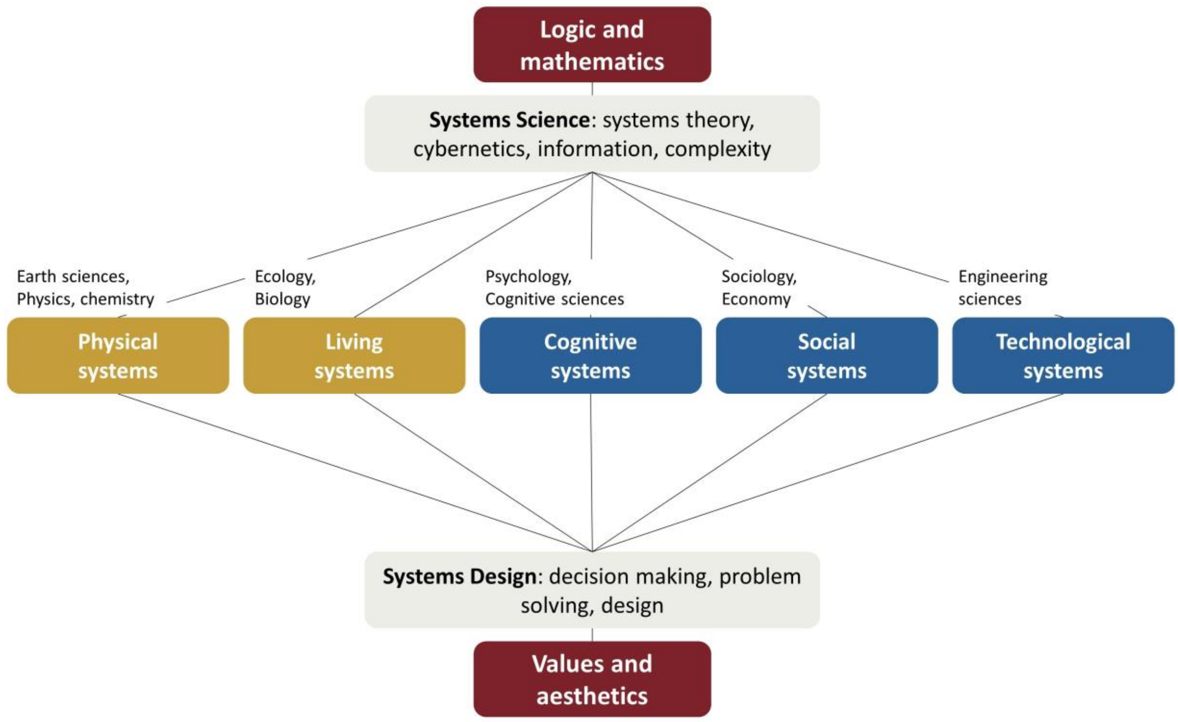

Figure 21: Map of science - system science and system design (Hieronymi, 2013)

"The recent years ... have seen IT-based innovations that truly impact everybody's lives. Everything that can be digitized will be digitized, and this trend is continuing at an amazing speed" (van der Aalst et al., 2018, p. 443). In their contribution to the 60th anniversary of the BISE journal, van der Aalst et al. (2018) reflected on the past, present and future of IT and IS and presented the shared view of leading IS scholars. In their view, the discipline becomes more multi-paradigmatic, enabling holistic solutions to problems. The authors highlighted the impact of the developments in IT and referred to the growth of computing power that has brought IT and the real world closer. Hurdles of digitalising enterprises have been solved, and the future emphasis will be on better, more user-friendly and easier-to-interconnect software systems, taking into consideration Responsible Data Science (RDS), securing fairness, accuracy, confidentiality and transparency (van der Aalst et al., 2017). Recently, in line with Industry 5.0 aspirations and following up on previous work by Dedrick (2010), a call for green IS research accelerated. Exemplary systems were named to help companies reduce carbon emissions (Lehnhoff et al., 2021).

The interdisciplinarity of IS influences the concept of knowledge creation. On closer examination, knowledge creation in IS has two dimensions. IS research can advance knowledge within the boundaries of the IS discipline, but it can also engage with other research disciplines. Following this path, Tarafdar and Davison (2018) theorised four types of knowledge contribution structured by intra- and interdisciplinarity, as shown in Figure 22.

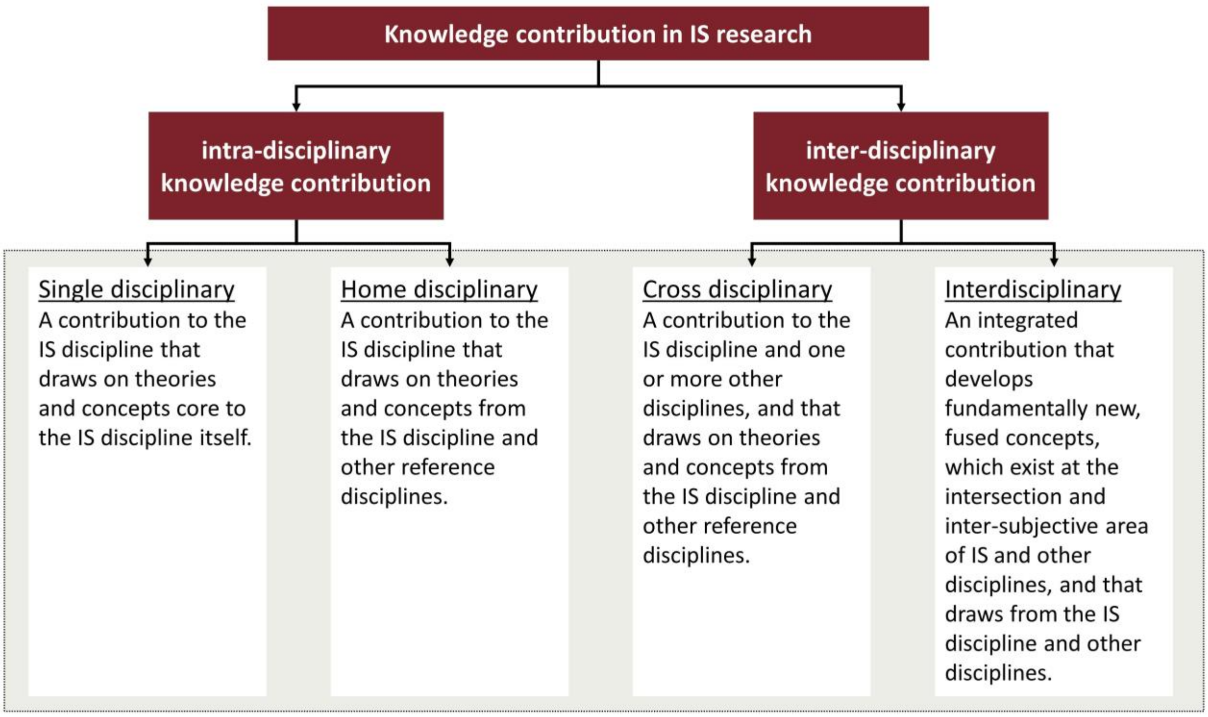

Figure 22: Intra- and inter-disciplinary research in IS (Tarafdar and Davison, 2018)

A literature review in the Basket of eight journals of the AIS unveiled that 84% of the publications were intra-disciplinary. Fewer interdisciplinary IS research were identified, mostly related to psychology, strategy, organisational behaviour, economics, operations research and sociology. Notably, only one article related to health care was identified in the analysis. The authors stated, "The IS discipline needs a robust disciplinary core that is strong in its indigenous understanding of IS phenomena together with a supple and open-minded disciplinary boundary that can confidently engage with other disciplines" (Tarafdar and Davison, 2018).

The contribution in this dissertation is cross-disciplinary within the category of inter-disciplinary knowledge contribution. As shown in Figure 23 and adopted from Tarafdar and Davison (2018), it utilises IS research frameworks, draws from adjacent theories and alternates between industrial and healthcare applications. The analysis conducted by Clarke et al. (2020) of more than 500 articles in the Basket of eight journals of the AIS showed that most publications (96%) took a single perspective on one stakeholder only, and most of them (93%) took the perspective of the system sponsor. Following the recommendations of Clarke et al. (2020), single-perspective and dual-perspective research are used in this dissertation with the views of system stakeholders and system users.

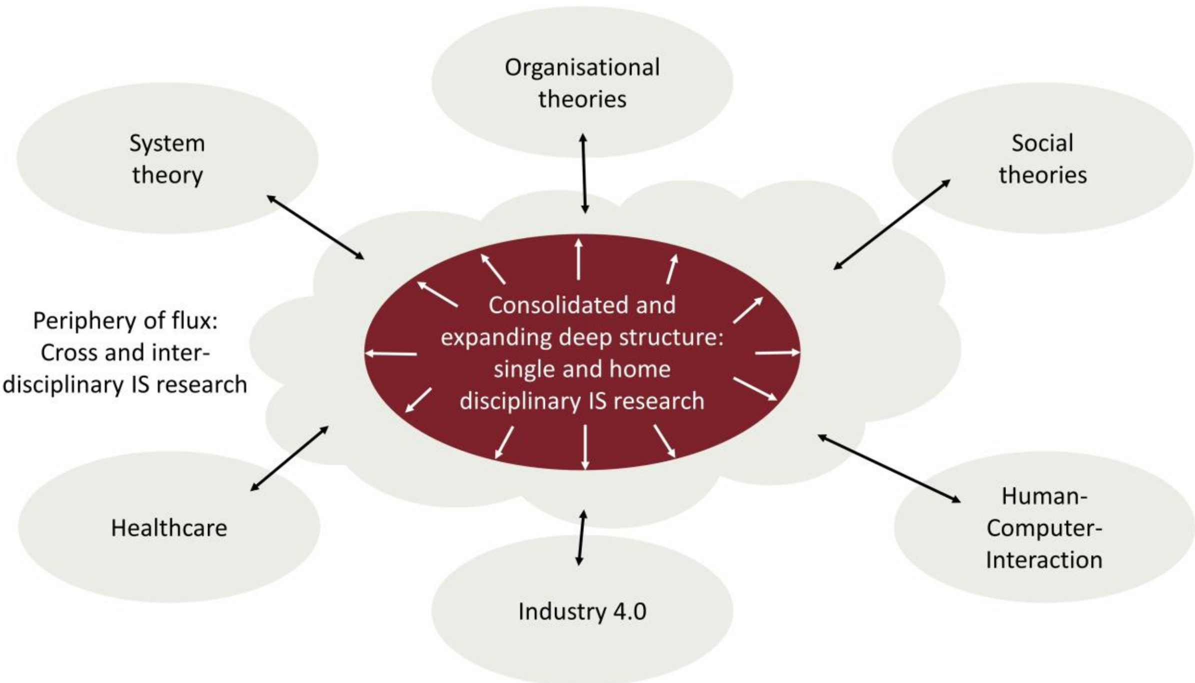

Figure 23: IS environment adapted from Tarafdar and Davison (2018)

In summary, it can be said that the need for IS research continues to increase, driven by innovations, digitalisation of the working and private environment, and extensive global networking of systems and devices. At the same time, the need for secure, resilient, and user-friendly systems is continuously increasing. Therefore, research will shift from technology-focused to behavioural and social issues-oriented methodology. This dissertation supports this shift and follows Van der Aalst et al (2018) regarding the approach toward better, more user-friendly and easier-to-interconnect software systems.

a. Research challenges

The scientific classification of information and assistance systems and the recognition of the reference disciplines in engineering and social sciences impact the research challenges. Kolp et al. (2019) presented an overview of scientific areas and corresponding research challenges. The areas were outlined in connection with the International Conference on Research Challenges in Information Science (RCIS). Since then, minor changes have occurred, as the topics of interest of the RCIS 2022 reveal. The area of business process management was broadened to enterprise management and engineering, while digital transformation was added as a new research challenge. Also, user-centred approaches were more broadly formulated as user-oriented approaches, including the vital challenge of human factors in IS. The eight scientific areas and corresponding research challenges are shown in Table 7 (International Conference on Research Challenges in Information Science, 2022).

Scientific area	Research challenges
IS and their engineering	Requirements engineering, model-driven engineering, data-driven evolution, method engineering
User-oriented approaches	Social computing and social network analysis, user-centred design, collaborative computing, human factors in IS
Data and information management	Databases and information, information search and discovery, information security and risk management, conceptual modelling and ontologies
Enterprise management and engineering	Business process engineering and management, process mining, enterprise modelling, digital transformation
Domain-specific IS engineering	E-health, E-government, E-commerce, Industry 4.0, web-based applications and services, smart cities, digital humanities
Data science	Big data and business analytics, decision information systems, knowledge discovery and management, information and value management
Information infrastructures	CPS, web information systems (WIS), grid computing and cloud computing, IoT, pervasive and mobile computing

Reflective Research and practice	Research methodologies in IS, the impact of information on the enterprise and the individual, lifecycle models, design science and rationale, action research and case studies in IS

Table 7: Topics International Conference on Research Challenges in Information Science (2022)

Research frameworks have been developed to specify research challenges for specific application domains. Cohen et al. (2019) analysed the design and management of digital manufacturing assembly systems in Industry 4.0. They identified the main technical research trends as standardisation, integration, service-oriented architecture (SOA), intelligent devices, new Industry 4.0 applications and technology transfer. These were complemented by the main organisational research trends resilient smart factory, employer skills evolution and employers' working activities. Mettler and Raptis (2012) provided a research framework for Health Information Systems (HIMs), elaborating on the challenges, trends and enablers. They highlighted the opportunities in E-Health, clinical systems, personal life, independent living, patient-centred systems, clinical support systems, medical DSS, home care and chronic disease systems, personal guidance, patient safety and quality improvement systems. The research challenges and opportunities reflect the breadth and the need for further knowledge in IS, particularly for assistance systems as one form of IS.

b. User assistance systems

One form of IS is user assistance systems. Morana et al. defined user assistance as:

> "... an intelligent system’s capability to assist users while performing their task by means of human-, task-, and/or context-dependent augmentation of the human–computer interaction. User assistance systems bridge the gap between the system’s functionalities and the human’s individual capabilities with the goal of positively influencing task outcomes."
>
> (Morana et al., 2020, p. 189)

The authors classified user assistance according to the degree of interactivity and intelligence. Interactivity represents the bidirectional interaction between users and the user assistance system. This interaction can be, for example, in the form of dialogue using text and voice channels. The intelligence of a user assistance system describes the level of context-specific task fulfilment support provided by the system. The advances in AI support accelerate the development of more intelligent user assistance systems incorporating even emotional intelligence in recognising human affect and adapting corresponding responses via the user interface (Rouast et al., 2021). Figure 24 shows a conceptualisation of a user assistance system. The user is reflected by the interplay between human cognition, affect and behaviour, according to Stangor et al. (2014), while systems can be optimised for specific user dimensions. The user interacts with the assistance system using various input and output channels, including text, voice or graphics. The user assistance system itself is described by the interactivity and the intelligence components that also provide the interface to the backend systems (Morana et al., 2020).

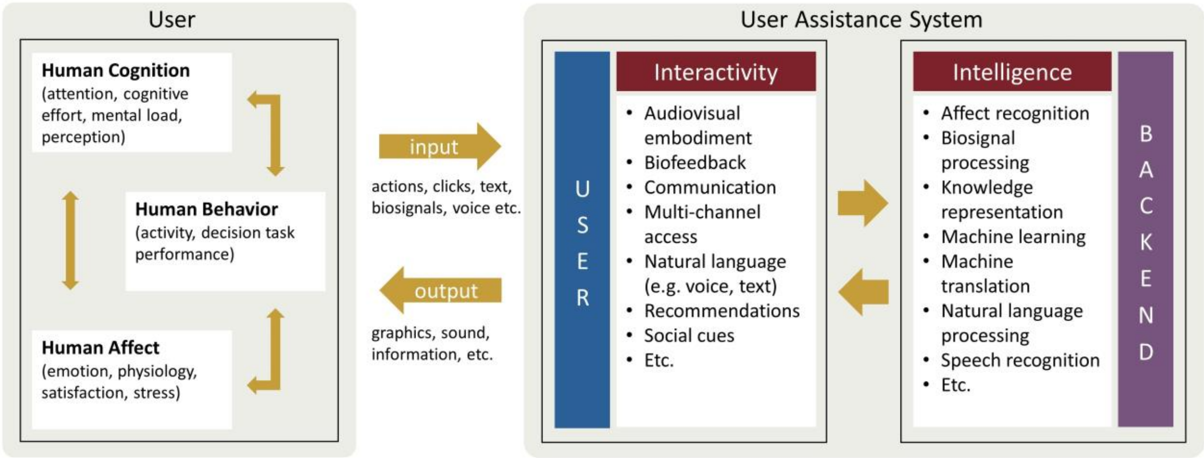

Figure 24: Conceptualisation of user interaction with user assistance (Morana et al., 2020)

Additional classifications of user assistance systems have been developed in the IS and engineering domains. Some authors classify by the nature of assistance or level of information provided. Others, for instance, Reinhart (2017), classify by the degree of autonomy, interactivity, or intelligence, distinguishing between execution, perception and decision assistance. Execution assistance systems such as lifting aids assist in physical tasks. In contrast, perception and decision systems are classified as cognitive assistance. Cognitive perception assistance supports the five human senses, while cognitive decision assistance supports complex decision-making.

Aehnelt and Bader (2015) differentiated five types of information assistance: a) raising awareness by providing information about occurrences within the work environment; b) operational guidance, which filters complex information to a required minimum; c) monitoring to identify quality issues; d) documenting process steps and quality issues including tracking back functionality; e) guarding users against overload by balancing the level of information. Rising awareness, monitoring of quality issues, and process documentation are essential in many medical applications due to the severity of potential treatment errors. According to Ludwig (2015), user assistance systems can be classified into three categories depending on their degree of autonomy: a) automatic or background assistance; b) assistance by supporting the user with an appropriate bundling of functions; and c) assistance through decision support.

Morana et al. defined user assistance in Healthcare Information Systems (HIS): "... as a people, activity, and context-dependent augmentation of task performance by bridging the gap between the system's functionalities (technology) and the individual capabilities of people with the goal of positively influencing task outcomes" (Morana et al., 2017, p. 4). They utilised the level of interactivity and intelligence of assistance systems according to Maedche et al. (2016) and defined three corresponding modes as outlined in Table 8 based on the activity level between user and system. The classification of Morana et al. (2017) is applied in this dissertation. The dimensions of people, activity, and context support the process-oriented analysis of the technology-dominated applications.

Scientific area	Research challenges
Supportive mode	The system provides some information, but the user performs the task primarily. Such systems show low interactivity and intelligence.
Cooperative mode	The system and the user perform parts of the task. Such systems are characterised by high interactivity and medium intelligence.
Notifying mode	The system performs a significant share of the tasks. The user is only notified of the progress and the results. Such systems have low to medium interactivity but high intelligence.

Table 8: Types of user assistance systems (Maedche et al., 2016)

Urbach (2019) presented 21 digitalisation cases from several economic and societal sectors on how organisations transform themselves in the interplay with digital developments. Information and assistance systems are the core of many instances presented therein. S. Hinrichsen et al. (2016) gave a concise overview of assembly assistance systems in a morphological chart. The chart guides selecting and discussing industrial assembly assistance systems. Similar categorisations were developed by Merazzi and Friedel (2017), Merkel L. et al. (2017) and Bortolini et al. (2017). Additionally, Zaeh et al. (2009) developed a multi-dimensional measure to determine the complexity of manual assembly operations, which considers human performance, attention allocation, and learning aspects to effectively predict assembly complexity. The following examples of assistance systems in industry and healthcare show the versatile fields of application of assistance systems.

i. Applications in industry and crafts

Numerous forms of user assistance are utilised in industrial and crafts applications, and selected assistance systems are emphasised below. The aim is to give the attentive reader an overview of the diversity of user assistance applications in their contextual environment.

Cognitive assembly systems help employees in complex tasks such as incoming/ outgoing goods inspection, manual assembly or disassembly (Müller, Vette-Steinkamp et al., 2018). The system *Der Schlaue Klaus* is one example of a cognitive assistance system. It uses sensors to determine the necessary guidance based on an integrated knowledge system. The system consists of an industrial camera, specially designed lighting elements, and an image processing unit to guide employees cooperatively through the work process. It is supplemented by a user display for system control and assembly information. The camera images are captured, analysed and combined with previously defined knowledge elements. The assistance system uses the data and results from the cognitive process to generate guidelines for the employee tailored to the specific situation. The system supervises the assembly process and automatically triggers subsequent work steps. The system thereby eliminates paper-based work instructions.

Figure 25: Assembly and quality inspection system (RK Rose+Krieger GmbH, 2022)

Automated machines in manual assembly and Human-Robot Collaboration (HRC) enable intelligent forms of factory design. Figure 26 shows an end-of-line inspection area with a mobile inspection system equipped with tablets and collaborative robots in an Industry 4.0 environment. The system is based on collaborative robots and can be used regardless of location. It is robust, intuitive and can be combined with an optical inspection and quality control module based on 3D imaging. Intelligent pre-processing and learning classification procedures can be created for individual inspection requirements (Bosch Rexroth, 2022).

Figure 26: End-of-line inspection (Bosch Rexroth, 2022)

Many other assistance systems are available for industrial applications, and technological advancement leads to new variants of existing systems or entirely new systems emerging. The barriers to entry in industrial applications are comparatively low, as long as the investment is justified and the safety of the application is guaranteed.

ii. Applications in healthcare

Assistance systems with different degrees of intelligence and interactivity are also used in many applications in the healthcare sector. These include, among others, decision support, medical ventilators, patient monitoring systems and robot-assisted systems for surgery and radiology.

Robot-assisted surgery is rapidly growing in hospitals. The field refers to using robots controlled by the surgeon as surgical tools. In other words, the robot does not act independently or autonomously but rather in a supportive way translating the actions of the surgeons into robot movements and thus into the patient on the operating table. The systems' precision helps, for example, to compensate for the trembling of surgeons. After initially sobering experiences in orthopaedics in the 1980s and 90s, robots are now widely used in minimally invasive surgery, gynaecology and urology. Improved ergonomics for surgeons is a crucial benefit of robot-assisted systems. The most commonly used system is DaVinci®, followed by the Senhance® system, shown in Figure 27. The system consists of robots that are positioned alongside the bed. They hold the camera and instruments that the surgeon controls from the console while receiving haptic feedback from the system. The patient's anatomy is presented to the surgeon on the screen (Dietmar Stephan and Frank Willeke, 2019).

Figure 27: Robot-assisted surgery (with courtesy of Marien Gesellschaft Siegen gGmbH)

Virtual Reality (VR) and Augmented Reality (AR) are used for various assistance applications in the healthcare domain, as shown in Figure 28. Thus, surgical plans are reviewed in collaborative scenarios with colleagues before the actual surgery is performed. Spatial computing platforms and modern AR equipment help physicians interact with patient-specific data consisting of CT and MRI images potentially enriched with additional information (Brainlab, 2021). Augmenting computer-generated information into the real world, for instance during surgeries, supports physicians in real-time with guidance and decision support. The combination of real and virtual objects is based on accurate 3D-registration and can be enhanced by additional tracking mechanisms that enable instrument guidance and precise implant positioning (NextAR, 2022).

Figure 28: Virtual Reality and Augmented Reality applications (Brainlab, 2021; NextAR, 2022)

The collaboration between humans and robots can assist healthcare tasks in rehabilitation. Figure 29 shows a robot-based rehabilitation system to diagnose existing abilities and support upper extremity therapy. The system combines virtual therapeutic training scenarios through a HoloLens® and a display. The training scenarios instruct, correct, and evaluate everyday tasks. The different levels of assistance and repetitions allow skills to be relearned through stimulation of the nervous system. The system has integrated sensors to record real-time motion parameters such as the elbow and arm's forces and positions. The HRC dynamically calculates the level of support and adapts to the specific situation (BEC GmbH, 2022).

Figure 29: Robotic rehabilitation system (with courtesy of BEC GmbH)

Also, the pharmaceutical logistic in pharmacies and hospitals has been automated to a considerable extent in the last decade. The efficient registration, stocking and commissioning of medication are performed by automation, saving pharmacist time. Increasing digitalisation based on new telematics infrastructure and services such as electronic prescriptions will enhance pharmaceutical developments such as 24-hour and self-service terminals in pharmacies. The lack of qualified staff due to demographic change also accelerates the deployment of such systems (Apostore, 2022; Gematik, 2022; Meditech, 2021).

Figure 30: Pharmacy robots for medication (Meditech, 2021)

Various additional assistance systems for healthcare applications are available, for example, in nursing and rehabilitation. Often mentioned examples are lifting aids and exoskeletons to stabilise patients' musculoskeletal systems and help them relearn movements. The healthcare sector benefits considerably from assistance systems, even if these benefits are often not visible to patients.

c. Industrial and medical Cyber-Physical Systems

The assistance systems presented for industry and healthcare applications interact with humans in a human-control-loop to a different degree. This fact becomes visible considering the definition of HCPS by Romero et al. (2016):

> "... systems engineered to: (a) improve human abilities to dynamically interact with machines in the cyber- and physical- worlds by means of ‘intelligent’ human-machine interfaces, using human-computer interaction techniques designed to fit the operators’ cognitive and physical needs, and (b) improve human physical-, sensing- and cognitive capabilities, by means of various enriched and enhanced technologies (e.g. using wearable devices). Both H-CPS aims are achieved through computational and communication techniques, akin to adaptive control systems with the human- in-the-loop."
>
> (Romero et al., 2016, p. 679)

The degree of linkage between computational and physical elements varies, as does their intelligence and interactivity, resulting in system differences in adaptability, autonomy, functionality, safety, and usability. "Cyber-physical systems progressively operate in social spaces, such as in the smart grid, disaster response systems and transportation systems where humans are the users, survivors or drivers" (Dey et al., 2018, p. 73). This fact is particularly valid for MCPS that interface with physicians, nurses, patients and accompanying persons of patients. MCPS promise to reduce healthcare cost and improve health monitoring and support to overcome the shortage of healthcare personnel. However, they have high demands on reliability, security and safety, often manifested in laws and regulations. MCPSs are based on the integration of a network of medical devices.

MCPSs for assisted applications support health monitoring without controlling the patient’s everyday life. They offer medical advice, for example, by measuring real-time physiological data through biosensors. MCPSs for controlled applications are applied in intensive care or surgery rooms where oxygen supply and ventilator systems for breathing support, infusion pumps or monitoring sensors are used. The design of such systems has numerous challenges, including inoperability, security, privacy and overall Quality of Service (QoS) (Dey et al., 2018). In some application scenarios, the social component of socio-technical systems must be given special consideration leading to Social Cyber-Physical Systems (SCPS) (Frazzon et al., 2013). These considerations can also include special cultural or personal requirements for designing such systems.

d. State of knowledge and need for action

The classification of information and assistance systems in the research landscape shows the interdisciplinarity of the research field as described by the research questions. The selected examples from industry and healthcare reflect the influence of such systems on organisations, work processes and people. Understanding the broader context beyond the pure user system relationship is essential because latent contradictions may become salient when implementing an IS (Weeger et al., 2021). However, new approaches can also trigger promising developments. Weinhardt et al. (2020) described in their editorial for the BISE journal the potential of citizen science for IS research. Considering the fast-growing degree of digitalisation, citizen science approaches could be one way of framing IS research relevant to society and impacting it.

4. The empirical object of the study

In the following section, the empirical investigations focus to a large extent on laser-based assistance systems in industry and healthcare. Laser-based assistance systems are widely used to support manual positioning and marking activities as well as quality inspection tasks. They are suitable as objects of investigation for several reasons. On the one hand, they are an integral part of industrial production and manufacturing lines worldwide and are used in assembly lines, group assembly stations and field assembly. They support pre-assembly, final assembly, post-assembly and disassembly tasks. Furthermore, lasers are used in numerous applications in hospitals and medical practices and are often known to the treating staff and patients.

Thus, numerous manual functions in individual and group-work scenarios can be investigated. Laser-based projection systems display work plans by sequentially structured laser projections onto the work object. Laser projection is a display technology that competes with monitor-based solutions, guided light cones, video projectors or AR, but also offers opportunities for knowledge transfer. Laser projection in assembly and IS provides the advantage of a highly visible and precise in-situ presentation of the defined content. The user's requirements for the operability of the laser projection system may well vary with the size of the work object and the workgroup. Due to the predominant projection of geometric objects, laser-based assistance is independent of the language and culture of the people performing the activities. The in-situ projection onto the assembly object or the patient has also the advantage that research studies are only slightly influenced by secondary activities. In addition, laser-based assistance systems are flexible and scalable. Their use in industry and healthcare supports comparative evaluations. Therefore, laser-based assistance systems are an ideal object of investigation for the analysis of the defined research questions of this dissertation.

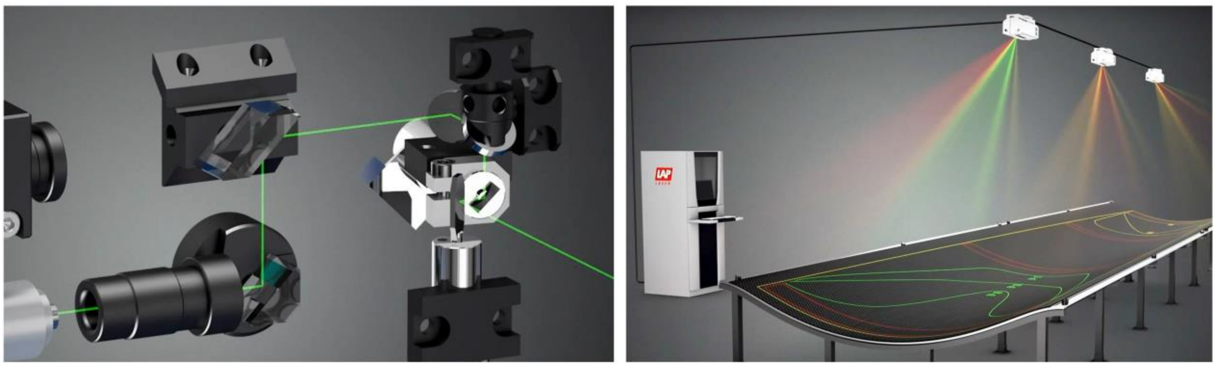

Figure 31: Laser projector and system (with courtesy of LAP GmbH Laser Applikationen)

Figure 31 shows the components of a single laser projector and the system configuration with a central workstation connected to three laser projectors placed above a dedicated work area. The operating principle of the laser projector is visualised with the inside view of the laser projector. The green laser beam generated by a diode laser source is corrected by optical lenses and directed by mirrors onto two galvanometers with perpendicular axes. These galvanometers are equipped with mirrors and can deflect the laser beam within a defined range. The oscillating direction of the first galvanometer defines the first axis of the projection area, while the second galvanometer adds the second axis to the projection area. An optical prism can superimpose a red laser beam on the green laser beam for yellow colour projection. The laser spot creates an image by following a path defined based on the CAD data. The fast movement of the laser spot results in an image that the human eye perceives as a line or a curve. The laser projection system receives calibration data defined by laser targets placed on the work area. The system then receives projection data in the tool coordinates system. The calibration procedure defines the position of the single laser projectors and enables them to correctly display the projection data structured according to the digital work instructions that users want to project. The projected lines then help users place objects in the correct order at the right place. Laser projection systems are scalable, and the length and width of the projection area can be extended. Control of laser projection systems is often realised with conventional IR remote controls or via the user software (LAP GmbH Laser Applikationen, 2022b).

a. Laser assistance in industrial production

Laser assistance systems are used in many industrial sectors due to their specific properties. Industrial applications for laser-guided manual assembly were already described in the early 1990s by Browne (1991) and have since then established themselves as valuable tools in production lines worldwide. The laser lines projected onto the assembly object or work surface in the work area are visible to the human eye and form a detection and measurement plane. The precise display of contours on flat surfaces or three-dimensional objects benefits, for example, the aerospace industry, electronics manufacturing, and the wood and concrete prefabrication industry. In addition, mounting parts commissioning can also be supported with lasers. The in-situ projection onto assembly objects is ergonomic, and the laser lines do not overstimulate the human senses. Aspects such as wearing comfort, hygiene, and battery runtimes, which must be considered when using smart devices, are irrelevant for laser assistance systems.

Furthermore, such systems are easy to operate, and teach-in times are short. In combination with a camera, the functionality of the systems can be extended. Laser assistance systems are also deployed as quality and ergonomic workstations for manual assembly thanks to their scalability, low investment and maintenance costs, and benefits for workers. Production processes can thereby be implemented in a flexible and adaptable manner (Müller-Polyzou et al., 2018).

i. Composite manufacturing

Industrial projection lasers are used in manual composite manufacturing worldwide. A total of 2.18 Mt of global composite consumption (21%) was processed in 2015 using the manual manufacturing processes of hand and prepreg lay-up. Even with increasing automation, a considerable share of composites will continue to be manufactured in manual processes in a market that grew at 8% p.a. from 1960 to 2010 and 4% p.a. from 2010 to 2019. Because of the COVID-19 crisis, a 14% drop was reported for 2020 in all application sectors, except rotor blade manufacturing, which continues to prosper, stimulated by the trend towards renewable energies (Estin & Co, 2021; JEC Group, 2017).

In the aerospace industry, laser assistance systems are important manufacturing systems for the manual production of composite parts, as shown in Figure 32. The pictures show the control of the work steps at the GUI of the system computer and the placement of the Fibre-Glass Reinforced Plastic (FGRP) fuselage parts in the cleanroom. Increased efficiency in production, quality through process reliability, high flexibility, robustness and low investment costs are the decisive criteria for using laser projection systems. Thus, the systems significantly contribute to reducing composite manufacturing costs (Aligned Vision, 2021).

Figure 32: Composite production (with courtesy of LAP GmbH Laser Applikationen)

In rotor blade production for wind turbines, laser assistance systems are used for placing Glass Fibre Reinforced Plastic (GFRP) composite plies into the curved mould. Digital work plans derived from CAD data are projected by the laser system using projectors fixed under the ceiling of the production hall. The CAD contours are projected from a 10-12 metre distance onto the mould's surface, allowing the laying of the GFRP-plies along the displayed laser lines with millimetre accuracy. Additionally, the laser systems indicate the positions of additional moulded parts mounted into the rotor blade for reinforcement. Again, whole teams can be guided simultaneously while working on different tasks.

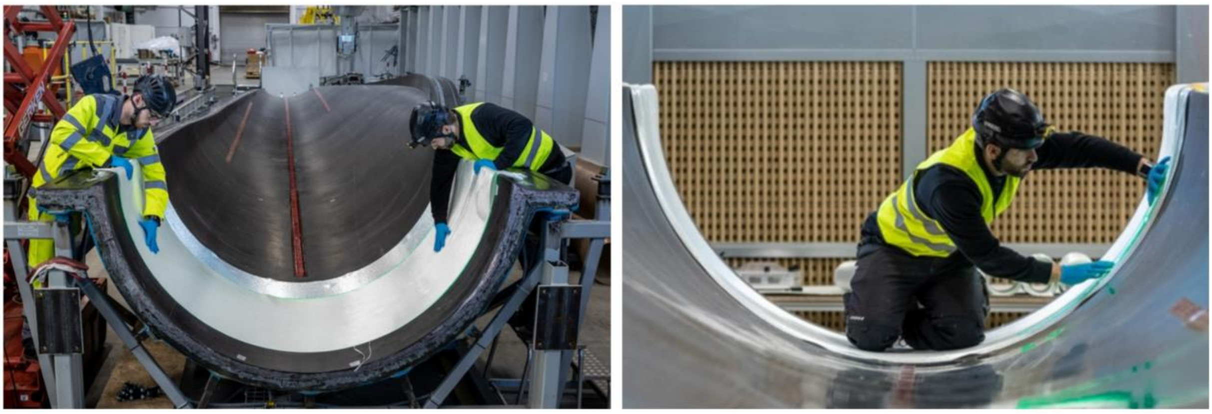

Figure 33: Rotorblade production (with courtesy of LAP GmbH Laser Applikationen)

Overall, the demand for low manufacturing costs in composite production is contrary to the increasing number of product variants in many target industries and the dynamics with which these are manufactured. Market developments that are difficult to plan, for example, in composites for e-mobility, require flexible and versatile composite production facilities.

ii. Wood and concrete prefabrication

Other application areas for laser assistance systems can be found in industrial wood processing and the precast concrete industry. Here, the placement of large and small components and bonding or drilling must be performed precisely on large parts. The laser assistance system offers the advantage that the projections can be made from considerable distances and on the entire component. The work consists of coordinated tasks on the same object carried out simultaneously by a team of workers.

One example of the use of laser assistance systems in this sector is the production of prefabricated wood houses where workers are supported in manufacturing and assembling timber elements. The laser assistance system transforms the construction CAD data into precise laser lines and contours for wall, roof, and ceiling elements. In this application, the laser projections show the mounting locations, positions, and orientations of frames or plates to perform manual tasks quickly and precisely. The laser contours can also indicate drilling holes for electrical cables and sockets and cut-outs for windows and doors. Figure 34 shows the placement of a component, drilling hole support and a quality inspection task using the control software. Different laser colours, text and projected symbols indicate various tasks on the same work surface and provide additional assistance in carrying out the work steps (LAP GmbH Laser Applikationen, 2022a).

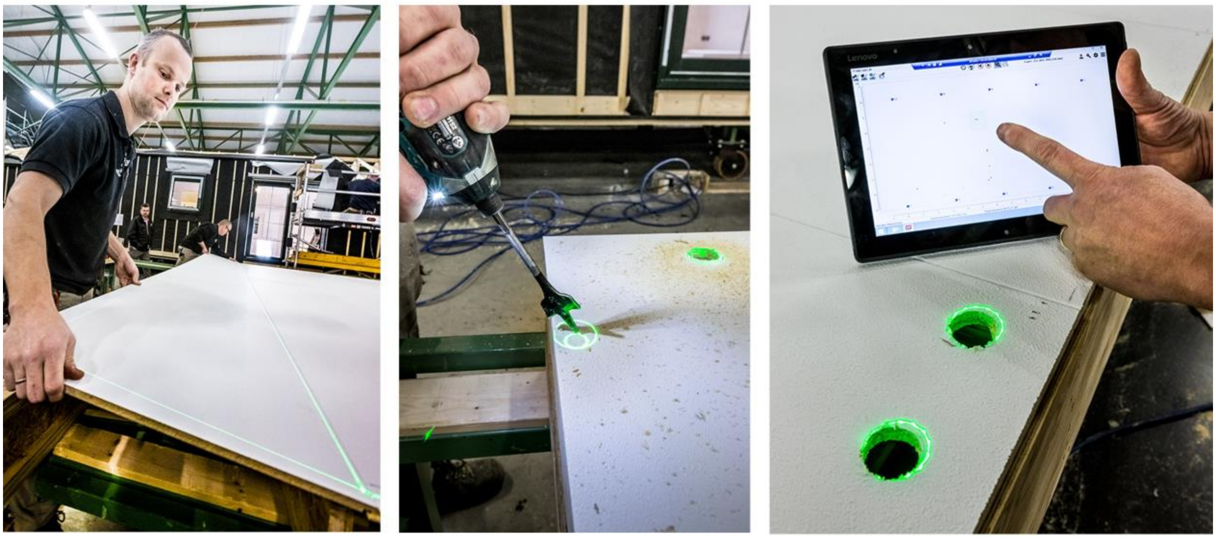

Figure 34: Industrial woodworking (with courtesy of LAP GmbH Laser Applikationen)

Furthermore, laser assistance systems are used for industrial wood truss production in multiple shapes and sizes. Typical laser applications in this field support stacking laminates before pressing, visualising areas with different strength gradings, and checking that visible knotholes are not within the final shape of the wood truss. Furthermore, the position of clamps and steel reinforcements can be indicated even on large elements such as roof trusses or bridge arches, as shown in Figure 35 (Z-LASER GmbH, 2022).

Figure 35: Industrial wood truss production (with courtesy of LAP GmbH Laser Applikationen)

Another example is the production of precast concrete parts for the construction business. The production of precast wall elements is shown in Figure 36 with a precast wall element, laser-guided placement of electric sockets, and reinforcement and cut-outs for windows and doors at the casing site. Once all components are placed on a table according to the production plan, concrete is poured on the table filling the whole wall element except for the cut-outs. Corresponding computer-controlled production lines use long, rotary or carousel tables for serial production of customised walls.

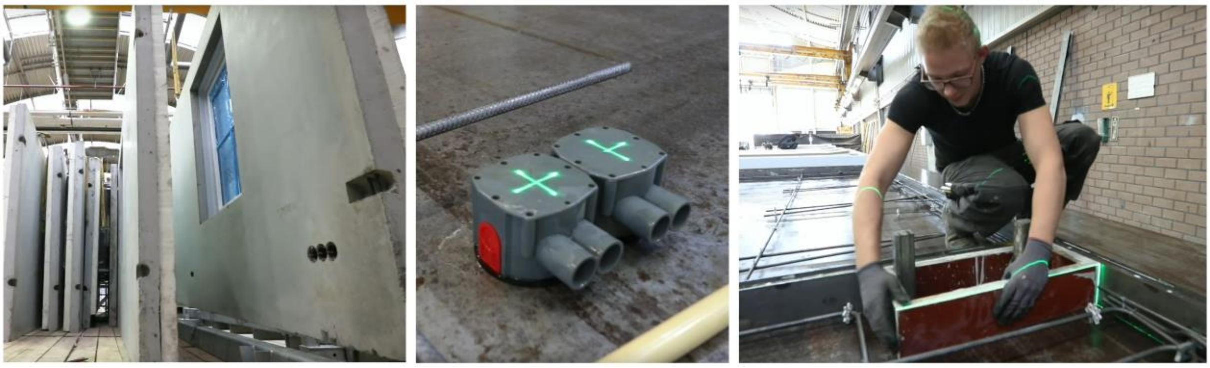

Figure 36: Precast concrete parts production (with courtesy of LAP GmbH Laser Applikationen)

After pouring the concrete, the workers use the laser projections to control all elements' presence, correct position, and orientation. This quality control is crucial for double-wall production, in which two separately produced walls are joined together (Unitechnik Systems GmbH, 2022). Modern architectural requirements and a high degree of manual work for precast elements stimulate research and development. Digital networking of planning and production tools, increased usage of sensor data from the production process, and new production methods such as additive fabrication can support more efficient and customised production. In particular, the latter can support the demand for more customised and graded surfaces (Bašková et al., 2020; Fromm and Gerbers, 2016; Spisakova and Kozlovska, 2020).

iii. Assembly and quality inspection

In addition to the described applications, laser assistance systems are used in other industries for manual assembly and quality inspection tasks. The systems support mainly manual and hybrid assembly tasks with a small number of assemblies but a high number of product variants, as shown in Figure 37. They are more flexible than automatic assembly stations (Lotter and Müller, 2018). Laser assistance systems can be used at individual assembly stations, flow production lines, group assembly stations and on-site production of large products, sometimes called XXL production. They support mainly the assembly subtasks of handling, joining, controlling and marking according to the former standard VDI 2860 (Association of German Engineers VDI, 2022).

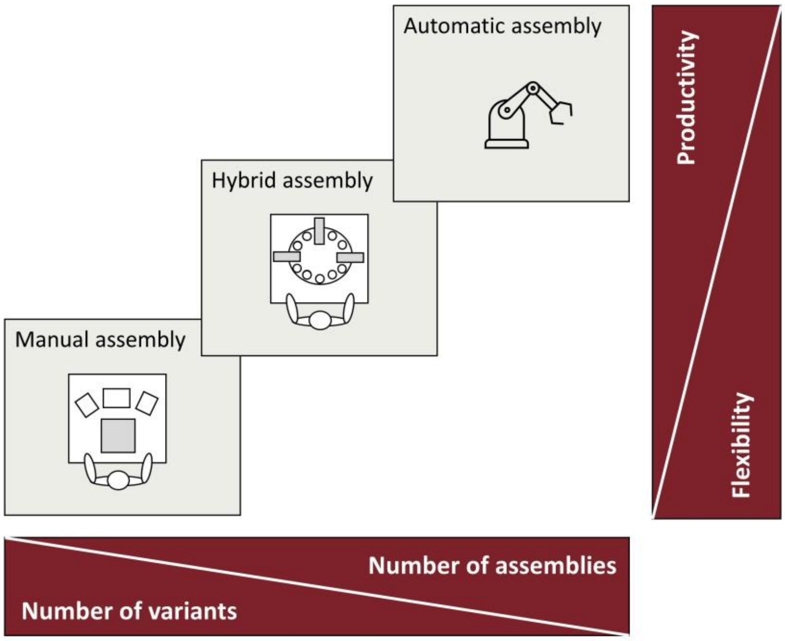

Figure 37: Manual, hybrid and automatic assembly (Lotter and Müller, 2018)

The result of the work is based on primary and secondary assembly functions according to DIN 8593, DIN 8580 and VDI 2860, which serve as the basis for the corresponding work instructions provided by the work preparation department. In many cases, however, the work instructions can still be found in printed form at the assembly workstation.

One example of assembly and quality inspection at a single-person workstation is shown in Figure 38. The pictures show the assembly of a control cabinet equipped with electrical components. The laser projection system with two laser projectors mounted on the top of the workstation indicates the assembly location of the components according to the predefined work sequence. Collaboratively, tasks such as template drilling, cable duct placement, wiring and label positioning can also be supported.

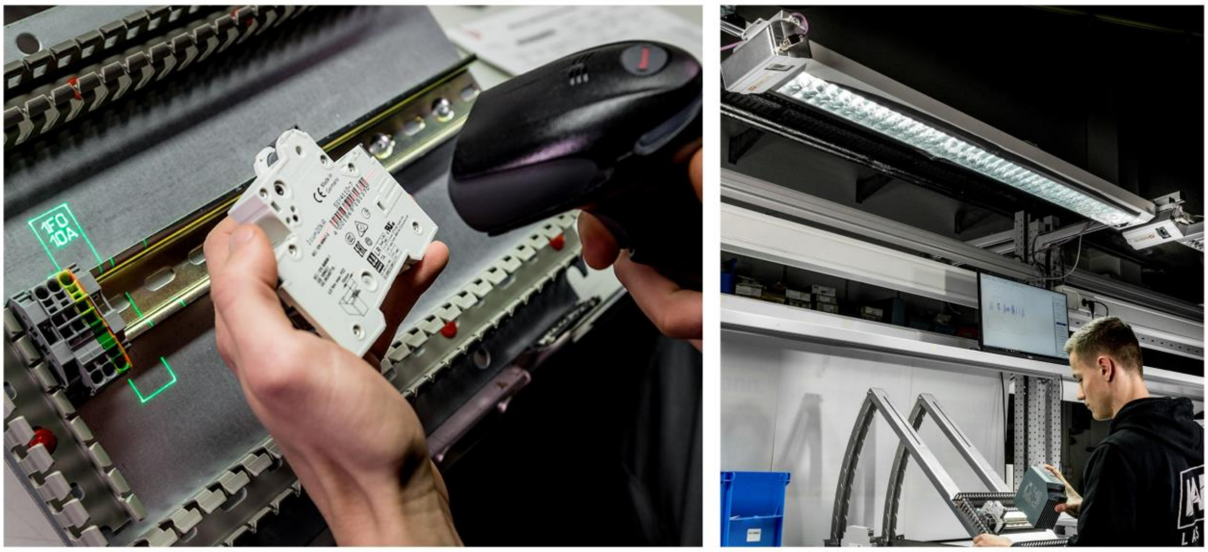

Figure 38: Electrical cabinet assembly (with courtesy of LAP GmbH Laser Applikationen)

A laser system integrated into an assembly line is presented in Figure 39. The laser projector is marked with a red circle for better visibility and supports parts commissioning during product assembly. The system was installed as a Cyber-Physical showcase at the Mittelstandszentrum Saarbrücken and centre for mechatronics and automation technology ZeMA (ZeMA gGmbH, 2022). Similar production lines and assembly in group workplaces are used in many industrial production sites, such as the production of household appliances.

Figure 39: Laser system integrated into an assembly line (with courtesy of ZeMA gGmbH)

Other applications of laser assistance are known from the production of large-scale products such as aeroplane manufacturing and shipbuilding, as shown in Figure 40. A disproportionate increase in manufacturing efforts characterises the production of XXL products. At a certain point, the limits of scalability of a production system are exceeded so that, for example, new buildings or handling jigs must be designed. Very large products are often fully customised, complex and produced following the organisational principle of on-site production (Behrens et al., 2014). On-site production is flexible, with little standardisation and a low degree of automation. In the production of aeroplanes, wagons, trucks and busses, on the other hand, the line assembly principles are applicable due to a higher level of standardisation (Mach Florian, 2015).

Figure 40: Large-scale production in aviation and shipbuilding (Airbus, Meyer Werft)

In many assembly applications, humans, with their long-term production experience, control the quality of assembly tasks. Other reasons for quality control by the human eye can be poorly accessible installation locations, objects unsuitable for camera-based methods, the costs for automated quality inspection or the required flexibility in the production line. Examples of such quality control tasks are, among others, the inspection of welding lines and spots, adhesives or the presence and correct fit of rivets. Laser projection systems can, in some configurations, also be used for measuring tasks. A method for assembly assistance and position data feedback using two projection lasers was presented by Müller and Ball (2016). In addition, cameras enable additional possibilities for assembly and quality assurance applications.

b. Laser assistance in medicine

Laser assistance systems are also used in human medicine applications. Laser lines are projected onto the human body as reference points, lines, or contours. Physicians use laser lines and intersections to position patients and therapeutic devices. Thus, the precision and good visibility of the laser projection are critical, while its non-contact operation supports general hygiene in the clinical environment.

i. Laser assistance for interventional radiology

Laser guidance supports physicians when inserting needles at angiography and CT systems to perform image-guided biopsies and percutaneous ablations. The laser helps insert one or multiple needles at planned locations and angles at the patient body. It aligns the laser cross with the planned path, while the progression of the needles is monitored based on imaging systems. Practitioners are supported by software-assisted path planning and guided insertion for safety-critical work tasks, as shown in Figure 41. The laser guidance system is integrated into CT scanners and angiography systems (Siemens Healthcare GmbH, 2022).

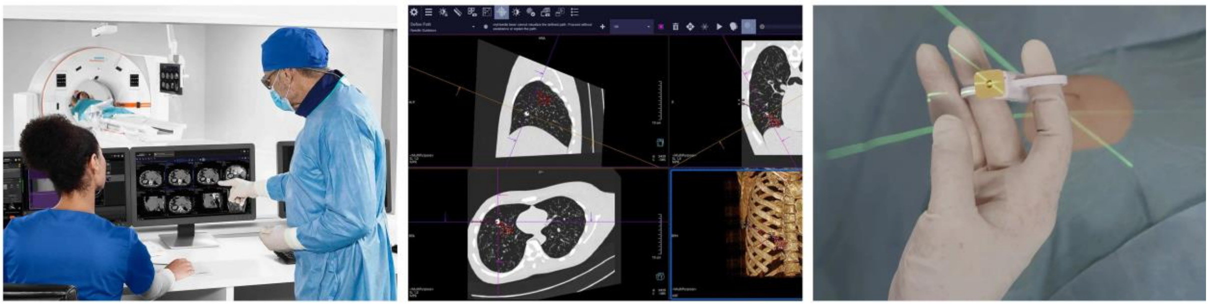

Figure 41: Laser-guided needle insertion (Siemens Healthcare GmbH)

In addition to this specific application, many imaging devices, such as Computer Tomography (CT) devices, also have built-in lasers to help place patients in a defined position.

ii. Laser assistance in radiotherapy

The principle of modern RT is based on a working process consisting of 3D imaging, therapy planning and irradiation at the linac, as shown in Figure 42. Today, linacs are used worldwide in the precise treatment of tumours.

Figure 42: Radiotherapy work process (own figure)

In RT, reproducible patient positioning is a primary concern (Carl et al., 2018). Patient positioning refers to reproducing the patient's position defined during the simulation for treatment planning on the basis of CT and potentially additional Magnetic Resonance Tomography (MRT), providing soft-tissue information. The same patient position must be reproduced accurately in the treatment room at the linac. Various techniques are available for these positioning tasks. Using marks on the patient's skin as reference points and lasers in the treatment room is the most widely used technique because of its satisfying accuracy, ease of use and low cost (Guo et al., 2020). Consequentially laser patient positioning systems are listed on the WHO list of priority medical devices for RT (World Health Organization, 2017b).

The 3D-imaging process performed for tumour marking is called *simulation*. Most RT centres use a dedicated planning-CT device and an external laser system to perform this task. First, the patient is immobilised in a defined position using immobilisation devices shown in Figure 43. The kind of immobilisation devices used depends on the tumour. Patient-specific antibacterial thermoplastic face masks with foam head supports are used for head and neck cancer. The masks are fixed on the patient couch in defined index positions. Additional knee and foot support stabilises the patient's position and increase patient comfort. Breast boards with flexibly adjustable arm- and hand support are combined with head supports to treat left and right breast cancer, while abdominal compression systems or pressure belts are used for thoracic and abdominal treatments (Orfit Industries NV, 2022).

Figure 43: Patient immobilisation devices for radiotherapy (Orfit Industries NV, 2022)

Asfia et al. (2020) analysed 3D printed patient-specific immobilisation devices and compared them to traditional ones. The reported benefits include improved patient comfort, high accuracy between immobilisation devices and patients, and reproducible setup with beam attenuation properties similar to thermoformed immobilisation devices. The advantages are set against the disadvantages of slow 3D printing and potential inaccuracies in the digitisation of patients. Asfia et al. (2020) conclude that further research Is needed for the 3D printing of immobilisation devices.

The target points defined in the simulation and planning-CT are made visible on the patient by a laser system and marked with skin marks, as shown in Figure 44. The target point can either be the iso-centre of the device or defined reference points. For CT and MRI imaging devices, systems with movable laser lines are installed in the imaging rooms. The patient can later be positioned based on the skin marks at the linac using a laser system installed in the treatment room and the same type of immobilisation devices used before.

Figure 44: Laser marking at CT and MRI (with courtesy of LAP Laser Applikationen GmbH)

The CT and MRI images taken in the defined patient positions are then used for RT planning with expert software. Radiation planning involves calculating how the radiation dose prescribed by the radiation oncologist can be best applied to the tumour, considering the linac's technical capabilities. Special care is taken to ensure that Organs-at-Risk (OARs) such as the bladder, rectum or heart receive as little radiation as possible. In addition, the number of fractions in which the prescribed total dose is administered is defined during therapy planning (Elekta Solutions AB, 2022; RaySearch Laboratories, 2022; Varian Medical Systems, Inc., 2022). The dose division into several radiation fractions is related to the fact that cancer cells divide more often than normal cells, making them vulnerable to irradiation. Cell division occurs during the M phase, which is the time when radiation causes Deoxyribonucleic Acid (DNA) damage to the cancer cells. Therefore, each radiation fraction must cause more harm than a cancer cell's repopulating ability. Normal cells heal defects better than cancer cells, leading to radiotherapy's overall wanted effect (Schlegel et al., 2018).

The positioning of the patient at every fraction is called inter-fraction positioning. External laser systems installed in the treatment room visualise the iso-centre of the linac. The laser lines and the previously applied marks on the patient are then used to reproduce the patient's position from 3D imaging. Figure 45 shows the radiation therapist positioning a patient immobilised on the patient couch with a face mask. The radiation therapist uses the couch control to move the patient on the couch to the iso-centre position (Jacob Van Dyk, 2020; Schlegel et al., 2018).

Figure 45: Laser positioning at a linac (with courtesy of LAP Laser Applikationen GmbH)

Laser positioning systems are installed in more than 7,600 RT centres worldwide and on approximately 15,000 linacs (IAEA, 2019). They are important assistance systems for the responsible staff and offer opportunities for innovation (Leuphana University Lüneburg, 2022b).

c. Reflection and conclusion

The examples of laser-based assistance systems in industry and healthcare reflect the versatility in application and the similarity of manual positioning and quality inspection tasks. Thus, laser-based assistance systems are well suited for analysing the research questions in the industry and healthcare context. The analysis and subsequent design of socio-technical information and assistance systems for labour-intensive tasks presuppose a paradigm that allows technical systems to be examined in the different cases of the application context, solving real-world application problems while ensuring an expansion of the scientific knowledge base.

5. Design science research paradigm

Design Science Research is a paradigm that supports the design of IS for real-world applications. Dresch et al. defined DSR as:

> "... a methodological approach concerned with devising artifacts that serve human purposes. It involves the development of innovative constructions, intended to solve problems faced in the real world, and simultaneously makes a kind of prescriptive scientific contribution. An important outcome of this type of research is an artifact that solves a domain problem, also known as solution concept, which must be assessed against criteria of value or utility."
>
> (Dresch et al., 2015, p. v)

In this sense, DSR is sometimes also called Constructive Research. In 1996 Simon published the first edition of his book *The Sciences of the Artificial,* in which he distinguished between natural science and the science of the artificial known today as *design science*. Stating that the world is more artificial than natural, he criticised that traditional science can not be the only source of knowledge (Simon and Simon (1998), Simon and Laird (2019)). Artificial is everything humans have designed, including tangible objects such as machines and intangible elements such as organisations. "In contrary traditional sciences explore, describe, explain and potentially predict" (Dresch et al.). In their early work, Hideaki Takeda et al. (1990) formulated a method for developing research based on design. They described the abstract General Design Theory (GDT) as a descriptive model to explain how design is conceptually performed. Their design cycle methods with abduction, deduction and circumscription inspired other authors such as March and Smith (1995) and later Kuechler, W. and Vaishnavi, V. (2008) to develop the DSR paradigm. Nunamaker and Chen (1990) used a system development approach for IS development. They focused on engineering and practical application instead of system design. The authors introduced theory-building, stating that system development, experimentation, observation, and performance testing can contribute to research. System development in this sense includes prototyping and product development. Experimentation includes simulation, field experiments, observation case studies, field studies, and surveys.

Walls et al. (1992) proposed to use design science for research and theory development in the IS domain. In their view, developing prescriptive theories contributes to developing practical and effective solutions. March and Smith (1995) also advocated the application of design science fundamentals to conduct research in IS. However, they proposed integrating natural sciences to explain the created artefacts and using design science to construct and evaluate artefacts. Elaborating on organisational management, Romme and Endenburg (2006) argued that traditional science contributes to understanding existing organisational systems, while research on creating new systems should apply design science. The authors also proposed design science to generalise organisational management knowledge and secure research results publication.

In academic management research, van Aken (2004) proposed design science to overcome the relevance problem. He stated that description-driven research resulting in *organisation theory* should complement prescription-driven research based on design science resulting in *management theory*. He proposed that the research products be field-tested and grounded on technological rules. These technological rules evolved later into design propositions for a particular class of problems. Important in the description of DSR is its positioning against explanatory research and adjacent areas, as depicted in Table 9 (van Aken, 2004; van Aken et al., 2016). Also, the authors stated: „Design-oriented research … makes a creative jump to what can be" (van Aken et al., 2016).

Explanatory research	Design Science Research	Adjacent areas
- Describe and explain the present and the past - Observation of phenomena - Results in causal models - Justification by description and explanatory validity - Focus on truth using logical deduction - Used in management sciences, physics, and operations management	- Improve the present - Involved as actors - Results in a generic design - Justification by pragmatic validity and outcome - Focus on effectiveness after a creative jump - Used in engineering and medicine	- Action research focuses on case-specific improvements instead of generic knowledge creation - Evaluation research verifies the effectiveness of systems or processes

Table 9: Positioning DSR against explanatory research (van Aken, 2004; van Aken et al., 2016)

In their inaugural essay of the new design science department at the Journal of Operations Management, van Aken et al. promoted DSR for knowledge creation in the Operations Management (OM) community. The authors highlighted that contrary to the material artefact focus of engineering, most OM systems are socio-technical. They argued that DSR is particularly suited to deal with the social component of such systems. DSR can thereby support the OM community in creating strong partnerships between research and practice; a claim verified in this dissertation by the intensive cooperation with research institutes and companies. Design science is an applied science and epistemological paradigm that prescribes solutions for solving problems and can help reduce the gap between theory and practice (van Aken, 2004, Romme 2003). Some authors have created DSR genres to structure the field of IS research. In his MIS Quarterly editor's comments on *Diversity of Design Science Research*, Rai (2017), with contributions of leading IS scholars discussed commonalities and differences in the practice of DSR in IS. Rai identified genres presented in Table 10 with key characteristics and contributions.

Design Science genre	Characteristics
Complexity	- Enterprises depend on socio-technical IS while system attributes are often not known, and control often exceeds human capabilities - "... design science must deal effectively with the messy complexity of real IS problems and avoid the reductionism found in research that simplifies the problem space to one in which known theories and solutions readily apply" (Rai, 2017, p. 5) by Alan R. Hevner - In stable system environments, kernel theories of behaviour can be applied to predict artefact performance (predictive planning), while in fast-changing settings, agile processes can be used (adaptive learning) - "...design scientists will increasingly move away from the limitations of kernel theory predictions to the more adaptive solution search approaches of fast design iterations under the intellectual control of the design team" (Rai, 2017, p. 6) by Alan R. Hevner - Iterative design cycles of DSR support refining artefacts to cope with uncertainty factors
Computational	- Computational Design Science emphasises interdisciplinarity in developing new data representations, algorithms, methods and human-computer innovations, securing impact and relevance - Computational Design Science supports an interdisciplinary information-centric and domain-oriented approach - Often computational Design Science does not require a theory but a demonstration of novelty and validity
Optimisation	- The creation of artefacts requires a model of the problem, and optimisation supporting IS design by proposing prescriptive solutions - "Modeling and simulation artefacts can be especially useful for decision support in dynamic problem environments (e.g., in public health or emergency response contexts) where problem instances are

	too complex to specify and solve comprehensively in an optimization framework" (Rai, 2017, p. 9) by H. Raghav Rao and Sumit Sarkar - Contributions to IS can be theoretical or based on simulations
Representation	- IS will be more effective if the model represents stakeholders' perceptions of phenomena in the domain area. The path from conceptual model to system implementation should be documented - IS researchers need to distinguish between conceptual modelling that represents the real-world and data modelling - "design science label plays a valuable legitimizing function, but good work of this genre has been performed, and continues to be performed, without it" (Rai, 2017, p. 12) by Andrew Burton-Jones and Jeffrey Parsons
Economics	- Economic design science focuses on the design of artefacts supporting economic activities, decision-making and resources organisation - Research is informed by economics and behavioural theories, OM algorithms, computer science and contextual environments - Affordances of new technologies can redefine economics, and researchers need to evaluate systems and not only IT artefacts - "With the Internet as a platform for computing and economic activities, there is the need to bring together economic, behavioural, and computational perspectives to understand how to design innovative platform-based business models" (Rai, 2017, p. 14) by Alok Gupta, Wolfgang Ketter and Arun Rai

Table 10: Design Science genres according to Rai (2017)

Rai (2017) highlighted common characteristics across the genres of developing and evaluating solutions, thereby adding knowledge to the IS and application domains. He outlined commonalities in the search processes for new solutions and their evaluation in context and unveiled significant differences in the actual artefacts being designed. In summarising, Rai (2017) presented the diversity of DSR in the IS community. Peffers et al. (2018) described five DSR genres, as shown in Table 11, distinguished by theory, artefact creation, research process and evaluation.

DSR genre	Characteristics
IS design theory	Focus on the composition and presentation of design theory. An artefact instantiation is not required, and the evaluation can be conceptual.
DSR methodology	Describes practical and outcome-oriented artefact development and evaluation. Theories are used to argue that the artefact might work.
Design-oriented IS research	Focus on instructions for the design and operation of IS. The utilisation of theory is goal-oriented, the evaluation is method-oriented and strong rigour is expected.
Explanatory design theory	Summarises theory development and feature evaluation using hypothesis testing. The evaluation puts a strong emphasis on method and theory development.
Action design research	Describes practice-inspired research resulting in the design of problem-solving artefacts. The process is intervention-driven with several iterative evaluations and design stages.

Table 11: DSR genres and their characteristics (Peffers et al., 2018)

This dissertation focuses on supporting economic activities in the context of labour-intensive processes in industries and healthcare. It investigates, among others, how the affordance of new technologies creates new opportunities. It also uses modelling and simulation techniques in design cycles to optimise an artefact's application. The dissertation can therefore be assigned to the *economics* and the *optimisation* genre, according to Rai (2017). The intended results will answer the research questions and provide instructions on designing IS. Therefore, this dissertation is also assigned to the *DSR methodology* and *design-oriented* genre, according to Peffers et al. (2018).

a. Design theory

The IS community has been discussing design theory since the early 1990s controversially. The discussion turned around the necessity of kernel theories and the need for theorisation. Venable (2006) reinforced this by stating that artefact development can be grounded on theory, or theory can be the outcome of design work. In his essay *Against Theory: With Apologies to Feyerabend* Hirschheim (2019) complained that IS scholars focused too much on theory development and recommended that IS research become more relevant, resilient and resourceful. Referring to the dissent among experts on Information System Design Theory (ISDT), Fischer et al. (2010) cluster Design Theories into ISDT categories. They discuss design theory based on the three classes of general statements according to Chmielewicz 1994 as presented in Table 12 and four theory types shown in Table 13.

General statements	Description
Theoretical statements	Describe cause-effect relationships supporting explanation and prediction
Technological statements	Express means-end relationships supporting goal-oriented description
Normative statements	Specify concrete choices based on values and known side effects

Table 12: General statements (Chmielewicz, 1994)

Key theory types	Description
Explanatory theory	Several theoretical statements that explain the subject of research
Predictive theory	Several theoretical statements that predict the subject of research
Normative theory	Normative statements form a normative theory
Prescriptive theory	Integration of explanatory, predictive and normative statements for artefact creation

Table 13: Key theory types (Fischer et al., 2010; Gregor, 2006)

Fischer et al. (2010) confirmed that kernel theories from natural or social science serve as foundations for artefact creation, following Walls et al. (1992), but emphasised that no definition of kernel theories should be explanatory, predictive, normative or prescriptive. To summarise, Fischer et al. classified ISDTs according to two dimensions. The first dimension *design theory as a key artefact* describes whether ISDT is recognised as an output of IS DSR and relates to the level of artefact generalisation. The second dimension *kernel theories required for grounding* describes whether kernel theories are needed for artefact creation. Based on the two dimensions, Fischer et al. classify selected academic contributions into *ISDT schools* as shown in Figure 46.

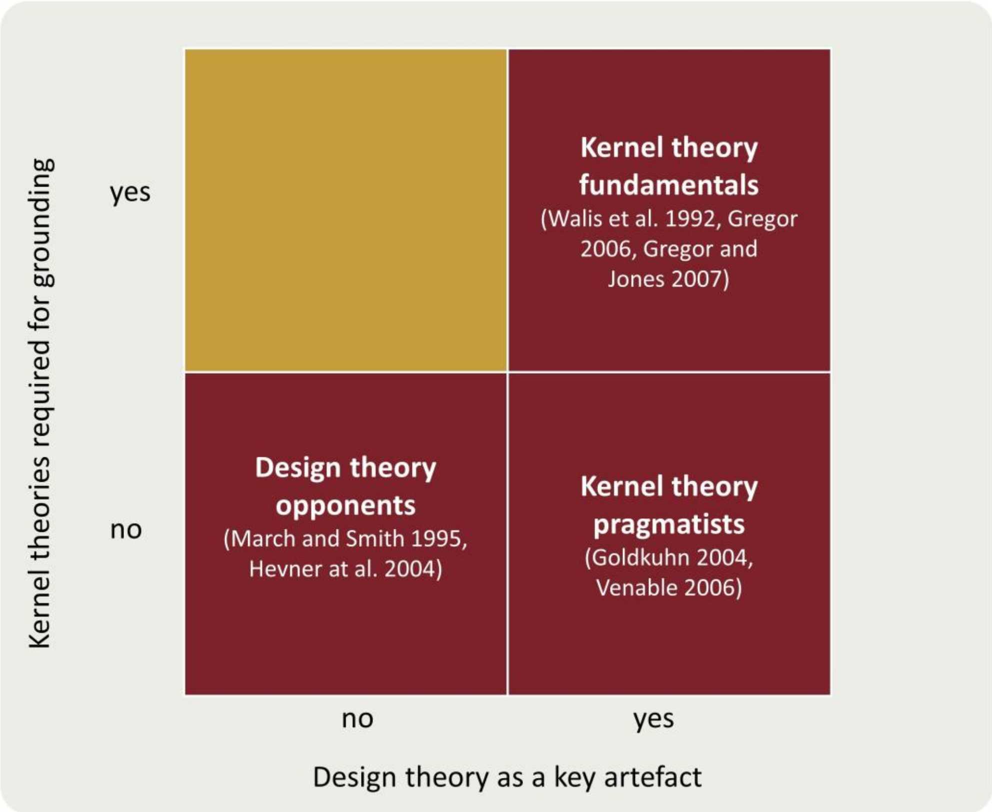

Figure 46: Three schools of IS design theory (Fischer et al., 2010)

Gregor and Hevner (2013) recognised two schools in the design science paradigm. The *Design Theory Camp* with Gregor and Jones (2007), Markus et al 2002, Walls et al. (1992) and the *Pragmatic Design Camp* with Hevner et al. (2004), March and Smith (1995) and Nunamaker and Chen (1990). Gregor and Hevner (2013) tried to harmonise the two positions to enhance implementation and rigour in DSR.

Iivari analysed design theory contributions with a focus on the often-cited publications of Walls et al. (1992), Venable 2006, Gregor and Jones (2007), Baskerville and Pries-Heje (2010), Pries-Heje (2010) and Niehaves and Ortbach (2016). He complained about the frequent use of the word theory in DSR publications and advocated “less theory, but better design theory” (Iivari, 2020, p. 504). He believed that the forces of legitimising IS as a research discipline were often more in focus than advancing the knowledge base. Iivari stated there is no broad consensus on design theory in DSR in IS and discussed this thesis controversially. The analysis of Iivari concentrated on the designed product as an outcome of IS research. Iivari analysed the publications Walls et al. (1992), Venable (2006), Gregor and Jones (2007), Baskerville and Pries-Heje (2010), Niehaves and Ortbach (2016) according to conceptualisations of design theory in DSR IS using IS and software artefacts for the argumentation. He synthesised the results in Figure 47, visualising the coverage of the design theories within the chain of kernel theory, IT artefact and effects on the outer world. He categorised the design theories into design theory 1 to 3 and design theory 4 as a combination of 1 to 3 and concluded that DSR researchers should carefully use the concept of design theory and indicate how they use it in their work.

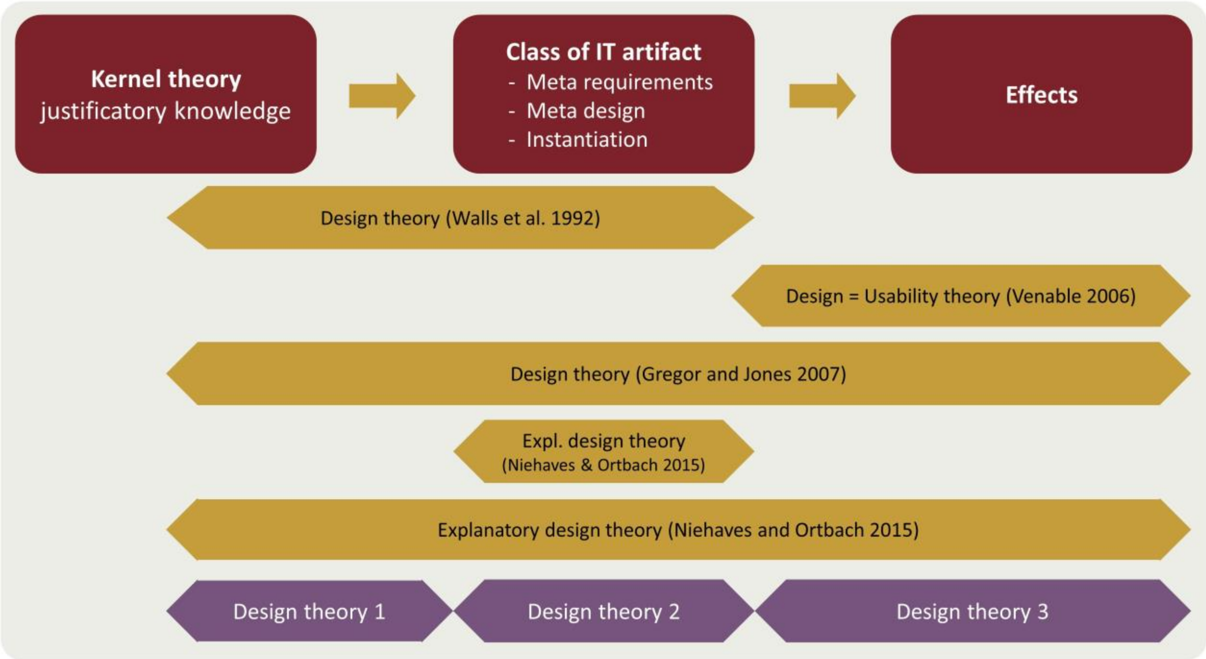

Figure 47: Different conceptions of design theory (Iivari, 2020)

Following this, Iivari discussed the role of kernel theories in DSR for IS, emphasising the scientifically justified use of kernel theories as a prerequisite for design theories. Considering the classification scheme of Fischer et al. and the conceptions of the design theory of Iivari, one can summarise selected key contributions of design theory as shown in Table 14.

Publication	Key aspects
Walls et al. (1992)	- Advocated the use of design science for research and discussed the concept of prescriptive theories for developing practical solutions to existing problems - Design theories are grounded on explanatory, predictive or normative theories - Introduced seven characteristics of IS design theory and believed that single instances are no design theory - Natural, social sciences and mathematics kernel theories are mandatory - IS design theory with design product and process - Meta requirements as class goals to which theory applies
March and Smith (1995)	- Advocated integration between design science and traditional science - Design science creates things that serve human purposes - Differentiated between descriptive natural science and prescriptive design science

	- Theory building is characteristic of natural science and not of design science - An instance itself is already a valid DSR output
van Aken (2004)	- Advocated design science for research in the management field and organisations - Research results should be prescriptive to ease their application by organisations - Research results should be generalisable to allow solving a class of problems
Hevner et al. (2004)	- Advocated DSR without using the term design theory - Defined seven guidelines for DSR in IS - DSR in IS is based on a knowledge base, but artefacts do not have to be grounded on kernel theories - Instances are valid outputs of DSR in IS
Goldkuhl (2004)	- Advocated the use of design theory for IS to inform the design process, with kernel theories being an essential part of it - Defined four types of groundings: conceptual, value, explanatory, and empirical - Only theorised practical knowledge should be design theory
Venable (2006)	- Advocated theory building as central for DSR activities - Design theory does not need to be prescriptive, and kernel theories are applicable but not necessary - Design theory for IS needs only technology, external problem and utility - One instance of a solution is not enough, but generalisation is needed
Gregor and Jones (2007)	- Advocated that design theory for IS consists of purpose and scope, constructs, principles of form and function, artefact mutability, testable propositions, justificatory knowledge, principles of implementation, expository instantiation - Purpose and scope correspond to meta requirements. The principles of form and function correspond to metadesign - Introduced justificatory knowledge substituting kernel theory. Justificatory knowledge can include existing design theories and practical theories-in-use
Baskerville and Pries-Heje (2010)	- Advocated two types of design theory: explanatory with requirements satisfying objectives and practice design theory focusing on processes - Adopted an internal view on system requirements as in software development with explanatory design theory addressing the relationship between meta requirements and meta-design within the IT artefact
Niehaves and Ortbach (2016)	- Advocated a model of Explanatory Design Theory (EDT) influenced by SEM - Introduced kernel theories to explain the relationship between meta requirements and meta-design

Table 14: Contributions of design theory based on (Fischer et al., 2010)

An essential term in the context of design for practical use is affordance. The affordances allow for managing the relationship between IT, the context of use and design for practice (Fayard and Weeks, 2014). IS scholars often conceptualise affordances as IT-user relationships (Maier and Fadel, 2009). This dissertation focuses on the artefact as a key contribution of the DSR for IS and follows the school of opponents, particularly the ideas of Hevner, which will be outlined in more detail in the following. Affordance aspects are considered in the design of the artefacts and tested in the evaluation phases.

b. Knowledge contribution

"Rather than producing general theoretical knowledge, design scientists produce and apply knowledge of tasks or situations in order to create effective artefacts" (March and Smith, 1995, p. 253). Artificial artefacts are one form of knowledge in DSR. March and Smith (1995) define the four artefacts *constructs*, *model*, *methods* and *instantiations*. Constructs are the basic elements and are used to describe phenomena. Models are built from constructs and describe tasks or situations. Methods are developed to describe ways of performing activities. The physical implementation of constructs, models or methods in products occurs in instantiations. Figure 48 provides an overview of the artefacts and their interrelationships. In more detail, constructs are a conceptualisation using vocabulary and symbols to describe problems and solutions within a specific application domain. In this way, they represent the knowledge of a particular discipline. Constructs can be highly formalised, including entities, attributes, relationships, and identifiers. However, constructs can also be informally formulated. Models describe reality, representing real-world situations in the problem and solution domain. A model consists of constructs and propositions that express the relationship between the constructs. A model is a solution component for a design task. Methods are based on constructs and can take the form of algorithms or guidelines showing how to perform a specific task. Models can be connected to methods by providing input to them. Methods can also be used to transform one model into another. Instantiations are the implementation of IS artefacts into the natural environment. The operational instantiation is used to evaluate and prove its feasibility and effectiveness. Artefacts must be evaluated as part of the design science work to demonstrate their feasibility after being built (March and Smith, 1995).

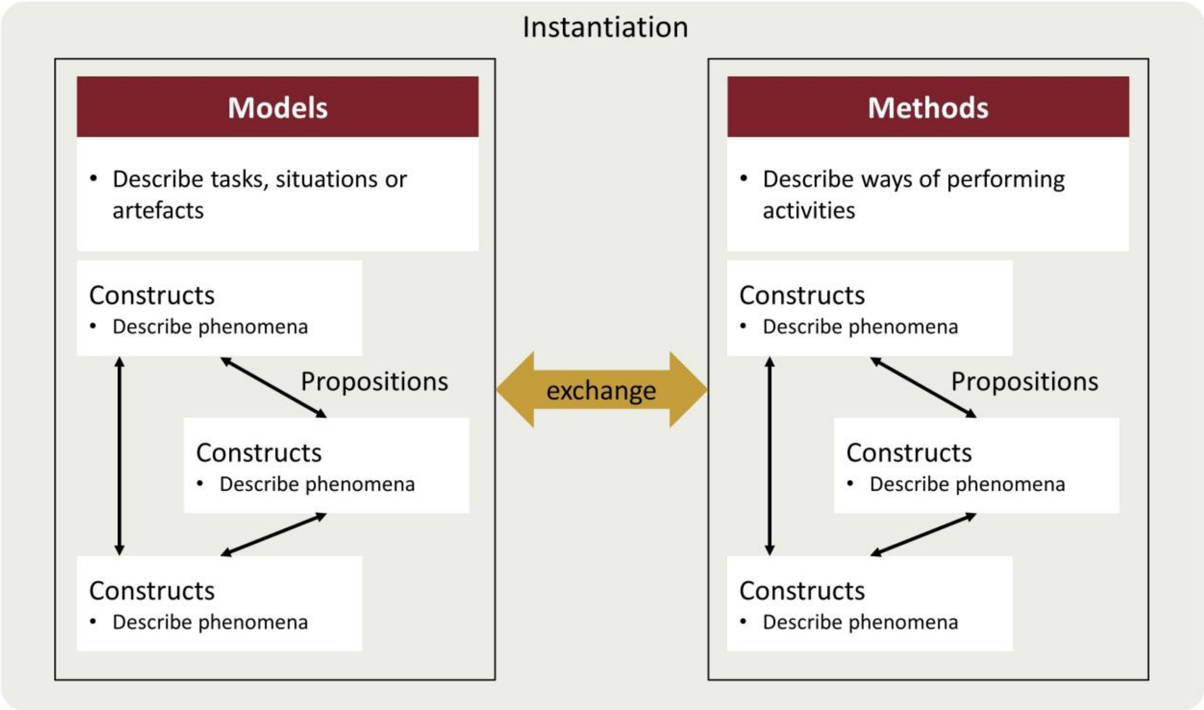

Figure 48: Overview of types of artefacts (March and Smith, 1995)

Hevner et al. (2004) shared the view of March and Smith (1995) that artefacts do not include people or organisational elements. "We conceive of IT artefacts not as independent of people or the organizational and social contexts in which they are used but as interdependent and coequal with them in meeting business needs" (Hevner et al., 2004). The authors acknowledged that the organisational perspective of implementing IS is essential, but the capabilities of artefacts are equally important. Furthermore, the design of artefacts requires creativity and domain competence in areas with often limited theoretical knowledge. In this sense, the creation of artefacts extends the intellectual boundaries of human problem-solving. Also, artefacts must be well-described to allow their implementation in the application domain (Hevner et al., 2004). Gregor and Hevner (2013) characterised the nature of artefacts as either material or abstract.

Weigand et al. (2021) proposed a top-level ontology for DSR artefacts. The authors differentiated between technical objects and artefacts and between technical and non-technical artefacts. They claim that their DSR artefact is universal and add artefact maker and user as agents, distinguishing between designing and making activities. Figure 49 presents an IS application artefact described using the ontology. The human agent uses the application according to a use plan prescribed in user interactions and supports business processes in an organisational context. The artefact interacts with various components and with input and output data. The authors also foresee that CPS IS will create a new type of artefact and might become more prominent than traditional IS, thus requiring an adapted terminology (Weigand et al., 2021).

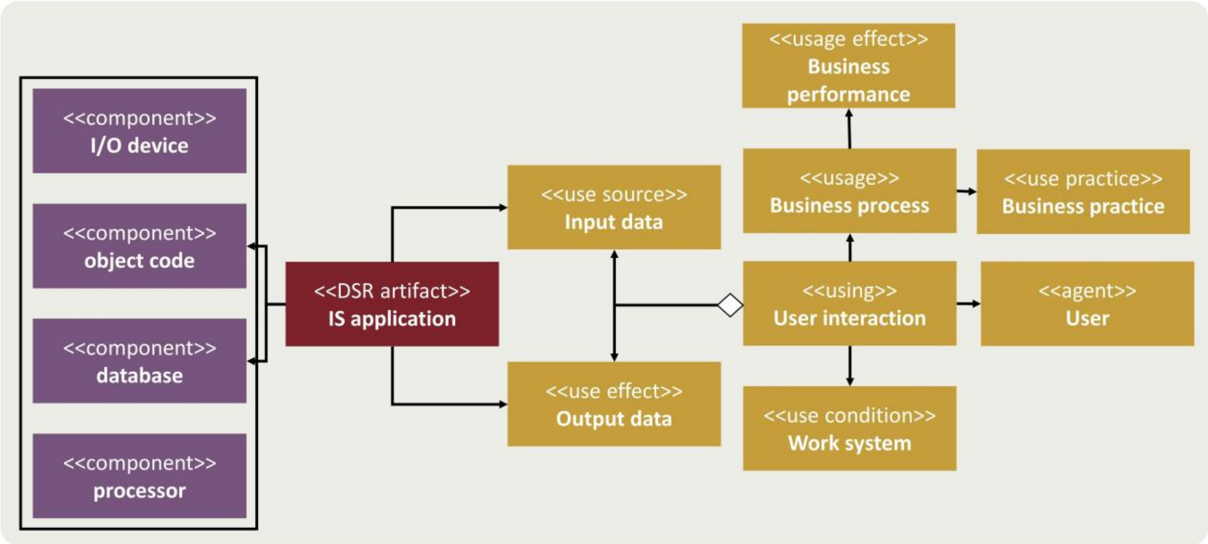

Figure 49: Information system application based on the ontology of Weigand et al. (2021)

Design knowledge can be expressed in different forms and levels of abstraction, such as in the above-described artefacts and design principles or theories. The level of detail depends on the background knowledge of the designer who wants to apply the knowledge (Chandra et al., 2015).

> "The appropriate and effective consumption and production of knowledge are related issues that researchers should consider foremost throughout the research process—from initial problem selection, to the use of sound research methods, to reflection, and to communication of research results in journal and conference articles."
>
> (Gregor and Hevner, 2013, p. 338)

Gregor and Hevner (2013) made a considerable contribution by proposing the DSR knowledge contribution framework and DSR theory as the fifth type of theory according to the taxonomy of Gregor (2006). They claim that knowledge contribution to DSR is not only reached by creating theories but also by partial theory and new design artefacts. Gregor and Hevner (2013) also position *justificatory knowledge* as nearly synonymous with kernel theories from natural science, social science or mathematics. Justificatory knowledge refers to informal knowledge from the application domain and experience from practitioners. Table 15 summarises the different forms of knowledge contribution that a DSR project can produce. Knowledge contributions in a project can also be across several levels. The research presented in this dissertation contributes to the level 1 and 2 knowledge types within the different design cycles utilising justificatory knowledge from the application domains (Gregor and Hevner, 2013).

	Contribution types	Example artefacts
More abstract, complete, and mature knowledge	Level 3: Well-developed design theory about embedded phenomena	Design theories (mid-range and grand theories)
↕ ↕ ↕ ↕ ↕ ↕	Level 2: Nascent design theory – knowledge as operational principles/ architecture	Constructs, methods, models, design principles, technological rules
More specific, limited, and less mature knowledge	Level 1: Situated implementation of artefact	Instantiations (software products or implemented processes)

Table 15: DSR contribution types (Gregor and Hevner, 2013)

Gregor and Hevner (2013) also elaborated on the DSR knowledge base, which they presented in the form of descriptive (Ω omega) knowledge and prescriptive (Λ lambda) knowledge, as shown in Table 16. To ground the research, the authors presented a research path that started by investigating the existing knowledge in the Ω and Λ knowledge. The descriptive knowledge of Ω, including phenomena descriptions and sense-making knowledge, informed the research question. Additionally, existing artefacts or design theories from the Λ knowledge base were investigated that were linked to similar research questions. Such knowledge can be attributed to the same, similar, or different application domain of the research problem. Table 16 presents the various forms of knowledge contribution of a DSR project.

Ω descriptive knowledge	Λ prescriptive knowledge
Phenomena (natural, artificial, human) • Observation • Classification • Measurement • Cataloguing **Sense-making** • Natural laws • Regularities • Principles	**Constructs** • Concepts • Symbols **Models** • Representation • Semantics/ Syntax **Methods** • Algorithms • Techniques

• Patterns • Theories	**Instantiations** • Systems • Products/ Processes **Design Theory**

Table 16: DSR knowledge base (Gregor and Hevner, 2013)

According to Gregor and Hevner (2013), identifying the contribution can sometimes be challenging because it depends on the artefact designed, the field of knowledge, the audience and the publication channel. Furthermore, the degree of knowledge contribution might be incremental for artefacts or partial for theories. "A fundamental issue is that nothing is really "new." Everything is made out of something else or builds on some previous idea" (Gregor and Hevner, 2013, p. 344). In summarising, a DSR project can contribute different types and knowledge depending on the problem and solution maturity, as presented in Figure 50.

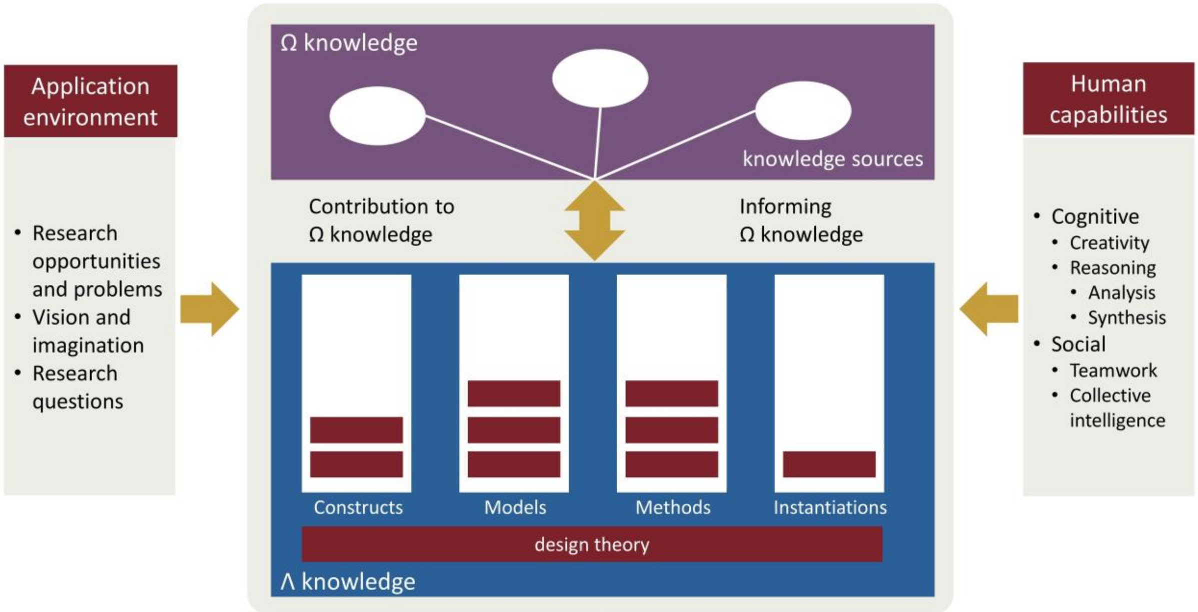

Figure 50: The roles of knowledge in Design Science Research (Gregor and Hevner, 2013)

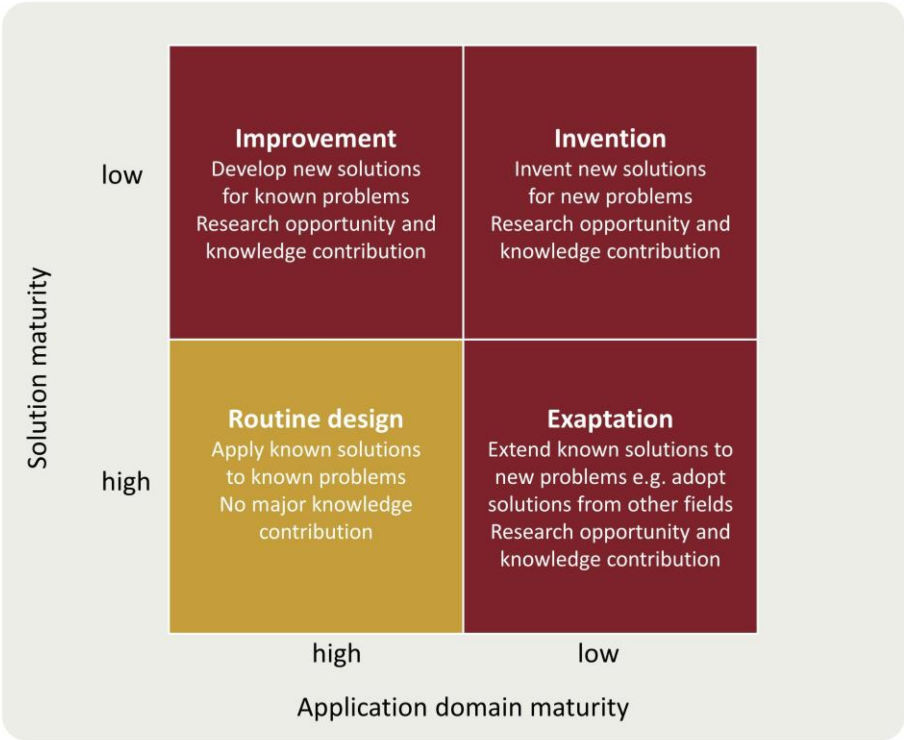

Figure 51: DSR knowledge contribution framework (Gregor and Hevner, 2013)

The two maturity dimensions define a four-quadrant matrix, as presented in Figure 51. Based on the matrix, *routine design*, *improvement*, *exaptation,* and *invention* are described as DSR project types and outlined in Table 17.

Type of project	Characteristics
Routine design	- Known solutions to known problems - Existing knowledge and artefacts are used to solve a problem - The design does not need research methods to solve problems - Professional design or commercial systems need to be distinguished from DSR - No contributions to Ω and Λ knowledge and no publication in academic journals are possible
Improvement	- New solutions for known problems - Creation of more efficient and effective artefacts such as products, processes, services, technologies, or ideas - Building innovative artefacts requires a deep understanding of the application domain

	- Improvements in efficiency, productivity, quality, and competitiveness must be demonstrated and communicated - Research work should be grounded in kernel theories from Ω knowledge, and evaluation of improvements can also enhance Ω knowledge - Improvement projects contribute to the Λ knowledge base on levels 1-3 - Most DSR projects are improvement projects
Exaptation	- Known solutions extended to new problems - Utilisation of artefacts from one application domain to another based on researchers' experience in multiple disciplines and application domains - Artefacts are adapted or exapted to the new problem context - Design knowledge from one application field is applied to another - Common project type because new technology opens research opportunities - Exaptation contributes mainly to Λ knowledge at levels 1-3, but increased understanding of artefacts can also extend Ω knowledge
Invention	- New solutions for new problems - Inventions can be DSR if an artefact is created that can be applied and evaluated in real-life and new Ω and/or Λ knowledge is created - Most invention research is recognised as artefacts or instantiations - Knowledge flows are typically from prescriptive to descriptive and could result in a new application domain

Table 17: Types of DSR projects (Gregor and Hevner, 2013)

"The limited knowledge accumulation and evolution of DK [design knowledge] in DSR as observed in the IS community is problematic because single contributions tend to remain isolated with little to no relation to other solutions" (vom Brocke et al., 2020, p. 521). The expansion of the knowledge base in DSR is challenged by vom Brocke et al. (2020). The authors argued that a model that composes design knowledge from multiple perspectives would benefit IS research, considering that design knowledge ages. They described the need to reuse design knowledge to address more complex problems and update it over time.

The authors described how to position design knowledge contributions in the problem and solution space with the supporting conceptual and methodical tools. First, they presented a design knowledge model with the components for a DSR project, as shown in Figure 52. It contains the problem space described by the application context and the goodness criteria from technology, information, interaction and society domains. Corresponding success measures can include security, reliability, performance, accuracy, timeliness, usability, user experience, accessibility, or fairness. It also contains the solution space with the knowledge represented in the form of artefacts, design principles and theories. The solution space is supported by design process information and kernel theories. The solution space can improve in the different design cycles of the project. Both the problem and the solution space are interlinked based on evidence. The confidence of the evaluation depends on the type of evaluation performed, the rigour of the applied methods and the quality of the results. The maturity of design knowledge can be judged based on the projectability of the problem to other real-world issues, the design solution's strength, and the evaluation's confidence (vom Brocke et al., 2020).

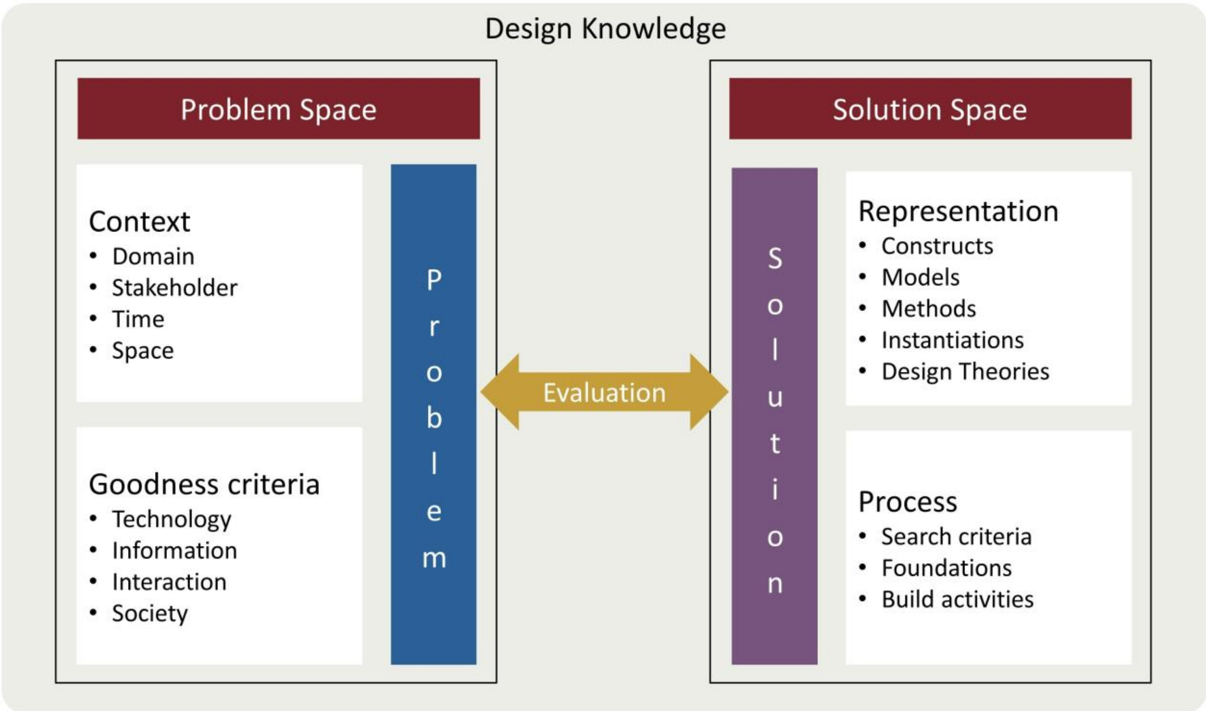

Figure 52: Design knowledge model (vom Brocke et al., 2020)

Concluding, Goldkuhl (2020) presented epistemic knowledge types related to the design science process phases: pre-design knowledge, including evaluative and explanatory knowledge; in-design knowledge, including prospective knowledge with design hypotheses and post-design knowledge, including prescriptive knowledge with design principles. He presented a landscape with several epistemic types, including evaluative, critical, appreciative, normative, explanatory, prospective, prescriptive, categorial and attributive knowledge (Goldkuhl, 2020). Knowledge contribution in DSR means generalising research results. Generic designs can be transferred within a specific application domain to other contexts. The transfer is based on a generic design model without losing effectiveness in application. Generalising systems with significant social components requires higher effort than pure technical systems. It is essential to understand what is specific to the context and what is generic and transferrable for knowledge contribution by generalisation. Analysis of scenarios with contextual deviations can support the process of knowledge generalisation (van Aken et al., 2016).

"The characteristic that distinguishes design science knowledge from other forms of knowledge is that it includes design principles: prescriptive statements that show how to do something to achieve a goal" (Gregor et al., 2020). Design Principles (DP) are widely accepted to capture, document and share knowledge about the design of IS artefacts. Researchers have reached a consensus about the content and structure of DPs (Romme and Endenburg (2006), Gregor and Jones (2007)), vom Brocke et al. (2020)), even though the terminology and formulation vary in software design, computing, education and management (Gregor et al., 2020). Purao et al. (2020) considered DPs as knowledge outcomes. The authors presented four dimensions influencing DPs, as shown in Table 18.

Dimension	Description
Influences	- Theory-inspired DPs based on prior theories and kernel theories provide justificatory grounding - Prior design efforts of the team support reflection and formalising new DPS - Instantiations of artefacts and associated practices can inspire other designers - Results from formative and summative evaluation of DSR can emphasise elements that have produced the desired outcome
Temporality	- The research team can engage in discovering DPs as part of their design, build and evaluation cycles - The research team can discover DPs in a separate learning and reflection stage - Formulation of DPs before implementing the artefact - Discovery of DPs after deployment of the artefact - The archaeological approach generates DPs based on significant and/or successful IT artefacts deployed in the past
Actors	- The researcher or the research team engaged in the design science effort is responsible for the formulation and communication of DPs - Collaboration with relevant stakeholders or application experts can secure that the formulated DPs fulfil the application domain specifics - Academic partners not involved in the design process can formulate the DPs
Content	- A common way of formulating DPs is: “in [situation] S, to achieve [outcome] O, perform [action] A” (Romme and Endenburg, 2006) - DPs can also be formulated by separating the form and function of the artefact (Gregor and Hevner, 2013)

	- Some design science researchers formulate DPs without a defined structure - Special structures have been presented for action-oriented and materiality-oriented DPs (Chandra et al., 2015) - A more detailed structure has been proposed by Gregor et al. (2020): "For Implementer I to achieve or allow A for User U in Context C employ Mechanisms M1, M2, M3… involving Enactors E1, E2, E3, … because of Rationale R."

Table 18: Dimensions of design principles origins (Purao et al., 2020)

Chandra et al. (2015), in their contribution to the 48th Hawaii International Conference on System Sciences, focused on designing artefacts that are intended for human use. In their view, "Design principles interpret descriptive, explanatory, and predictive knowledge—which can be referred to as the kernel theory—into something that can be used in the practice of building purposeful IS artefacts" (Chandra et al., 2015, p. 4040). Chandra et al. (2015) analysed DPs in terms of action-oriented, materiality oriented and both action and materiality-oriented formulation corresponding to the focus on technology and its utilisation. They identified inconsistency in the formulation of DPs published in leading IS journals, described a consistent way to formulate DPs, and introduced a precise structure while outlining boundaries. "Provide the system with *[material property—in terms of form and function]* in order for users to *[activity of user/group of users—in terms of action]*, given that *[boundary conditions—user group's characteristics or implementation settings]*" (Chandra et al., 2015, p. 4045). They also proposed measuring the effectiveness of DPs by the ease of instantiation into an artefact, the artefacts goal fulfilment and the effectiveness in the application context. Applying the concept of Chandra et al. (2015), Seidel et al. (2018) presented a sensemaking support system for environmental sustainability transformations.

"Design principles ... are an important part of design theory, as they contain the distinctive element that distinguishes design knowledge: the prescriptive statements" (Gregor et al., 2020, p. 8). The DPs scheme for IT-based artefacts in socio-technical systems presented by Gregor et al. (2020) is detailed. Their work was motivated by inconsistencies in the treatment of DPs and the lack of attention to the people dimension (Chandra et al., 2015). Hence, they analysed the roles of human actors and their use of DPs for socio-technical systems. Figure 53 visualises the roles in the process of DP development. Originating from the abstract domain, the implementer applies the DPs of an abstract solution to the instantiation of the solution. The instantiation of the solution fulfils the user's aims while the enactor performs actions to accomplish the purpose. The theoriser abstracts design knowledge from a concrete instance problem, increasing the knowledge base. Gregor et al. (2020) emphasised that the different actors in this process must be considered when formulating DPs. The level of generality and possible decomposition to lower levels might be needed for clear communication. Additionally, a DP title can help communicate its key topic. According to the authors, IT-based systems change their behaviour because of the involvement of humans, which in turn demands humans to be considered.

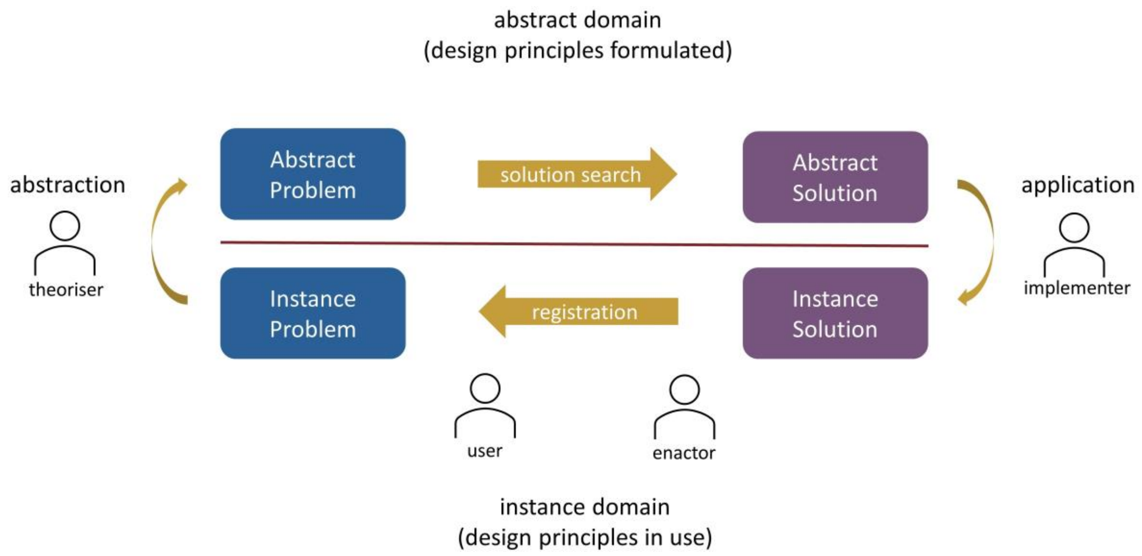

Figure 53: Design principles in use (Gregor et al., 2020)

In summarising, Gregor et al. (2020) introduced a new conceptual scheme for DPs outlined in Table 19. The scheme includes common elements such as goals and mechanisms to reach them. However, it is extended by the roles of the human actors, the context of DPs, the consideration of the complexity of IT-artefacts and types of causations, as well as several mechanisms to achieve the goal and the optional rationale justifying the DP.

Structure	Components
For **Implementer I** to achieve or allow **Aim A** for **User U**	Aim, Implementer and User
In **Context C**	Context (boundary conditions, implementation setting, further user characteristics)
Employ **Mechanism M1, M2, M3**… involving **Enactors E1, E2, E3**, …	Mechanism (acts, activities, processes, form/ architecture, manipulation of other artefacts) Subsidiary components/ artefacts that can have their own DPs
Because of **Rational R**	Theoretical or empirical justification for the DP

Table 19: Components of the Design Principle Scheme (Gregor et al., 2020)

In this dissertation, the four defined dimensions, according to Purao et al. (2020), have been used to select a specific approach to formulate DPs. The formulation is influenced by kernel theories, prior design efforts, and instantiations in the industry and healthcare domain. The DPs were formulated in an additional learning and reflection stage. The author collaborated in selected design cycles with academic and non-academic application domain experts when developing the DPs and followed the structure "in [situation] S, to achieve [outcome] O, perform [action] A." according to Romme and Endenburg (2006). Tool support for DSR is available based on the development of *MyDesignProcess.com* by vom Brocke et al. (2017). It is argued that such tools support the structuring, documentation, maintenance and presentation of DSR research projects and findings. Instead, this dissertation presents research findings in peer-reviewed academic publications.

c. Relevant kernel theories

Kernel theories from different academic domains inspired this dissertation. Knowledge from IS, information infrastructure, and electrical and mechanical engineering domains informed the present work, particularly in designing and implementing the technical case studies. System theory, organisational rationalism and social theories also played a significant role.

Human factors are critical aspects due to the human actors in socio-technical systems. User-centred design based on cognitive science theory, ergonomics and behavioural science was used in this dissertation to understand phenomena in the design cycles. In particular, the aspects of memory, attention, action, cognition, perception and navigation were considered.

From a psychological point of view, memory is defined as "the ability to retain information or a representation of past experience, based on the mental processes of learning or encoding, retention across some interval of time, and retrieval or reactivation of the memory" (American Psychological Association, 2022, no pagination). The widely accepted multi-store model introduced by Atkinson and Shiffrin (1968) distinguished between working memory and long-term memory. According to the model, the central executive component is used for decision-making, planning and related activities, while the articulary loop and the visuospatial sketchpad hold auditory and visual information. MacGregor (1987) defined working memory capacity as three to four items of a word, phrase or image. The long-term memory consists of semantic, procedural, and episodic memory. The semantic memory is responsible for the meaning of information, while the procedural memory stores activity performance-related knowledge. The episodic memory includes autobiographical information. Finally, the permastore holds the information we will never forget. Chunking information into meaningful fractions helps store information turning it into memory that can be retrieved later (Benyon, 2020).

Attention is defined as a "state in which cognitive resources are focused on certain aspects of the environment rather than on others and the central nervous system is in a state of readiness to respond to stimuli" (American Psychological Association, 2022, no pagination). Stress can negatively influence attention to activities, which is defined as "a self-initiated sequence of movements, usually with respect to some goal" (American Psychological Association, 2022, no pagination). The way in which attention is allocated to activities has been described in selective and divided attention theories, each of them with a different approach (BROADBENT, 1958; Egeth and Kahneman, 1975). Attention aspects are essential for the design of socio-technical systems, especially for safety-relevant healthcare systems.

Cognition is "all forms of knowing and awareness, such as perceiving, conceiving, remembering, reasoning, judging, imagining, and problem solving ..." (American Psychological Association, 2022, no pagination). Research has developed from a task-based human information processing view to a position that considers system users as autonomous actors, self-governing their behaviour (Greenbaum and Kyng, 2020; Norman, 1986). Distributed cognition theory extends the approach with external artefacts supplementing human memory and knowledge (Hutchins, 2000). Embodied cognition is linked to affordance and perceived affordance of technologies used in the design of socio-technical systems (Norman, 2002).

According to the American Psychological Association (2022), perception is:

> "… the process or result of becoming aware of objects, relationships, and events by means of the senses, which includes such activities as recognizing, observing, and discriminating. These activities enable organisms to organize and interpret the stimuli received into meaningful knowledge and to act in a coordinated manner."
>
> (American Psychological Association, 2022, no pagination)

Perception allows us to sense the environment, including the workspace of socio-technical systems, by interpreting visual, auditory, or haptic information. Perception helps people to navigate through the environment, with navigation being defined as "the mechanisms used by an organism to find its way through the environment, such as to a migration site or its home site" (American Psychological Association, 2022, no pagination). Navigation includes object identification, exploring the environment and finding ways toward specific destinations. The socio-technical system design should help users obtain knowledge about the system and the workspace (Benyon, 2020).

d. Research paradigm applied

The research paradigm applied in this dissertation is the three-cycle framework of Hevner (2007) based on Hevner et al. (2004). The presented framework provides a well-formulated structure for DSR projects based on the relevance, rigour and design cycle, as shown in Figure 54. The relevance cycle secures the significance of the research for the organisation that applies the designed artefact to solve a real-life problem in context. The relevance cycle bridges the design work with the application environment that consists of people, organisational system, technical system, problems, and opportunities. The relevance cycle turns around system requirements and field testing, while the rigour cycle bridges the design work with the knowledge base. The knowledge base includes the foundations of scientific theories, methods, experience, expertise, meta-artefacts and own experience. The rigour cycle turns around grounding the research work in the knowledge base by providing additions to the knowledge base.

Rigour is essential for DSR to be considered valid and reliable. Demonstrating the designed artefact's validity is needed to satisfy the intended use and secure the academic contributions of the design work. For this purpose, the rigour cycle is informed by scientific theories and methods, experience, expertise, and meta-artefacts of design products and processes. The design cycle circles between the design of product or process artefacts and the evaluation of those artefacts. Methods from the knowledge base support the design work in terms of construction, justification and evaluation activities (Gregor and Hevner, 2013; Hevner et al., 2004; Hevner, 2007; Hevner and Chatterjee, 2010).

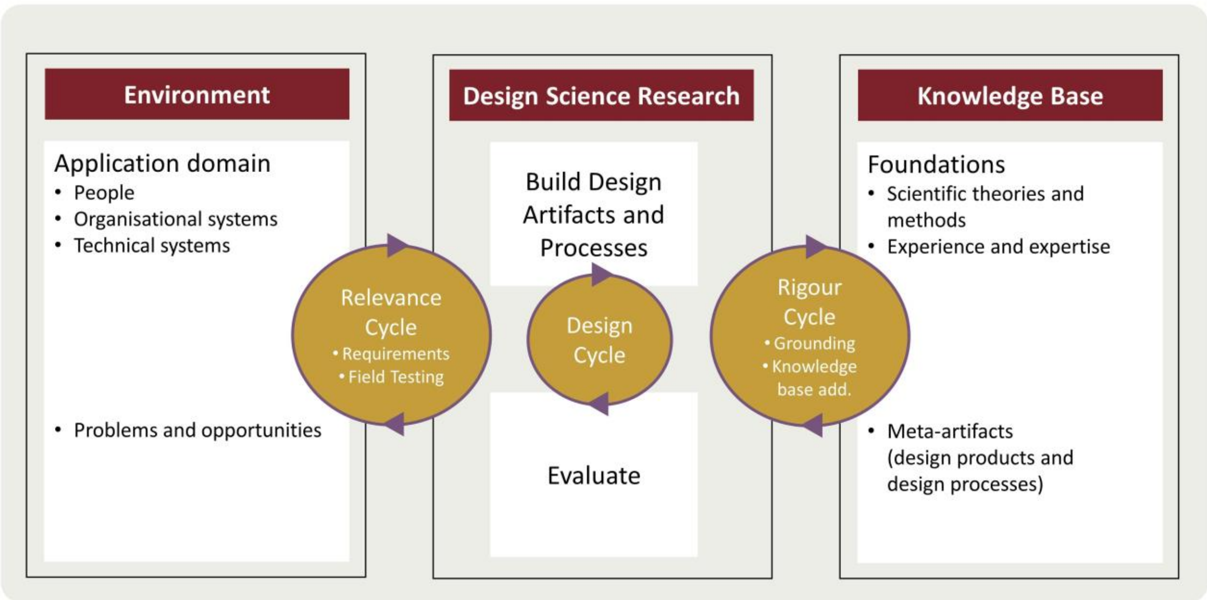

Figure 54: DSR framework (Hevner et al., 2004)

A DSR project often starts with identifying the problem in the corresponding application environment. In this phase, requirements and acceptance criteria for the evaluation are often elaborated. Design work results must be tested in the application domain, for example, in the form of field studies and can lead to changes in requirements. Innovation in design work is secured by reference to the existing knowledge base of meta-artefacts, experience and expertise. Thus, DSR work relies on the current knowledge base and benefits from creativity. Additions to the knowledge base can include new theories, methods, product artefacts, process artefacts or DPs. In summarising, the DSR paradigm, according to Hevner et al. (2004), addresses practitioners in the environment domain and scientists in the knowledge base domain, while the interplay of the three cycles characterises pragmatic science drawing on a statement from the management field: "Only ‘Pragmatic Science’ balances both rigour and relevance" (Tranfield et al., 2003, p. 219).

e. Research methods applied

Nunamaker and Chen (1990) believed that “… systems development and other research methodologies are complementary and … an integrated multi-dimensional and multimethodological approach will generate fruitful IS research results” (Nunamaker and Chen, 1990, p. 103). This approach applied qualitative, quantitative, and mixed research methods in the DSR design cycles. Furthermore, the system development framework of Nunamaker and Chen (1990) provided the basic structure for inquiry and data collection. The methods applied and presented below include hermeneutic approaches building on prior research work and empiric approaches providing new empiric data and knowledge.

i. Systematic literature review

A Systematic Literature Review (SLR) is an efficient method for analysing the knowledge base for a specific topic and has been recommended by Webster and Watson (2002) for the IS field. The results of a comprehensive SLR provide a basis for DSR projects in terms of existing artefacts and relevant theories. Considering that academic knowledge is increasing continuously, it is suggested that every research project should start with an SLR (Saunders et al., 2019). The secondary study of an SLR consolidates relevant primary studies identified within the SLR scope. The term *systematic*, in this sense, refers to a transparent, reproducible, and unbiased method for the selection and review of the literature. Additionally, synthesising the selected articles should produce new knowledge (Gough et al., 2012).

The method of SLR has a long history in biomedical science, education, psychology, social and behavioural science and an increasing number of publications using SLR are reported. Tranfield et al. (2003), for example, analysed methods from medical science for their applicability to management science to promote practitioner and context-sensitive reviews. They argued that systematic reviews compared to narrative ones are more replicable, scientific, and transparent with less bias. SLRs provide a broader decision base to interpret own findings and offer grounding within the global knowledge base. SLRs can also be used for policymaking, allowing evidence-based decision-making (Dresch et al., 2015). An SLR supports the rigour cycle primarily and adds to the relevance cycle of the DSR paradigm, according to Hevner et al. (2004). Most SLR approaches have a standard structure of search, selection, and evaluation processes following the definition of the review topic.

Two major types of reviews can be distinguished. First, SLRs aggregating homogeneous primary studies are often quantitative using deductive methods. Second, heterogeneous primary studies, often qualitative, are compiled in a configurative review using inductive interpretation and exploration methods. A thorough SLR requires time and resources, and stakeholders can influence the review process at different stages. The review process can benefit from the active involvement of such stakeholders based on their organisational or practical knowledge. The SLR work can be performed in teams applying common standards and expert software tools. The team approach can increase the speed and the quality of the SLR project. The first step of the search strategy is defining the review topic concerning the scope in terms of breadth, depth, time, and available resources. Also, the search terms, sources, inclusion and exclusion criteria must be defined together with the target languages and publication period.

Minimising bias can be achieved by including synonyms, antonyms, and various spelling of terms in the search term and strictly applying inclusion and exclusion criteria. The search process is performed electronically in academic databases but can also include grey literature. In the various SLRs conducted for this dissertation, the search was complemented by online search engines to ensure no publications were overlooked. Forward and backward searches based on the literature reference list added further relevant studies to the search process (Dresch et al., 2015). The search strategy should be documented in a search protocol, as shown in Table 20. "Without a protocol that is publicly accessible, it is difficult to judge between appropriate and inappropriate modifications." (Moher et al., 2009, p. 2)

Section	Description
Concept	Summary of the problem and topic of review
Context	Research contexts such as industry, location or sectors
Period	The period is considered in the review

Language	Language is considered in the process
Strategy	Deductive, inductive, aggregative, explorative
Search string	Search string consists of search terms connected by Boolean and proximity operators
Inclusion criteria	Criteria that determine the inclusion of studies
Exclusion criteria	Criteria that determine the exclusion of studies
Sources	Databases, proceedings, Internet, or others

Table 20: Systematic literature review protocol (Dresch et al., 2015; Moher et al., 2009)

The step following the identification process is the removal of duplicates and the screening for relevant studies. The screening processes applied in the projects of this dissertation were deliberately broad in scope to not miss out on essential studies. The selected articles were then assessed as full-text to secure their relevance. A final set of studies was then included in the content analysis based on categorical, open or mixed coding schemes using expert software for qualitative analysis (ATLAS.ti GmbH, 2021). The overall sorting and documentation of processes were conducted in literature management software (Swiss Academic Software, 2021). The synthesis combines the content analysis results, creating new knowledge for DSR cycles. The synthesis usually is not linear but often requires several iterations of data organisation, pattern recognition, data integration and robustness check.

Many publications are available on SLR proposing frameworks and guidelines for performing reviews. This dissertation uses the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) concept and checklist in its 2009 version, as shown in Figure 55 (Liberati et al., 2009; Moher et al., 2009). In 2020, an updated version of PRISMA was published supporting quantitative and qualitative mixed methods with the primary goal of evaluating health interventions (Page et al., 2021). However, PRISMA 2009 is the core of PRISMA 2020 and fulfils the requirements of this dissertation.

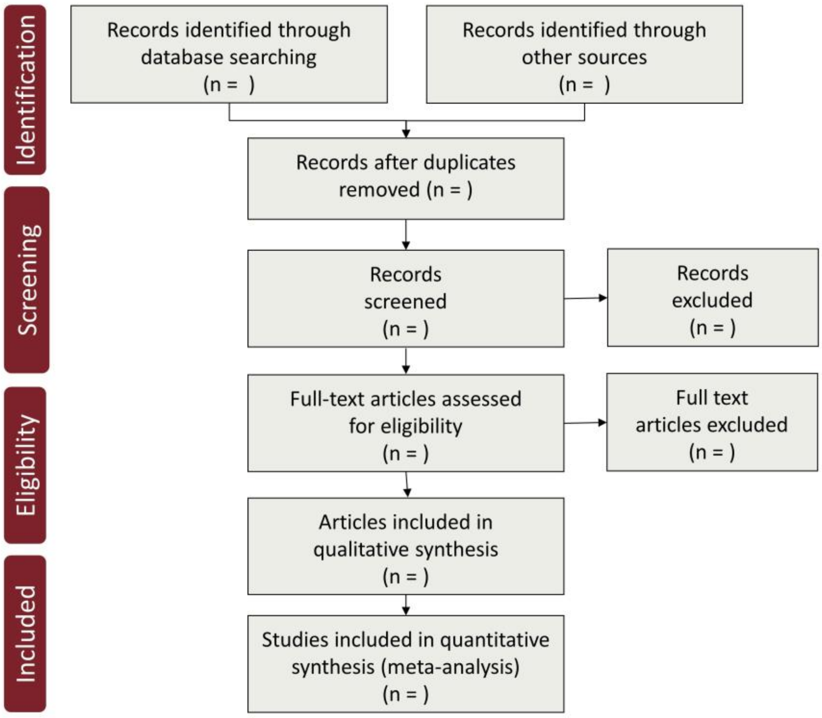

Figure 55: Preferred Reporting Items for Systematic Reviews and Meta-Analyses (Liberati et al., 2009; Moher et al., 2009)

Finally, SLR is not only an appropriate method to inform the DSR work conducted, but it also supports research question construction (Sandberg and Alvesson, 2011).

ii. Content analysis

Content analysis is a method applied to analyse predominantly textual content using quantitative or qualitative approaches. "In quantitative content analysis the process of categorization is running automatically, following a fixed algorithm, whereas in qualitative content analysis the assignment of categories to text passages always remains an act of interpretation" (Mayring, 2019, p. 1). In this sense, the quantitative content analysis uses category frequency or statistical methods, while qualitative analysis uncovers meaning using interpretation. Mixed methods or hybrid approaches can also be applied which can be called: "... a qualitatively orientated category-based content analysis ..." (Mayring, 2019, p. 2). Qualitative content analysis is bibliometric and can be used to analyse semi-structured interviews or published material. Mayring (2008) defined four steps of a content analysis, shown in Table 21.

Step	Description
Material collection	The material to be analysed is deliminated, and the unit of analysis is defined

Descriptive analysis	Formal characteristics of the material are assessed, providing the background for subsequent content analysis
Category selection	Structural dimensions and related analytic categories are selected to be applied to the collected material
Material evaluation	The material is analysed according to the analytic dimensions

Table 21: Process steps of content analysis (Mayring, 2015)

Hsieh and Shannon (2005) distinguished conventional, directed, or summative qualitative content analysis, which differs in coding schemes and origins. In conventional content analysis, codes are derived from the text data, while research findings guide the initial codes in the directed approach. The summative approach involves counting keywords and interpreting the context. Therefore, all three schemes interpret meaning from data and belong to the naturalistic paradigm (Hsieh and Shannon, 2005). Categories for classification of the reviewed material can be derived deductively or inductively, as visualised in the step models in Figure 56.

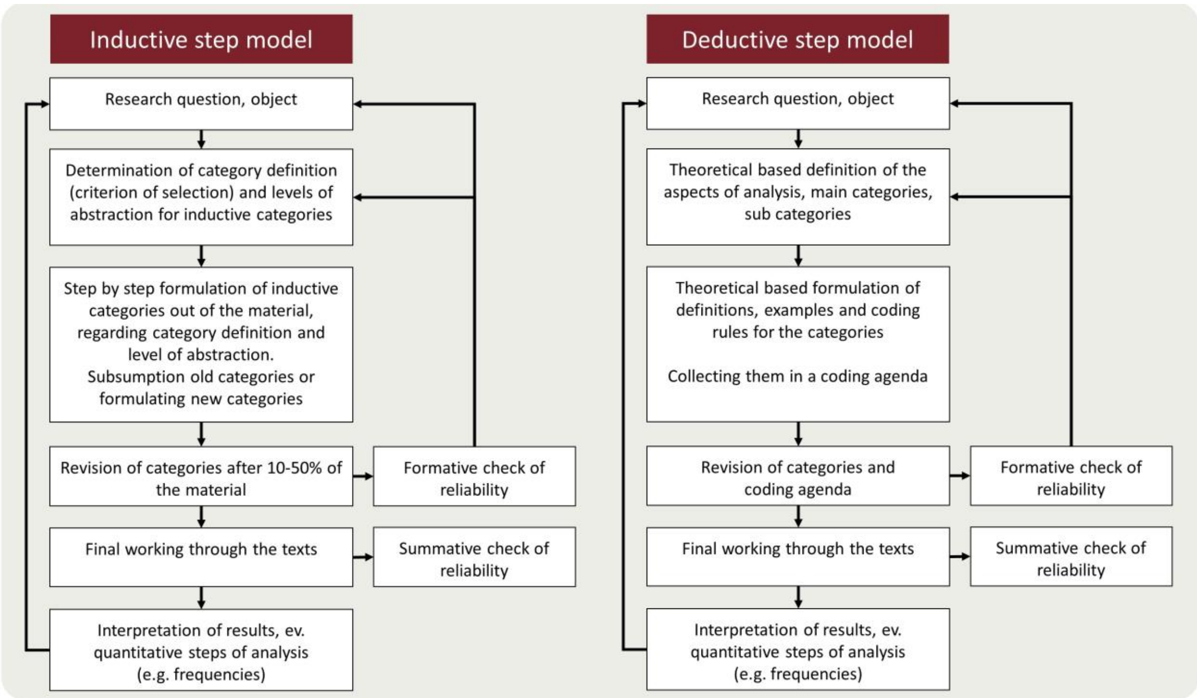

Figure 56: Inductive and deductive content analysis (Mayring, 2000)

In the deductive approach, categories are defined before assessing the material. In the inductive approach, categories are derived from the assessed material during the content analysis. Mayring (2019) distinguished eight different techniques for text comprehension and interpretation. These were summarising, inductive category formation, narrow context analysis, broad context analysis, formal structuring, content structuring, type-building content analysis and scaling structuring. Additionally, mixed evaluation methods can also be applied. The reliability of the content analysis can be enhanced by involving a team of researchers. Inter-coder reliability can be calculated with the Cohen kappa when using deductive approaches. In inductive approaches, discussions between the researchers can lead to assessment or code definition changes (Mayring, 2000, 2019; Seuring and Gold, 2012).

Qualitative content analysis is oriented to the research question, in contrast to open or explorative approaches such as grounded theory. It allows the processing of large quantities of verbal or visual data either from one's research or existing one where the latter is unobtrusive (Cho and Lee, 2014). The selection and argumentation of a specific approach to content analysis increase the trustworthiness and validity of the research work conducted. The same applies to the careful documentation of the process, code groups and codes applied.

iii. People, activity, context, technology

The people, activity, context and technology (PACT) framework supports human-centred user experience design by understanding how people use systems, which activities are performed in which context and the technology features applied. "People use technologies to undertake activities in contexts" (Benyon, 2020, p. 26). Consequently, changes in technology in hardware, software, communications and content imply a change of the activities in context, as shown in Figure 57. Activities within their context lead to technology demands for people to fulfil their tasks. According to Carroll (2002), technologies offer opportunities to influence and change activities. Designers take this context into account when creating interactive systems. In a backwards-looking approach, the four dimensions of the PACT concept can be used when analysing systems and structuring relevant knowledge.

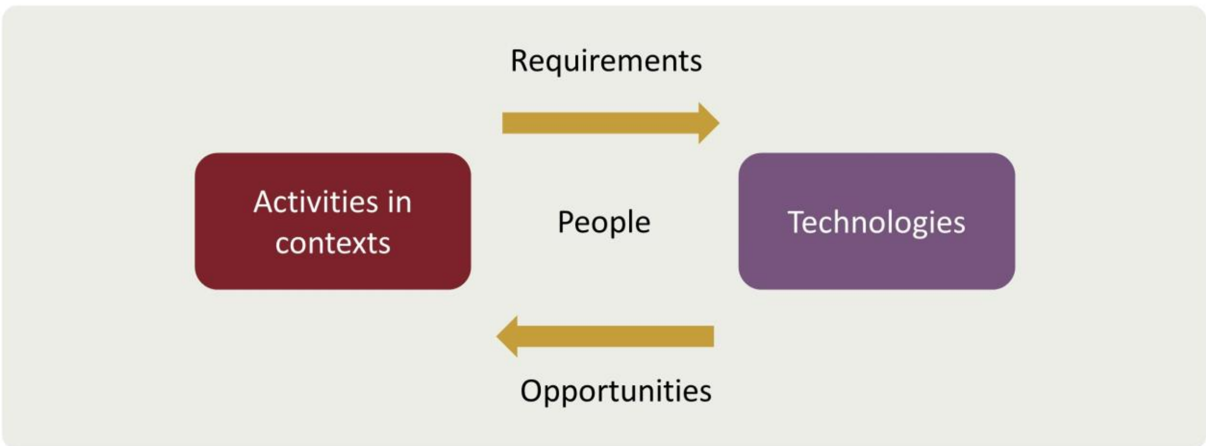

Figure 57: Activities and technologies, Benyon (2020) based on Carroll (2002)

The people dimension in the PACT concept reflects physical, psychological, mental, social and attitudinal differences impacting systems usage. Differences in physical characteristics and the five senses influence how people perceive technologies in context. Ergonomic DPs reflect these differences combined with psychology and work studies competencies. As described by Komlos (2004), they are often based on anthropometric research and applied as human factors in interactive systems design to improve efficiency, health, and safety. People also differ psychologically, for example, in their personality, emotions, spatial or memory capabilities, including their preferences for words or numbers, which impacts the design of user interfaces. The OCEAN model with the big five personality traits openness, conscientiousness, extraversion, agreeableness and neuroticism classifies people into personality types that can be used for system design or to understand the differences in job performance as described by Rothmann and Coetzer (2003). Mental models play an essential role in system design within the people dimension. People interact with systems and observe the system's behaviour from the perspective of their actions. In this way, and by studying supplementary material such as manuals, people build a mental system model (Norman, 2013). Overall, system design support people in forming correct and useful mental models. Additionally, the people dimensions reflect social and attitudinal differences among the system users.

Activities are distinguished by their cooperation, complexity, temporal and safety-critical characteristics, and demands on human-system interaction. This considers whether activities are performed individually or in groups, under time pressure or with interruptions. Likewise, frequently performed activities can be made simple, and activities that are not performed frequently can be designed to be easy to learn. Activities also influence the human-machine interface and its requirements. For safety-relevant activities, certain factors must be considered in systems design. For example, incorrect operation of systems in health applications can endanger patients. For this reason, activities for medical devices are examined in the light of relevant standards such as ISO 14971:2019 *application of risk management to medical devices* and IEC 62366-1:2015 *application of usability engineering to medical devices* (International Organization for Standardization ISO, 2015a, 2019a). The PACT concept also reflects how activities are performed using IS. The activities' context can be analysed under physical, social and organisational aspects. The place of system usage defines lighting conditions, background noise, humidity and temperature, Internet connectivity and system accessibility. Also, the service and maintenance aspects of technical systems are influenced by environmental conditions. The social and organisational context defines whether system users can rely on support from others, privacy issues, and social norms that can impact the acceptability of systems. The impact of IS on organisations has been subject to comprehensive research leading to the emergence of the academic field of Management Information Systems (MIS) as outlined by Kuechler, W. and Vaishnavi, V. (2008) and reviewed by Zhang (2013).

The technology dimension of the PACT concept finally focuses on the input and output modalities and communication and content factors. Input and output devices play an important role in designing interactive systems. The technical capabilities of input and output devices define how designers can create the human-machine interface. This includes the way and form of data input and output and the overall system control. Technical developments, for example, in sensor technology and data processing, offer possibilities for new system design whereby developments are often influenced by the consumer sector, as the example of Siri and Alexa shows. Consequently, Seymour et al. (2018) comprehensively presented the potential of Natural Face Technology (NFT) and enabled realistic and interactive avatars for emotionally engaging human-machine interaction. For example, displays in various qualities and shapes and innovation in vision technologies such as small and powerful projectors combined with camera technology can redefine the user experience of interactive systems. Also, voice and haptic output technologies combined with force-feedback loops are used to design the way users interact with systems. Finally, the technology dimension of PACT also includes communication aspects with its various forms and characteristics of wireless and wired networks and content elements. Content can be described as accurate, up-to-date, relevant, and by its presentation to system users in the form of pull or push strategies. The PACT framework can be used to design and analyse human-centred interactive systems (Benyon, 2020).

iv. Structured questionnaires

Questionnaire surveys provide a systematic form to collect data about people, preferences, and behaviours efficiently. Structured questionnaires are well suited to study individuals and can be used on-site or in remote settings when using online questionnaires. Furthermore, they can be used to survey entire countries or regions in a multi-language setup efficiently. Online questionnaires allow respondents to answer questions at their convenience. However, formulating questionnaires is time-consuming and must ensure those questionnaire items are understandable and unambiguous, generate productive data, and are easily analysed (Benyon, 2020). However, meta-analysis confirms that online questionnaires result in lower response rates than other research methods (Daikeler et al., 2020). Furthermore, biases must be considered when planning and conducting questionnaire-based surveys (Bhattacherjee, 2012). Several structured questionnaires have been developed and utilised in this dissertation. Both online and paper-based questionnaires were intensively used in the design cycles. The questionnaires consisted of both structured and unstructured questions. Structured questions were used for statistical evaluation, whereas unstructured open questions allowed participants to express their opinions and ideas. Furthermore, the standardised questionnaires System Usability Scale (SUS) and After Scenario Questionnaire (ASQ) was intentionally included in the questionnaire design. The questionnaires were optimised for high participation rates and combined with additional measures such as telephone calls to further increase the survey acceptance.

"Usability does not exist in any absolute sense; it can only be defined with reference to particular contexts" (John Brooke, 1996, p. 207) However, it is difficult to measure and compare usability between different systems. The standard ISO 9241 *Ergonomics of Human System Interaction, in particular, Part 210: Human-centred design for interactive systems*, refers to effectiveness, efficiency and satisfaction as aspects of system usability (International Organization for Standardization ISO, 2019b). To solve the problem, John Brooke described the often-referenced System Usability Scale (SUS) test as a reliable and low-cost method for assessing a system's perceived and subjective assessment of task-based usability. The SUS was developed using a pool of 50 potential questions that were tested. The questions leading to the most extreme responses and an equal amount of solid agreement and disagreement values on a five-point Liker scale were assembled.

As presented in Table 22, the SUS questionnaire measures the perceived system usability with ten questions that reflect the need for support, training, and the overall complexity of system usage. The questions are formulated with an alternating positive and negative tone. The responses on the 5-point Likert scale range from 1 equals *strongly disagree* to 5 equals *strongly agree* (Likert, 1932). The SUS is used after task completion, and users are asked to fill in the questionnaire before any peer discussions. All questions need to be answered, while the centre point should be selected if a user cannot respond to a question. The score contributions from each item are summed up to calculate the SUS score. Each item's score ranges from 0 to 4. For items 1, 3, 5, 7 and 9, the score contribution is the scale position minus 1, while it is five minus the scale position for items 2, 4, 6, 8 and 10. The scores are multiplied by 2.5 to obtain the overall SUS between 0 and 100.

SUS questions	**1**	**2**	**3**	**4**	**5**
I think that I would like to use this system frequently					
I found the system unnecessarily complex					
I thought the system was easy to use					
I think that I would need the support of a technical person to be able to use this system					
I found the various functions in this system were well-integrated					
I thought there was too much inconsistency in this system					

I would imagine that most people would learn to use this system very quickly					
I found the system very cumbersome to use					
I felt very confident using the system					
I needed to learn many things before I could get going with this system					

Table 22: System Usability Scale questionnaire (John Brooke, 1996)

Bangor et al. (2009) developed a scheme, as shown in Figure 58, that helps translate the 0 to 100 SUS scores into an absolute judgement of usability. For this purpose, they performed empiric studies with an extended version of the SUS questionnaire to create acceptability ranges that correlate with the SUS scores. The rating helps to understand and communicate SUS findings.

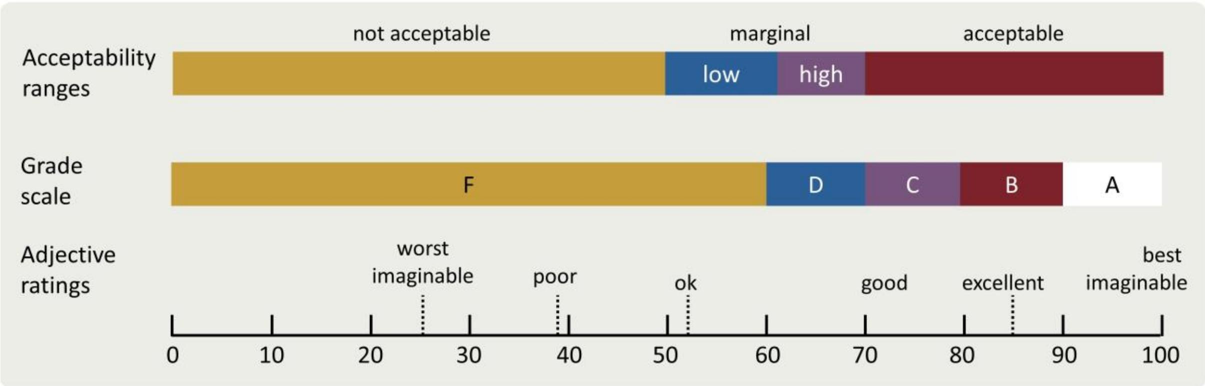

Figure 58: Comparison of SUS scores (Bangor et al., 2009)

Furthermore, Lewis (2018b) used data from 166 unpublished industrial usability studies with the SUS to model the relationship between single SUS items and the overall SUS score. The results allow researchers to benchmark single SUS items according to mean SUS scores for an experience of SUS=68 and SUS=80. Therefore, the values in Table 23 can be used to interpret single SUS items efficiently.

SUS questions	**Target for SUS=68**	**Target for SUS=80**
I think that I would like to use this system frequently	≥ 3.39	≥ 3.80
I found the system unnecessarily complex	≤ 2.44	≤ 1.85
I thought the system was easy to use	≥ 3.67	≥ 4.24
I think that I would need the support of a technical person to be able to use this system	≤ 1.85	≤ 1.51

I found the various functions in this system were well-integrated	≥ 3.55	≥ 3.96
I thought there was too much inconsistency in this system	≤ 2.20	≤ 1.77
I would imagine that most people would learn to use this system very quickly	≥ 3.71	≥ 4.19
I found the system very cumbersome to use	≤ 2.25	≤ 1.66
I felt very confident using the system	≥ 3.72	≥ 4.25
I needed to learn many things before I could get going with this system	≤ 2.09	≤ 1.64

Table 23: Item benchmarks for SUS questionnaire (Lewis, 2018b)

"The System Usability Scale (SUS) is the most widely used standardized questionnaire for the assessment of perceived usability" (Lewis, 2018d, p. 577). A comprehensive analysis of the SUS, including its psychometric properties, reliability, validity and sensitivity, has been conducted by Lewis (2018d). The author highlighted, among others, the flexibility of the SUS regarding minor changes and translations but recommended procedural steps to ensure error-free questionnaire completion. In an additional article, Lewis analysed the relationship of the SUS with the Computer System Usability Questionnaire (CSUQ), proving that CSUQ scores can be interpreted by applying a grading scale (Lewis, 2018c). In recent work, Lah et al. (2020) elaborated on the relationship between measures of perceived usability and the Perceived Usefulness (PU) and Perceived Ease of Use (PEU) components of the modified Technology Acceptance Model (mTAM). The authors provided evidence that Perceived Ease of Use (PEU) measures perceived usability.

Zwakman et al. (2021) analysed the suitability of the SUS as a standardised measurement method for AI-based voice assistant usability using explanatory factor analysis. They anticipated differences between GUI and voice-based systems and proposed the Voice Usability Scale (VUS) based on Amazon's Alexa voice assistant analysis. The authors suggest that VUS overcomes the drawbacks of the SUS for measuring voice-assistant usability.

The After Scenario Questionnaire (ASQ) developed by James R. Lewis (1991) consists of three questions to capture the ease of task completion, satisfaction with the time needed for the task completion and satisfaction with the supporting information during task completion. The participants answered the questions listed in Table 24 immediately after completing a scenario-based usability study.

ASQ Questions	1	2	3	4	5	6	7
Overall, I am satisfied with the ease of completing this task.							
Overall, I am satisfied with the time it took to complete this task.							
Overall, I am satisfied with the support information (online help, messages, documentation) when completing this task.							

Table 24: After Scenario Questionnaire (Lewis, 1995)

The responses on the 7-point Likert scale range from 1 equals *strongly disagree* to 5 equals *strongly agree*. The corresponding ASQ score is calculated using the arithmetic mean of the three response values. If the participants do not answer all questions, the ASQ is calculated by averaging the responses. James R. Lewis (1991) presented a psychometric evaluation that shows that the three items can be summarised to one common result, which supports easy reporting of studies results (James R. Lewis, 1991; Lewis, 1995).

Finally, the *modular evaluation of key Components of User Experience* (meCUE) questionnaire was applied to measure the user experience of technical products in specific case study scenarios. The meCUE is scientifically founded and focuses on acquiring user experience with interactive technological devices. It consists of four validated modules for product perceptions, user emotions, consequences of usage, and a judgment of attractiveness. The meCUE questionnaire can also be adapted to specific research tasks because of its modular form (Minge et al., 2017; Minge, 2018).

v. Interviews, group discussions and focus groups

Interviews, group discussions and focus groups effectively gather information from various stakeholders. Interviews and discussions can be organised in unstructured, partially structured or highly structured forms and conducted face-to-face, via telephone or by video conference. Non-standardised forms are, for example, narrative interviews, while more structured forms can be performed as guided interviews or panel discussions (Raithel, 2008). Structured interviews are thoroughly prepared, and the interviewer follows a defined path of formulated questions. Structured interviews can be prepared and conducted with a reasonable effort, but the interviewer needs to be able to manage unexpected responses. In semi-structured interviews, the interviewer uses a set of prepared questions but can also note additional data and explore new topics of interest. Such interviews are more demanding for the interviewer, but more information can be gathered (Benyon, 2020). Different types of data analysis are used depending on how the interviews are conducted. Narrative interviews are often first transcribed before being coded in the content analysis. Video interviews can also be coded directly using expert software for qualitative analysis (ATLAS.ti GmbH, 2021). In semi-structured interviews, the free responses are often clustered for subsequent analysis. Structured interview results, on the other hand, can be directly analysed quantitatively and statistically using expert software (IBM, 2021).

Focus groups are an informal technique used in various areas, including ergonomic design (Caplan, 1990). Small groups of six to nine users are brought together for a limited time. The focus group, led by a moderator, discusses new concepts and identifies issues for two to three hours. This situation often leads to a group dynamic with spontaneous reactions and new creative ideas. The moderator follows a structured approach, often with a preplanned script. Overall, the moderator must guide the group interaction without limiting the discussion. Several focus groups should be performed for the findings to be more representative. Focus groups can discuss either hypothetical systems or use system prototypes. Following the users' written consent, focus groups can also be video recorded for subsequent analysis, for example, using qualitative analysis software (ATLAS.ti GmbH, 2021).

Overall, focus groups are time-consuming concerning preparation, conduction and analysis. In particular, the analysis of the unstructured data can be elaborated in terms of resources (Nielsen, 1993). "... focus groups can be effectively designed, fielded, and analyzed from varying perspectives and priorities" (Tremblay et al., 2010, p. 600). Focus groups are appropriate for DSR because they allow comprehensive discussions regarding the artefacts developed. Focus groups are flexible, allow direct interaction with participants, provide large amounts of rich data, and one can build upon comments of other respondents. They also facilitate critical analysis of research results and can generate new possibilities to obtain better solutions to problems (Tremblay et al., 2010). As shown in Figure 59, Tremblay et al. (2010) presented two types of focus groups that can be used to evaluate artefacts developed by DSR. Exploratory focus groups are used to achieve incremental improvements in the design of artefacts. Artefacts are reviewed in the focus groups, and changes are implemented accordingly. Confirmatory focus groups demonstrate the utility of the developed artefacts in the environment of the application field.

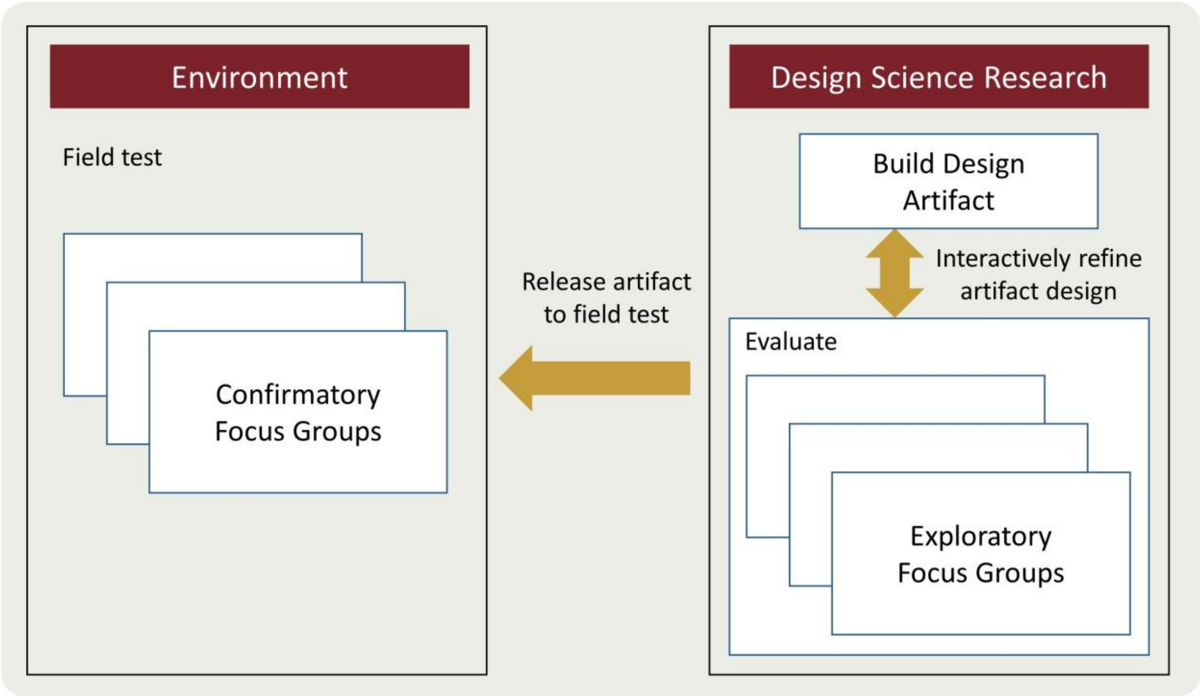

Figure 59: Focus groups in Design Science Research (Tremblay et al., 2010)

According to Bruseberg and McDonagh-Philp (2002), focus groups can also be combined with other techniques. Focus groups have been applied for industrial and healthcare design work, and "Designers ... need to understand that consulting users directly is not a way to take away the task of designing from designers, but to enhance their designing process through deep immersion into the user experiences, aspirations, and dreams" (Bruseberg and McDonagh-Philp, 2002, p. 36).

vi. Case study

The goal of single or multiple case studies is to understand social phenomena of complex real-life problems by collecting and analysing empirical evidence. "... case studies are the preferred strategy when "how" or "why" questions are being posed, when the investigator has little control over events, and when the focus is on a contemporary phenomenon within some real-life context" (Yin, 2003, p. 1). Therefore, "... case studies tend to be exploratory, descriptive, and explanatory ..." (Dresch et al., 2015, p. 22). Case studies observe and analyse real phenomena within their context and are well-suited when the boundaries between phenomenon and context are not obvious. Case studies rely on multiple sources of evidence and can benefit from prior propositions. They are often based on quantitative or qualitative methods, including questionnaires before and after case study execution, observations, and group discussions. Four major types of case studies can be distinguished. Single and multiple-case studies, as well as holistic and embedded ones, as shown in Figure 60. Multiple case studies are more robust but require high effort for preparation, execution and evaluation (Yin, 2003).

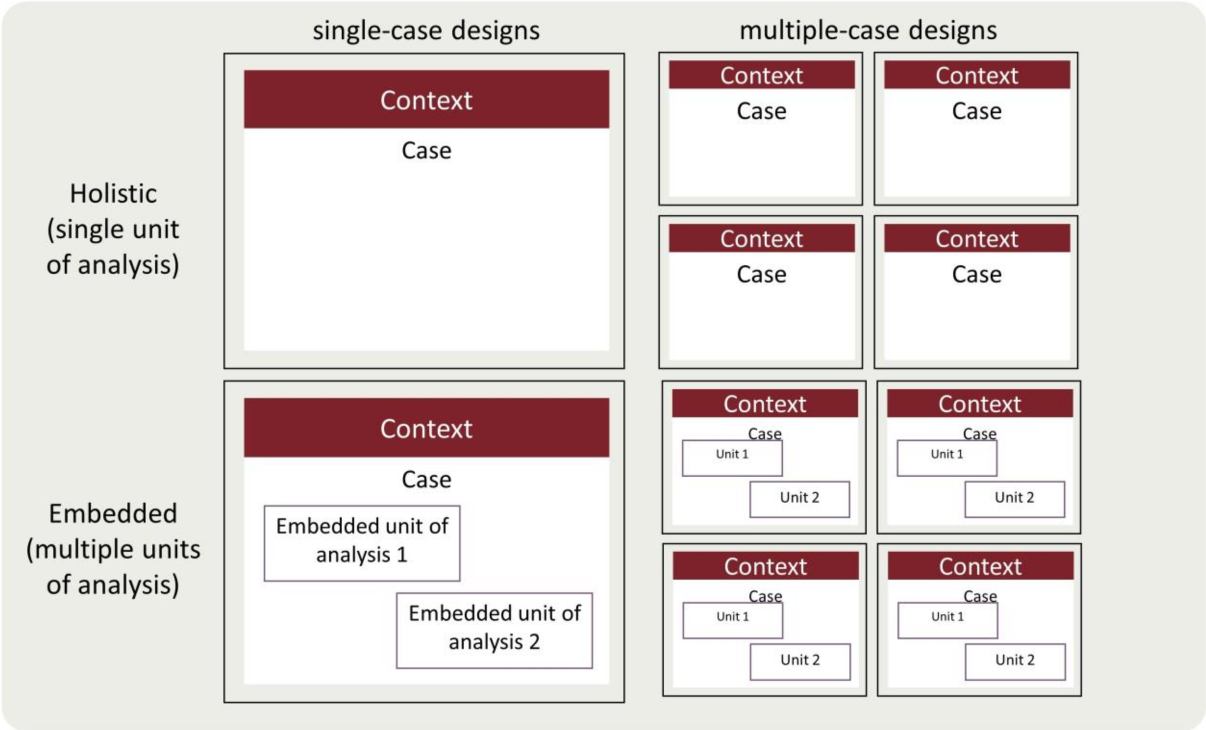

Figure 60: Classification of case studies (Yin, 2003)

Several methods can be used to increase the validity of case studies. Besides using multiple sources of evidence, case study reports can also be reviewed by experts. Pattern-matching can increase internal validity, while external validation can use theories or replication of case studies. Reliability of case studies should be secured by preparing case study protocols. The preparational design of a case study defines the research questions, corresponding case propositions, the unit of analysis, the logic that links data to propositions and the criteria for result interpretation (Yin, 2003). In this dissertation, several case studies have been conducted. The multiple-case study design was mainly selected with the embedded multiple units of analysis. The conduction of the case studies included the technical preparation of the case environment, the training and preparation for the specific case study, the development of participant and observer questionnaires, the development of case study protocols, screening of candidates, conduction of pilot cases and the final execution of the case studies. In summarising, it can be stated that "Using case studies for research purposes remains one of the most challenging of all social science endeavors" (Yin, 2003, p. 1).

vii. Observations

Observation of users at the workplace or in a defined case study is a standard method in usability engineering and provides information that can complement usability testing. In doing so, the observer should not interface with the observed scenario but instead, be quiet and virtually invisible with the goal that the users work with the systems in their usual way. The observer should document the findings and take notes of situations that could be discussed during a debriefing session. Towards the end of an observation session, the observer can start interacting with the user to potentially collect additional information, for example, about features that the user did not utilise. Observation can reveal unknown user behaviour and thus help to improve system design (Nielsen, 1993). Observation can also be supplemented by a video recording requiring the users' written declaration of consent (Bundesamt für Justiz, 2022).

A particular form of observation originating from product design is the contextual inquiry, according to Beyer and Holtzblatt (1998) and Holtzblatt (2012). The observation takes place at the user's workplace. The users are observed while performing their tasks. In passive inquiries, the observation is followed by a discussion with the user, while in active inquiry, questions are asked during the observation. The four contextual inquiry principles are context, partnership, interpretation and focus, as listed in Table 25. Contextual inquiry is based on the immersion of the observer into a situation. Reflection and understanding provide input on multiple aspects of product usage at the workplace.

Contextual inquiry principles	Description
Context	Work tasks should be observed within their context at the actual workplace. User stories can help during the observation.
Partnership	Participants are experts in their field and contribute to the design. The observer understands patterns in the scenario while the user contributes with expert knowledge.
Interpretation	The observed scenario must be interpreted, including abstraction, to create conceptual interpretations.
Focus	The workplace observation should focus on a particular aspect.

Table 25: Principles of contextual inquiry (Beyer and Holtzblatt, 1998; Holtzblatt, 2012)

This dissertation applied observations in individual case studies during the design cycles. The findings were documented in customised observation questionnaires, which, among other aspects, also reflected the user experience. Furthermore, the knowledge base was continuously increased in the industry and healthcare application domains through numerous on-site visits and expert discussions based on the contextual inquiry method.

viii. System modelling

System modelling has its foundations in the system and general systems theory, according to Bertalanffy (1968). It conceptualises natural or artificial systems, including functional, architecture and data structures. System modelling is the basis for analysing and simulating systems in application areas. It helps to explain real systems and supports comparison and extrapolation. In system engineering, system modelling helps formulise development requirements and often supplements specifications in Technical Data Packages (TDP). Systems can be modelled with an external perspective focusing on interactions with other systems within the context. Such context models also define the boundaries of a system. System models can also be behavioural, such as state diagrams, reflecting how systems react to external stimuli. Structure models present the system's different modules, including the data architecture. Data processing modules detail how data is processed at various stages, while classification models visualise common characteristics of entities. On the other hand, process models visualise the processes supported by a system. Process models can be complemented by data flow models that show how information flows from one process to another (Haberfellner et al., 2019; Shea, 2020). Two forms of system modelling, both with their ontology, semantics and syntax, are used in this dissertation. First, Business Process Modelling Notation (BPMN) was used to describe healthcare applications' business processes, workflows, and information flows (OMG Object Management Group, 2022). Second, Unified Modelling Language (UML) was used to describe the architecture of a conceptual artefact designed in a DSR cycle (Object Management Group, 2017).

ix. Discrete event simulation

Discrete Event Simulation (DES) is a modelling technique that simulates complex systems' behaviour and environment, including the interaction between individuals and entire populations. The term discrete reflects the fact that the time flow of the simulation is based on time intervals between specific discrete events. This reduces the simulation time and increases modelling flexibility. Initially developed for industrial engineering and operations research, DES is often used for healthcare simulation and optimisation. DES models are based on entities, attributes, events, resources, queues and time, as shown in Table 26 (Karnon et al., 2012).

Core elements	Description
Entities	Entities are objects with attributes that consume resources and react to events. The objects enter queues. In healthcare models, entities are often patients.

Attributes	Attributes are specific features of entities such as age, sex, and health status. Attributes can change and are used to determine the behaviour of entities.
Events	Events can happen to entities or the environment in any logical sequence.
Resources	Resources are objects that entities can use to provide services to entities. Resources can be treatment devices, physicians, or nurses in healthcare models.
Queues	Entities are queued if a resource is occupied. Queues have a maximum capacity and a handling strategy.
Time	A simulation clock references the time of the simulation, which is organised into discrete events.

Table 26: Core elements of DES models (Karnon et al., 2012)

Zhang (2018) analysed the application of DES in healthcare decision-making by systematically reviewing the academic literature. He identified the four leading application categories *health and care systems operation* (65%), *disease progression modelling* (28%), *screening modelling* (5%) and *health behaviour modelling* (2%). More than 68% of the *health care and care system operations* models simulated problems of individual healthcare centres or hospitals. A healthcare example is presented by Werker et al. (2009), who developed a simulation model to reduce radiotherapy planning and patient waiting times. A simulation as an experimentation of real-world systems with a simplified model is sometimes the only way to investigate alternative scenarios. Real-world testing could be too time-consuming, expensive, or even dangerous. Parametric simulation models provide the additional advantage of influencing the system behaviour during simulation (White and Kane, 2007). This influence could also be dynamic by connecting the model with a real object:

> "Sensors that allow for continuous monitoring of technical systems increasingly make it possible to create such individualized dynamic models. This type of model has been termed 'Digital Twin,' since it closely represents the inner state of the physical twin object."
>
> (Bruynseels et al., 2018, p. 3)

Wright and Davidson (2020) highlighted the difference between a model and a Digital Twin. According to the authors, the Digital Twin is characterised by a model of the object, evolving data related to the object, and dynamically updating the object model. The authors claim that "Digital twins are of most use when an object is changing over time, thus making the initial model of the object invalid, and when measurement data that can be correlated with this change can be captured" (Wright and Davidson, 2020, p. 4).

Finally, a prerequisite for DES is that the system's state is fully described at each instant in time. In contrast to continuous simulations, the system state does not change between two events. The changes between the system states are often modelled with transition probabilities. Therefore, multiple simulations with the same input parameters will create stochastically distributed results which need to be interpreted accordingly. In this dissertation, DES is used in one design cycle to evaluate the impact of risk mitigation measures on radiotherapy business KPIs.

f. Expert software utilised

In the context of this dissertation, expert software was used. The software tools made specific design tasks possible in the first place or simplified them to a considerable extent. The software used includes both analysis and modelling tools. The software packages are briefly presented ordered by frequency of use to support a better understanding of their use in the design cycles.

The *Citavi* literature management and knowledge organisation software was used in the SLRs to search, categorise, screen, and evaluate the abstracts of the publications. The cloud-based version supported collaborative work within the research team, for instance, validating the literature screening to increase research rigour (Swiss Academic Software, 2021).

The *ATLAS.ti* software was intensively used for structured qualitative data analysis in design cycles. ATLAS.ti supports various coding forms and analysis of the codes in code trees and co-occurrence tables. The software was used to code documents and analyse interview recordings. Furthermore, the RT workflows were analysed with ATLAS.ti based on videos from RT practice (ATLAS.ti GmbH, 2021).

The *Limesurvey* software was used to create online questionnaires, conduct surveys, and analyse industrial and healthcare projects' results. The software supports common question and answer schemes and the design of an optimised implementation for the survey (LimeSurvey GmbH, 2021).

The software *SPSS* was utilised for statistical analysis of research results. The results of the online questionnaires were mapped in structure and content in SPSS and statistically reviewed. Descriptive statistics functions with distributions, means, and standard deviations were used (IBM, 2021).

The business process modelling software *MS Visio* supported the modelling of RT business processes based on UML. The business processes, underlying IT systems and staff responsibilities were modelled in swim lanes. The process diagrams visualised the complex relationships and interactions and were used in expert discussions and as the basis for further research projects (Microsoft, 2022).

The *Unity®* development platform for creating and operating interactive, real-time 3D content was utilised in a bachelor thesis supervised by the author of this dissertation. *Unity®* was used to develop and deploy a Digital Twin model for subsequent case study analysis (Unity Technologies, 2022).

Google Dialogflow is a cloud-based service within the Google Cloud environment that can be used to develop AI-based conversational chatbots. The service is based on the deep learning technologies of Google Assistant. Virtual agents using Natural Language Understanding (NLU) models were defined and could recognise the intents and the context of use cases and act accordingly. Google Dialogflow was used to implement a text-based conversational chatbot (Google Cloud, 2021).

The *AnyLogic* simulation software allows modelling, simulating, and optimising complex systems and processes for industry and healthcare. The software enables the modelling of real-world problems, supports experimentation on digital system representations and provides 2D and 3D visualisation features. The *AnyLogic* simulation modelling software was used within this dissertation to analyse RT processes (The AnyLogic company, 2021).

The web-based *diagrams.net* software allows the creation of diagrams to visualise complex processes and structures. The features include, among others, the creation of flowcharts, UML, network diagrams, mockups and system architectures. This dissertation used the software to create the system architecture of the target design and selected use cases (JGraph Ltd, 2021).

The *f4transkript* software supports the manual transcription of recorded interviews. It supports manual typing, correction with variable speed control, timestamps, comments and automation of tasks. The software was used to transcribe a series of interviews for the subsequent content analysis (dr. dresing & pehl GmbH, 2021).

The Siemens® *Totally Integrated Automation Portal (TIA)* includes software for programming PLCs and HMIs. It allows access to the automation project, from planning to engineering and operation. TIA was used to configure and programme the components of the CPS used in one case study (Siemens, 2022).

The *Fibersim* software supports the design and manufacturing of composite parts, considering the part geometry, material behaviour and manufacturing processes. The software was used to prepare a case study for producing composite parts (Siemens Digital Industries Software, 2020).

The *ergoCAM* software is a tool for planning and preparing cutting processes. It was used to prepare a case study for composite production (ProCom Automation, 2021).

AUTODESK® Inventor is a comprehensive software tool for 3D mechanical design, documentation and product simulation. The software was used to design and simulate load models for creating a CPS for a case study (Autodesk, 2022b).

The *Rhinoceros 3D* software is a cost-efficient software tool for 3D mechanical design and simulation. The software allows the integration of user-specific plug-ins and was used for one design cycle to improve work processes (Robert McNeel and Associates, 2022).

g. Reflection and conclusion

The DSR paradigm, combined with the qualitative and quantitative research methods, provides a sound framework for the investigations of this dissertation. However, the selection, preparation and application of numerous research methods are very time and resource-consuming. Furthermore, the methods must adapt to the changed objects of investigation. For this, the IS community undertakes further efforts to extend the analysis methods to cope with the new challenges of the digital world. For example, Cecez-Kecmanovic et al. (2020) highlight new approaches for investigating digital trace data from machines or human operators that could be used in future research.

6. Design science research cycles

In this section, the DSR framework, supported by research methods, is applied to twelve design cycles in the industry and healthcare path to answer this dissertation's research questions. Expert software supports the investigations at various artefact build and evaluation stages. A design concept was developed to position and visualise the selected application fields of the industry and healthcare path within the underlying DSR framework. Applications from composite production, manual assembly and radiotherapy have been deliberately chosen to represent important areas of a global business on the one hand and applications of laser-based assistance on the other hand.

a. Design concept

The design cycles are first presented within the overall design concept to allow a better comprehension. The DSR framework with the three units *Environment*, *Design Science* and *Knowledge Base* and the *relevance*, *design* and *rigour* cycles is presented in Figure 61. The industrial path is divided into two sub-areas No. 1 *composite preforming* with one design cycle and No. 2 *industrial assembly* with six design cycles. The healthcare pathway is divided into two sub-areas No. 3 *radiotherapy cancer treatment* with two design cycles and No. 4 *radiotherapy business continuity* with three design cycles. Abstract design principles are derived from the different design cycles, adding to the overall knowledge base. Finally, a taxonomy of DPs and reference model for designing socio-technical systems for labour-intensive processes are developed, presented and verified.

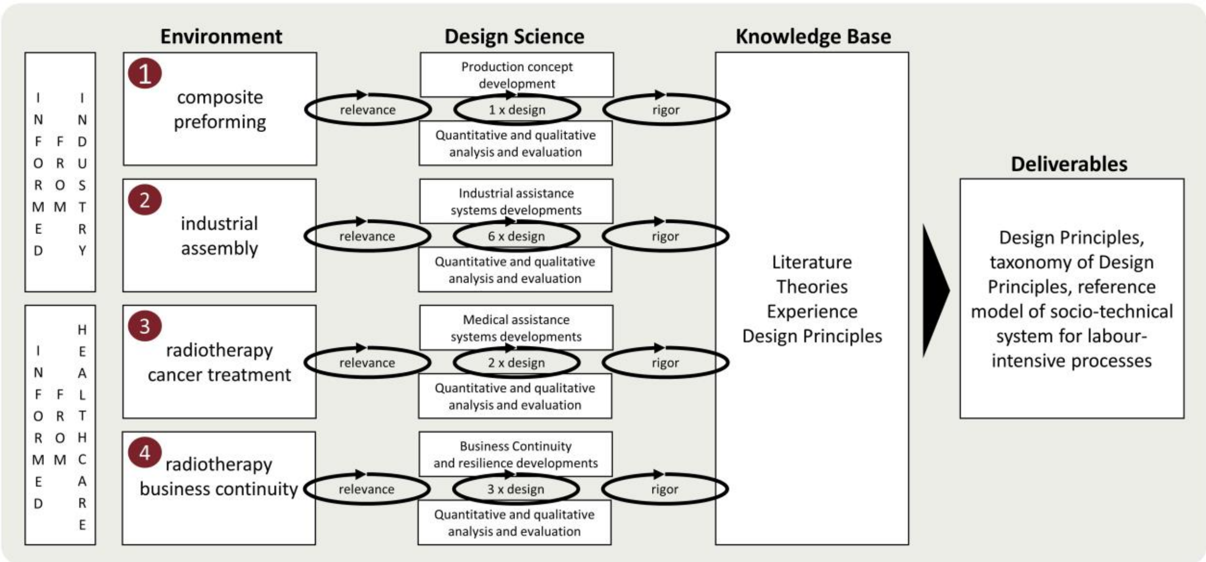

Figure 61: Design Science Concept overview (own figure)

The details of the single DSR cycles are presented using the categories of Kuechler, B. and Vaishnavi, V. (2008) and flow charts as presented by Francisco and Da Klein (2020). The uniform structure and presentation method secure research transparency. The knowledge contribution is reached following reflection, abstraction and circumscription discussions leading to the formulation of DPs according to the structure of Romme and Endenburg (2006).

b. Design cycles industry path

In the following section, the individual design cycles of the industry path with the selected application fields are presented.

i. Assistance system for manual composite preforming

Awareness: Production is increasingly digitalised and automated, changing the work conditions in composite manufacturing. These changes pose challenges for SMEs, which benefit from the experience of their employees, often acquired over many years of service with the company. At the same time, those employees provide flexibility in production to SMEs. However, the high degree of manual work also increases the production cost (Matt et al., 2020). Conventional automation solutions are expensive and often have a limited value for SMEs (Zheng et al., 2019). Semi-automated assistance systems designed for composite preforming could be a solution to increase effectivity and efficiency in SME composite production lines while simultaneously providing quality workspaces for production workers and the ageing workforce. Thereby, the goal of lower production cost, increased flexibility, higher versatility and the creation of quality workspaces could be reached (Dammers et al., 2020).

Suggestion: It is suggested that the introduction of well-designed, cost-effective production cells based on laser assistance enables SMEs to semi-automate composite production. These solutions could increase process efficiency, minimise human errors, and offer quality-ergonomic workspaces with high production flexibility (Müller-Polyzou and Georgiadis, 2018). Thus, the design of such systems should focus besides economics also on system acceptance and subjective benefits for production workers on the shop floor. Laser-based production cells can assume different configurations. A standardised production cell with one laser projection system, one infrared calibration camera and composite moulds on wheels is proposed as a tentative design in Figure 62 (Dammers et al., 2020).

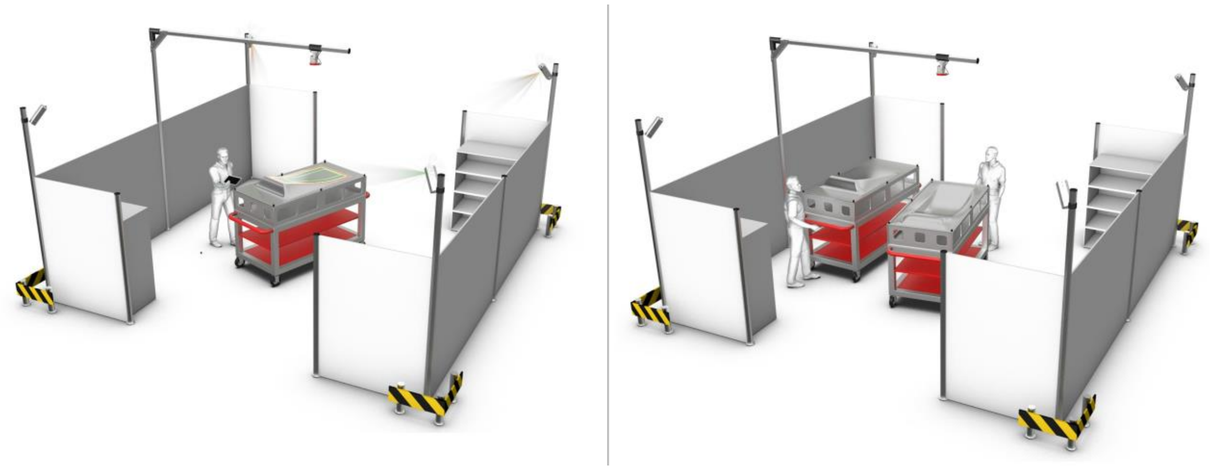

Figure 62: Laser-based production cells (with courtesy of LAP GmbH Laser Applikationen)

Development: A semi-automated production cell was designed and implemented in a composite shop floor scenario at the Institut für Textiltechnik (ITA) of RWTH Aachen University (Institut für Textiltechnik of RWTH Aachen University, 2022). The instantiation included a laser production cell with camera-based automatic calibration, adjacent material loading from a ply cutter table, and an automotive composite mould on wheels for free positioning within the production area. Work instructions for composite preforming were created for an automotive bonnet of Porsche 964 Singer Vehicle Design 1990 (Singer Vehicle Design, 2021). The instructions were created as paper-based ply-book and digital work plans for two composite workers forming one production team. The paper-based ply-book included ply position and draping information. The lay-up was designed using Siemens Fibersim and included a draping simulation based on a glass fabric 163 g/m² with warp 12 ends/cm and weft 11.5 ends/cm (R&G Faserverbundwerkstoffe GmbH, 2022; Siemens Digital Industries Software, 2020). The design had large-scale, geometrically complex and small strengthening plys. Afterwards, the 14 plys were nested using the software ergoCAM and cut on a CNC cutter machine Premiumcut 1620 (Bullmer, 2020; ProCom Automation, 2021). The created artefact of this design cycle is an industry-type instantiation of the semi-automated laser-based production cell, including material loading and tools storage (Dammers et al., 2020; Kehr, 2020).

Evaluation: A comparative dual perspective user study was conducted using a case study with an A/B test, as shown in Figure 63. The eighteen participants formed three groups with teams of two participants each. Group one consisted of three teams with randomly selected students of technical studies. The second group consisted of three teams with students with experience in composite preforming. The third group consisted of professional composite workers. The study was conducted to analyse the efficiency and usability of the system instantiation as a cooperative assistance system. The system was therefore compared to paper-based ply books as a reference. The production efficiency and accuracy were evaluated using objective measurement data. The perceived usability, effectiveness, and efficiency were measured using the SUS and the ASQ methods supported by the observation of participants.

Figure 63: Composite preforming case study at RWTH Aachen (own figure)

The comparative user study in the form of a case study included multiple cases and embedded multiple units of analysis. The study was dual-perspective, reflecting the usability interests of system users and efficiency interests of factory decision-makers. Aggregated results and deviations were analysed:

Results:

- Average production time savings of 45.4% were achieved using the designed system compared to paper-based ply books. The time savings varied with the complexity of the composite plys and the experience level of the participants.
- Using the system, the position accuracy of plys increased, particularly for multi-stack lay-ups.
- Only minor differences in the angular accuracy of the fibre orientation were recognised between the two methods.
- Composite lay-up errors were eliminated using the designed system.
- The system achieved a perceived SUS of 84.2%, reflecting excellent system usability.

Deviations:

- The angular accuracy of the composite ply lay-ups was only slightly improved. However, statements from the workers relativising the importance of fibre orientation reflect the importance of independent and automatic fibre orientation control.
- The system performance was negatively affected by covered laser targets and workers' shading of the laser projection. Calibration of the laser projection system requires laser reflector targets. The system does not function without successful calibration.
- The flickering of the laser projection was found to be disturbing. A better quality of the laser projection was mentioned as a suggestion for system improvement.
- Usage of the system IR remote control interrupted the work process unnecessarily.

Conclusion: The designed artefact is a flexible semi-automated production system that supports the business requirements of SME composite manufacturers. The system reaches high perceived efficiency and effectiveness, confirmed by the measured task fulfilment and position accuracy values. The production cell represents a quality workspace for manual composite preforming at SMEs and in smart factories supporting production workers' system acceptance (Dammers et al., 2020). In response to the first research question, the artefact presents an example of how a quality workspace in manual composite production can be designed.

Knowledge contribution:

Reflection:

- The high SUS supports the ease of use measure of technology acceptance (Lah et al., 2020).
- Information density provided in-situ on the work area is satisfying for workers. However, besides the CAD contours, the evaluated system supported only additional text-based information projected onto the work tool.
- The projection of a few geometries simultaneously seems not to overstrain users' memory.
- The in-situ projection keeps the user's attention on the work task and eases the user's navigation in the workspace through visual perception. However, attention has to be divided using the IR remote control.
- The system artefact is practical support for labour-intensive composite preforming. No barriers exist to the fast teach-in of laypeople, and the system is suitable for the ageing workforce.
- The cell-based approach allows the system to be deployed in sizeable composite production lines using push and pull principles.
- Production cells are cost-efficient for SMEs. Only limited security concepts are needed, and laser systems require low maintenance.

- The system has a high degree of flexibility because of the mould on wheels. Partial automation by camera-based mould recognition and subsequent import of work plans is feasible.
- Simultaneous work on two or more moulds of different sizes in one cell is possible.
- The system shows high ergonomics because users can move the moulds freely within the cell area, change the mould's working height, and determine the speed of the worker guidance.
- The projection frequency must be ergonomically dimensioned according to the application. It is expected that flickering hinders the visual perception of users and increases arousal.
- The system supports overall process stability by automatic laser projector calibration.
- The system can be integrated into production systems or function stand-alone without any dependencies. It is robust and supports production resilience.

Abstraction:

- The production cell concept is not bound to composite preforming, but can also be used for other applications such as assembly tasks.
- Semi-automated assistance systems can create quality-ergonomic workspaces supporting flexibility and versatility in production.

The design principles presented in Table 27 are derived from the reflection and abstraction process as knowledge contribution in the *improvement* area, according to Gregor and Hevner (2013).

DP	Description
DP I1.1	For the design of assistance systems in semi-automated workspaces, to achieve high user acceptance and subjective perception, a user-centric design shall be applied to the system, workspaces, material handling and tooling.
DP I1.2	For the design of assistance systems in semi-automated workspaces, to secure process stability of manual tasks and to provide quality assurance to process responsible employees and workers, automatic process control methods should be applied.

Table 27: Design Principles industry cycle one

The design process with the related activities is depicted in Figure 64 according to the phases described above.

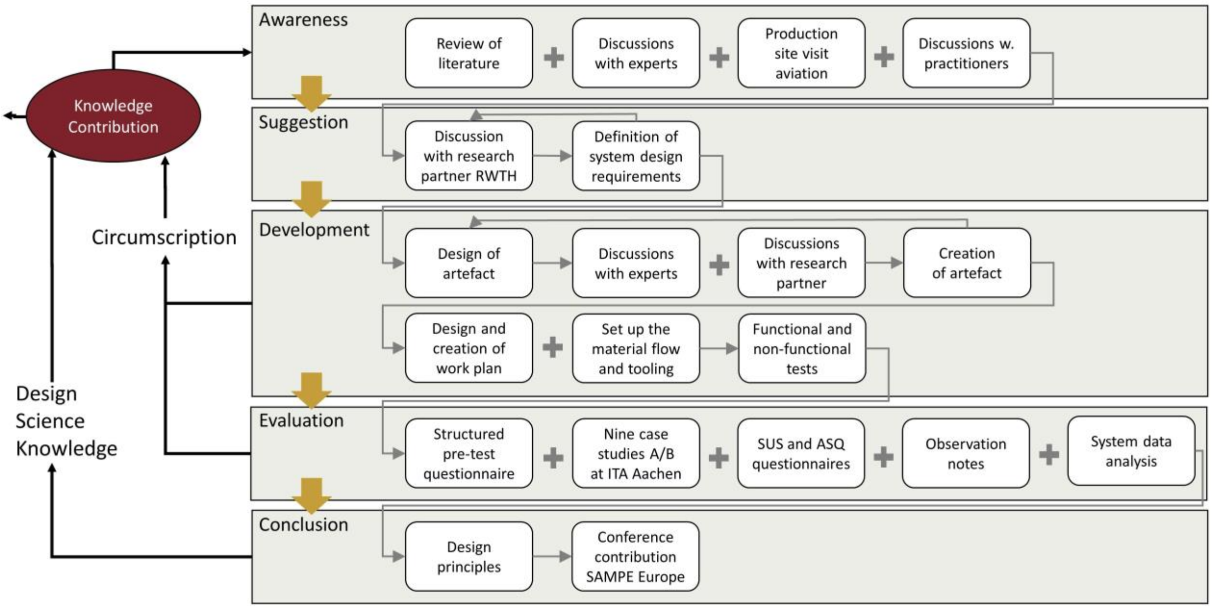

Figure 64: Design Cycle Assistance system for manual composite preforming (own figure)

Transfer challenges remain for applying the formulated DPs in adjacent industries. The work tasks for composite preforming are particular. Sticky material is used, and tools are specially adapted for the composite preforming process. The quality requirements, especially in producing parts for the aviation industry, are high. Reworking, if at all possible, is associated with high effort and costs (Dammers, 2022). On the other hand, there are no significant restrictions regarding the component size, as small, medium, and large components can be produced using the preforming process. The question that remains is whether the DPs can be transferred to manual assembly tasks. Furthermore, it should be evaluated whether the DPs elaborated from the teamwork scenario could be transferred to single-person workstations still reaching high perceived usability. Finally, whether semi-automated laser assistance systems can be integrated into the digital factory concept should be investigated. Further design cycles and evaluations are therefore proposed.

ii. Cyber-physical assistance system for manual assembly

Awareness: The smart factory is characterised by the high connectivity of intelligent devices in a network of CPS, which are horizontally connected and vertically integrated with management systems. Integrating industrial automation and control technology with manual assembly systems could create CPSs that offer opportunities for manufacturing companies. Companies could, for example, benefit from an incremental transformation toward the digital factory, thereby securing cost-efficient reconfiguration of production systems. Furthermore, integrating modern technology could create quality workspaces for shop floor workers compensating for some effects of the demographic change

(Meier and Mueller-Polyzou, 2018; Müller-Polyzou et al., 2018; Müller-Polyzou et al., 2020; Müller-Polyzou, Meier et al., 2019).

Suggestion: It is suggested that the deployment of a well-designed CPS for manual assembly tasks with the integration of feature-rich automation technology can create quality workspaces for digital factories. Additionally, it is anticipated that the system's horizontal and vertical integration will increase the efficiency of the manual assembly process. Finally, industrial-type automation and control technology supporting standardised communication protocols should support the system's versatility. A corresponding CPS for manual assembly shall be designed and integrated into a digital factory.

Development: An instantiation of a single-person laser-based CPS for manual assembly tasks was designed and implemented in a digital showcase factory at Leuphana University (Leuphana University Lüneburg, 2022a). As shown in Figure 66, the digital factory consisted of seven interconnected CPSs based on industry-type components and fulfilling different production tasks. The CPS were cabinets on wheels and could be freely positioned on the shop floor. The assembly station was based on an aluminium substructure on which a monitor was mounted for displaying the work instructions. The substructure was mechanically designed with AUTODESK® Inventor, holding the three-colour laser projector stably mounted at the top of the workstation (Autodesk, 2022b).

Load carriers for assembly parts were placed within the user's ergonomic reach, while the assembly station's work surface was equipped with 3D printed holders for different mounting objects. The work surface was black coated for better visibility of the laser line, while an HMI was integrated into the work surface to control the laser projection for the assembly process. The HMI communicated with a Programmable Logic Controller (PLC) integrated with the laser projection software installed on the soft controller. The industrial signal light indicated the status of the CPS. RFID transponders were used to read and document the assembly jobs in lot size one. The Siemens® TIA portal was used to configure and program the components (Siemens, 2022). The assembly object was a car model with 64 variants defined by the user and stored on an RFID transponder. The transponder was processed at the CPS for loading the corresponding work plan. The user was then guided through the parts commissioning and assembly process via the monitor and synchronised laser projection. The projection sequence of the work plan consisted of polygons derived from CAD data. After completion of the assembly process, the RFID transponder was updated (Müller-Polyzou, Meier et al., 2019).

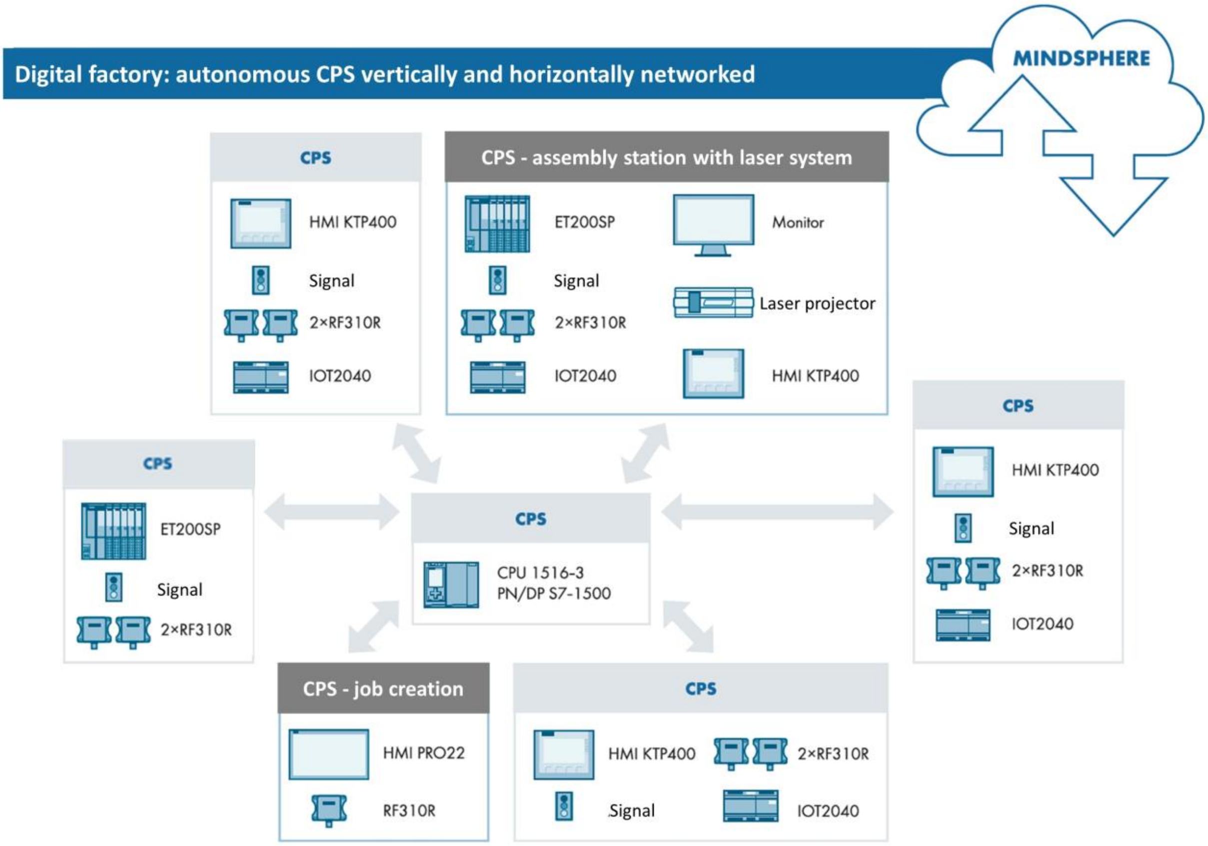

Figure 65: Digital Factory at Leuphana University (own figure)

Evaluation: Three case studies with embedded multiple units of analysis focusing on the assistance system's perceived efficiency, effectiveness, and system usability were conducted. Two of the case studies were realised in a shop-floor scenario at the digital factory of Leuphana University. One additional comparative case study was conducted at the Motek trade fair for automation in production and assembly in Germany. Overall, single perspective research was applied, aiming at the systems user perspective. Figure 66 shows the case study set-up at Leuphana University with an assembly operator mounting the object guided by laser projection and synchronised work instructions on the monitor. The system belongs to the category of cooperative assistance systems.

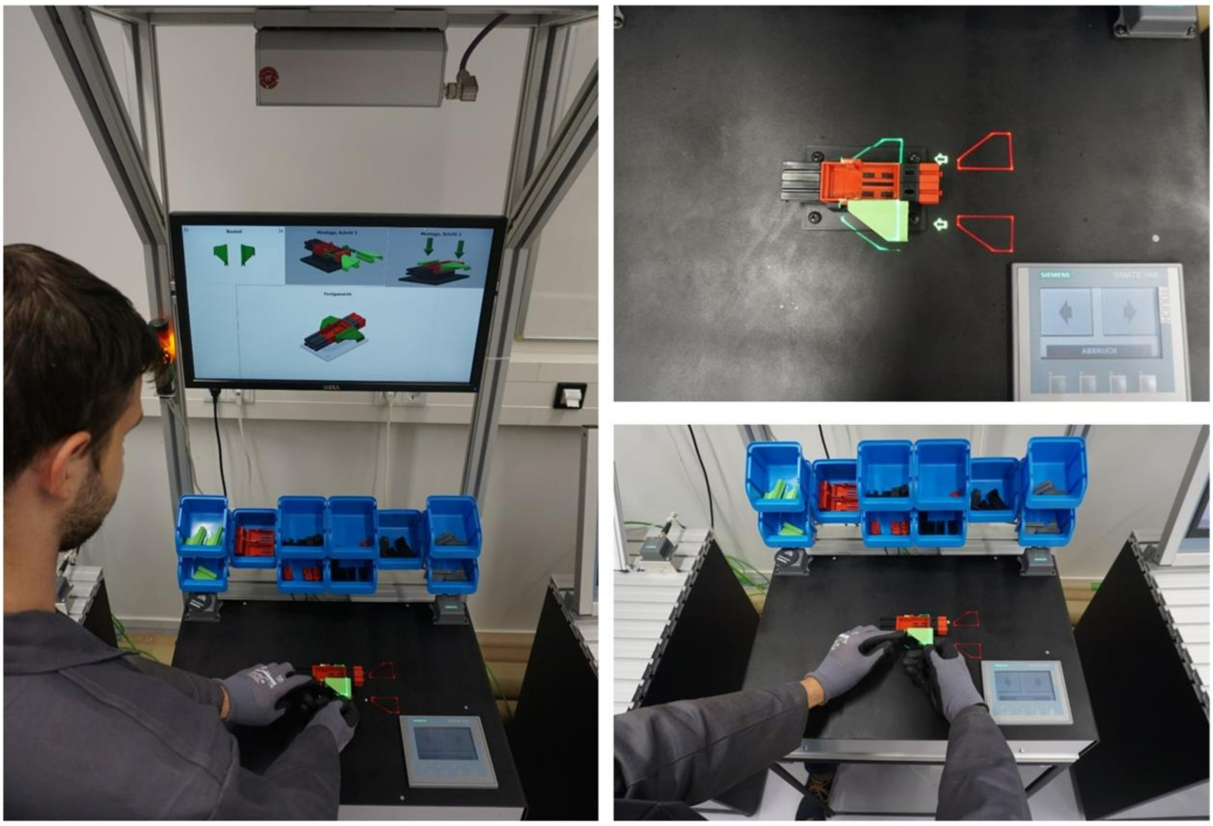

Figure 66: Manual assembly case study at Leuphana University (own figure)

The case studies were conducted without technical interruptions, showing that the system worked reliably. The evaluation generated the following aggregated findings:

Results:

- The expectations on assembly systems expressed by the case study participants confirmed the research dimensions of this dissertation, namely effectiveness, efficiency, and usability. Most of the expectations (69%) were usability related, highlighting the importance of a user-centric system design, confirming technology acceptance aspects and the DP I1.1.
- The users evaluated the system design of the CPS positively with a perceived SUS of 81.8%, indicating good to excellent system usability.
- Most participants perceived the task fulfilment as effective (average=3.2 out of 4) and efficient (average=3.1 out of 4) based on the ASQ.
- Case study observations showed that 95.5% of the participants did not have difficulties using the system. Accordingly, no critical statements were made during task completion. The participants did not have problems navigating the workspace.

- Low error rates reflect the ease of use of the designed CPS. The participants were not trained to use the system. Still, 68.2% of the participants performed the task without any error and 27.3% with only one error.
- The reference case study at Motek with randomly selected participants confirmed the findings of the shop floor case studies. The perceived effectiveness and efficiency reached maximum values. System usability in terms of information provided during task fulfilment reached 87%.

Deviations:

- The laser targets used for system calibration affected the system performance when they were covered, e.g. by the users or by dirt. Covered laser reflector targets are more likely in small work areas, but users can avoid this effect when trained.
- The object holder needs to fulfil ergonomic requirements. For example, the different thicknesses of the participants' fingers impacted the easiness of task execution. The physical and age-related differences in performance should be taken into account.
- Laser projection could improve assembly parts commissioning by indicating load carriers.
- The station's height was not adjustable but was designed according to the mean physiological value, resulting in non-optimal ergonomic working situations for individual participants.
- Users had to divide their attention between the laser projection, the information provided on the monitor, the system control and the actual assembly tasks.

Conclusion: A flexible and versatile CPS for manual assembly tasks was designed and instantiated with modern automation technology, considering general ergonomic requirements. Information provision was orchestrated using the monitor and the three-colour laser projection. The CPS was vertically and horizontally integrated into the digital factory creating a quality workspace reaching high perceived effectiveness, efficiency, and system usability values. In response to the second research question, the artefact presents applicable principles for designing a CPS for manual assembly fulfilling the objectives.

Knowledge Contribution:

Reflection:

- Integrating modern automation technology into the assembly station creates a quality workspace and can be realised incrementally and with manageable effort.
- Horizontal and vertical integration embeds the CPS into the digital factory and supports the digital transformation of the production.
- The integration needs to consider the capabilities of the technical components and the communication network bandwidth and latency to secure a high user experience.

- User-centric system design according to DP I1.1 is critical. The different interfaces and digital work instructions must be orchestrated with the user-system interactions. Additionally, the system's interaction within the production chain must also be specifically considered.
- The effort to prepare the work plans were high, but it was not explicitly analysed.
- The case study instantiation did not include automatic quality check features. Automated process control methods according to DP I1.2 could be implemented to secure the quality of the manual assembly tasks.
- The use of third-party components must be accompanied by fail-safe engineering to secure a reliable system and high user experience. Fail-safe engineering will also support potential resilience strategies. Professional automation technology components already provide a high physical and operational robustness.

Abstraction:

- Assistance systems for labour-intensive assembly tasks can be upgraded to flexible CPS. Integrating automation technology and adding reliable horizontal and vertical integration increases the system's value as a quality-ergonomic workspace within digital factories.
- CPSs for manual assembly support factories' digital transformation and increase production lines' flexibility and versatility.

The design principles presented in Table 28 are derived from the reflection and abstraction process as knowledge contribution in the *exaptation* area, according to Gregor and Hevner (2013).

DP	Description
DP I2.1	For the design of Cyber-Physical assistance systems, to create quality workspaces, feature-rich technology should be integrated into the ergonomically well-designed workspace.
DP I2.2	For the design of Cyber-Physical assistance systems, to achieve high perceived work effectiveness, efficiency and system usability, human-machine interfaces should be optimised for simplicity, and user-system interactions should be orchestrated and well-coordinated with the digital work plan.
DP I2.3	For the design of Cyber-Physical assistance systems, to secure high system flexibility and versatility, seamless and robust horizontal and vertical integration using secure standard interfaces and protocols should be realised.
DP I2.4	For the design of Cyber-Physical assistance systems, to secure high system flexibility and versatility, system scalability, upgradability and relocatability should be considered.

DP I2.5	For the design of Cyber-Physical assistance systems, to secure production efficiency, seamless integration into up-and downstream production steps should be ensured.

Table 28: Design Principles industry cycle two

The design and implementation process with important activities is depicted in Figure 67.

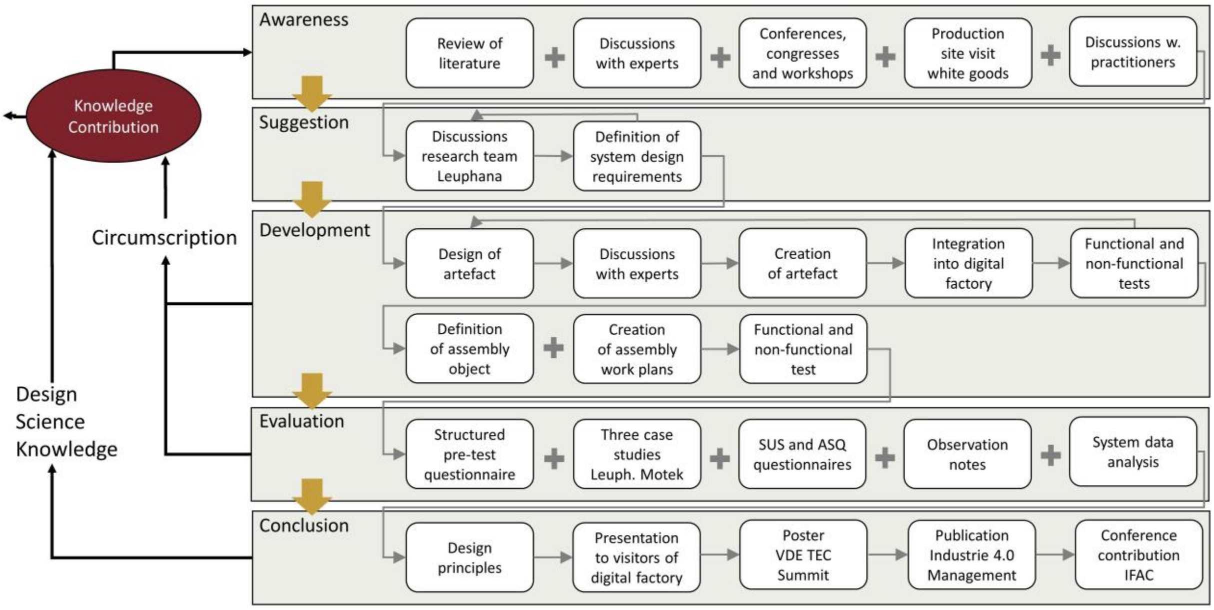

Figure 67: Design Cycle Cyber-Physical assistance System for manual assembly (own figure)

The CPS case studies confirmed the two design principles (DP I1.1 and DP I1.2) abstracted from the preforming case study. Additional design principles (DP I2.1 to DP I2.5) were elaborated, supporting the design of CPS for digital factories. Transfer challenges remain for the application of the design principles to adjacent applications. Furthermore, the question still to be answered is how work system planning and the creation of digital work plans can be supported in a user-friendly way. Additionally, a knowledge gap exists regarding the production services that should be available when such systems are integrated into higher-level production systems.

iii. Work preparation for cyber-physical assistance systems

Awareness: The utilisation of laser-based assistance systems in production demands work system planning and the preparation of customised digital work plans. Laser system planning must consider obstructions and laser line visibility on the tool and object surfaces. Additionally, digital work plans need to be created for the laser projection. These plans are often based on construction data, sometimes in CAD exchange or industry-specific formats. Work preparation tasks are time-consuming and represent barriers to system flexibility and versatility. A user-friendly tool could support creating and editing digital work plans and support work system planning. It is anticipated that such a tool would increase the acceptance of user assistance systems by simplifying the preparatory processes (Müller-Polyzou and Märtterer, 2018).

Suggestion: It is suggested that an integrated plug-in for a CAD program should be designed and developed to support users in work system planning and laser projection data creation. The tool should enable work system planning by laser projection simulation and support the creation of projection data based on imported CAD construction files. Integrating the plug-in into a widely available and cost-effective CAD programme should be realised to keep entry barriers for users low.

Development: A plug-in for the Rhinoceros 3D CAD program for work system planning and projection data generation was designed and instantiated (Jess Maertterer, 2022; Robert McNeel and Associates, 2022). The plug-in artefact supports the simulation of industrial workspaces by placing laser projectors and simulating laser projections, as shown in Figure 68.

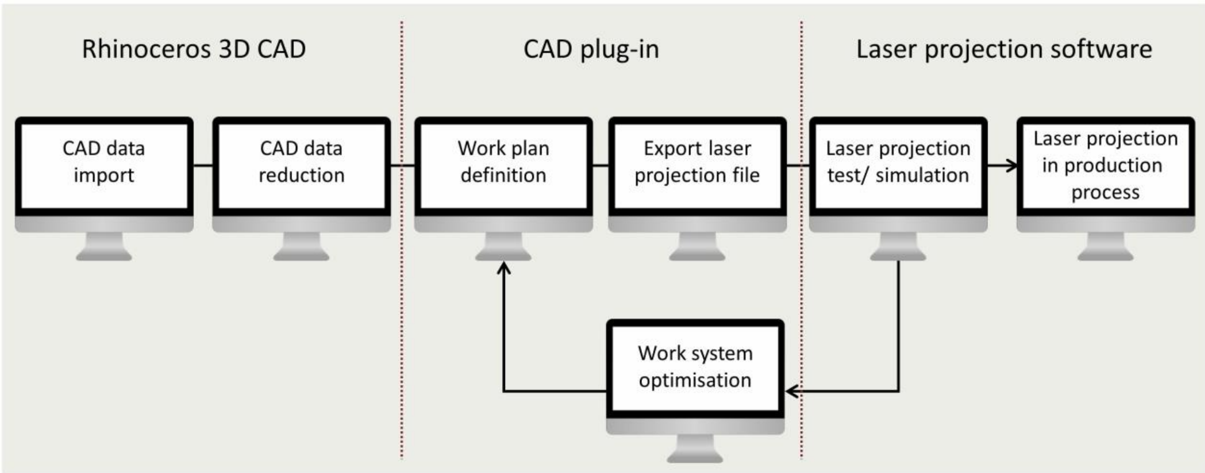

Figure 68: Work preparation process using the plug-in artefact (own figure)

A CAD construction file is first imported into Rhinoceros 3D to create the digital work plan. The original CAD data is then reduced to the required contours for the digital work plan and subsequent laser projection. In the next step, the plug-in features allow particular properties to be assigned to the projection layers, which are interpreted during the laser projection runtime. Several user functions are supported, such as the planned interruption of the projection, resumption of the projection, text as additional information displayed on a monitor, display of images or videos, automatic switching between projection layers after a defined time, automatic calibration and assignment of barcodes for acknowledgement of work step fulfilment. The digital work plan is then exported to the laser projection software for testing, simulation and implementation in the production process. Potentially needed optimisations can be performed by importing the laser projection file into Rhinoceros 3D.

Figure 69 shows the work system optimisation with the exemplary placement of a laser projector over a composite mould as part of the work system planning process. The two square pyramids that visualise the projection area in two different working modes define the laser projector position. Additional laser projectors can increase the overall projection area and secure coverage of all mould surfaces. In addition, a higher number of projectors for the same projection area improves the quality of the laser projection. The part indicated in yellow colour represents one work step within a complex digital work plan of a fuselage composite part (Müller-Polyzou and Märtterer, 2018).

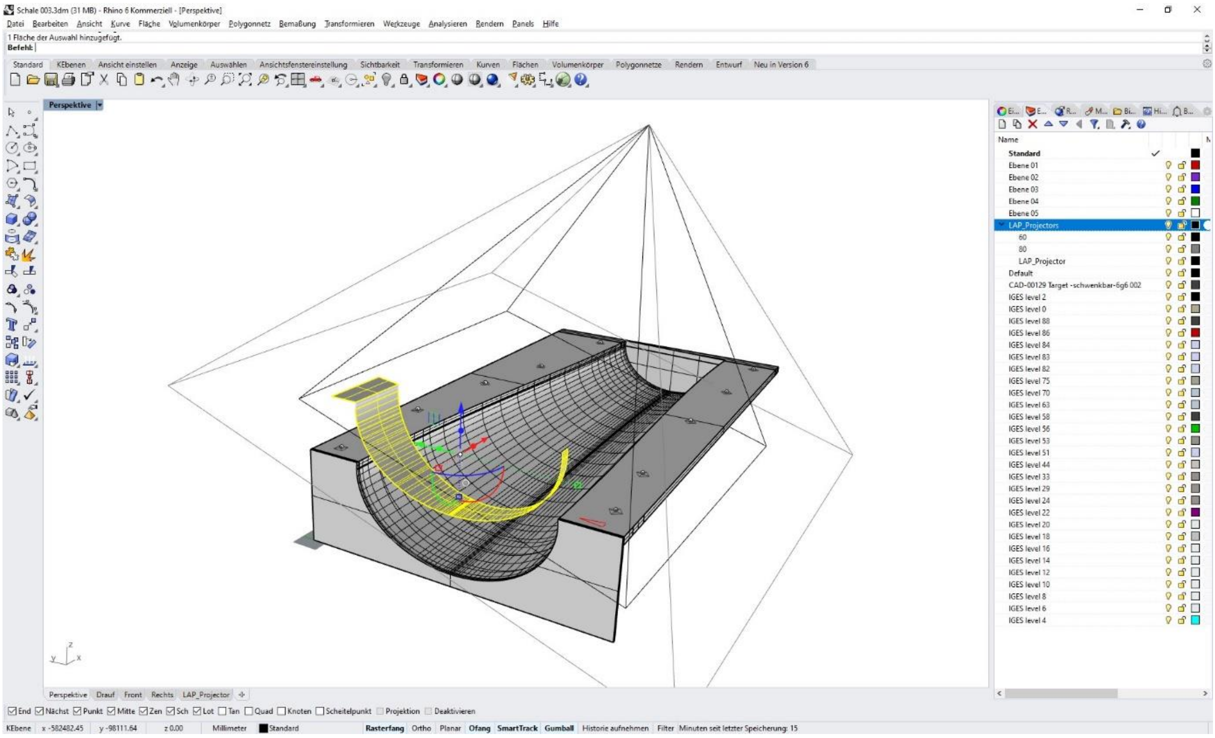

Figure 69: Work system planning and digital work plan generation (own figure)

Evaluation: A structured online interview was conducted in June 2022 with an expert user of the artefact. The product manager worked for four years with the plug-in supporting industrial projects in aviation and automotive. The plug-in was mainly used for application engineering and sales support. In the structured interview, the frequency of use of the plug-in features was assessed using a Likert scale from zero to four (Likert, 1932), and then different aspects of the implementation were subsequently discussed. Next, the interviewer completed the SUS and the shortened ASQ questionnaire with the artefact user. Afterwards, the interviewee had the opportunity to communicate boundaries and suggestions for improvement.

Results:

- Features used very often or often (Likert stages 3-4):
  - File import-export features
  - Simulation of projection steps
  - Visualisation of the position and alignment of laser projectors and tools
  - Projection area control and avoidance of shadowing
- Features occasionally used (Likert stage 2):
  - Creation of surface normal-vectors
  - Text as additional information displayed on a monitor
- Features used very seldom or seldom (Likert stages 0-1):
  - Creation and structuring of projection steps
  - Planned interruption of the projection
  - Resumption of the projection sequence
  - Display images or videos on monitors by providing links to file locations
  - Automatic switching between projection layers after a defined time
  - Assignment of barcodes for acknowledgement of specific work steps
- The SUS reached a score of 60%, representing marginally acceptable system usability.
- The ASQ resulted in high perceived effectiveness (score 4 of 4) and efficiency (score 4 of 4).
- More native integration of the functions in the CAD GUI is recommended. Thereby, the user experience with the plug-in could be further increased.

Deviations:

- Users of other CAD software criticise the limitation of the plug-in to Rhinoceros 3D CAD because they need to buy, install and learn the specific CAD software. Users propose developing plug-ins for other widely deployed CAD software solutions like AUTOCAD® or CATIA® (Autodesk, 2022a; Dassault Systèmes, 2022).
- CAD data is the fundamental prerequisite for the use of laser-based assembly systems. These are often not available for legacy products, which initially require reengineering.

Conclusion: The plug-in for Rhinoceros 3D CAD simplifies necessary tasks of work preparation but needs further improvement in system usability. It improves work system planning for laser-based systems and supports the efficient creation of laser projection data. However, the actual structuring of the digital work plan is still performed in the projection software. It is anticipated that the artefact will influence the user acceptance of CPS in terms of usefulness and ease of use once its usability is enhanced and the plug-in is integrated into other CAD programmes that are frequently used. In response to the third research question, it is anticipated that the artefact, once optimised in its implementation, will increase the acceptance of CPS.

Knowledge contribution:

Reflection:

- Efficient and user-friendly work preparation is necessary for cooperative assistance systems supporting DP I2.5 and should be addressed by system providers.
- The plug-in can support user-centric work system design according to DP I1.1 and digital work plan creation according to DP I2.2.
- Users must purchase and learn using the new CAD software and plug-in. The additional cost and effort are a barrier to system acceptance. Especially for older workers, learning new software is often difficult or represents an additional burden.
- Reducing CAD data in complexity to projection data can be time-consuming. Other potentially more automatic means of creating projection data could be identified.

Abstraction:

- Work preparation tools are a necessity for assistance systems. Work system modelling and simulation should be provided as a feature to ensure versatility supporting DP I2.4.
- User-friendly and efficient work plan creation and management are practical and support user acceptance if designed for ease of use. The design also helps fast time to production.
- Work preparation should be an integral feature of cooperative assistance systems. It should be easy to use but feature-rich depending on users and applications. Work preparation features can also be integrated into adjacent systems or upstream process software.

The design principles presented in Table 29 are derived from the reflection and abstraction process as knowledge contribution in the *improvement* area, according to Gregor and Hevner (2013).

DP	Description
DP I3.1	For the design of Cyber-Physical assistance systems, to increase efficiency in work preparation, application-specific system planning and work plan preparation features should be supported.
DP I3.2	For the design of Cyber-Physical assistance systems, to increase the user experience in work preparation, adjacent systems should be seamlessly integrated, and technical and non-technical acceptance barriers should be eliminated.

Table 29: Design Principles industry cycle three

The design and implementation activities of this short DSR cycle are presented in Figure 70.

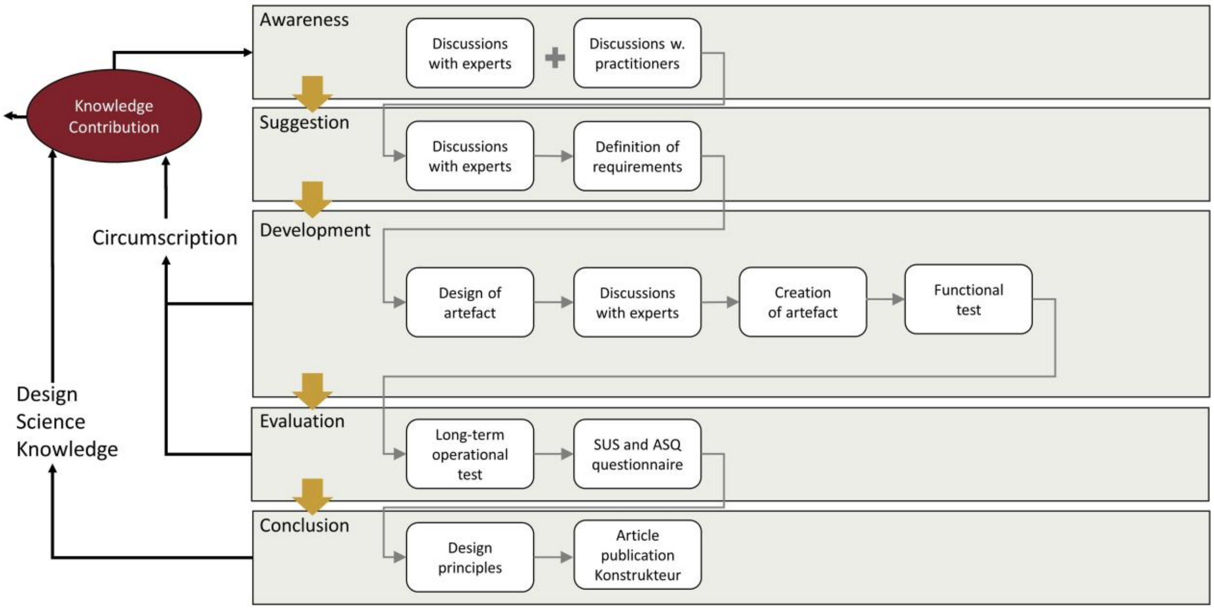

Figure 70: Design Cycle Work preparation for Cyber-Physical assistance systems (own figure)

The transfer challenge that remains is how work system preparation can be supported in more intuitive and user-friendly ways, reducing the barriers to system acceptance for all age groups. For this purpose, deeper integration of the laser projection system with market-leading CAD software platforms or creating digital work plans by other means could be examined.

iv. Integration of assistance systems into production control

Awareness: Industry- and often customer-specific MES solutions are utilised as on-premises or cloud-based Software as a Service (SaaS) solutions, while the functional scope of MES solutions often varies considerably. Numerous interfaces and additional user requirements such as Plug & Produce increase the complexity. Well-grounded data is needed to support the design of integration strategies for CPS into higher-level production control systems to increase efficiency, flexibility and versatility in the fields of application (Müller-Polyzou, Meyer, Georgiadis, 2019).

Suggestion: It is suggested that laser-based assistance systems should be designed in a way that supports integration into MES to be flexibly controlled and provide process data for analysis and documentation. To meet the requirements of digital factories, CPS should be easily reconfigurable. MES should support reconfiguration through Plug & Produce and thus increase the flexibility and versatility of smart factories. Developing a knowledge construct, including MES integration services and protocols, is suggested for this design cycle.

Development: MES articles of Industry 4.0 opinion leaders were analysed using mixed coding techniques and content analysis utilising software for qualitative analysis. Eight articles were analysed, including five expert interviews, one expert talk, one research paper, and one speech reflecting different perspectives of industry participants, associations and academia. The content analysis using atlas.ti proposed five statements that should be evaluated in the DSR cycle (ATLAS.ti GmbH, 2021).

1. Users of laser assistance systems use MES in their production lines
2. Users of laser assistance systems utilise different MES features
3. Users of laser assistance systems use and prefer industry standards for MES integration
4. Users require secure data exchange between production equipment and MES
5. Users of laser assistance systems need Plug & Produce approaches

Evaluation: The statements were evaluated using an online survey addressing 19 companies worldwide. The companies' representatives were systematically selected according to their production experience. The experts were familiar with laser assistance systems and worked at national and international production sites. The participants (n=11) worked in the automotive industry (31.6%), aerospace (31.6%), renewable energies (15.8%) and other manufacturing industries (21%). Most participating companies (63%) belonged to the large enterprise segment with more than 10,000 employees. The online survey available in German and English was conducted using LimeSurvey (LimeSurvey GmbH, 2021). Fourteen questions were presented with single-choice, multiple-choice, and 5-point Likert scales (Likert, 1932).

Results:

- Statement 1: 91% of companies already used MES from various manufacturers. However, only one company had integrated a laser system. 46% of the respondents considered equipment integration as crucial for the future. The results showed that MESs were widely deployed and that the integration of laser assistance systems in the production environment was discussed.
- Statement 2: 64% of the experts considered the services *order control and detailed planning* and *process and performance management* important. *Machine and production data acquisition* and *quality management* were rated by 55% of the respondents as important for the future. The results showed which MES features should be supported by assistance systems.
- Statement 3: Regarding interfaces and protocols, besides being experts, 55% of the participants could not state which interfaces and protocols were used, while 18% of the respondents used OPC UA and XML. There was no unanimous opinion on which interfaces and protocols would be used in the future to integrate laser assistance systems into MES.

- Statement 4: 82% of the companies considered secure data and information exchange between systems important or very important. It is, therefore, an essential requirement for communication protocols when integrating assistance systems.
- Statement 5: 64% of the respondents did not use Plug & Produce, while the concept appeared attractive to them. 36% of the participating companies perceived Plug & Produce as important. However, the same number of experts could not assess its importance. In contrast, no company rated Plug & Produce as unimportant. Companies seemed to be indecisive regarding Plug & Produce. The result coincides with the indecision about interfaces and protocols.

Deviations:

- No extraordinary deviations were noted in the content analysis and online survey.

Conclusion: The evaluation reinforces the importance of MES in manufacturing companies and the associated need for the robust and safe integration of laser-based assistance systems into production control. In response to the fourth research question, the knowledge artefact provides insights into selecting value-adding MES services that should be supported by assistance systems and integrational aspects of assistance systems into production control.

Knowledge contribution:

Reflection:

- MESs are widely used in manufacturing industries. Integrating assistance systems into MES provides benefits, but still, silo solutions exist.
- The MES services *order control and planning* and *process and performance management* must be supported when integrating assistance systems into MES. The integration should be robust and support resilience efforts.
- The MES services *process management*, *machine and production data acquisition* and *quality management* should be supported to be prepared for future manufacturing. Performance management must consider the human being in socio-technical systems. Socio-technical aspects in particular related to the ageing workforce should be considered.
- There is uncertainty and restraint regarding integration standards and protocols. Plug & Produce should be supported to increase the versatility of the production.
- Data exchange is a prerequisite for integrating assistance systems into MES and must be designed securely.

Abstraction:

- CPS integrated with business support systems should support production control services, confirming DP I2.5 and monitoring and quality management services supporting DP I1.2.
- The CPS integration with business support systems should be secure, confirming DP I2.3.
- The integration of CPS with business support systems should use technology-agnostic Plug & Produce features following the advice of DP I2.4 and DP I2.5.

The design principles presented in Table 30 are derived from the reflection and abstraction process as knowledge contribution in the *improvement* area, according to Gregor and Hevner (2013).

DP	Description
DP I4.1	For the design of assistance systems, to increase operational efficiency and effectiveness, vertical integration to business control systems with secure and technology-agnostic Plug & Operate features should be implemented.
DP I4.2	For the design of assistance systems, to increase user acceptance, business control systems should provide features for production control and monitoring as well as quality management based on machine and production data.

Table 30: Design Principles industry cycle four

The design and development activities are depicted in Figure 71 according to the DSR phases, leading to the knowledge contribution of the design cycle.

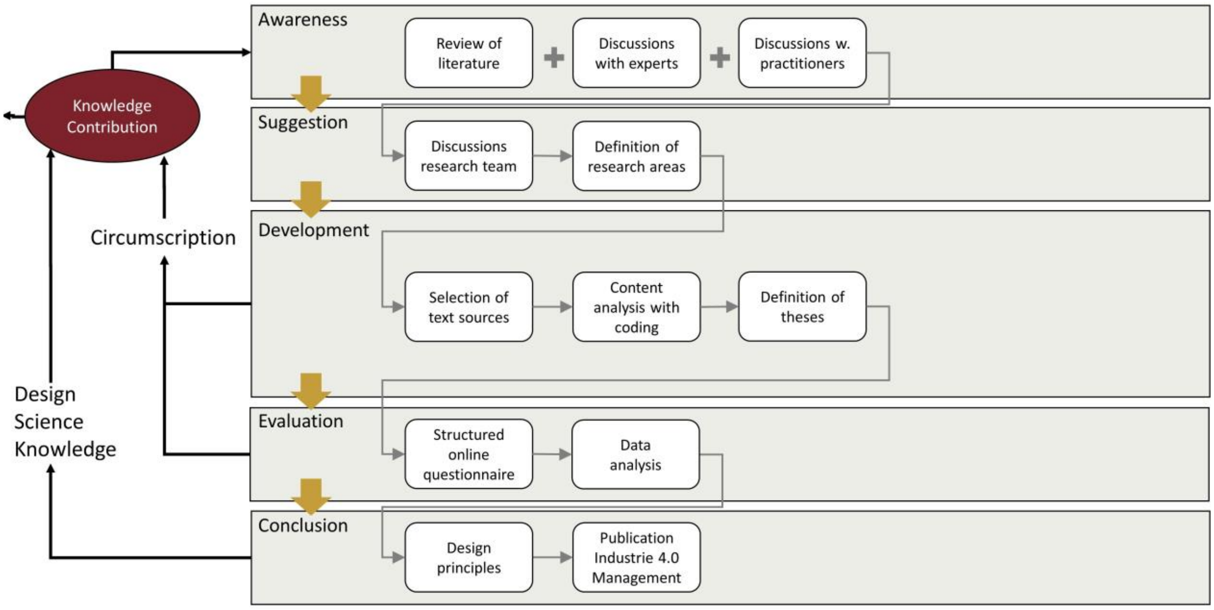

Figure 71: Design Cycle Integration of assistance systems into production control (own figure)

The question that remains is how the vertically integrated CPS can be further optimised regarding the human-machine interaction to support quality workspaces in labour-intensive processes. In future design cycles, ways should be developed to improve the interaction between MES and users of assistance systems in terms of system and quality control. Improvements in system and quality control could also enhance the workspace for older employees or those with reduced performance.

v. Intuitive control of laser-based assembly assistance

Awareness: The laser-based system for manual assembly tasks utilises an industrial IR remote control that is cost-effective and robust. However, the users' operation of the remote control interrupts the manual work process and the attention of system users frequently. In addition, the remote control must be kept close to the assembly operator, and the orientation towards the laser projectors causes unergonomic movements. The question arises whether Natural User Interface (NUI) devices based on gestures, haptics, or speech are industry-suitable alternatives to the existing control concept and whether such ideas increase users' work efficiency and effectiveness (Mueller et al., 2020).

Suggestion: It is suggested that intuitive control concepts be selected following a systematic investigation and integrated into the cooperative assistance system. The goal is to increase the user-friendliness of the system control based on intuitive concepts and behaviours known from consumer devices. Furthermore, innovative operating concepts could increase user-system-cooperation. The selection of control concepts should consider the industrial applicability and user-friendliness, while the baseline comparison should be the conventional IR remote control. It is suggested to design and develop an instantiation of a cooperative assistance system with an integrated NUI selected in the systematic investigation process (Mueller et al., 2020; Müller, Müller-Polyzou et al., 2018; Müller, Vette-Steinkamp et al., 2018).

Development: Consumer control concepts were analysed and evaluated according to technical, commercial, and user-oriented criteria. The criteria included the level of Individual Protection Equipment (IPE), device battery capacity, wireless connectivity aspects, general integration capabilities, commercial availability, market price, range of professional services, assumed usability of concept in the industrial context, control features and the availability of a feedback channel. As shown in Figure 72, three operating concepts were integrated into the laser assistance system to prepare single-user perspective case studies after the selection process. First, a smartwatch connected via WLAN was integrated for use on the wrist, providing haptic and optical feedback. Second, gesture recognition was realised through a wristband attached to the user’s forearm. Electrodes detected the movements of muscles and mapped them to gestures. The wristband connected via Bluetooth provided user feedback in the form of vibration patterns. Third, voice control and voice feedback were integrated using headphones and a microphone. The utilised speech analysis software was installed on the control computer of the assistance system, while the headphone equipped with a microphone was connected via Bluetooth.

A flexible object holder with a rotary encoder was also developed and integrated into the workbench. The laser projection automatically followed the rotation when the object holder rotated. However, the case studies did not evaluate this function as their primary focus was the control concepts.

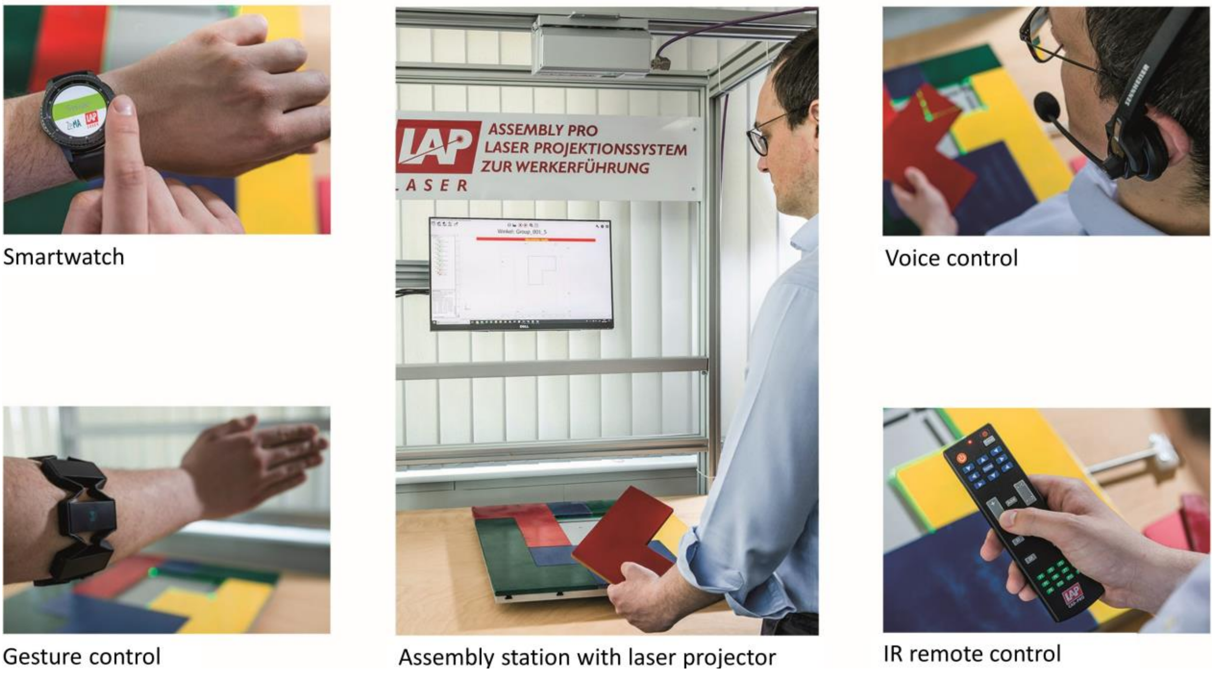

Figure 72: Case study intuitive control concepts (with courtesy of LAP GmbH Laser Applikationen)

Evaluation: The case study environment consisted of an ergonomically designed laser-based assembly station with the control concepts integrated via TCP/IP. The case studies with multiple embedded units of analysis were performed with a puzzle representing a two-dimensional, reproducible assembly task with low difficulty. A low and constant degree of difficulty was chosen to focus the users on the object of analysis. Structured questionnaires were used to analyse the perceived efficiency and effectiveness of task processing and the user-friendliness of the control concepts. Additionally, an expectation questionnaire was used to collect previous experience and expectations. An observer questionnaire was used to record the time needed for task completion, the number of commands, and the number of critical remarks made during the case study. The observer also judged the participants' sovereignty, parts handling, and overall structuredness. The control concept questionnaires included questions about the application scenario, whether the task objective could be fulfilled, and whether the control concept was perceived as visually, haptically or intuitively appealing. The ASQ was applied to assess the perceived effectiveness and efficiency. Subsequently, the participants rated the user-friendliness of the operating concepts using the SUS. Furthermore, selected questions from meCUE were used to measure the usefulness and positive and negative emotions. In total, 30 participants from four companies participated in the study, and 25 completed the questionnaires (Müller, Müller-Polyzou et al., 2018).

Results:

- The participants (n=25) indicated that they were satisfied to a medium degree with the IR remote control, but 16 participants suggested changes to the control concept. One suggestion for improvement was to enable hands-free working.
- The smartwatch was familiar to 80% of the participants, and 56% already had experience with voice control. Before the test, 45% of participants opted for voice control, 35% for the smartwatch and 20% for gesture control.
- On average, it took participants 83 seconds to complete the task using gesture control, 61 seconds using the smartwatch, 60 seconds using the voice control and 55 seconds using the IR remote control. The IR remote control was thus the most efficient method.
- When using gesture control, the average number of input errors was 4.4, leading to frustration and critical comments. The participants seemed overburdened in some cases. Most positive statements were made when participants used voice control. The participants appeared confident and secure in dealing with the smartwatch and voice control.
- Regarding visual perception, the smartwatch was preferred. The haptics was rated best for voice control. The remote control, smartwatch, and voice control hardly differed regarding ease of use, whereas gesture control was rated worse. The voice control was preferred in intuitiveness, while the wearing comfort was rated highest for the smartwatch.
- Remote control (SUS=51.5), smartwatch (53.5), and voice control (58.4) can be regarded as user-friendly. The SUS confirms the results, with the gesture control reaching 33.3 points, significantly lower than the other operating concepts.
- The perceived effectiveness of voice control was rated ten percentage points higher than the IR control, and efficiency was 12 points higher. Compared with the IR remote control, gesture control reached a perceived effectiveness value of -47% and an efficiency value of -50%.
- The average rating for voice control was 3.1 and 2.7 out of 4 points for usability and usefulness. The smartwatch evokes positive emotions, while the most negative emotions were associated with gesture control. In line with the previous results, 44% of participants opted for the voice control, and 24% for the existing IR remote control and the smartwatch.
- As reasons for their decision favouring voice control, the participants stated that it is reliable and enables hands-free work.

Deviations:

- The participants could not fulfil their task objective using the wristband. Physiological differences in the test subjects created additional difficulties in the case studies.
- Arousal and negative emotions increased fast when users experienced difficulties with the control concepts. The effect did not seem to be influenced by the observation situation.

Conclusion: The control of laser-based assistance systems can be improved by integrating intuitive NUIs. In summarising, users prefer hands-free voice control to interact with the cooperative assistance system. High perceived system usability, efficiency, and effectiveness can be achieved using NUIs for laser-based assistance systems. Thus, the design cycle responds to the fifth research question and presents solutions to improve the control of assistance systems using NUIs.

Knowledge contribution:

Reflection:

- The method of voice control is system and task agnostic. Voice control is already known to users in the logistic industry and at home from the personal voice assistants Alexa, Siri and Google Assistant. A quantitative study in Germany revealed that 37% of individuals aged 55 or more used such devices, but 69% were concerned about data safety showing a gap between the perceived usefulness and trust in voice assistants (Jakob et al., 2021).
- Voice control can be implemented in many languages and thereby internationally used.
- Voice control devices are comfortable to wear and fulfil industrial requirements such as hygiene, battery capacity, usage range, industrial protection degree and manageable cost.
- Voice control keeps the hands free for work which supports ergonomic work. Thereby, users can concentrate on their actual work tasks without dividing their attention.
- Concerns remain regarding reliability in noisy working environments. However, systems based on sophisticated noise cancellation methods are already used in noisy areas such as airports and logistics centres (Advanced Mobile Group, 2022).
- The design of NUIs needs to be user-centric, consider anthropometrics and focus on acceptance with an overall subjective perception of usefulness and ease of use.
- NUIs can potentially focus users' attention on the work tasks and support users' cognition by providing direct feedback or additional information.
- Voice information can be adapted in information density and quality according to user cognitive capabilities and experience. Specific profiles can be provided for users with reduced performance, limited language skills, and workers trained on new work processes.

Abstraction:

- Voice-based assistance system control can be used for different CPS types supporting labour-intensive processes, confirming DP I2.1.
- Tasks with many work steps will benefit from hands-free and uninterrupted system control. Such system control is optimised according to DP I2.2.
- NUIs improve ergonomics and the overall quality of workplaces, in line with DP I2.1.

The design principles presented in Table 31 are derived from the reflection and abstraction process as knowledge contribution in the *exaptation* area, according to Gregor and Hevner (2013).

DP	Description
DP I5.1	For the design of assistance systems, to support high perceived operational efficiency, effectiveness and usability, hands-free control methods should be implemented.
DP I5.2	For the design of assistance systems, to support high perceived operational efficiency, effectiveness and usability, voice control shall be used as an intuitive, natural user interface.

Table 31: Design Principles industry cycle five

The overall design, development and evaluation process with important activities is shown in Figure 73 according to the phases.

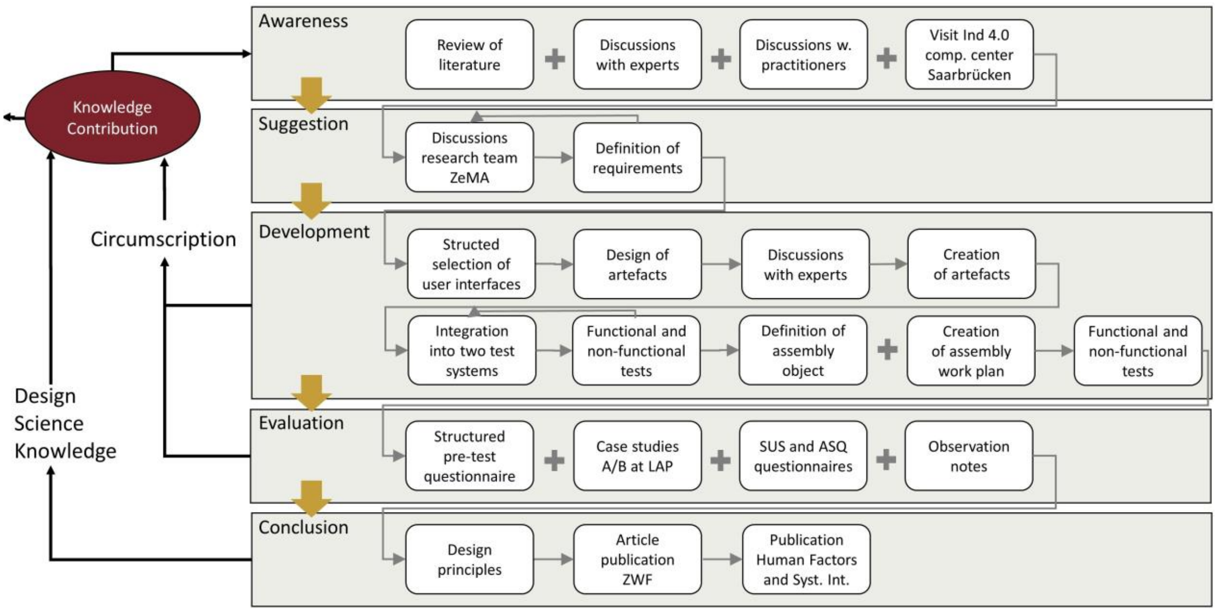

Figure 73: Design Cycle intuitive control of laser-based assembly assistance (own figure)

Some research challenges will have to be answered in subsequent DSR cycles. For example, it should be analysed whether the system control can be automated. Thus, it should be evaluated if users perceive automatic switching of work steps as more efficient, effective, and user-friendly than human-system interaction. Finally, the integration of NUI in non-assembly systems should also be analysed.

vi. Camera-controlled laser projection for manual assembly

Awareness: Assembly systems are usually controlled via Graphical User Interfaces (GUI) or system-specific controls. Intuitive control concepts have been analysed in the previous DSR cycle showing a preference for voice control concepts. However, human system input is still required. In principle, user interactions increase with the increasing number of product variants, decreasing batch sizes and complexity of manual assembly tasks. To further enhance the assembly process, a camera-controlled assistance system could automatically load digital work plans from the MES, as analysed in a previous DSR cycle, and switch automatically between the work steps of the work plan (Taubert et al., 2018).

Suggestion: It is suggested that the laser-based assembly station should be enhanced with Machine Learning (ML) image recognition. In the design, the progress of the assembly process shall be analysed by an AI algorithm in near-real-time using input from a camera system installed on top of the work surface with a view on the workbench. The change between the different work steps of the digital work plan should then occur automatically so that users can concentrate their attention on the assembly tasks. The design concept eliminates the need for user interfaces such as remote control, voice control or HMI panels. Furthermore, well-timed and information density optimised digital work instructions projected on the work surface and a passive panel in an ergonomically friendly position should secure the system's usability. Finally, the digital work plan for assembling the fully customised product should be loaded automatically from the MES system utilising RFIDs. An instantiation of the camera-controlled laser-based assembly station should be developed and integrated into a digital factory environment.

Development: A system instantiation was installed in the showcase factory of the Mittelstandszentrum 4.0 Hanover, which produces a customised ballpoint pen (Mittelstand-Digital Zentrum Hannover, 2022). The pen was individualised and consisted of six parts varying in colour and shape. The six parts lead to 36 variants of the ballpoint pen. However, personalised engraving and riffle were performed in previous steps, resulting in a fully personalised ballpoint pen at lot size one. The single parts of the pen were stored in a tray and used during production, allowing production job identification via integrated RFIDs. The tray could be put in a specially designed holding device with an integrated RFID reader at the workstation. Afterwards, the system user picked the single parts from the tray and assembled them according to the digital work plan. The laser system indicated parts on the tray and visualised the part and work instructions on a passive, inclined black coated panel. The position of the components on the tray was unknown and could vary. After successful assembly, the completed ballpoint pen was placed in a compartment of the tray.

An industry-type USB Full HD (1920x1080) colour camera with a 12mm/ F1.8 lens was placed on the top of the workstation, and the algorithm developed by Viola and Jones (2001) was trained with images taken by the camera. Previous analysis of a different number of training images and ambient light conditions proved that less than 100 images per part were sufficient for reliable performance. For each part of the ballpoint pen, 30 pictures showing the part (positives) and 50 pictures not showing the part (negatives) were used in various lighting scenarios to create a software library to be processed by the main program, resulting in the instantiation of the camera-controlled assembly station. The concept of the assembly station with selected elements is shown in Figure 74 (Taubert et al., 2018).

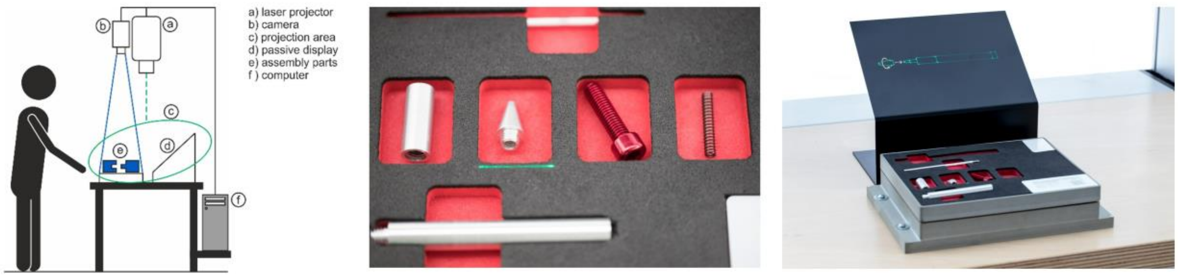

Figure 74: Camera-controlled projection (Mittelstand-Digital Zentrum Hannover, 2022)

Evaluation: A single perspective case study with embedded multiple units of analysis and an A/B test was conducted at the Industry 4.0 showcase factory to evaluate the design concept in a real-life environment. The sample group of seven manufacturing trainees of an SME (n=7) received an introduction to the test environment and filled out an expectation questionnaire. Apart from demographic information, the participants were asked about their expectations of an assistance system. Afterwards, the participants assembled the ballpoint pen using the given instructions. After finalising the assembly, the participants filled in a second questionnaire, including SUS and ASQ sections, consisting of twelve statements and a 5-point Likert scale from zero (strongly disagree) to four (strongly agree) (Likert, 1932). The participants were observed during the assembly process to identify potential issues. Following the second questionnaire, the participants were asked to assemble the ballpoint pen again, using paper-based work instructions commonly used in production environments. The paper instruction described a different assembly order to prevent the participants from mounting the ballpoint pen from memory. The combined SUS and ASQ questionnaire gathered data, and an explorative group discussion concluded the case study (Taubert et al., 2018).

Results:

- Overall, the participants expected high usability, robustness, and effectiveness from an assistance system for manual assembly.
- All participants completed the assembly on average in 59 seconds (6 seconds standard deviation) without any assembly errors.
- The participants understood the instructions provided by the system without further guidance. After completion, 85.7% of the participants stated their expectations had been fulfilled.
- The camera-controlled assembly system reached an average SUS of 81.8%, characterising high system usability. It reached a perceived efficiency of A=2.9 and effectiveness of A=3.3 of four and received positive feedback for being easy to learn and use.
- The participants needed seven seconds longer to complete the task using paper-based instructions, and they made, on average, 1.6 mistakes, for instance, by completing assembly steps in a wrong order.
- The RFID-based automatic loading of the digital work plans from the MES functioned reliably.
- The system performed robustly during the test day, even with changing ambient light conditions. Furthermore, the system worked reliably over three months, during which showcase factory visitors of different ages and competence levels used the system.

Deviations:

- The Viola-Jones algorithm performed well under different ambient light conditions. However, training the algorithm for specific assembly objects and defining the work plan was time-consuming, contradicting previous design efforts to improve work preparation processes.

Conclusion: The automatic loading of work plans from the MES and the camera-based automatic assembly process control without user interaction showed promising results, including the high perceived system usability. The perceived effectiveness and efficiency were high but could still be improved. Therefore, it is concluded that integrating camera-based automatic features increases the effectiveness and efficiency of manual assembly stations. In response to the sixth research question, it can be postulated that the designed artefact allows automatic control of assistance systems.

Knowledge contribution:

Reflection:

- The MES integration for loading the digital work plans was robust and designed according to DP I2.3 and DP I4.1. The implementation required no user interactions and ensured uninterrupted production. Increased user attention to the work tasks is anticipated by eliminating the need for user interaction to load work plans manually.
- Users perceived the information provided on the passive black-coated display well. The provided information did not overload users' memory, and the display was ergonomic in its position, easy to read and supported parts commission and assembly tasks. Both findings confirmed DP I2.2 and DP I6.2. The user-centric design according to DP I1.1 was well accepted.
- The usability of the assembly station was increased by enhancing the system with AI and camera-based automation following DP I1.2 and DP I6.1. AI could, in the future, automatically identify new products and initiate loading the corresponding digital work plan from the MES, eliminating the need for RFID technology.
- The camera system enhanced overall process stability. Additional camera-based quality inspection features could be implemented, potentially decreasing arousal of making mistakes.
- The ageing workforce or employees with reduced performance will benefit from reduced human-system interaction. Overall, the system supports users independent of their affinity for technology. It is therefore well suited for the ageing workforce caused by demographic change.

Abstraction:

- Assistance systems should use advanced technologies to reduce the number of human-machine interactions and help users focus their attention on their work tasks.
- Assistance systems should implement automatic Quality Assurance (QA) features to avoid failures in labour-intensive processes and provide a sense of safety.

The design principles presented in Table 32 are derived from the reflection and abstraction process as knowledge contribution in the *improvement* area, according to Gregor and Hevner (2013).

DP	Description
DP I6.1	For the design of Cyber-Physical assistance systems, to support perceived operational efficiency, effectiveness and usability, assistance systems should be equipped with automatic quality and system control features.
DP I6.2	For the design of Cyber-Physical assistance systems, to support perceived operational efficiency, effectiveness and usability, well-balanced information and work instructions should be presented in an ergonomically friendly position in-situ onto the object, work area or special display.

Table 32: Design Principles industry cycle six

The overall design cycle with important activities is outlined in Figure 75.

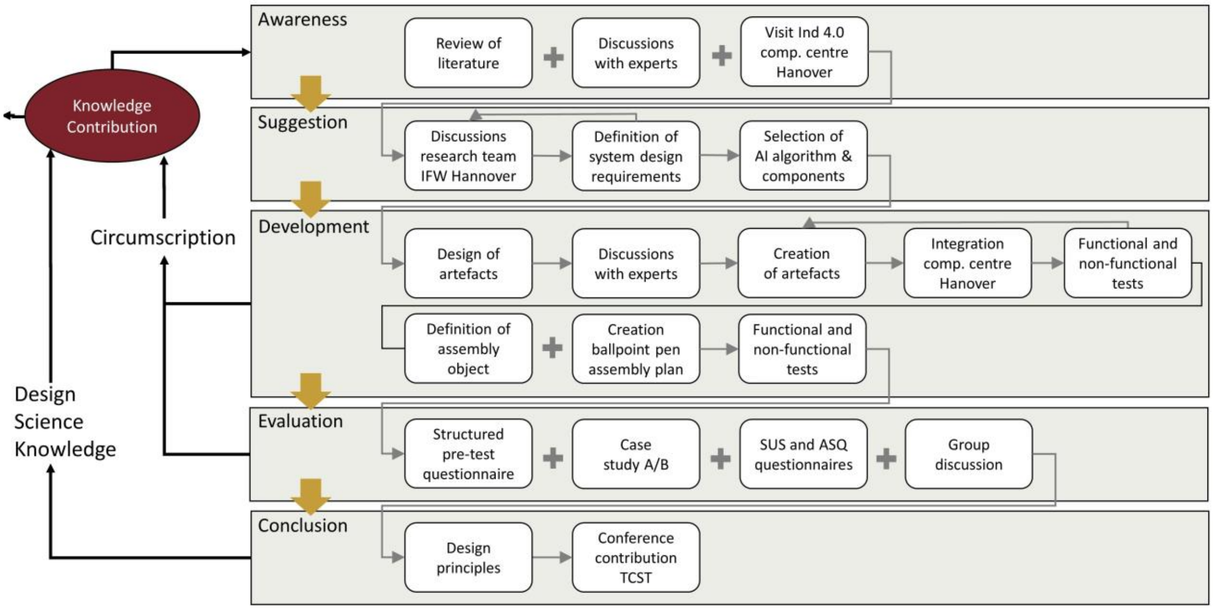

Figure 75: Design Cycle camera-controlled assembly system (own figure)

The previously conducted design cycles analysed both individual and group workplaces. In addition, horizontal and vertical networking was investigated as an essential basis for CPS in digital factories. Furthermore, system control through human-machine interaction and process automation was considered. In concluding the industry path, the digital representation of a laser-based assistance system will be examined in the following design cycle.

vii. Digital twin of a laser-based assembly system

Awareness: Short product lifecycles, many product variants and market volatility put high demands on manufacturing companies. Changes in production lines require modifications on assembly stations, including the planning and simulation of such changes. In production lines with socio-technical systems, such changes must consider the operators' needs. Digital Twins of production systems can accompany the real-life system during the entire lifecycle, thereby simplifying the reconfiguration of production lines and systems. The virtual representation of the system can also support preventive maintenance or repair services. The question that arises is which requirements a Digital Twin of a laser-based assembly station should fulfil. The required capabilities, the overall appearance, and user interfaces are particularly interesting (Meier et al., 2021).

Suggestion: It is suggested that a Digital Twin of a laser-based assembly system should be designed with its capabilities being derived from the physical entity and user requirement analysis. The ability to process digital work plans could allow laser projection testing before the actual deployment in production lines. Additionally, the virtual visualisation of laser projections on the work tool could support users in making fact-based decisions. The spatial placement of the laser projector at the workplace and the manual control of the laser beam could allow potential shadowing obstacles to be detected. The Digital Twin could also assess the quality of the laser projection supporting ergonomic workplace optimisation. Furthermore, the necessary task of laser reflector placement could help the overall system planning. The Digital Twin of the laser-based assembly system could be implemented as an AR application for deep immersion. It is suggested to instantiate a tentative design as a PC and Microsoft HoloLens® application (Meier et al., 2021).

Development: A systematic user requirement analysis was performed to identify and describe the capability model of the Digital Twin. Five structured expert interviews were recorded and transcribed using the f4transkript software and qualitatively analysed using the atlas.ti software (ATLAS.ti GmbH, 2021; dr. dresing & pehl GmbH, 2021). The interviews were conducted with a department head, a salesperson, a product manager, a service employee and an application engineer of a company offering industrial laser projection systems. The interviews were inductively coded, and code trees were developed. The content analysis results were summarised and back-tested with the interviewees using an eight-item questionnaire with a four-item Likert scale, increasing the rigour of the research (Likert, 1932; Mayring, 2015). A requirement specification sheet was formalised, including the software architecture and UML-visualisation of the five use cases: *inserting the digital twin*, *performing calibration process*, *displaying projection*, *displaying system information* and *performing projection functions*. The use case *inserting the digital twin* is exemplarily shown in Figure 76.

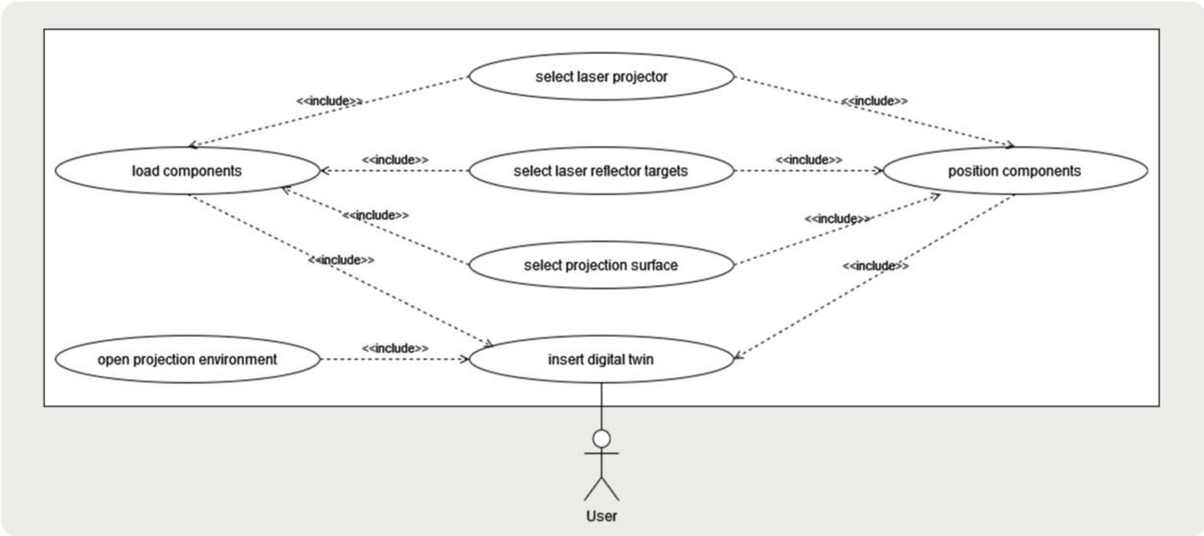

Figure 76: Digital twin use case in UML (Brach, 2019)

Afterwards, a value-based analysis of potential implementation tools compared usability, interfaces, calculation, analysis, and customised modelling features. The software architecture of the Digital Twin was subsequently implemented in Unity® (Unity Technologies, 2022). The implementation realised two categories of capabilities: *workplace preparation and overall system set-up* and *virtualisation of laser-system functions during system operations*. Finally, the Digital Twin was implemented as an application for the Microsoft HoloLens®. In the AR implementation, users can control the artefact through hand gestures and voice. Figure 77 shows the 3D model of the Digital Twin created with Unity®. The 3D model shows the laser reflector targets placed on a work tool, the laser projector and beam on the tool, the virtual laser projection on the tool, and the area covered by the laser projection.

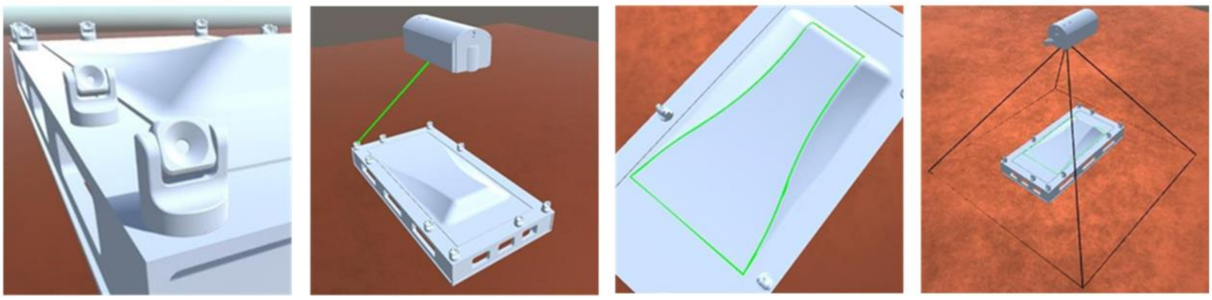

Figure 77: 3D views of the digital twin of the laser-based assistance system (Brach, 2019)

Evaluation: The structured interviews and the content analysis confirmed multi-perspective research insights into user requirements for DTs of laser-based assembly stations. In its instantiation as a PC and HoloLens® application, the DT was functionally and non-functionally tested in the Digital Learning

Factory of Leuphana University (Leuphana University Lüneburg, 2022a). Students and research associates regularly performed functional and non-functional testing during agile software development. Further insights were drawn from the accompanying explorative discussions and the non-structured observation of the respective users when testing the systems.

Results:

- The capabilities defined during the requirement phase were technically tested and accepted by the test users.
- The implementation proves that the Digital Twin of the laser-based assistance system supports the planning, simulation, and training of new employees on the shop floor.

Deviations:

- The required functions were implemented, but usability in the AR environment showed considerable improvement needs in the general user experience.
- From an ergonomic point of view, spectacle wearers could not use the AR glasses well, and the control via gestures and languages did not work reliably.
- The instantiation would have to be developed further for a comprehensive case study. However, technical and non-technical feasibility was the main focus of this design cycle.

Conclusion: Both Digital Twin implementations support the planning and simulation of laser-based assistance systems for shop floor scenarios. Their use is multifaceted along the product lifecycle, and different user groups describe divergent requirements. The artefact can be used in an expanded version to reconfigure production lines or train new employees. DTs can also be enriched with production data and offer value-added production services. In response to the seventh research question, the design cycle provides knowledge on how to design the DT and its usage for workplace planning and simulation. However, besides the usability that needs to be improved, a high number of standards can be considered when realising DTs. In their survey for the Change2Twin consortium, Flamigni et al. (2021) identified 33 standards of particular interest. This situation challenges implementations in reality.

Knowledge contribution:

Reflection:

- The Digital Twin complements the physical assistance system and provides value to involved stakeholders throughout the lifecycle of the assistance system. The user-centric requirement analysis was conducted according to DP I1.1.

- The DT model is limited to the work planning process at this stage. It could be enhanced by becoming a virtual representation of the assistance system in daily operation supporting DP I2.4 and DP I3.1.
- Digital Twin implementations should consider the organisational unit's specific user requirements to increase the perceived usefulness. Users can be manufacturers, engineering service providers, systems suppliers and various departments within these organisations.
- Several tools can be used for DT implementation. The virtual representation must be developed with appropriate tools for the specific purpose. Moreover, it should support perception and navigation tasks and the users' immersion into the 3D environment.
- The technology acceptance models show some aspects such as experience, computer self-efficacy and anxiety that speak against using data glasses among older workers.
- The usability of DTs is essential to increase the perceived ease of use. Hands-free control methods according to DP I5.1 and NUI according to DP I5.2 should be optimised for usability for different user groups.
- Additional capabilities can be implemented, and connections to the tangible asset should be secured to enrich the DT with operational data and the option to loop back data. Production control, monitoring and quality management would provide additional value following DP I4.2.
- A DT of a HCPS should also include a virtual representation of Operator 4.0. Such Human-Digital Twins (HDT) allow ergonomics investigations, user-specific production planning, customised training, and user behaviour prediction. The HDT can be wirelessly connected to actual users by wearable devices (Löcklin et al., 2021; Wang et al., 2022).

Abstraction:

- Digital Twins of Cyber-Physical assistance systems support controlled work system changes, operational flexibility, and versatility of production systems but need to be specifically designed and implemented for the corresponding use cases.
- Digital Twins can also enhance the product portfolio of system providers and enable new business models and revenue streams.

The design principles presented in Table 33 are derived from the abstraction and reflection process as knowledge contribution in the *exaptation* area, according to Gregor and Hevner (2013).

DP	Description
DP I7.1	For the design of digital twins of Cyber-Physical assistance systems, to support planning and simulation, a user-centric approach should be applied to identify requirements and develop a purposive capability model.

DP I7.2	For the design of digital twins of Cyber-Physical assistance systems, to support user acceptance and to increase operational capabilities, virtual or augmented 3D visualisation should be implemented.

Table 33: Design Principles industry cycle seven

The overall design, development and evaluation process with important activities is depicted in Figure 78 according to the phases described previously.

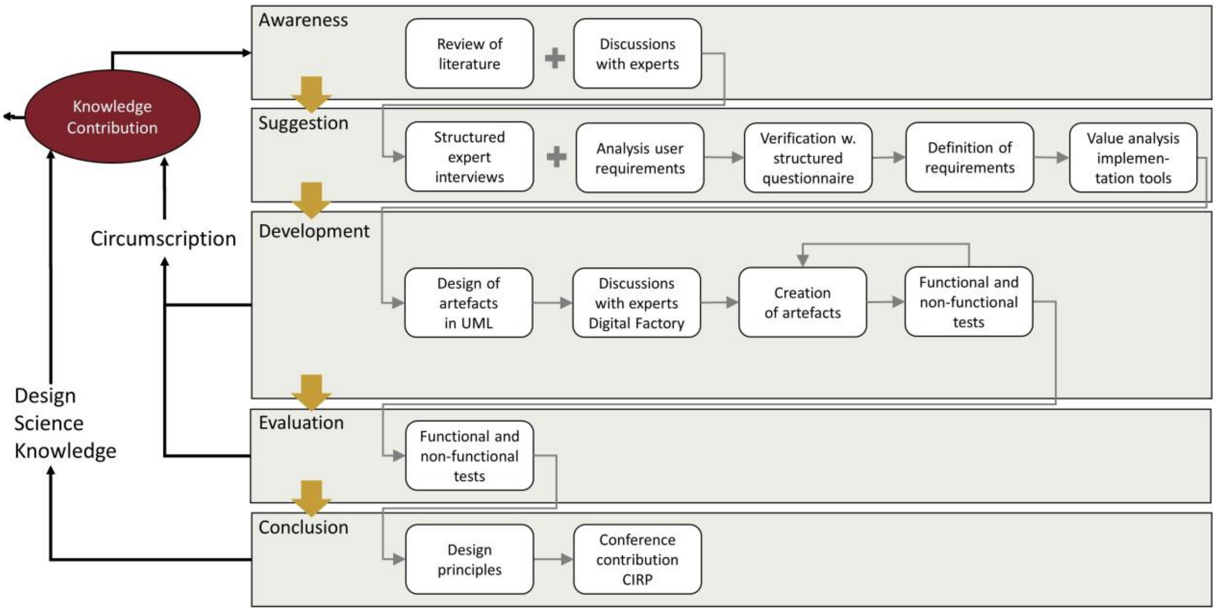

Figure 78: Design Cycle Digital twin of a laser-based assembly system (own figure)

With their extensive empirical studies, the DSR cycles of the industrial path have revealed new insights, especially in the areas of system control, quality control and integration. The transfer challenge that remains is whether and how the elaborated findings can be applied to the healthcare environment and what additional challenges arise from the specific medical context. "Unlike traditional engineering models, Digital Twins [in healthcare] reflect the particular and individual, the idiosyncratic. Traditional engineering models reflect the generic: they apply to multiple instances" (Bruynseels et al., 2018).

c. Design cycles healthcare path

In the following, the individual design cycles of the healthcare path are presented stringently according to the phase's awareness, suggestion, development, evaluation and conclusion, as applied in the previous industry design cycles. The healthcare environment's unique features are examined using radiotherapy applications for cancer treatment, as introduced in section Healthcare 4.0.

i. Assistance systems for radiotherapy to increase efficiency and safety

Awareness: Increasing the efficiency and reducing the risks of cancer treatment with radiotherapy is highly significant in the healthcare segment (Jacob Van Dyk, 2020). Using intelligent systems for user assistance in a digitally connected environment could support radiotherapy professionals in performing their labour-intensive work tasks more efficiently and effectively (Krämer and Stoffers, 2019; Müller-Polyzou, Reuter-Oppermann et al., 2019). A profound understanding of the radiotherapy tasks and workflows could identify areas that benefit from cooperative user assistance and provide valuable design input for developing such systems (Engbert et al., 2019; Müller-Polyzou, Reuter-Oppermann, Engbert, Schmidt, 2021).

Suggestion: It is suggested that the work processes of radiotherapy practice should be modelled to identify potential areas in which intelligent user assistance systems can lead to efficiency and effectiveness gains. Identifying work tasks, technical systems, and user groups in a multi-perspective research approach is a prerequisite for process modelling. It is also suggested that based on the findings, hypothetical user assistance systems should be designed to address the identified improvement areas in the radiotherapy work processes. Finally, it should also be evaluated if such systems can reach acceptance among users, increase efficiency, and reduce treatment risks.

Development: First, modern radiotherapy practice was analysed, focusing on the active user groups and the involved technical systems. The complex radiotherapy processes reflected the interconnections between people, data, and technical equipment. The analysis was conducted in three structured interviews and one interactive group discussion with medical physicists. The identified mode of operation was then structured into the workflows (WF) *admission*, *imaging*, *treatment planning*, *plan verification*, *patient treatment*, and *after-care* processes. Furthermore, the WF diagnosis and machine QA were considered. In each category, the corresponding process activities were discussed and, if necessary, further refined. The processes were then modelled in swim lanes reflecting the involved technical systems and expert users, as indicated in Figure 79. A professional software tool was used to model the radiotherapy processes in UML notation (Microsoft, 2022; Object Management Group, 2017). The detailed radiotherapy process models are available as supplementary material in Müller-Polyzou, Reuter-Oppermann, Engbert, Schmidt (2021) and Engbert et al. (2019).

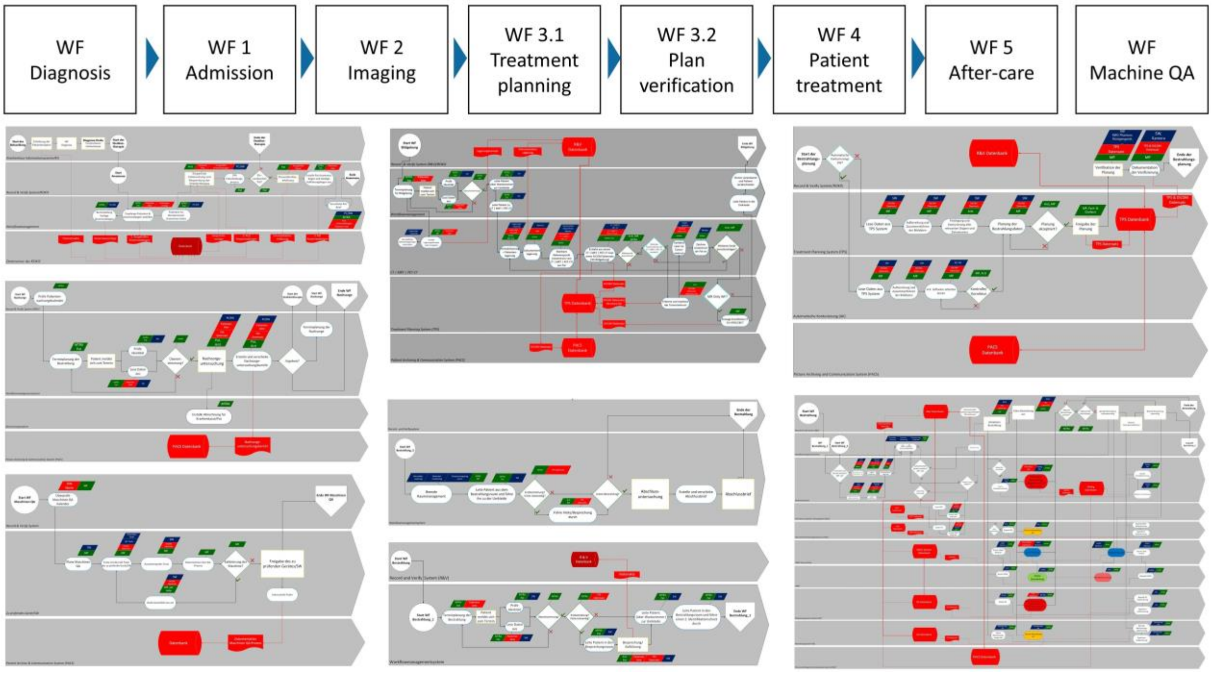

Figure 79: Radiotherapy processes (Müller-Polyzou, Reuter-Oppermann, Engbert, Schmidt, 2021)

Based on the process map, seven improvement areas were identified in a second structured group discussion with medical physicists and healthcare engineers. Subsequently, a hypothetical user assistance system was described for every identified improvement area. In a further validation step, the seven user assistance systems were discussed in a structured interview with a medical physicist, during which an additional user assistance system was identified. Thus, eight hypothetical user assistance systems were described and classified according to their interactivity, intelligence, and activity mode. The user assistance systems are listed in Table 34 (Müller-Polyzou, Reuter-Oppermann, Engbert, Schmidt, 2021).

Area	User assistance system
Digital anamnesis	Patients can enter their anamnesis data on a mobile device
Patient positioning	User assistance with photographic documentation of patient positioning and support of patient positioning at the linac
Patient immobilisation	User assistance with verification and documentation of patient immobilisation devices at CT/ MRT/ PET-CT
Imaging information system	User assistance with information about the type and location of tumours, displaying diagnostic images and providing information about the CT/ MRT/ PET-CT scan
Patient validation	Patient validation at the linac with patient identifying technologies

Therapy planning and scheduling	User assistance to coordinate, document and monitor irradiation planning
Appointment planning	User assistance with appointment planning functionality
Risk management	User assistance that supports the monitoring, recording and archiving of relevant risk parameters

Table 34: User assistance systems for radiotherapy (Müller-Polyzou, Reuter-Oppermann, Engbert, Schmidt, 2021)

The artefacts developed in this design cycle are the detailed radiotherapy process model and the user assistance systems constructs.

Evaluation: First, the radiotherapy process model was verified in an explorative group discussion with the head of a medical physicist team of an advanced radiotherapy centre in Germany. Then, an empirical study was conducted to investigate the potential impact of the user assistance systems artefacts. A structured online survey with medical physicists in Germany was implemented in April 2019. The sample was randomly selected from a list of RT centres in Germany (DEGRO, 2020). One hundred RT centres were contacted by phone, followed by an e-mail invitation and reminder. Of those, 50 fully completed the online questionnaire, with 58% of the participants being medical physics experts and 42% managing medical physics experts. The incentive-free online survey in 12 sections addressed, among others, key figures of the RT centre, the state of digitalisation, and aspects of automation. The assistance systems were then tested in terms of user acceptance, the increase of perceived efficiency and the estimated risk reduction while using the systems. The empirical data were analysed using the IBM SPSS Statistics software (IBM, 2021). The results were comprehensive and published in Müller-Polyzou, Reuter-Oppermann, Engbert, Schmidt (2021).

Results:

Essential Design Requirements (DRs) for radiotherapy user assistance systems could be derived from the findings and are presented in Table 35.

DR	Description
1.1	User assistance systems must increase efficiency in radiotherapy work processes
1.2	User assistance systems must reduce the risk for the involved employees
1.3	Systems should increase patient comfort and well-being
1.4	Systems must be optimised for usability and acceptance for different cultures and regions
1.5	Systems must balance intelligence and interactivity for user groups

1.6	User assistance systems should always leave the final decision to the user
1.7	Systems must ensure data privacy, and the integration must consider cyber security standards
1.8	User assistance systems must be integrated into risk management systems, comply with standards and be reliable
1.9	Systems should be integrated with patients and referring physicians to maximise value and be documented for global certification

Table 35: Design Requirements for radiotherapy assistance systems

Deviations:

- No deviations were recognised in the process modelling and the online survey.

Conclusion: The intensive expert discussions validated the radiotherapy process model representing the state-of-the-art RT practice. Additionally, the model can act as a denominator for individual workflows in global radiotherapy with adaptations that might be required depending on the deployed diagnosis, treatment, and IT/ IS systems. The online survey results confirmed the need for additional user assistance systems in radiotherapy that improve efficiency, reduce treatment risks, and reach high user acceptance. Knowledge constructs, including initial design requirements for radiotherapy assistance systems, were developed in response to the eighth research question.

Knowledge contribution:

Reflection:

- Patient self-services can be integrated into patient management systems to improve efficiency and reduce manual data entry failures by RT staff. The user-centric design described in DP I1.1 should also be extended to include patient-centric design aspects.
- Patient self-services support general patient engagement, support patients as self-governed actors, and promote patient empowerment.
- Administration support services such as appointment planning are essential areas that directly influence the following process steps. Per DP I2.5, seamless integration with up and downstream processes would improve work efficiency.
- Patient positioning is an integral part of radiotherapy and is directly linked with imaging and treatment activities. Related user assistance systems have the potential to become central elements in radiotherapy. Their design should be user-centric according to DP I1.1 and DP I2.2.

- The imaging process activities can be considered necessary work preparation for the following treatment fractions at the linac; therefore, DP I3.1 and DP I3.2 can be directly applied.
- Patient validation, documentation of the patient's position at the planning-CT and verification of the patient's treatment position can be improved with automatic process control methods according to DP I1.2, DP I4.2 and DP I6.1.
- Conformity with usability standards such as ISO 9241 and country-specific regulations is a prerequisite for medical products and is linked to DP I1.1, DP I2.2, DP I5.1, DP I5.2 and DP I6.2.
- RM systems decrease business risks, increase patient and staff safety, and increase the resilience of radiotherapy practice. It also supports the continuity of radiotherapy business.

Abstraction:

- The business processes involve various user groups and patients at different process steps. To optimise process efficiency and safety, user assistance systems must be balanced in interactivity and intelligence and consider the specific work context.
- In order to reach high acceptance levels, user assistance systems need to increase the perceived efficiency of work tasks and the safety of system users based on system usability.
- The systems should provide user profiles with tailored functionalities and provision of information (Toreini et al., 2022). International language support should be implemented, and GUI design should consider cultural specifics. The systems could adapt to the differing cultural design preferences by automatically generating interfaces as proposed by Bernstein, Katharina Reinecke and Abraham (2013).
- The system's well-functioning should be secured in adverse situations, for example, by applying technical redundancy or resilience concepts. The system should provide a secure technical interface for integration purposes.

The design principles presented in Table 36 are derived from reflection and abstraction as knowledge contribution in the *improvement* and *exaptation* area, according to Gregor and Hevner (2013).

DP	Description
DP H1.1	For the design of medical user assistance systems, to increase acceptance, the system should be user- and patient-centric, balance interactivity and intelligence, and provide perceived efficiency or safety gains.
DP H1.2	For the design of medical user assistance systems, to increase acceptance, the system should make suggestions and leave the final decision to the user.
DP H1.3	For the design of medical user assistance systems to transform into a Medical Cyber-Physical System, vertical and horizontal integration should be realised.

DP H1.4	For the design of medical user assistance systems to be accepted by users, the system should secure well-functioning under adverse conditions.
DP H1.5	For the design of medical user assistance systems, to allow global deployment as a medical product, the system must support international data security standards and be protected against cyberattacks.
DP H1.6	For the design of medical user assistance systems, to allow global deployment as a medical product, the system must comply with the valid national data protection laws.
DP H1.7	For the design of medical user assistance systems, to allow global deployment as a medical product, the system must fulfil the international standards for medical software, risk management and usability.

Table 36: Design Principles healthcare cycle one

The design process with relevant activities in the five phases is depicted in Figure 80.

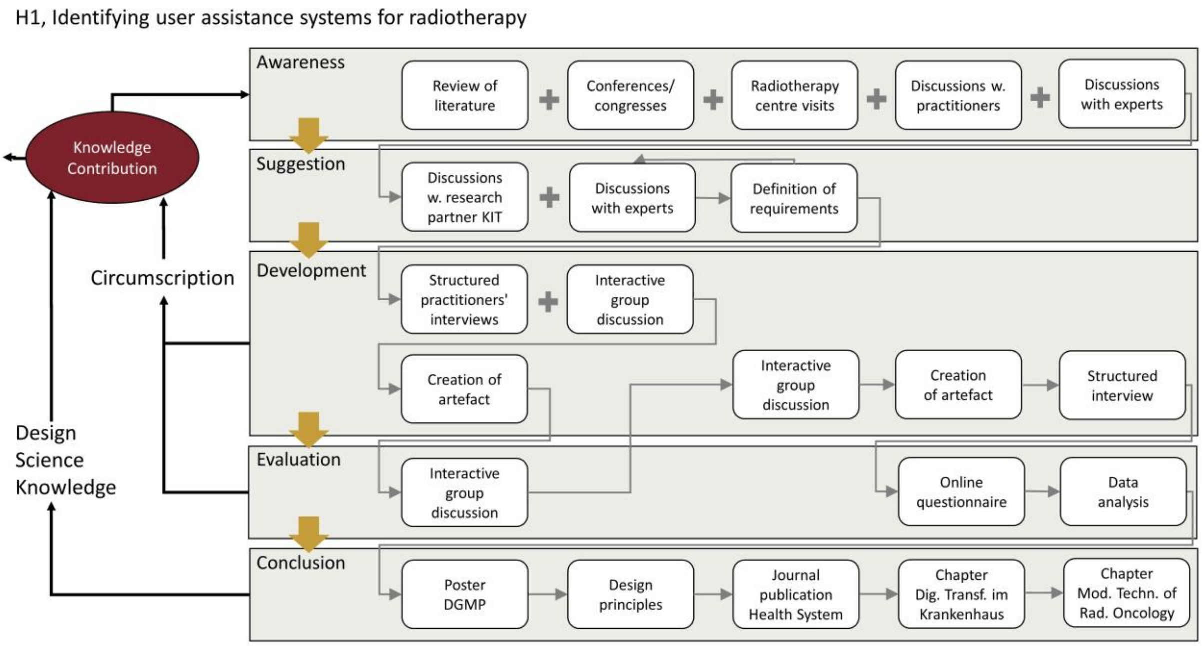

Figure 80: Design Cycle Assistance systems for radiotherapy (own figure)

The extensive design cycle has raised many issues that will be explored in more detail in further cycles. In addition, the foundations were laid regarding the need for and use of assistance systems in radiotherapy. Finalising the DSR cycle, it remains to be analysed which learnings can be transferred from industrial assistance systems to the healthcare sector. Also, the impact of business disruptions on well-structured radiotherapy processes should be investigated, considering the importance of uninterrupted radiotherapy treatment and society's increasing need for resilience.

ii. Medical cyber-physical assistance systems for radiotherapy

Awareness: Effective radiotherapy for cancer treatment requires the precise and reproducible positioning of patients at linacs. User assistance systems can support specialists in performing patient positioning efficiently and accurately (Guo et al., 2020). Surface Guided Radio Therapy (SGRT) systems, as shown in Figure 81, as a sub-group of Image-Guided Radio Therapy (IGRT) systems, are widely deployed and offer opportunities for innovation (Al-Hallaq et al., 2022; Hoisak and Pawlicki, 2018, 2018; Hosaik et al., 2021; Padilla et al., 2019). Consequently, additional research should increase the knowledge on the design of patient positioning systems and identify design requirements for innovating such systems to increase the efficiency and safety of radiotherapy practice (Müller-Polyzou et al., 2022).

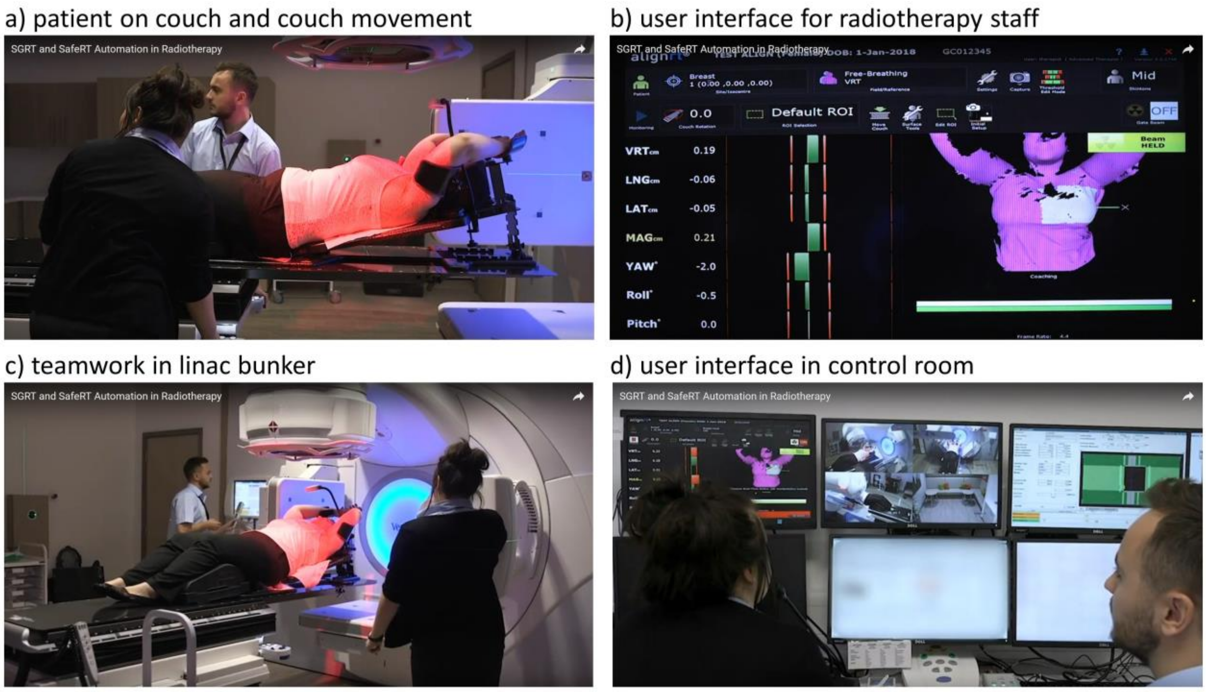

Figure 81: SGRT work context (own figure based on Dorney (2019))

Suggestion: It is suggested to conduct an SLR and an empiric study on patient positioning systems in radiotherapy to enhance the knowledge base and derive DRs for developing an intelligent and interactive MCPS for assisting radiotherapy patient positioning. An artefact in the form of a conceptual patient positioning system model should be designed based on the existing knowledge and new research findings. A specific use case that visualises and describes the active system components and human-machine involvement should be described.

Development: The development of the DSR cycle was performed in three phases. In phase one, an SLR documented with the PRISMA method was conducted by reviewing 1,805 academic articles and classifying them according to relevant categories. The SLR revealed 234 publications related to IS for further analysis. Fourteen articles that describe IS instantiations related to imaging and therapy processes in patient positioning were identified. Of those, nine articles dealt with patient positioning. A forward and backward search focusing on SGRT was performed, adding six articles eligible for full-text assessment. The content analysis was performed with the identified SGRT articles because of the innovation potential of the technology. The content analysis followed an inductive deductive coding approach, and code networks were developed to represent the codes' relationships. The frequency of code usage (grounding) and the connections' density were used for the analysis. The PACT dimensions formed the roots of the code networks, while the following codes comprised subcategories of the PACT dimensions. Additional codes were elaborated inductively.

The SLR showed the status of the systems and technologies already researched. Figure 83 indicates that activities and the technology dimensions of PACT were more scientifically grounded than the people and context dimensions. The results of the SLR increased the design knowledge in the problem and solution space, according to vom Brocke et al. (2020), and provided input for the design of the structured online survey of phase two.

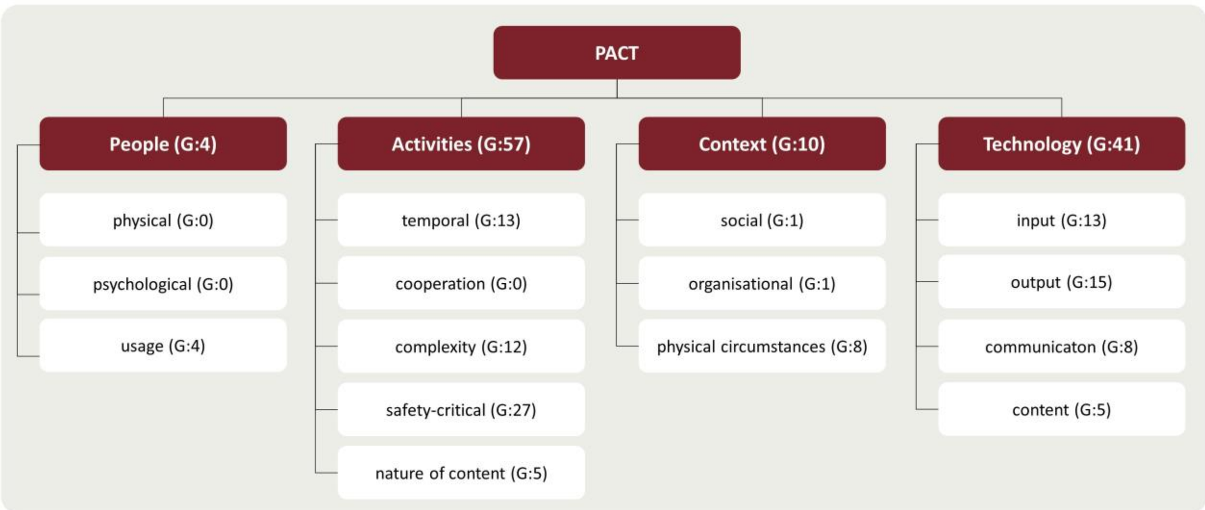

Figure 82: Code frequency SGRT literature (own figure)

In phase two, single-perspective research was applied with a structured online survey that targeted medical physicists responsible for patient positioning systems. The survey was implemented in German and was conducted in November 2020. The participants were selected from the German Association for Radiation Oncology (DEGRO) members (DEGRO, 2020). The survey was sent out in a personalised e-mail to 78 RT centres, of which 68 participated and 45 completed the questionnaire representing approximately 15% of the RT centres in Germany. The survey's results were published in Müller-Polyzou et al. (2022) and were used to develop the DRs for the patient positioning artefact, as listed in Table 37.

DR	Description
General 1.1-1.11	• The system MUST increase patient positioning accuracy • The system MUST reduce patient positioning time • The system MUST prioritise positioning accuracy against patient positioning time • The user MUST have decision-making power over the system • The system SHOULD be designed to increase the reputation of the RT centre • The system COULD be designed to support a non-technical room feeling • The system COULD have an appealing design • The system COULD be intelligent and able to learn • The system COULD reduce waiting times for employees and patients • The system COULD be markerless and not apply irradiation to patients • The system SHOULD support system deployment worldwide
Integration 2.1-2.6	• The system MUST support multiple linacs of different suppliers in private and public cancer centres worldwide • The system MUST have standardised interfaces for integration purposes • The system SHOULD improve the interaction of imaging modalities and linac • The system SHOULD support automated task execution such as quality assurance and procedure documentation • The system SHOULD be integrated to support real-time couch control • The system SHOULD support collision avoidance with the linac
HMI 3.1-3.12	• The system MUST be easy to learn and operate • The system SHOULD be operable from a mobile device • The system MUST have a tablet computer for system control • Information MUST be displayed on a monitor in the control room • The system SHOULD embrace a wall-mounted monitor in the treatment room • In-situ projection onto the patient body SHOULD be provided • The system COULD also present information on a tablet computer

	• The system MUST present a list of immobilisation devices used to position the patient at the linac • The system MUST present patient data, including a profile picture • The system COULD present an image of the patient with immobilisation devices and a superimposed reference position • The system COULD display the breathing curve of the patient • The system COULD be customisable and make the operation enjoyable
System features 4.1-4.5	• The system MUST support respiratory gating techniques • The system SHOULD support stereotactic treatment • The system MUST detect the movement of patients during treatment • The system MUST validate the correct usage of immobilisation devices • The system COULD predict tumour movement without fiducial markers
System safety 5.1-5.7	• The system MUST increase user safety in patient positioning for RT practice • The system SHOULD recognise and validate patients to increase safety and avoid unnecessary work steps • The system MUST alert to errors • The system SHOULD intervene in case of errors • The system SHOULD stop the treatment in case of intrafractional movements • The system COULD cover a large region of the body and recognise changes • The system MUST be protected against cyberattacks

Table 37: Design Requirements MCPS artefact

The design requirements were used in phase three to develop the patient positioning artefact shown in Figure 83. It contains an information processing unit connected to a user tablet for location-independent system operation and monitors in the control and linac room. Stereotactic cameras with build-in projectors are installed in the CT and the linac rooms. The projectors are used for sensory reasons and augment information onto the patient's body, while the image processing unit uses the point cloud of the cameras in the CT and linac room to calculate the body surface. This concept forms the basis for patient positioning and respiratory gating applications. Selected data and metadata are stored in the central system database and made available for processing by the three business logic units: supportive, cooperative, and notifying services.

The supportive services business logic implements services that help employees with their tasks. Examples are import and export functions and rules definitions for task automation. The cooperative business logic implements services where the user interacts with the assistance system. Both supportive and cooperative services can be implemented as wizards or forms for data input and textual, voice or image guidance. The notifying business logic secures time-critical alert services. The supportive business logic can also provide expert advice in collaboration with the decision support unit, including a central knowledge base, knowledge acquisition, inference engine, and explanation component. Expert services such as clinical decision support can be implemented for patient positioning or immobilisation device usage. The connector secures safe integration to the OIMS or other third-party systems via the standardised interfaces DICOM and HL7. The elaborated knowledge elements and conceptual positioning system artefact are the basis for specific use cases (Müller-Polyzou et al., 2022).

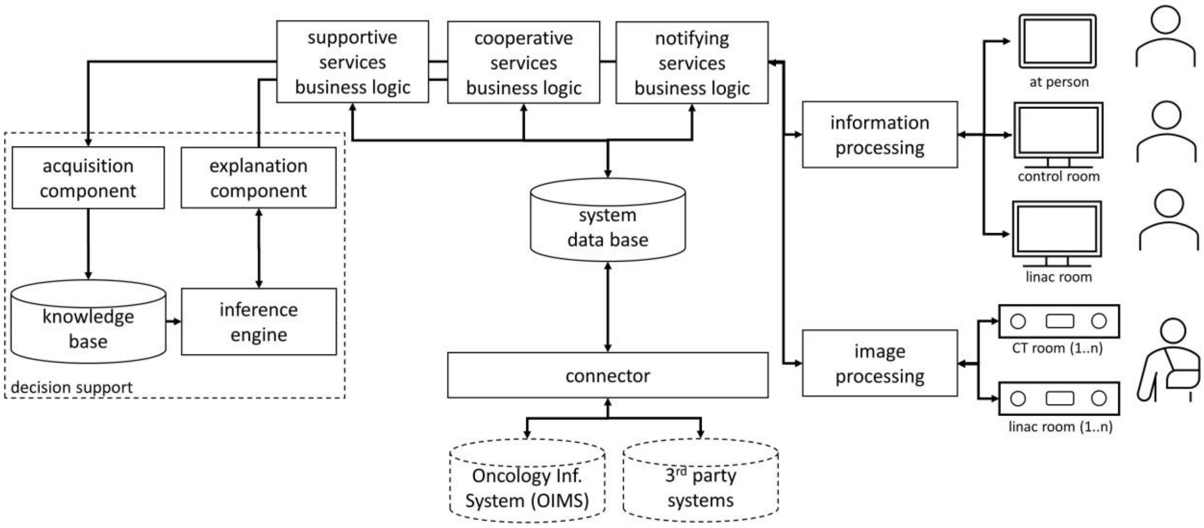

Figure 83: Conceptual positioning system for radiotherapy (own figure)

Patients should never collide with moving parts of the linac, such as the gantry or imaging devices. Advanced non-coplanar radiotherapy treatment techniques increase the risk of collision because of the changing angles of the patient's couch (Smyth et al., 2019). Collision avoidance is typically simulated during treatment planning, considering the patient anatomy known from imaging processes and the mechanical dimensions of the linac machine used for treatment (Islam et al., 2020; Miao et al., 2020). However, reliable collision avoidance mechanisms must also secure the safety of patients in unforeseen situations, such as spontaneous movements of the limbs. The conceptual system presented in Figure 83 can provide collision avoidance services.

Using UML, the corresponding use case is described in Figure 85 (Object Management Group, 2017). The description focuses on the essentials. The supportive and cooperative services are not used in this case, even though they could increase the overall user experience. The decision support service warns the user against a likely collision case before initiating the treatment. The AI-based service can utilise irradiation planning, build-in imaging and third-party equipment data. Results can be further improved using general patient data, body characteristics or the specific pain situation. By predicting a collision, the user can act and resolve the risk before starting the radiotherapy treatment. At this point, the alert service starts collision observation and intervenes in case of danger. The service immediately stops the linac movement and patient irradiation in such a case. An overwrite function is incorporated to proceed with the treatment while consciously accepting the risk.

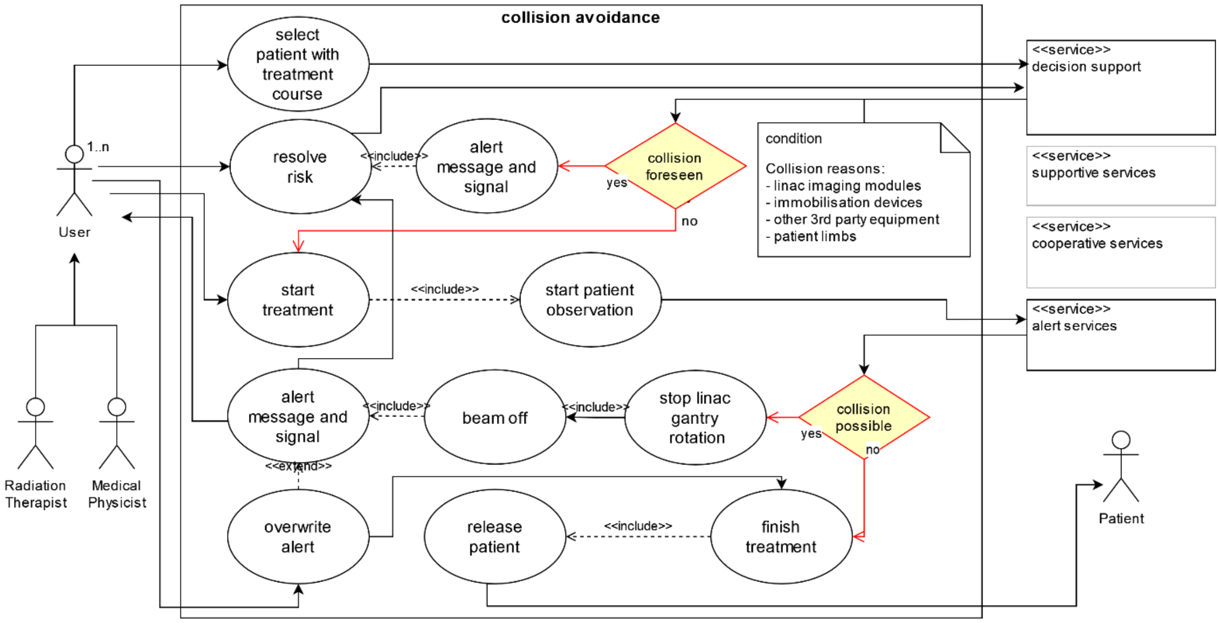

Figure 84: Collision avoidance use case (own figure)

The system can play a central role in radiotherapy with its sensory and computational capabilities. It integrates into the workflow and connects imaging modalities with treatment at the linac. Furthermore, several linacs can be equipped, and joint data management and utilisation can be implemented.

Evaluation: The conceptual patient positioning system and the exemplary collision-avoidance use case were evaluated in three expert discussions with medical physicists, two being head physicists of radiotherapy departments of university hospitals in Germany and one working in a private RT centre. The conceptual system and the exemplary use case were verified against the long-term clinical experience. In the discussions, the necessity for the specific use case and the flexibility and application possibilities of the conceptual system was confirmed. In addition to the threefold structure of the business logic consisting of supportive, cooperative and notifying services, further research opportunities arising from the connection to the decision support unit were highlighted. The interviewees mentioned the possibility of integrating the system with the imaging modalities of the linac, which is expected to become more critical with the dissemination of adaptive radiotherapy treatment, which is "… a closed-loop radiation treatment process where the treatment plan can be modified using systematic feedback of measurements" (Di Yan et al., 1997).

Results:

- Academic articles focus on effectiveness, efficiency, usability and safety aspects. They describe technical solutions for body surface acquisition, such as photogrammetry-based camera systems with structured or scattered light projection, ToF camera systems, cameras using IR markers placed on the patient's body, and AR solutions.
- The analysis of the PACT dimensions shows that the activities (50.9%) and the technology dimension (36.6%) are firmly grounded.
- The dimensions of people (3.6%) and context (8.9%) are only slightly addressed in the academic literature concerning socio-technical information systems, which is paradoxical, especially in the light of the demographic change.
- Forty-one DRs in five categories were derived from the content analysis and the comprehensive online survey providing a sound requirement base for system development.
- The conceptual patient positioning system developed according to the defined DRs fulfils the expectations of RT experts. The exemplary use case of collision avoidance was verified against clinical experience.

Deviations:

- No deviations were identified in this research cycle.

Conclusion: In response to the ninth research question, the artefact describes an intelligent assistance system that supports patients' precise and reproducible positioning in radiotherapy. The proposed system incorporating supportive, cooperative and notifying service modes closes the gap between technology and the individual skills of the specialists by applying varying degrees of intelligence and interactivity. The core functionalities of positioning the patient on the linac are fulfilled, and new services of patient validation, collision avoidance and couch control are implemented in a standardised, safe and automated manner. The requirements for user experience, especially of the users in their specific work context, concern the simplicity of learning and operation while increasing the user's safety.

Knowledge contribution:

Reflection:

- The SLR revealed that the academic publications pay little attention to the people and context dimensions of assistance systems. A user-centric approach according to DP I1.1 will support focusing on these dimensions.
- The proposed system artefact incorporates DPs elaborated in previous design cycles. The SGRT technology supports quality workspaces described in DP I2.1, secures integration according to DP I2.3 and DP I2.5, and intra-fractional motion control according to DP I1.2 and DP I6.1 in-situ projection as advised by DP I6.2.
- Also, the essential principles of balancing interactivity and intelligence according to DP H1.1 and system integration as prescribed by DP H1.3 are considered in the conceptual system. The artefact supports distributed cognition between users and the system.
- Positioning with SGRT takes longer compared to laser systems. The intelligent combination could exploit the advantages of both technologies.
- Positioning patients is based on visual, auditory and haptic information and requires spatial awareness. It is usually performed with a coworker, and patient safety depends on the accurate task execution.
- A Digital Twin representation of the patient positioning system considering DP I7.1 and DP I7.2 could support optimising RT processes and resources with DP I4.2.
- New developments in sensor technology can lead to higher positioning accuracy.

Abstraction:

- The patient positioning system artefact connects the required imaging with the treatment sub-process and is prepared for advanced closed-loop treatments.
- The system uses imaging data of the patient's body surface to provide essential and advanced radiotherapy services.
- The system collects and documents imaging and process data for quality assurance purposes.
- The assistance system provides supportive, cooperative and notifying services.

The design principles presented in Table 38 are derived from the reflection and abstraction process as knowledge contribution in the *improvement* and *exaptation* area, according to Gregor and Hevner (2013).

DP	Description
DP H2.1	For the design of a patient positioning system, to support efficiency and safety, the system should be optimised for accuracy and fast task execution with accuracy to be prioritised.

DP H2.2	For the design of a patient positioning system to support safety for users and patients, the system should alert to errors and intervene if necessary.
DP H2.3	For the design of a patient positioning system to support safety for users and patients, the user stays always informed and keeps control via modern interfaces with high usability.
DP H2.4	For the design of a patient positioning system to support acceptance, the system should be easy to learn, easy to use and focus on the essentials for task execution.
DP H2.5	For the design of a patient positioning system, to support acceptance, the system should leave the final decision power to the user by releasing single work steps within a cooperative or supportive workflow.
DP H2.6	For the design of a patient positioning system to support future changes in technology and workflows, the system should be designed for flexibility and versatility.
DP H2.7	For the design of a patient positioning system to support vertical and horizontal integration, the system should have standardised interfaces and secure data privacy and cybersecurity.

Table 38: Design Principles healthcare cycle two

The overall design process with important activities is depicted in Figure 85 according to the awareness, suggestion, development, evaluation and conclusion phases.

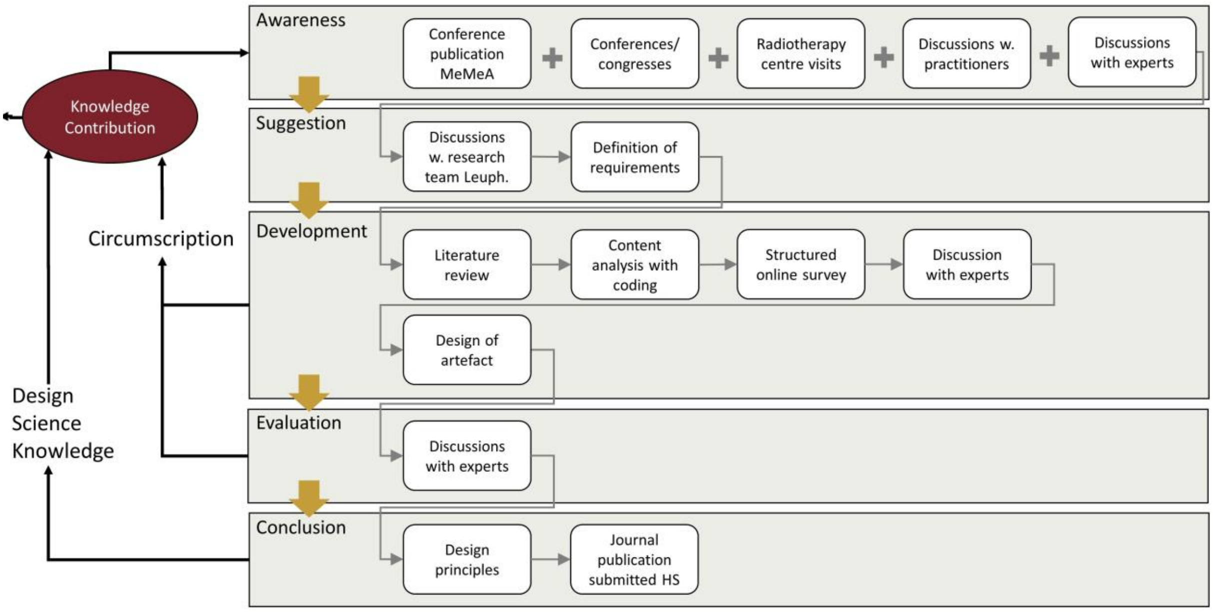

Figure 85: Design Cycle Medical assistance for patient positioning in radiotherapy (own figure)

The DSR cycle concludes with the conceptual patient positioning system fulfilling the design requirements and following the DPs elaborated in previous industry and healthcare design cycles. In summary, the design of a patient positioning artefact and DPs strengthens the knowledge base of patient positioning in radiotherapy and healthcare, while innovation will further drive the development of SGRT systems. No significant additional transfer learnings remain to be elaborated, but the critical topic of resilience should be investigated in the following DSR cycles, given the world's numerous global challenges.

iii. Influence of the COVID-19 pandemic on radiotherapy practice

Awareness: The COVID-19 pandemic has affected businesses and institutions worldwide. This is particularly the case in the healthcare system, including radiotherapy for cancer treatment, where patients rely on uninterrupted therapies. The question arising is to what extent radiotherapy processes and systems are affected by the pandemic disruption. Thus, it should be analysed which business contingency and risk management measures are already applied, evaluate the impact on processes and compare potential mitigation actions.

Suggestion: It is assumed that the pandemic disruption affects radiotherapy practice, like many other areas of our lives. The radiotherapy sub-processes are strongly interrelated within RT centres, hospitals, and with external providers, while patients must receive uninterrupted therapy to secure treatment success. Radiotherapy practice reserves technical redundancy for machine failures. However, it is assumed that the human factor has not sufficiently been considered in risk planning for radiotherapy practice. Therefore, it is suggested to increase knowledge on resilience in radiotherapy practice by developing related knowledge constructs.

Development: A knowledge construct was created supporting the development of resilient systems for radiotherapy. The basis of the analysis was the business process map of the radiotherapy centre developed in a previous design cycle. The knowledge construct presented insights into how radiotherapy practices reacted to the COVID-19 disruption and to which extent processes were affected (Reuter-Oppermann et al., 2020).

Evaluation: A structured online survey among medical physicists in Germany, Austria and Switzerland was conducted in March 2020. In total, 154 responses were analysed in the context of the COVID-19 dissemination. The survey was conducted using an e-mail distribution list of medical physicists in Germany (Deutsche Gesellschaft für medizinische Physik e.V. DGMP, 2022). The multi-perspective questionnaire consisting of nine sections and 15 questions was implemented in LimeSurvey and beforehand reviewed by a radiotherapy expert and extensively tested. Eighty-two participants (n=82) completed the questionnaire, while 72 responded partially (Reuter-Oppermann et al., 2020).

Results:

- Radiotherapy practice was affected by the COVID-19 disruption. 72.4% of the respondents stated that their processes were affected due to COVID-19, while the top three answers were *longer processing times* (54.2%), *patient no-shows* (42.5%) and *staff reduction* (36.7%). 75.8% expect further *unavailability of their personnel*.
- The participants expected further restrictions in the early phase of the pandemic. The first concern was the non-availability of personnel, longer processes due to protective measures, and more patients who would not keep their appointments. Also, *non-availability of personnel at co-handlers* and *failure due to lack of access to service personnel* were expected.
- All participants had implemented first contingency measures, especially *providing information for patients at the entrance of the radiotherapy centre* (89.6%) or *over the phone* (73.6%), *restricting access for accompanying persons* (77.4%) and *providing disinfectant* (72.6%).
- The lowest impact was expected for *patient verification*, *immobilisation*, *imaging*, and *treatment planning* processes. *Anamnesis*, *visits*, *examinations* and *patient decision-making* processes were expected to be affected, but *aftercare* and *appointment planning* were expected to be most affected by COVID-19.
- One implemented contingency measure was classifying patients into *urgency groups* (41%), known from emergency triage assessments (World Health Organization, 2005). Further measures were treatment-related, such as *hypofractionation* (33.7%), *recalculation of treatment plans for the continuation of therapy* (18.1%) and *compensation of treatment breaks with additional fractions* (18.1%).
- Survey participants stated that they would extend the existing measures if needed. The classification of patients into *urgency groups* would increase by 20.5 percentage points. *Hypofractionation* would be reinforced by 48.2% of the respondents, reflecting an increase of 14.5 percentage points. The compensation of treatments through additional fractions would be implemented by 45.8% of the respondents.

Deviations:

- The survey was conducted in the early phase of the pandemic when there was high uncertainty about COVID-19 and a lack of availability of personal protective equipment. In addition, there were few recommendations for action for radiotherapy centre operators.

Conclusion: The survey supports the design of business continuity and risk management solutions for radiotherapy centres to prepare for future challenges. In response to the tenth research question, the results show that most radiotherapy centres had implemented initial contingency measures pragmatically. However, the problem of high risk of infection both for patients and medical personnel, along with the associated risk of temporary loss of personnel and ordered business closure, remained. The design cycle has thus demonstrated that radiotherapy practice has low resilience to pandemic disruption caused by COVID-19.

Knowledge contribution:

Reflection:

- Radiotherapy centres were unprepared for a pandemic and had to initially implement solutions at their discretion, without assistance from professional associations. International experience from previous epidemics was not known to most experts. Even long-term employees had never experienced a similar situation.
- First contingency measures were applied pragmatically without knowing the impact on processes. The effects could not be simulated but were used on a trial-and-error basis.
- Technical risk management and redundancy did not secure business continuity in pandemic conditions. The temporary loss of personnel caused most business continuity risks.
- Digitalised centres could react fast by implementing remote system access, working from home and video conferencing with patients and coworkers. Many employees, including older ones, had to learn to deal with the new situation in the short term.

Abstraction:

- The resilience of critical healthcare processes should be increased by providing low-threshold business continuity assistance.
- A high degree of digitalisation increases the scope for action, such as letting employees work from home, providing remote system access for service technicians and communicating efficiently with patients.

Design principles:

The design principles presented in Table 39 are derived from the reflection and abstraction process as knowledge contribution in the *improvement* and *exaptation* area, according to Gregor and Hevner (2013).

DP	Description
DP H3.1	For the design of medical user assistance systems to increase resilience, remote system accessibility should be implemented.
DP H3.2	For the design of medical user assistance systems to support resilience, low-threshold access for stand-in personnel should be secured.
DP H3.3	For the design of medical user assistance systems to support business continuity, telehealth solutions should be made available.

Table 39: Design Principles healthcare cycle three

The overall design process with significant activities and the five phases is presented in Figure 86.

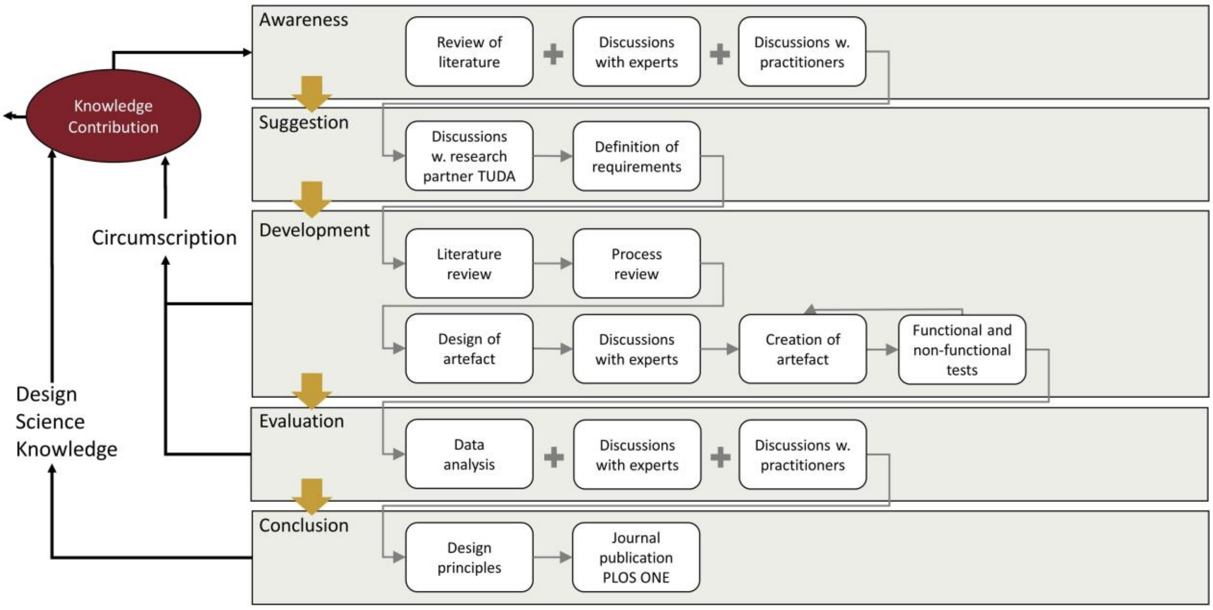

Figure 86: Influence of COVID-19 on radiotherapy practice (own figure)

The DSR cycle provided valuable insights into the resilience and effectiveness of existing BCM concepts in Germany's early phase of the dissemination of the COVID-19 pandemic. The transfer challenge remains to make systems more resilient to disruptions and provide tangible help to quickly and efficiently ensure business continuity when needed.

iv. Radiotherapy business continuity in a pandemic crisis

Awareness: The continuity of radiotherapy practice is vital for safe, effective, and efficient cancer treatment (Gay et al., 2019). The COVID-19 pandemic has caught radiotherapy organisations unprepared, and centres worldwide had to master unexpected challenges while patients relied on uninterrupted therapies. Highly digitalised centres could react quickly, but the lack of knowledge, specific guidelines and mitigation strategies exposed radiotherapy centres to unpredictable risks (Reuter-Oppermann et al., 2021; Viscariello et al., 2020).

Suggestion: It is suggested that an interactive computer-based DSS should be developed to help decision-making for maintaining safe, sustainable and efficient radiotherapy services in pandemic times (Schuff et al., 2011). A text-based conversational agent informing about risk mitigation measures for the radiotherapy business should be designed to provide reliable advice to responsible persons in RT centres. The system should provide recommendations and reasoning based on the global COVID-19 risk mitigation knowledge in a user-friendly way (Reuter-Oppermann et al., 2021).

Development: A SLR was conducted in phase one with a subsequent content analysis on 16 publications, including 12 country reports and four survey papers from international societies for radiation oncology. The SLR was conducted in September 2020 on ScienceDirect, focusing on BCM, RM, healthcare and COVID-19 to reveal experience with COVID-19 risk mitigation measures applied in RT centres worldwide. The analysis was complemented by a structured interview with a medical physicist working in a private RT centre and a member of the German association of medical physicists (DEGRO, 2020). The explorative interview, including 20 open and seven closed questions, was recorded for the subsequent content analysis. The publications, surveys, and interview was analysed using atlas.ti and an open-coding approach (ATLAS.ti GmbH, 2021). The codes were categorised into groups and sub-groups. Code networks were developed, as shown in Figure 87, for one code group, and code linkages were assigned. Codes, code groups and code networks were reviewed with subject matter experts.

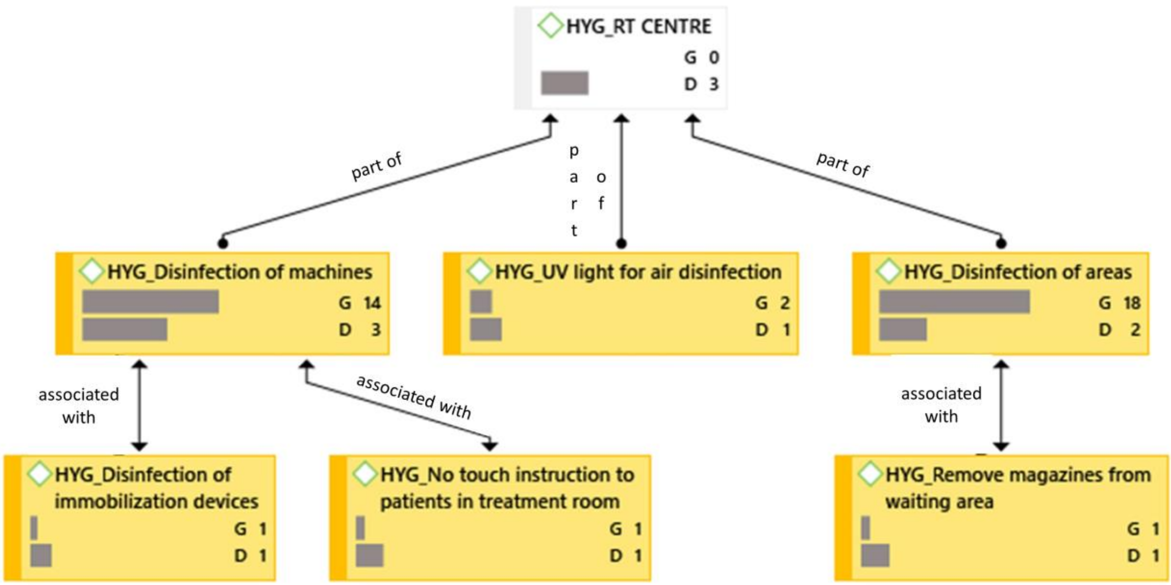

Figure 87: Code network hygiene category (own figure)

A total of 97 COVID-19 risk mitigation measures were identified, described, and assigned to the code groups and sub-groups. According to Saldaña (2021), themes were developed for sensemaking and afterwards visualised in a framework of COVID-19 riks mitigation measures, as shown in Figure 88. Four themes describe the fundamental risk mitigation measures applied in RT centres worldwide: *access*, *protection*, *therapy* and *hygiene*. The three additional themes of *organisational* aspects, *collaboration* and *communication,* were identified, which are based on the fundamental themes. The concept can be generalised and applied to other infection-related business crises (Reuter-Oppermann et al., 2021).

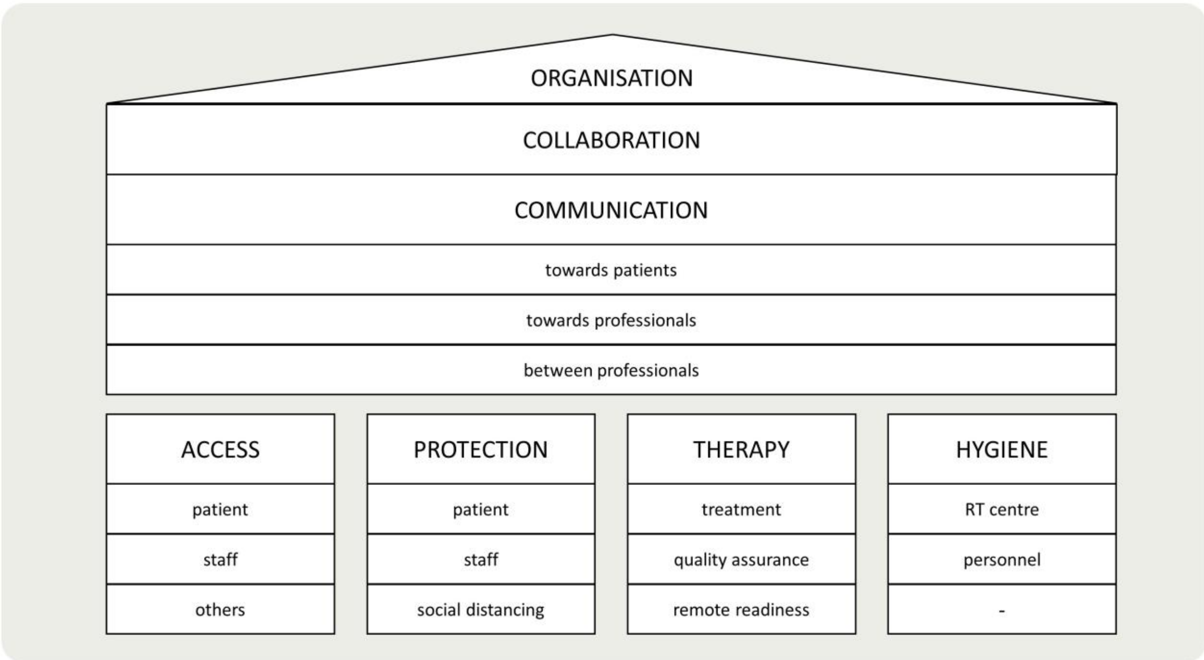

Figure 88: Themes of COVID-19 risk mitigation measures (own figure)

To enhance the DSS knowledge base, the 97 risk mitigation measures were evaluated by application area experts to understand their impact on risk reduction, resource demand (cost, time, personnel), liability risks and patient satisfaction. The evaluation results were reviewed in a group discussion with experts, completing the knowledge base.

A DSS system was instantiated in phase two following a requirement analysis describing personas and a defined use case. As shown in Table 40, design requirements were formulated based on previous work on user assistance systems and findings from the expert discussions in the current design cycle.

DR	Description

1	The system must provide RT-specific advice in a pandemic crisis
2	The system must recommend risk mitigation measures to support RT BCM
3	The system should only assist and make suggestions. Decisions about potential changes remain with the user
4	The system must be designed for usability and acceptance in different user groups
5	The system must provide a NUI in English. It should support the implementation of additional languages for broader use in the future
6	The system must operate on a standard web browser and not require additional hardware or software
7	The system must be reliable
8	The system should be prepared to integrate RT centres' data sources

Table 40: Design Requirements for the conversational chatbot (Reuter-Oppermann et al., 2021)

The DRs were implemented in a conversational AI-based chatbot using Google Dialogflow to model the NUI and apply the knowledge base (Google Cloud, 2021). The conversational chatbot was implemented as a web service to function on any device with a web browser. Figure 89 outlines the system architecture and the application's interface on a mobile phone. The user interacts with the system via the chatbot interface, which also supports the automatic correction of input errors. The natural language processing unit and explanation component forward the user input to the interference engine, making recommendations based on the knowledge base. The dotted line indicates that the DSS could also be connected to an RT simulation component that simulates the impact of risk mitigation measures for a specific radiotherapy centre. The acquisition component could utilise RT centre process data or OIS information to extend the knowledge base of the DSS.

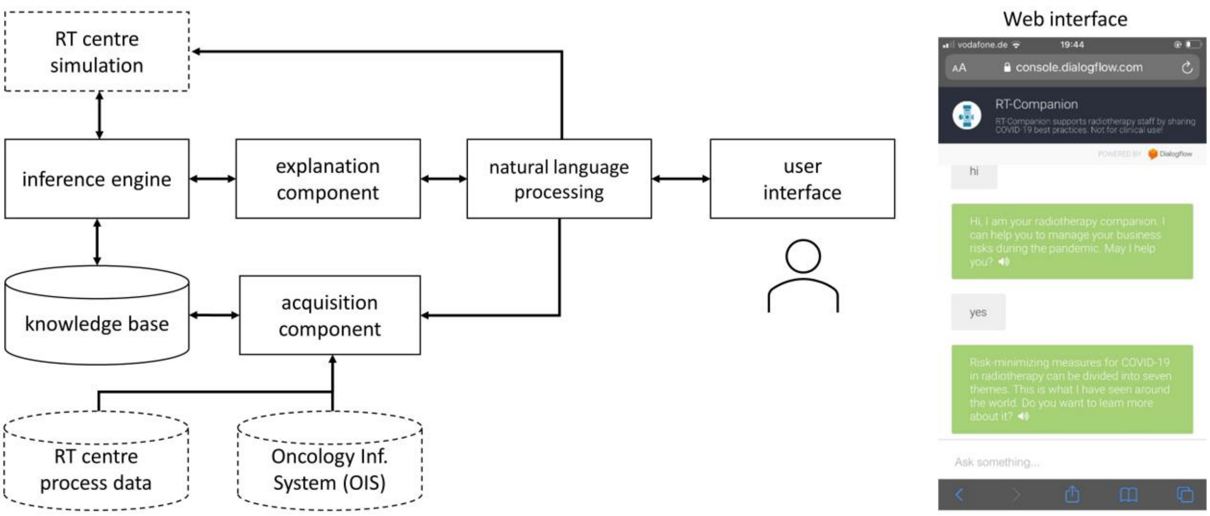

Figure 89: System architecture and interface of chatbot application (own figure)

The user communicates with the interactive chatbot agent consisting of a welcome intent, the knowledge base, an acquisition and a BCM and RM fallback intent, whereby every intent is based on training phases, actions, parameters and responses. Figure 90 presents the flow chart of the chatbot agent with the corresponding intents in a simplified presentation. The natural language processing module, shown in Figure 89, interprets the user's language and translates text or audio to structured data. The agent has been trained to match conversations to intents allowing the user input to be compared to the intent training phrases to find the best matching intent. Additionally, the rule-based grammar matching of Google Dialogflow is supported by build-in sentiment analysis to identify users' positive, negative or neutral attitudes. Native Interactive Voice Response (IVR) turns the text-based chatbot into a voice agent.

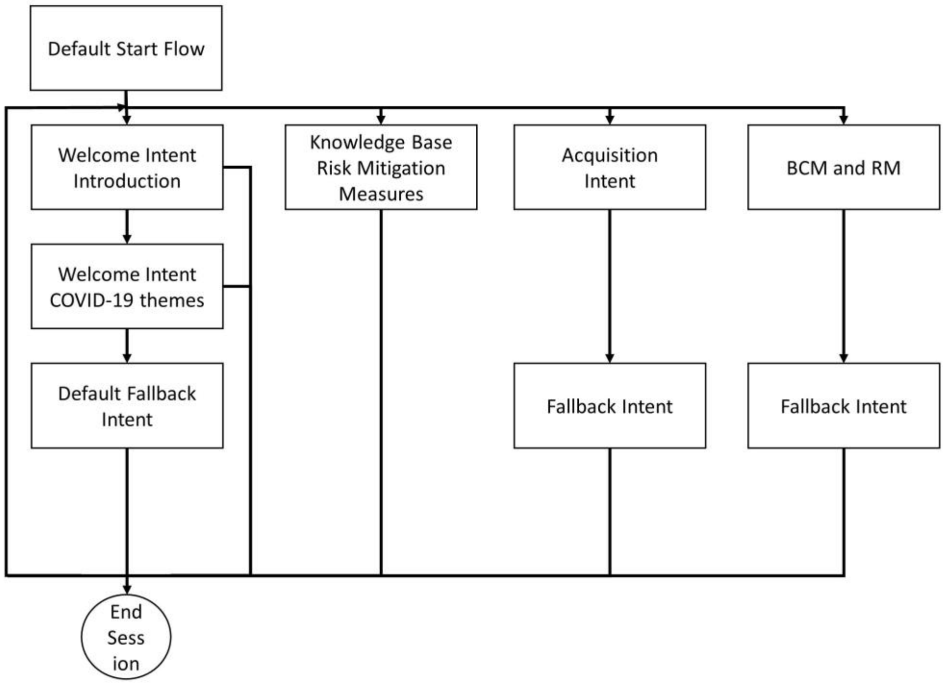

Figure 90: Flow chart of intents of the chatbot agent (own figure)

The artefacts developed in the DSR cycle were COVID-19 risk mitigation measures representing a knowledge construct and the instantiated conversational chatbot-based DSS.

Evaluation: Phase one increased the understanding of the COVID-19 risk mitigation measures applied worldwide, including their interrelation and impact on business operations. It revealed 97 risk mitigation measures that were evaluated and verified in interviews and group discussions with radiotherapy experts to reach a consensus. Themes were developed and reviewed for sensemaking. The results form the knowledge base for the DSS implementation. The DSS implemented in phase two was evaluated in an A/B test with eight physicists with long-term experience in radiotherapy. Group A consisted of four participants working as medical physicists in RT centres. The reference Group B contained four physicists working in RT healthcare companies. The system validation was conducted with objective performance indicators provided by Google Dialogflow and the participants' subjective feedback. The build-in analytic module of Google Dialogflow was used to analyse the agent's intent and session paths, as shown in Figure 91 (Google Cloud, 2021). Individual conversations were analysed to identify opportunities for chatbot improvement, while the SUS was used to evaluate the perceived usability of the DSS. The objective and the subjective data provided a solid base for validating the DSS (Reuter-Oppermann et al., 2021).

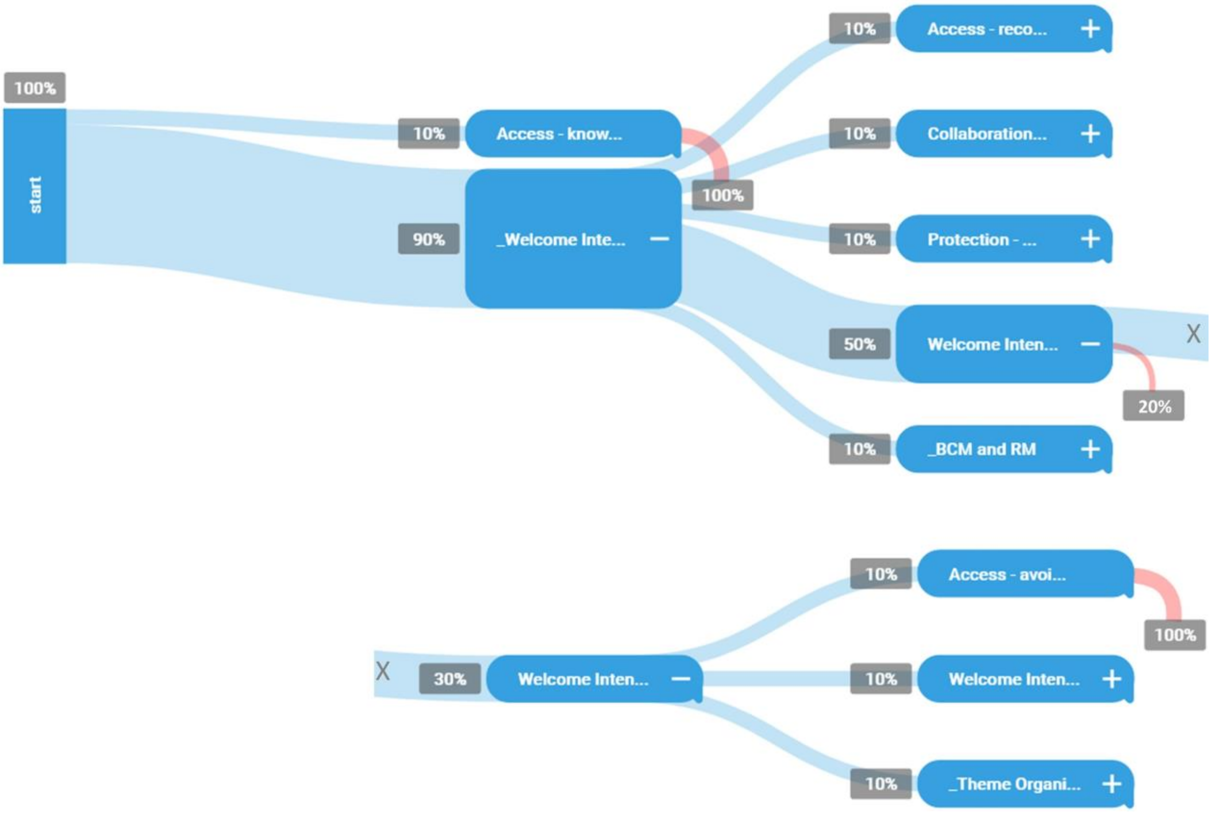

Figure 91: Example flow of chatbot session intents (Google Cloud, 2021)

Results:

- The review of the 97 risk mitigation measures and description using themes based on sensemaking discussions with radiotherapy experts validated the correctness of the identified risk mitigation measures and the assignment to the themes.
- Eleven chatbot sessions with 165 interactions were analysed. Still, 26.7% of the user inputs resulted in a standard response with a fallback intent, meaning that the input strings could not

be assigned to the correct intent. Manual training of the algorithm would improve successful matching.

- The analysis of the individual session paths showed that 78.8% of user requests were correctly matched either to risk mitigation measures, supporting intents or fallback intents.
- Cases of non-correct matching were identified. These were generic questions requiring an understanding of the context, questions that could not be generalised, and questions that were not reflected in the knowledge base and were thus responded to with a fallback intent.
- The DSS reached an average SUS score of 80 in Group A, reflecting good perceived system usability. The reference Group B reported a 10.6 point lower average SUS score of 69.4, thus reflecting the good perceived usability of the chatbot and indicating improvement potentials concerning the system usability.
- No problems were reported accessing the chatbot on the different mobile phone models of the participants.
- The system received positive feedback for being easy to use and learn, suggesting a high level of system acceptance.

Deviations:

- In total, 22 of the 97 risk mitigation measures were accessed in the chatbot test. The number shows that the DSS knowledge was not used to its full extent. It is assumed that participants stopped the tests once they understood the operating principle of the DSS.
- One participant asked several questions in German, even though the chatbot's welcome message and answers were in English.

Conclusion: The chatbot-based DSS for BCM in RT practice supports responsible staff in crises to maintain quality and safe treatment of cancer patients. The knowledge base is built on experience from RT centres worldwide, enriched with data from analysis and previous design cycles. Expert discussions indicate that a DSS embedded in an overall BCM framework can improve the business continuity of labour-intensive radiotherapy practice. The artefact is, therefore, in response to the eleventh research question, helpful for the design of socio-technical assistance systems supporting BCM in pandemic crises.

Knowledge contribution:

Reflection:

- The DSS fulfilled the DRs according to Table 40. A user-centric design was applied with personas and use case scenarios following DP I1.1. The chatbot with NUI was selected for the

DSS to secure simplicity following DP I2.2, DP I5.2 and DP H3.2. The decision support increased safety by advising users according to DP H1.1 and DP H1.2. The DSS worked reliable, and the web-based implementation increased resilience according to DP H1.4 and DP H3.1.

- The SUS reached acceptable values. However, the user experience could be improved in future work focusing specifically on chatbot design. Chatbot usability scale can support the design of conversational AI-based agents (Borsci et al., 2022).
- An option could be integrated for users to simulate the effect and consequences of risk mitigation measures when implementing them in their own RT centre. Such integration should be seamless and secure following DP I2.5, DP H1.3, and DP H1.5.
- The DSS could be extended with quantitative components measuring the impact of mitigation measures. Integrating RT process databases and OIS could serve the extension. Again the integration should be seamless and secure according to DP I2.5, DP H1.3, and DP H1.5.

Abstraction:

- Utilising the chatbot-based DSS, users can make informed decisions about risk mitigation measures supporting business continuity management.
- Decision support using low-threshold NUIs not only offers a level of business resilience and supports in times of crisis. It can also enhance medical assistance systems but must comply with DP H1.6 and DP H1.7.

Design principle:

The design principle presented in Table 41 is derived from the reflection and abstraction process as knowledge contribution in the *exaptation* area, according to Gregor and Hevner (2013).

DP	Description
DP H4.1	For the design of medical user assistance systems, to support informed user decisions, the system should comprise DSS functionality based on profound knowledge and offer low-threshold natural user interfaces.

Table 41: Design Principle healthcare cycle four

The overall design process with the included activities is presented in Figure 92, following the five phases.

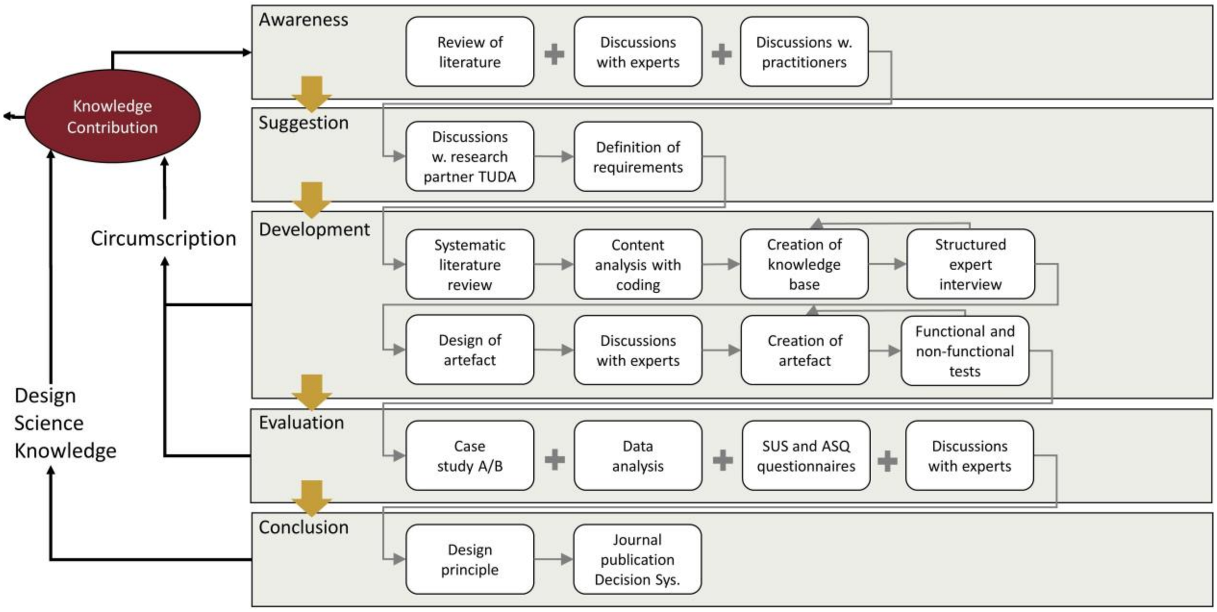

Figure 92: Decision Support for radiotherapy Business Continuity (own figure)

In this design cycle, the critical role of modern assistance systems in strengthening resilience and thus ensuring business continuity was investigated. Again, the importance of understanding the PACT dimensions for the specific use case of the DSS became obvious. The transfer challenge that remains is to understand the impact of defined risk mitigation measures on a particular RT centre. A simulation model could be developed to simulate the effects of risk mitigation measures in radiotherapy practice. The simulation model could also be integrated with the DSS to enhance its capabilities. In the first expansion phase, a simulation model could improve the performance of the DSS. At a later stage, a further development towards an accurate virtual representation of an RT centre could be realised.

v. Simulation of contingency measures for radiotherapy practice

Awareness: In radiotherapy, the efficient flow of activities in processes is essential for the safety and effectiveness of treatment while maintaining economic efficiency. Patient admission, imaging, radiation planning and delivery, and follow-up processes should be well-coordinated. A business continuity tool to support decision-making in a pandemic crisis should be able to simulate the impact of risk mitigation measures. In this regard, event-based or agent-based simulation models can support business decision-making (Jambor et al., 2022; Müller-Polyzou, Reuter-Oppermann, Jambor, 2021).

Suggestion: It is suggested to develop a parametric model that simulates the complex business processes of radiotherapy. The model should reflect the real-life situation of radiotherapy practice and evaluate possible changes in the process activities to improve decision-making. Furthermore, the impact of process changes could be estimated in advance and enhance the DSS developed in the previous design cycle. The proposed simulation model of an RT centre should quantify the impact of pandemic-related staff absences and selected COVID-19 risk mitigation measures on patient waiting times and throughput (Jambor et al., 2022; Müller-Polyzou, Reuter-Oppermann, Jambor, 2021).

Development: First, an aggregative-configurative SLR was conducted in April 2021 according to the concept described in the protocol in Table 42 and documented in the PRISMA graph in Figure 93.

Section	Description
Concept	The optimal use of resources for cancer therapy is particularly challenged when external parameters change. Simulation models offer a risk-free way to understand the impact of changes on existing processes.
Context	External radiotherapy processes in clinics and practices
Period	Unlimited
Language	English
Strategy	Mixed aggregative and configurative
Search string	Simulation methods, simulation and optimisation, radiotherapy and synonyms thereof in title, abstract and keywords
Inclusion criteria	Radiotherapy with linacs, simulation of radiotherapy processes, modelling of processes in radiotherapy, empirical data for radiotherapy models
Exclusion criteria	No external radiotherapy, no DES methods, simulation of clinical therapies and medications, proton and particle therapy
Sources	ScienceDirect, PubMed, Scopus, expert recommendations

Table 42: Protocol of SLR for simulation models in radiotherapy (Jambor, 2021)

In total, 756 abstracts were reviewed in a broad multi-perspective research approach. The abstracts were screened using Citavi, and the screening result was verified by two independent researchers (Swiss Academic Software, 2021). Following a full-text assessment for eligibility, ten articles remained for the qualitative synthesis using atlas.ti (ATLAS.ti GmbH, 2021). An inductive-deductive coding approach developed codes, code groups, and code networks. Thus, human and physical resources to be modelled could be verified, and important information about attributes, parameters, distribution functions, and KPIs could be obtained. In addition, what-if scenarios were analysed in the literature to understand what scenarios were simulated in previous research.

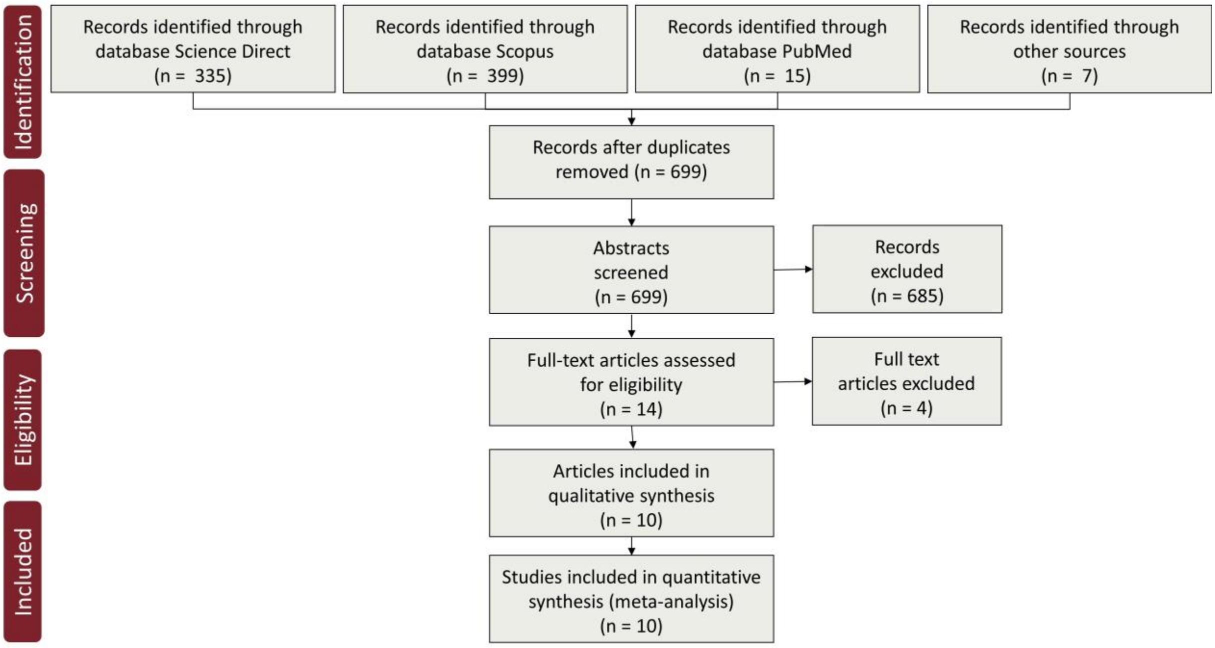

Figure 93: Systematic Literature Review DES in radiotherapy (Jambor, 2021)

Subsequently, a parametric simulation model of a radiotherapy facility was developed using the AnyLogic simulation software (The AnyLogic company, 2021). For this purpose, the SLR collected and analysed modelling and simulation requirements. However, many aspects of the academic publications varied considerably. Therefore, additional data required for the simulation, such as patient arrival rates and duration of irradiation, were collected and reviewed in structured online interviews with experts from radiotherapy facilities in Germany. Afterwards, daily routines in a radiotherapy practice with one CT and two linacs were modelled. The process map developed in a previous design cycle formed the basis for the modelling. In addition to the patients, the personnel resources radiation therapist, medical physicist and administrators and their work in the individual process step registration, consultation, planning CT, initial radiation, follow-up radiation, final examination and aftercare were modelled as shown in Figure 94. A typical RT practice floor plan was used to define the walkways for patients, whereby the patients' walking speed was determined depending on their age. In the future, the simulation model could also be expanded to include therapy planning and quality assurance process steps.

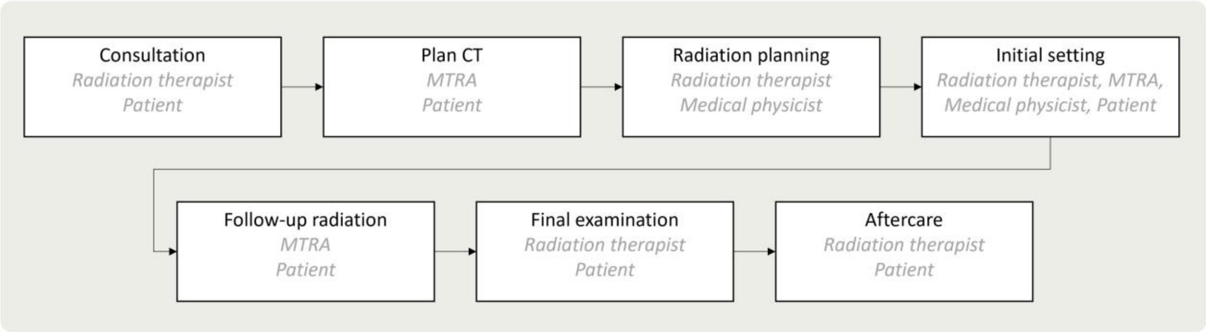

Figure 94: Simulation process (Müller-Polyzou, Reuter-Oppermann, Jambor, 2021; Viana et al., 2022)

Figure 95 visualises the normal patient pathway compared to the COVID-19 path with risk mitigation measures implemented in the centre. A patient's corona disease was represented by specific attributes and the overall incidence rate. Corona patients were observed at the entrance to the centre to ensure that they were wearing mouth-nose protection, their temperature was taken, and a rapid test was carried out. Corona patients were continued to be treated, but additional safety measures were taken, such as putting on a protective suit and using air ventilation and disinfection methods. The time required for the activities was considered in the simulation (Jambor et al., 2022; Müller-Polyzou, Reuter-Oppermann, Jambor, 2021; Viana et al., 2022).

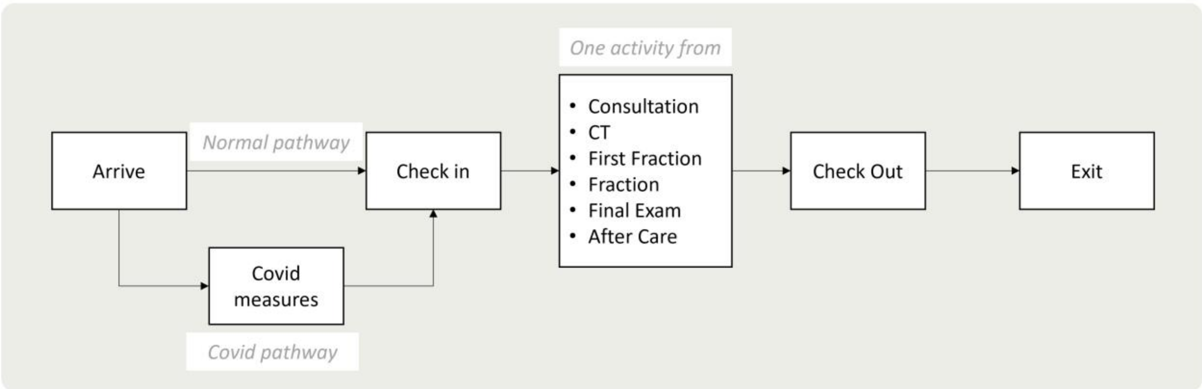

Figure 95: Simulation flows (Müller-Polyzou, Reuter-Oppermann, Jambor, 2021; Viana et al., 2022)

The simulation model has six main inputs, as presented in Table 43, four of them being parametric.

Input	Description	Parameter
COVID-19 incidence rate	Different prevalence rates (number in 100,000 citizens)	Yes
COVID-19 measures	COVID-19 measures prior to check-in (on/off)	Yes
Staff	Number of RTT, administrators, oncologists	Yes
Equipment	Number of linacs and CTs	Yes

Patient attributes	Patient type and age	No
Process time	Process service time distribution	No

Table 43: Input for the simulation model (Jambor, 2021)

Before the simulation runs were executed, a model validation and sensitivity analysis was performed (Pidd, 2004). It was checked whether input parameters were overwritten and whether the preset distribution functions resulted from the simulation runs. Also, the number of patients and the distributions of waiting times were validated after 200 simulations. Extreme scenarios were evaluated in the sensitivity analysis, in which the duration of the planning times and follow-up irradiations were identified as sensitive parameters. The number of simulation runs was determined graphically and set at 300 with a safety factor. Every simulation run represents one business day of the RT centre.

As presented in Table 44, nineteen scenarios were simulated in three categories. In the first category, no COVID-19 mitigation measures were applied. The second and third categories analysed system behaviour with active COVID-19 mitigation measures and COVID-19 incident rates of 100 and 1,000 calculated as COVID-19 cases in the remaining seven days in 100,000 citizens (Robert Koch Institut, 2022). Subsequently, different failure scenarios were simulated for each category based on the temporary loss of staff.

Loss of resources	No mitigation measures	Mitigation measures (incidence 100)	Mitigation measures (incidence 1,000)
No loss	Scenario 0	Scenario 7	Scenario 13
-1 oncologist	Scenario 1	Scenario 8	Scenario 14
-2 RTTs	Scenario 2	Scenario 9	Scenario 15
-4 RTTs	Scenario 3	Scenario 10	Scenario 16
-1 administrator	Scenario 4	Scenario 11	Scenario 17
-1 oncologist, -2 RTTs, -1 administrator	Scenario 6	Scenario 12	Scenario 18
-1 linac	Scenario 5		Scenario 19

Table 44: Simulation scenarios (Jambor, 2021)

Four KPIs were measured in the simulation runs. The first KPI was the total number of patients treated per day. The second KPI was the patients' total waiting time before check-in and treatment. Third, the utilisation of the staff and equipment resources was simulated. Finally, the waiting and processing times were measured for patients passing through specific processes.

Evaluation: The SLR, with the subsequent content analysis of the ten selected articles, showed how DES was used in radiotherapy and what gaps existed in knowledge. It directly indicated how various aspects of radiotherapy practice could be modelled, simulated and evaluated. The evaluation of the 19 simulation scenarios was then executed using 5,700 simulation runs.

Results:

- The content analysis of the identified literature revealed that all ten publications related to DES simulations of radiotherapy practice were country and institution-specific.
- Private radiotherapy centres were not modelled but only hospitals and university clinics. However, radiotherapy in hospitals often differs from private RT centres in terms of cancer types treated and the number of patients. In addition, the treatment of inpatients in hospitals requires interaction with other hospital departments and external co-therapists. Imaging equipment may also be shared between radiology and radiotherapy departments.
- The models described in the academic publications focused on different radiotherapy processes. Most publications were related to treatment planning (grounding=7), treatment (8) and first consultation by the oncologist (6). Appointment planning, imaging and contouring were only partially considered.
- The content analysis also showed that human resources such as oncologists, medical physicists, dosimetrists, RTTs/MTRAs and administrational personnel and physical resources such as CT, linacs and buildings were modelled.
- The models described in the publications modelled the patient pathway with the parameters urgency (5), cancer type (4), the number of fractions (4), treating oncologist (2), type of therapy (2) and curative/palliative treatment (2).
- Distribution functions express the variability of parameters in models. Mainly uniform (13) and deterministic (10) functions were used in the publications. Triangular (2), normal (2) and lognormal (2) were rarely used. Patient arrival rates were modelled with Poisson distributions.
- From the content analysis of the publications, the most important KPI was the time needed for individual process steps. Other important KPIs were resource utilisation (14), personnel costs (5), patient throughput (4) and appointment changes (2).
- Finally, the content analysis showed that resource scenarios were simulated most frequently, especially the number of occupational groups (29) and machines (17). The content analysis also indicated that scheduling is of particular interest.
- The simulations showed that radiotherapy processes and involved resources were well coordinated. Even minor disruptions, especially on the staff, significantly impacted patients' waiting time. The negative impact on business performance was high when team members

were assigned to execute COVID-19 risk mitigation measures, or the staff had to take over additional related tasks.

- Implementing COVID-19 measures at the radiotherapy centre entrance required administrational staff. This occupational group became a bottleneck with consequences for patient throughput and waiting times, an effect almost independent of the incidence rate.
- The simulations showed the critical concerns for radiotherapy BCM in pandemic times. Particular attention must be paid to staff absences and the additional time needed for staff to execute COVID-19 mitigation measures.

Deviations:

- The simulation model was developed for usage in different countries. However, country-specific data for Germany was used for parameter values and distributions.
- Medical physicists were no bottleneck in the simulations because they are mainly involved in supporting processes that can be partially performed remotely.
- Treatment planning activities were not considered in the simulation model because they can be carried out flexibly in time and remotely.

Conclusion: Staff in radiotherapy centres are critical resources, especially in times of pandemic crisis. First, the staff is exposed to a high risk of infection and may be absent due to sickness. Second, staff must take on additional risk mitigation tasks, which burdens them. Intelligent assistance systems for BCM must relieve these employees in their regular or risk mitigation-related tasks. In response to the twelfth and last research question, the design cycle with its artefacts outlined how DES can be used to support efforts to increase resilience and business continuity in radiotherapy practice.

Knowledge contribution:

Reflection:

- The risk of business continuity of radiotherapy treatment exists due to staff shortages.
- Administration staff gets additional tasks imposed.
- Waiting times of patients should be minimised to reduce the risk of infection.
- Patient self-management applications could provide relief to administrational staff.
- Particular attention must be paid to users when developing IS for business continuity.

Abstraction:

- Risk mitigation tasks and additional responsibilities are imposed on staff in crises, influencing existing business processes. Together with the risk of illness, this situation can affect business continuity. Assistance systems should provide support for practitioners and patients in this context.

Design principles:

The design principles presented in Table 45 are derived from the reflection and abstraction process as knowledge contribution in the *improvement* area, according to Gregor and Hevner (2013).

DP	Description
DP H5.1	For the design of medical user assistance systems, to support informed user decisions for business continuity, the system should relieve employees from regular tasks.
DP H5.2	For the design of medical user assistance systems, to support informed user decisions for business continuity, the system should be easy to use also for substitute employees.

Table 45: Design Principles healthcare cycle five

The overall design process with important activities is illustrated in phases in Figure 96.

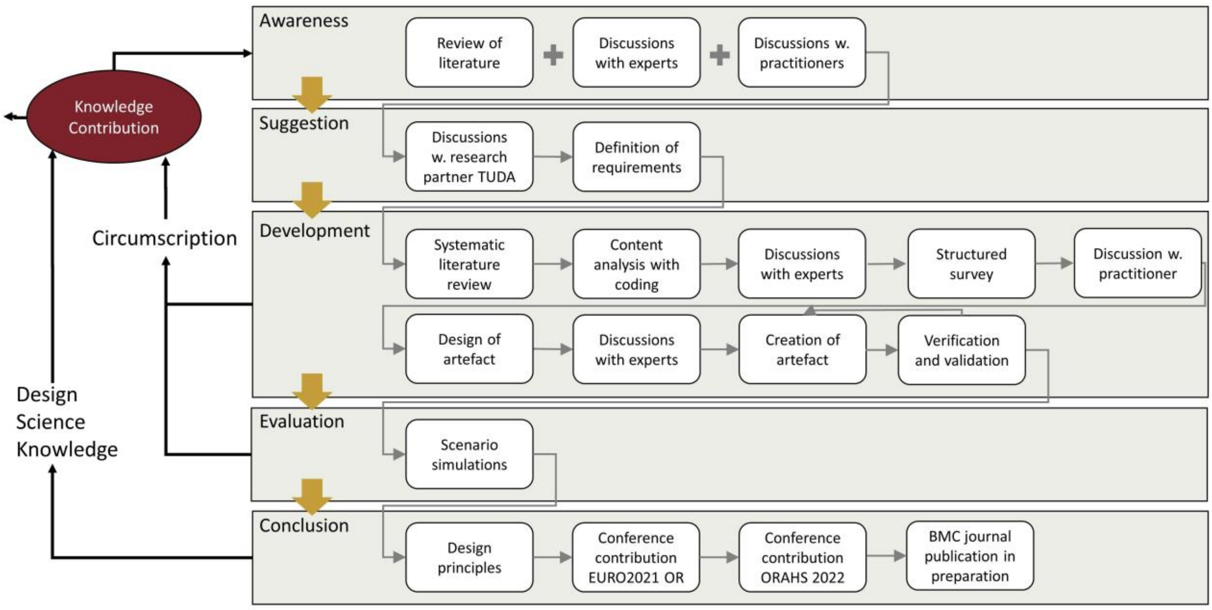

Figure 96: Design cycle Simulation of contingency measures for radiotherapy (own figure)

The design cycle presented above ends the DSR healthcare path and complements the previous DSR industry path findings. The seven design cycles of the industry path and five design cycles of the healthcare path have been extensively elaborated, qualitatively and quantitatively evaluated, and the twelve research questions have been answered in the discourse of the design cycles.

d. Reflection and conclusion

Extensive and resource-intensive primary research was conducted in seven industrial and five healthcare design cycles. Therefore, scientific methods were applied in a targeted manner within the DSR framework. Each design cycle was transparently presented and discussed with its activities and artefacts. After thorough reflection and abstraction across sector boundaries, more than 30 abstract DPs could be derived, expanding the knowledge base on designing information and assistance systems for labour-intensive processes. The DPs form the basis for developing a generally applicable reference model in the further elaborations of this dissertation.

7. A reference model for socio-technical systems

The following content presents a conceptual reference model for developing socio-technical systems. The reference model is based on the knowledge gained in the design cycles and the DPs derived thereof and classified in a taxonomy. It is industry and technology agnostic and supports the design of socio-technical information and assistance systems for labour-intensive processes, leveraging the knowledge additions and providing a bridge between abstract technology acceptance models and system design. The reference model is then narratively validated in a stepwise approach based on an SGRT system for patient positioning in radiotherapy.

a. Introduction to reference models

The goal of a reference model is to simplify reality and reduce complexity (Fettke and Loos, 2003). In this sense, reference modelling follows the approach of abstracting knowledge in DPs.

> "Reference models and reference architectures provide a description that is more abstract than what is inherent to actual systems and applications. They are more abstract than concrete architectures that have been designed for a particular application with particular constraints and choices."
>
> (Bassi et al., 2013, p. 21)

The conceptual reference model presented in this dissertation describes the design framework with a manageable number of components, thus allowing the derivation of models for specific applications in industry and healthcare. "... the implementation of a model derives from its design that derives from its reference architecture and that ultimately derives from our reference model" (Mayk and Regli, 2006, p. 47). This process is visualised in Figure 97, with the platform representing the means of technological system implementation.

Figure 97: Implementation derivation from a reference model (Bassi et al., 2013)

Additionally, reference models increase system design efficiency and improve the reusability of research efforts while providing a structured framework for communicating the generalised insights gained from the DPs (Bassi et al., 2013). A reference model provides the ground for a common understanding by modelling its concepts and relationships independently of the use case. A specific reference architecture can be derived from a reference model by describing essential system components. The reference architecture, in turn, provides guidelines for engineering a specific system based on a dedicated use case and system requirements (Fettke and Loos, 2003). An intermediary step of taxonomy development is performed to facilitate the reference model's development.

b. Taxonomy of design principles

The taxonomy development classifies the DPs following a distinct method. The taxonomy aims to support the reference model's development and inform experts in developing socio-technical systems for labour-intensive processes. The DPs were derived from the design cycles, including the understanding of the PACT dimensions. The people interacting with the systems were analysed in single-person and teamwork scenarios drawing from kernel theories and considering differences in physical, psychological and social characteristics. The main goal of the perceived usefulness and ease of use analysis was to secure the system's acceptance by the users. The activity and context analysis covered the industry and healthcare business context and application activities' temporal, spatial, social, organisational and safety aspects. The IS and IT environment were examined, and security and data privacy were addressed. The high number of design cycles and case studies considered that technologies vary in many aspects and evolve. The DPs abstracted from the findings of the twelve design cycles form the basis for the reference model to be developed. In a further step, the DPs must first be classified using a taxonomy.

"Taxonomies play an important role in research and management because the classification of objects helps researchers and practitioners understand and analyze complex domains" (Nickerson et al., 2013, p. 336). However, relating to the applied science nature of DSR, it is also essential that "... taxonomy should have a practical purpose by improving the practice to which it relates" (Omair and Alturki, 2020, p. 539). Still, Lösser et al. (2019), following their analysis, note that IS research publications use taxonomies, but most do not follow a distinct development method. The development process of the taxonomies often remains unclear, and taxonomies are usually not evaluated.

Building on previous work, Nickerson et al. (2013) developed a method to support design research by creating new taxonomies in IS, aiming to bring order to complex areas and unveil new research areas. The authors define the taxonomy T according to Equation 3 as "… a set of dimensions $D_i (i = 1, \dots, n)$ each consisting of $k_i (k_i \geq 2)$ mutually exclusive and collectively exhaustive characteristics $C_{ij} (j = 1, \dots, k_i)$ such that each object under consideration has one and only one C_{ij} for each D_i" resulting in the fact that "… these conditions mean that each object has exactly one of the characteristics in each dimension" (Nickerson et al., 2013, p. 336).

$$T = \left\{D_i, i = 1, \ldots, n | D_i = \{C_{ij}, j = 1, \ldots, k_i; k_i \geq 2\}\right\}$$

Equation 3: Definition of taxonomy (Nickerson et al., 2013)

A taxonomy can be developed inductively, deductively or intuitively. Inductive taxonomy development analyses empirical data to determine the taxonomy dimensions, while in deductive taxonomy development, theories and concepts form the basis for classification. The intuitive approach is based on the researcher's understanding and sensemaking of the investigated objects (Nickerson et al., 2013; R. Nickerson et al., 2010). Abductive reasoning has been introduced by Omair and Alturki (2020) as a technique that combines inductive and deductive approaches. The authors also proposed a decision tree for selecting a taxonomy development approach, as shown in Figure 98.

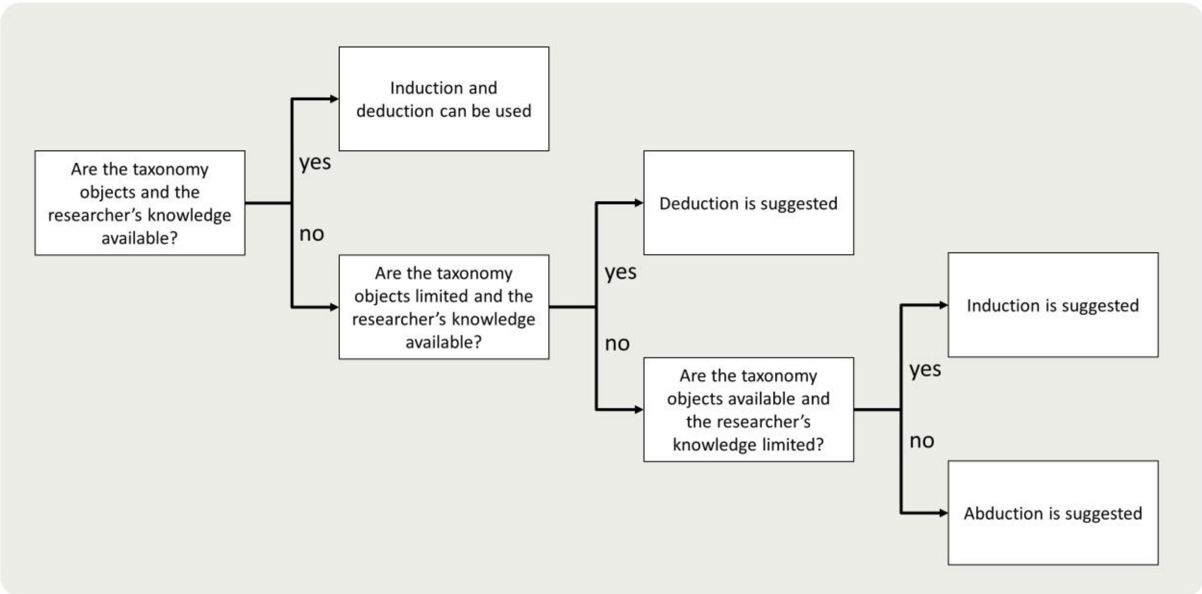

Figure 98: Decision tree for taxonomy selection (Omair and Alturki, 2020)

The taxonomy development method of Nickerson et al. (2013) with the induction and deduction approach was used to cluster the DPs into five categories described in Table 46. Conceptual aspects of the socio-technical system were used as the meta-characteristic.

> "The meta-characteristic is the most comprehensive characteristic that will serve as the basis for the choice of characteristics in the taxonomy. Each characteristic should be a logical consequence of the meta-characteristic. The choice of the meta-characteristic should be based on the purpose of the taxonomy."
>
> (Nickerson et al., 2013, p. 343)

The DPs inform the framework, reflecting the purpose of the taxonomy and supporting communication towards the users of both the taxonomy and the reference model.

Category	Description
Support	The category includes DPs of socio-technical system planning and work preparation required for users to successfully perform their activities in the context of using the socio-technical system. The category also includes the Digital Twin capabilities.
System	The category includes DPs related to people's control of the socio-technical system and process and quality control methods that designers can apply in socio-technical system development. It contains technical design aspects, directly impacting the activities and context domain.
Workspace	The category contains DPs focusing on the people domain of the PACT model. It also comprises DPs for ergonomics and principles that enhance the system's user experience in the workspace, considering activities and context. DPs with an impact on the user-system interrelationship are also included.
Integration	The category involves DPs related to integrating the system into the surrounding environment. It is strongly influenced by technology, but its design depends on the activities that the users of the socio-technical system carry out.
Continuity	The category of DPs is justified by the focus of the investigations on resilience and the increased need for business continuity in labour-intensive processes. It is strongly influenced by the COVID-19 pandemic and the overall risk situation in dynamically changing environments.

Table 46: The five taxonomy categories

The classification followed the mutually exclusive and collectively exhaustive restriction method according to Nickerson et al. (2013), meaning that each DP must have one of the characteristics in each category. In the iterative process, however, some DPs that combined essential aspects were split into several objects. Thereby 48 objects were created based on the initial set of DPs, fully maintaining the knowledge of the original DPs. Finally, the 48 DP objects were classified into categories and subcategories.

First, the three categories *support*, *system* and *workspace* forming the core of the socio-technical system were elaborated. The categories with 34 assigned DP objects are shown in Figure 99. It is noticeable that the category *support* contains only three DP objects (8.8%). On the other hand, the category *system* includes 16 DP objects (47.1%) and 15 (44.1%), referring to the workspace area. The balance between *system* and *workspace* DP objects indicates the importance of *workspace* aspects in socio-technical system design.

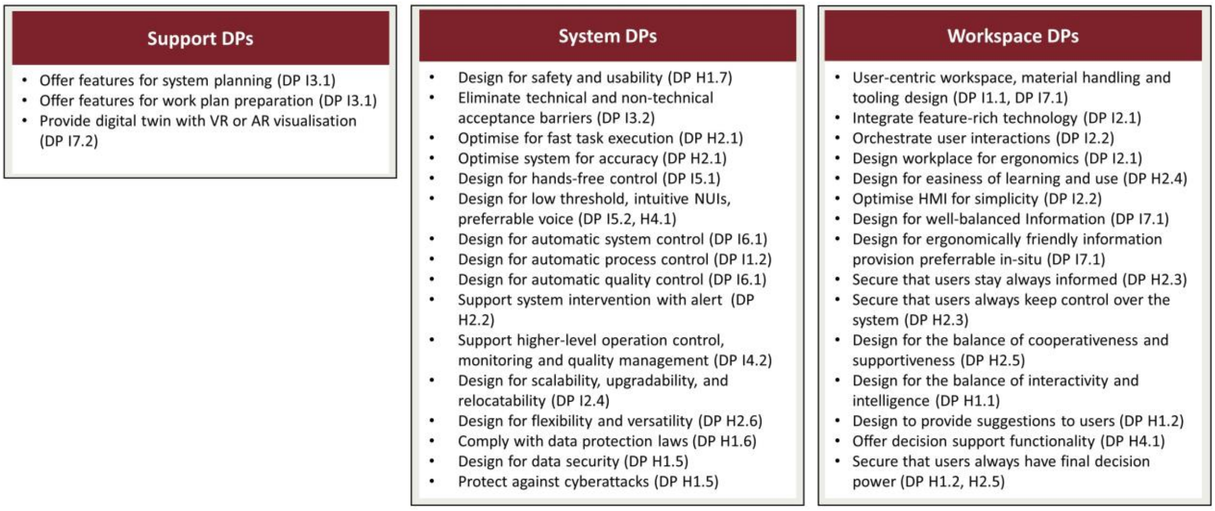

Figure 99: Categories of System Design Principles (own figure)

Afterwards, the two categories *integration* and *continuity* supporting the system, are shown in Figure 100. Eight DP objects (57.1%) form the *integration* category, while the *continuity* category contains six DP objects (42.9%).

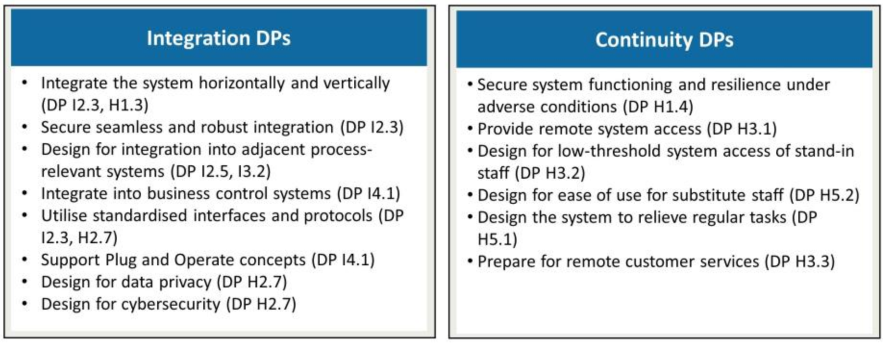

Figure 100: Categories of additional Design Principles (own figure)

The second level of characteristics of taxonomy elements is a consequence of the meta-characteristic. Based on the five distinct categories reflecting the system environment and applying the second level of abstraction, the taxonomy shown in Figure 101 was developed. As a result, the taxonomy grew from five categories to 15 subcategories supporting more differentiated reference modelling. The *system* and *workspace* categories are described in Table 47, while the *support*, *integration* and *continuity* subcategories are outlined in Table 48.

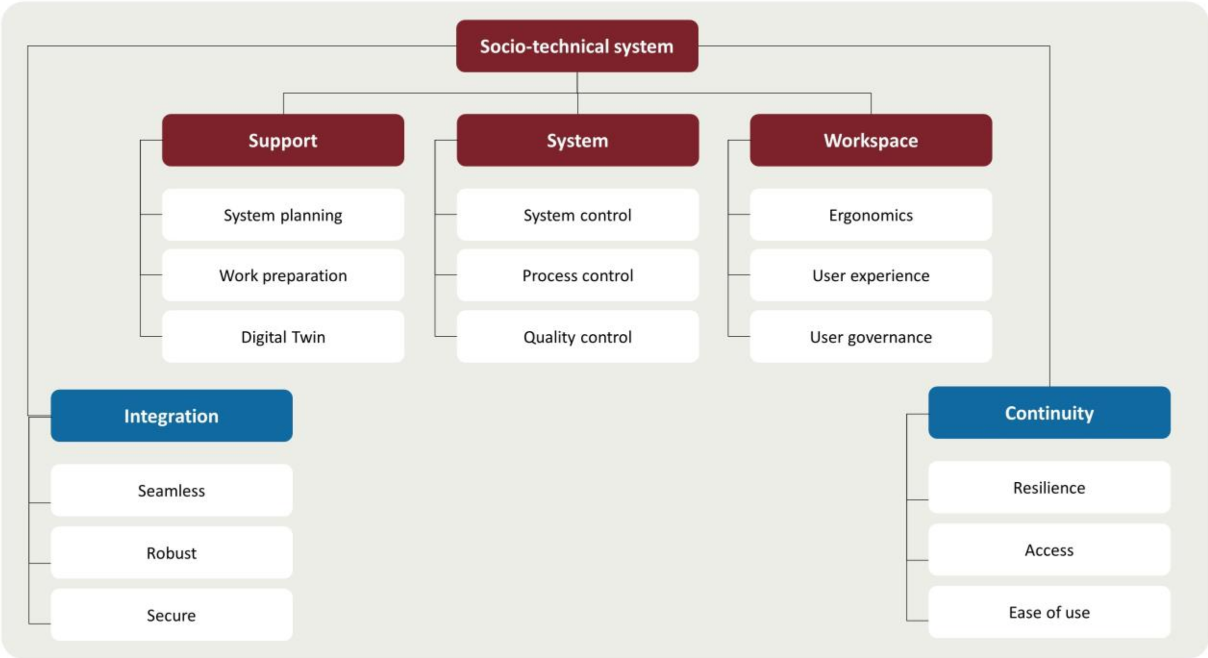

Figure 101: Taxonomy for socio-technical system design (own figure)

Some DP objects are assigned to subcategories but also influence other subcategories. For example, *system control* is strongly linked to *user experience*. In these cases, the assignment is based on the primary effect combined with the researcher's experience and knowledge, as Omair and Alturki (2020) proposed.

Category	Subcategory	Description
System	System control	The sub-category includes design options that describe how users can control the system's performance.
		• Eliminate technical and non-technical acceptance barriers (DP I3.2) • Design for safety and usability (DP H1.7) • Design for hands-free control (DP I5.1) • Design for low threshold, intuitive NUIs, preferable voice control (DP I5.2, H4.1) • Design for automatic system control (DP I6.1)
	Process control	The sub-category includes design options that describe how the system secures control over the working process.
		• Optimise for fast task execution (DP H2.1) • Optimise system for accuracy (DP H2.1) • Design for automatic process control (DP I1.2) • Support system intervention with alert (DP H2.2)

		• Design for scalability, upgradability, and relocatability (DP I2.4) • Design for flexibility and versatility (DP H2.6) • Comply with data protection laws (DP H1.6) • Design for data security (DP H1.5) • Protect against cyberattacks (DP H1.5)
	Quality control	The sub-category includes design options that describe how the system assures the quality of the work performed by the users.
		• Design for automatic quality control (DP I6.1) • Support higher-level operation control, monitoring and quality management (DP I4.2)
Workspace	Ergonomics	The sub-category includes design options related to the ergonomic design of the workspace in its entirety.
		• Design workplace for ergonomics (DP I2.1) • Design for ergonomically friendly information provision preferrable in-situ (DP I7.1)
	User experience	The sub-category includes design options that influence the user experience with the socio-technical system.
		• User-centric workspace, material handling and tooling design (DP I1.1, DP I7.1) • Integrate feature-rich technology (DP I2.1) • Orchestrate user interactions (DP I2.2) • Design for easiness of learning and use (DP H2.4) • Optimise HMI for simplicity (DP I2.2) • Design for well-balanced Information (DP I7.1) • Design for the balance of cooperativeness and supportiveness (DP H2.5) • Design for the balance of interactivity and intelligence (DP H1.1)
	User governance	The sub-category includes design options that impact the user-system power relationship.
		• Secure that users always keep control over the system (DP H2.3) • Secure that users stay always informed (DP H2.3) • Design to provide suggestions to users (DP H1.2) • Offer decision support functionality (DP H4.1) • Secure that users always have final decision power (DP H1.2, H2.5)

Table 47: System in the workspace design categories

Category	Subcategory	Description
Support	System planning	The sub-category includes design options that influence how the system is planned within its activity context.
		• Offer features for system planning (DP I3.1)
	Work preparation	The sub-category includes design options for digital work plans.
		• Offer features for work plan preparation (DP I3.1)
	Digital Twin	The sub-category includes design options for DTs.
		• Provide digital twin with VR or AR visualisation (DP I7.2)
Continuity	Resilience	The sub-category includes design options that increase the resilience of the system's functioning.
		• Secure system functioning and resilience under adverse conditions (DP H1.4)
	Access	The sub-category includes design options related to general system access in business crises.
		• Provide remote system access (DP H3.1) • Design for low-threshold system access of stand-in staff (DP H3.2) • Prepare for remote customer services (DP H3.3)
	Ease of use	The sub-category includes design options which support work to be carried out efficiently, even by standby personnel.
		• Design for ease of use for substitute staff (DP H5.2) • Design the system to relieve regular tasks (DP H5.1)
Integration	Seamless	The sub-category includes design options for the smooth interworking of systems.
		• Secure seamless and robust integration (DP I2.3) • Support Plug and Operate concepts (DP I4.1) • Integrate into business control systems (DP I4.1) • Utilise standardised interfaces and protocols (DP I2.3, H2.7)
	Robust	The sub-category includes design options that support the robustness of the interworking of the system.
		• Integrate the system horizontally and vertically (DP I2.3, H1.3) • Design for integration into adjacent process-relevant systems (DP I2.5, I3.2)

	Secure	The sub-category includes design options that enhance security related to the system's object of work and interconnections.
		• Design for data privacy (DP H2.7) • Design for cybersecurity (DP H2.7)

Table 48: System in the workspace influencing design categories

The taxonomy development ends with the fulfilment of the subjective and objective ending conditions, according to Nickerson et al. (2013), meaning that all DP objects were examined, and at least one DP object was classified in every subcategory. Furthermore, no new categories were added, and no characteristics were merged or split in the last iteration of the taxonomy development. Finally, every category and characteristic is unique, leading to a robust, concise, and comprehensive taxonomy to support the overall research goal.

c. Reference model of a socio-technical system

The taxonomy developed forms the basis for developing the reference model. The first level of the taxonomy reflects the socio-technical system elements, its relation to the environment, and its role in fulfilling its business objectives. "... a reference model provides the ground for a common understanding ... by modelling its concepts and their relationships" (Bassi et al., 2013, p. 22). According to Fettke and Loos (2003), a model of an IS consists of three components *object system*, *model system* and *representational relation*. The reference model described in this dissertation is the subjective interpretation of the industry-agnostic work environment in which the socio-technical system supports labour-intensive processes. The model system is the personal interpretation of the socio-technical system itself. Entity-relationship connections describe the relationship between the object and model system. The system, the workspace and the system users define the central unit of the reference model, as shown in Figure 102.

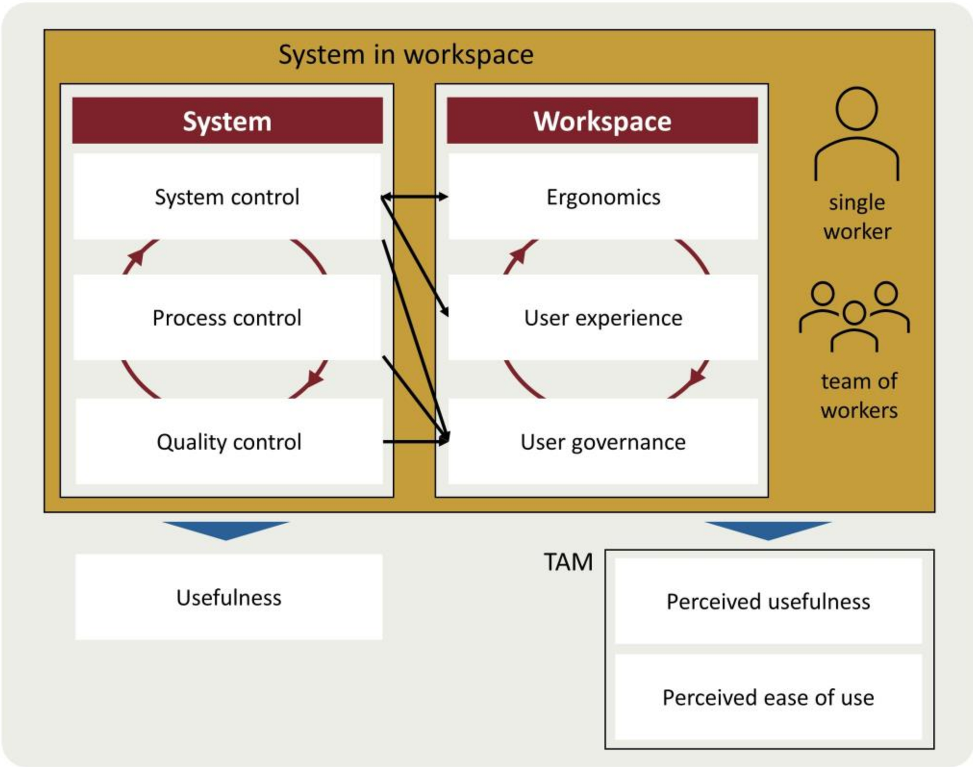

Figure 102: Reference model socio-technical system Step 1 (own figure)

The circle in the *system* unit indicates that the three elements, *system control*, *process control* and *quality control,* influence each other. For example, changes in system control initiated by the user directly affect the process and quality control of the system. Similar dependencies also exist in the *workspace* unit. The output of the interplay of the elements within the *system* unit impacts the system's efficiency and effectiveness and, thereby, its objective usefulness. A mutual interrelation applies to the three design elements of *ergonomics*, *user experience* and *user governance* within the *workspace* unit. The output of the interplay is subjective to the users and impacts the two dimensions of *perceived usefulness* and *ease of use* known from the TAMs. Moreover, *ergonomics* and *system control* are bidirectionally connected, while the type of system control and its implementation directly influence the *user experience*. Additionally, the *user's governance* over the system concerns the three elements *system*, *process* and *quality control* because any changes in these dimensions influence the user-system-power relationship.

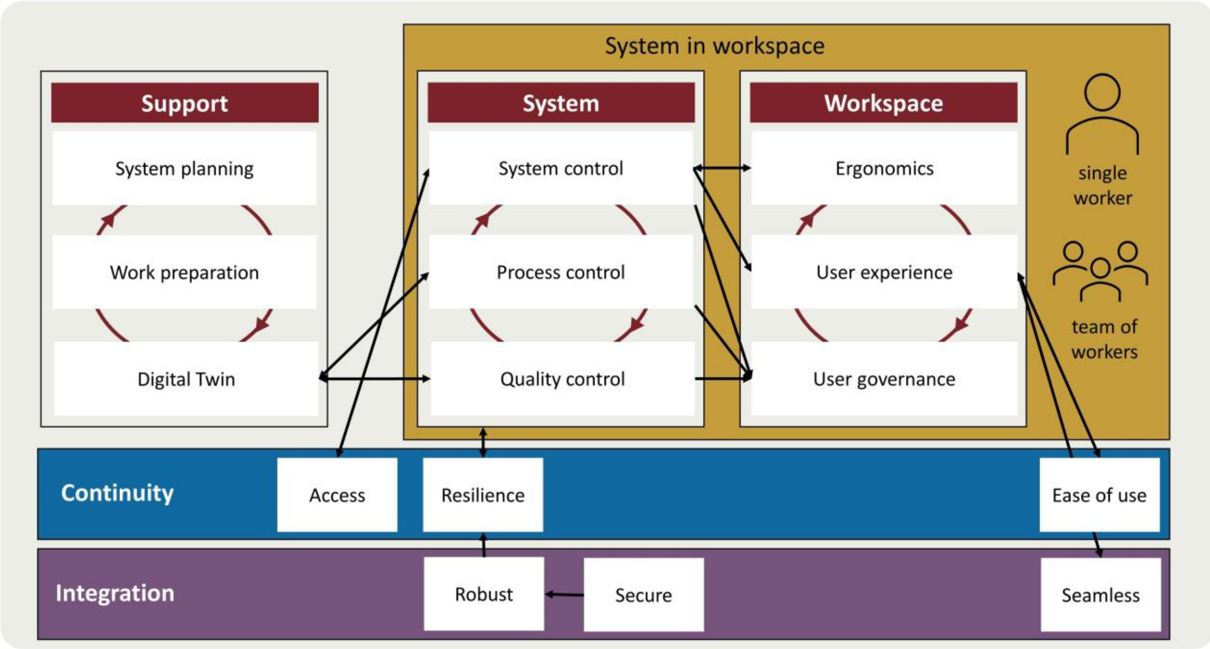

Figure 103: Reference model socio-technical system Step 2 (own figure)

The *support* unit includes the *Digital Twin* as a central element interlinked with *system planning* and *work preparation* design elements. The *Digital Twin* is bidirectionally connected with the system unit's *process* and *quality control* elements reflecting its importance and role in system operations. The two additional design layers, *integration* and *continuity,* complement the reference model. The design principles that fulfil secure integration support the system's robustness, which helps the resilience and is directly interlinked with the system unit. Moreover, access to the system’s control in adverse conditions is essential for overall business continuity. Finally, ease of use under business continuity considerations and seamless integration principles are interrelated with the user experience of the socio-technical system.

d. Narrative validation of the reference model

The reference model will be narratively analysed in the following section, reflecting the model of the camera-based SGRT system for patient positioning in radiotherapy cancer treatment. The system model is presented in Figure 83 as the resulting artefact of the corresponding DSR cycle.

First, the system-workspace context is validated, as shown in Figure 104. Tablets and monitors are used to control the SGRT system, while the interaction with the system control still interrupts the actual work process. A design based on NUI, particularly speech recognition, would increase efficiency and keep the hands of staff free for essential work activities. According to the reference model, it is anticipated that the user experience (a) will be enhanced by applying a NUI. It is also expected that non-ergonomic working positions with tablets and head moves towards in-room monitors will become obsolete, thereby increasing ergonomics in the workspace (b). Patient positioning tasks are often performed by two RTTs. A NUI based on speech recognition could allow both RTTs to interact with the system, avoiding sharing physical control devices. The change of system control can also influence the power a user has over the system, for example, by limiting or enhancing user commands. Implementing a user-centric NUI functionality will positively impact the system's user governance (c) and stimulate usage: "... interactions are more likely when consumers feel superior to the device..." (Schweitzer et al., 2019, p. 708). In the proposed design, the process and quality control are carried out during the actual work process, primarily via the camera sensor system. The collision avoidance use case presented in the corresponding design cycle was one example of a safety-related process and quality control feature. Additional features were described, such as immobilisation device recognition and patient positioning. Process and quality control are an essential part of the SGRT system and the intended use of the proposed medical system. Depending on the level of intelligence and interactivity and its implementation, the governance of the user over the system will be changed (d). According to the elaborated DPs, a user-centric design will leave the final decision power to the users and focus their attention on the labour-intensive tasks.

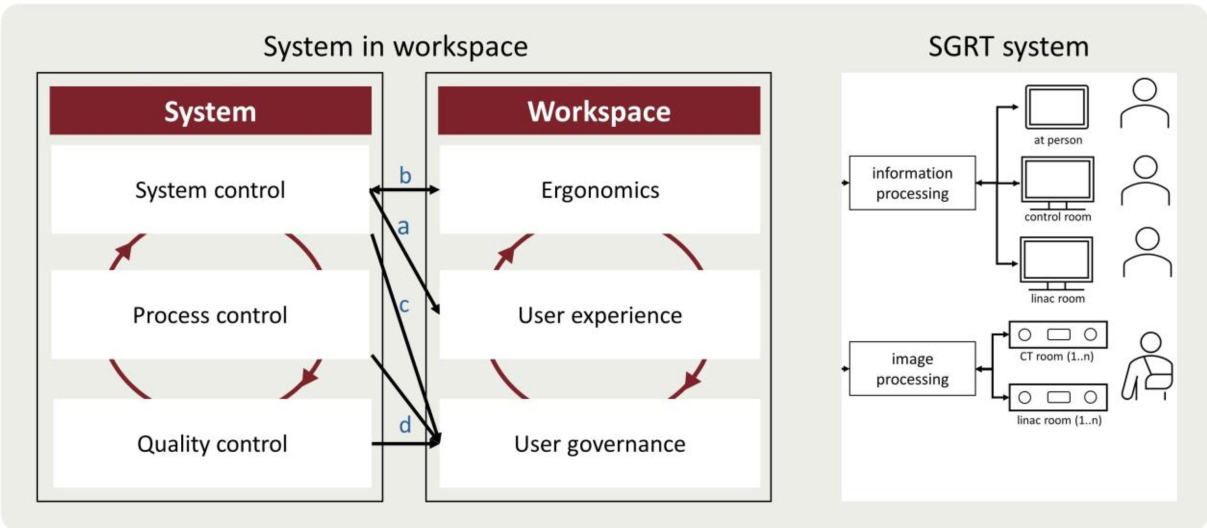

Figure 104: Validation of SGRT system with the reference model Step 1 (own figure)

Next, the support-system context is validated, as shown in Figure 105. The real-time coupling of a Digital Twin with the physical SGRT system generates data that can be used for process and quality optimisation, e.g. the reduction of throughput and machine downtimes. Bidirectional coupling increases transparency and creates new application possibilities, e.g. in the area of machine and patient QA. The DT could also be used for planning and training before implementation to reduce one entry barrier to SGRT system deployment (Hosaik et al., 2021). Finally, the DT implementation could also support DSS functions based on the cooperative services business logic.

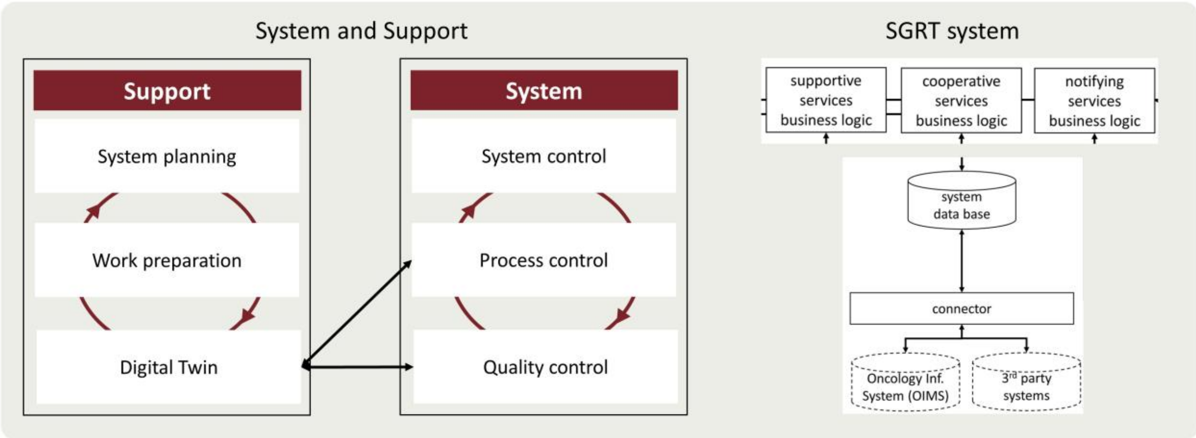

Figure 105: Validation of SGRT system with the reference model Step 2 (own figure)

In the next step, the system-workspace relationship with the underlying *integration* and *continuity* layers is analysed, as shown in Figure 106. The SGRT design supports third-party systems' integration via the system architecture's connector. The integration should be secure, supporting robust system operation and increasing the system's resilience. The integration should also be seamless, improving the overall user experience in the workspace. Design for business continuity should consider low-threshold system control access in times of crises, which could be realised by a specific user mode of the tablet GUI that is reduced to the necessary core functions of the system. Therefore, the *access* method supporting BCM is directly related to the system control (a). The supportive, cooperative and notifying services business logic is already designed to help business continuity and could also be prepared for extraordinary ease of use during crises (b). Both the design for *ease of use* for BCM and the underlying *seamless* integration (c) impact the user experience, as indicated in Figure 106. Finally, *secure* and *robust* integration promotes the system's *resilience,* indicated by the interrelation (d).

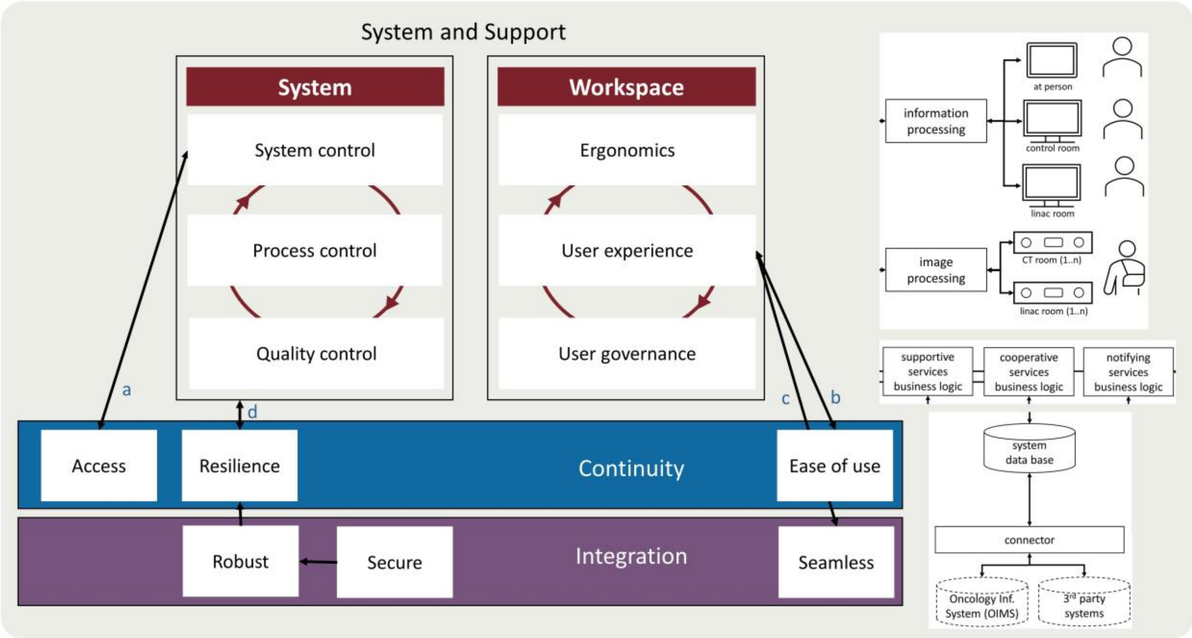

Figure 106: Validation of SGRT system with reference model Step 3 (own figure)

The step-by-step narrative validation of the reference model using the SGRT system example shows the model's applicability to a complex socio-technical system for labour-intensive patient positioning in radiotherapy. The reference model can thus consequently be also considered an extension of TAMs for these applications. Applying the model and DPs provides additional options to improve the SGRT system and validates the applicability of the reference model for the specific use case.

e. Conclusion

Based on the extensive empirical DSR work and guided by the research questions being answered in the twelve design cycles, the industry and technology-agnostic reference model for developing socio-technical systems for labour-intensive processes were developed and validated. For this purpose, the abstract design principles resulting from the twelve DSR cycles were classified using a newly developed taxonomy, forming the reference model's basis. The reference model was successfully validated with an MCPS for RT using a narrative validation method.

The reference model enhances the knowledge of the acceptance of socio-technical systems for labour-intensive processes in industry and healthcare. In this respect, it also complements existing models of technology acceptance. The reference model and DPs support the design of applications that support the functioning of industry and healthcare organisations and promote systems' resilience and business continuity. The abstract model also allows the comparison of systems and, at the same time, serves as a basis for the transfer of knowledge and further research. The validity of the reference model will be determined when it is used to design practical, real-world applications. It is then that it has to show its applicability. In addition, the reference model can be further developed and refined in the future if required.

The DPs and reference model incorporate an understanding of the societal impact of labour-intensive work and the impact of identified macro forces on socio-technical system design, supporting the overall need for IS research to shift from technology to social-issues-oriented research, also highlighted by Stephanidis et al. (2019) stating that:

> "… designing intelligent systems that can work truly in concert with the user is anticipated to be one of the key success factors of intelligent technologies. To this end, intelligence means supporting humans, anticipating their needs, recognizing and responding to human emotions and fostering human safety."
>
> (Stephanidis et al., 2019, p. 1258)

Therefore, research on intelligent and interactive assistance systems requires a deeper consideration of cognitive, social and technological aspects and theories from psychology, sociology and engineering that enable inter-disciplinary contributions, particularly in healthcare.

8. Summary and outlook

This dissertation deals with socio-technical information and assistance systems for labour-intensive processes in industry and healthcare. The empirically driven DSR work guided by the twelve designated research questions focused on elaborating DPs for developing socio-technical information and assistance systems that increase the effectiveness and efficiency of labour-intensive processes. The work supports the continuous efforts toward creating quality workspaces, socio-technical system acceptance and, in a broad context, the global SDGs. The dissertation differs from other research work because it is genuinely cross-disciplinary, building on comprehensive empiric data collected in quantitative, qualitative, single and dual-perspective research.

a. Objectives and results of the study

First, the problem area was described after introducing the topic, and critical influencing factors were highlighted. Then, the defined research questions were put into the context of the overall research goal. The second part of the dissertation discussed essential aspects of labour-intensive processes. The changes in the working world and influencing macro factors were examined, followed by a look into the future of work. Subsequently, the work environments and challenges in industry and healthcare were compared, focusing on the significant developments of Industry 4.0 and 5.0, Healthcare 4.0, Operator 4.0 and Patient 4.0. In the third section, information and assistance systems were introduced, the research challenges were outlined, and exemplary assistance systems in industry and healthcare applications were presented, emphasising the importance of practical use. The chapter was concluded by showing the state of knowledge and the need for action. Laser-based assistance systems were introduced as the empirical object of study, and selected examples for laser-based assistance systems in composite manufacturing, wood and concrete prefabrication, industrial assembly and quality inspection were presented. Subsequently, laser-based assistance systems in healthcare were demonstrated using distinct interventional radiology and radiotherapy applications.

The fifth section focused on the DSR paradigm, providing the basis for this dissertation. The theoretical background, concepts of knowledge gain and relevant core theories were described. Subsequently, the comprehensive research methods used in this thesis were presented in detail and scientifically anchored. The chapter concluded with a list of the software tools used in this work, a brief reflection and a summary. The sixth section formed the core of the scientific considerations of this dissertation. The design science cycles for the industry and healthcare paths were presented in context and as individual design cycles. Reflection, abstraction and circumscription allowed to answer the specific research questions and formulate the distinct DPs. Section six concluded with a summary of the research findings.

Finally, the seventh section concentrated on the elaborated DPs and described a taxonomy and reference model that can be used to develop socio-technical systems for labour-intensive processes. The reference model was afterwards narratively validated using a relevant example from radiotherapy practice.

b. Significance of the results

This dissertation is positioned in the field of applied sciences. The results are based on extensive empirical investigations in real-world applications and realistic work scenarios with a constant alignment between industry and healthcare studies. Many experts from industry and healthcare practice were involved in the design and evaluation phases of the design cycles to ensure the relevance for application. The approach enables a low-threshold transfer of the research results into practice. At the same time, the research results were intensively discussed, reflected and abstracted, providing theoretical contributions through concluding design science knowledge and circumscription. The following formulation of DPs and the development of an associated taxonomy and conceptual reference model expanded the prescriptive knowledge of information and assistance systems for labour-intensive processes.

c. Limitations

Like all research, this work is subject to limitations even though special care has been taken to ensure a low impact on design science knowledge contributions.

The interdisciplinary field under consideration in this dissertation was pervasive, so aspects of occupational psychology could not be considered in detail. Ergonomic elements and theories of cognition, memory, emotion, perception and interaction were considered in the design of the artefacts and case studies and the analysis of the findings. However, no explicit occupational physiology studies were conducted. The dissertation of Minow (2021) deals with aspects of occupational psychology for multi-variant work processes in the industry and offers insights that complement the research findings presented in this dissertation. Building on both works, the case studies described in the design cycles could be enhanced, for example, using eye-tracking or galvanic skin response technologies as physiological indicators to gain additional information and support the results of the observations. Furthermore, investigations could include long-term effects through less disruptive measurement methods like consumer wearables. Such long-term studies would complement the case studies, which are generally limited in their temporal dimension.

The survey results depend on the chosen population, sample, and final participants. Similarly, the results of qualitative and quantitative studies often vary depending on the participants selected. In industrial studies, populations can not be unambiguously defined by their occupational affiliation. Workers can be skilled or semi-skilled, have a long production experience, or are only used as temporary workers. Production engineers may have direct production responsibility or be part of a global quality assurance department. In the empirical surveys in radiotherapy, the population could be well defined based on the stringent occupational groups. However, some empirical studies have only been conducted on a national level in Germany. Further international studies could produce additional data that support the research findings or put existing ones into new perspectives. Nevertheless, the existing questionnaires and interview guidelines can be adapted for international studies with reasonable effort.

Students or graduates of technical courses were used in some case studies for the industrial surveys. As outlined in this dissertation, age and computer-literacy influence job performance. Younger generations deal differently with digital technologies and information. Additionally, gender-specific differences were not examined in this work. The samples show a high proportion of male participants, reflecting the industrial employment situation in the assembly in many countries. The sample sizes chosen do not represent the population, but small groups of subjects are often sufficient for meaningful usability results (Nielsen, 1993). Moreover, downstream expert interviews or confirmatory and exploratory group discussions verified the single and dual-perspective research results. The scientific assessment of the results was also supported by intensive SLRs, comparisons between the studies, case studies and the existing knowledge base.

A selection bias in selecting the samples can not be excluded in principle. It is possible that some participants particularly interested in the topics took part in the online surveys. Various motivational factors were used to reduce this effect, including personal contact by telephone. Seminar participants were approached without selection bias in the student-based case studies. Participation in the case studies was voluntary, but almost all seminar participants used the case studies to extend their knowledge. Case studies and interview participants were generally not remunerated for their time. However, for each participant, a small amount of money was donated to cancer foundations, increasing the motivation to participate in the studies while also helping those in need.

In reality, some of the activities studied in this dissertation are performed by larger teams. In this dissertation, the case studies examined most groups of two individuals working together. However, people in groups behave differently compared to individuals (Stoner, 1961). Technology can mitigate some of these effects (Summer and Hostetler, 1999). Larger workgroups could be examined in additional case studies, for instance, in the assembly of XXL products.

Knowns as the Hawthorne effect, case study observation can change the behaviour of participants of the observed group (Oswald et al., 2014). The effect influencing the result was counteracted through structured participants' preparation and immersion in the case study by gaining trust and making the participants feel unthreatened. Nevertheless, the effect cannot be completely ruled out.

When selecting the research methods, care was taken to use methods proven in academic studies and validated accordingly. However, all methods have their limitations. One strength of the DSR is that different subjective and objective research methods can be used in the design cycles, thus complementing each other. The implementation of selected artefacts as instantiations served the scientific investigation in the design cycles. The instances could be further improved with reasonable effort. For example, the AI-based chatbot could be optimised for humanlike behaviour with the help of the Turing test (Turing, 1950). According to Laranjo et al. (2018), the NUI conversational agents in healthcare is an emerging field of research. "... we must examine all of the physical, cognitive and sensory aspects that allow the user to interact with the system effectively" (Tosi, 2020, p. 331). Thus, a more robust experimental design and specialised usability tests such as the VUS, proposed by Zwakman et al. (2021), would provide further data for performance improvement.

The COVID-19 pandemic, finally, has made direct access to hospitals and radiotherapy practices difficult and sometimes even impossible. Therefore, some expert interviews could only be conducted via video conference. At the same time, however, this facilitated the subsequent content analysis with specialist software, as the interviews could directly be coded in the original file. In addition, the COVID-19 pandemic has also provided an exceptional opportunity to generate additional research results in a particular situation at an early stage of the pandemic outbreak.

d. Outlook

The subject area of socio-technical information and assistance systems for increasing effectiveness and efficiency in labour-intensive processes investigated in this dissertation is comprehensive due to its fundamental interdisciplinarity, the socio-technical dimension, and the rapid development of new technologies. Numerous investigations building on each other and the chosen practice-oriented DSR approach were selected to close the research gap. The overall design concept allowed a better comprehension of the twelve research questions addressed in the four application areas composite preforming, industrial assembly, radiotherapy cancer treatment, and radiotherapy business continuity.

The twelve research questions were answered in the concluding paragraphs of each design cycle based on artefact development, evaluation and an intensive discourse between the problem and solution space. The industry and healthcare design cycles were consistently presented according to Kuechler,

W. and Vaishnavi, V. (2008) and Francisco and Da Klein (2020). They added overreaching knowledge in the improvement and exaptation areas, according to Gregor and Hevner (2013). Additions to the knowledge base were provided on levels 1 and 2 according to the knowledge contribution model of Gregor and Hevner (2013) in the form of practicable DPs, a corresponding taxonomy, an industry and technology agnostic reference model, and comprehensive empiric data already being used by other researches.

The reference model maps socio-technical systems in their broader context. It includes the systems' dimensions and the system users’ workspace. In addition, supporting aspects of system planning and work preparation, including the Digital Twin concept, were considered in the development of the model. Integration aspects driven by the increasing digitalisation of all application areas are respected, as are essential elements of resilience and business continuity. The reference model and the DPs, supported by technology acceptance models, can now be used to develop socio-technical systems for real-life problems in industry and healthcare.

The limitations of the work also offer the possibility to verify the results of the empirical studies in other cultures and with other technologies. It would be fascinating to investigate systems based on the reference model in permanent use in organisations in different industrial and healthcare settings. Further research could also be performed on the resilience and support elements of socio-technical systems for RM and BCM. The COVID-19 pandemic has shown the need for IS system support in many organisations. Interesting investigations in the existing field are also conceivable through new academic methods. For example, an extended Quality Function Deployment (QFD) method was presented for the systematic design of cognitive assistance systems integrating business and worker requirements to increase productivity, quality work satisfaction and well-being. The authors proved that QFD could be applied to cognitive assistance systems in manual assembly (Pokorni et al., 2022).

Furthermore, new economies arise, providing services rather than optimising industrial production. Sharing, platform, token economy, and others offer novel research opportunities to researchers. In particular, circular economy extensively relying on IT connectivity and traceability and algorithm economy with products increasingly differentiating by software and algorithms instead of hardware are promising fields for IS research (Weinhardt et al., 2021). In summary, the research field of IS will further expand and offer fascinating opportunities to continue contributing to the fulfilment of the SDGs and master the global social, economic and environmental challenges.

9. Acknowledgements

The interdisciplinary scientific analysis of the problem area with quantitative and qualitative research methods was only possible through intensive collaborations with relevant research institutions, competence centres and professional companies. The exchange with research partners and experts from industry and healthcare has permitted the broad scope of this work.

The **Institut für Textiltechnik (ITA) of RWTH Aachen University** develops innovative processes and textile solutions for industrial applications. The ITA provides comprehensive technical facilities representing the textile process chain from raw materials to semi-finished textiles or components. The research institute made the realistic pre-forming case study included in this dissertation possible with its composite experts, technical facilities and machinery, including access to composite fabricators.

The **Learning Factory of Leuphana University** enables students and engineering scientists to test Industry 4.0 concepts and evaluate their implementations. Industrial solutions, including smart labels, RFID, PLCs, AR, 3D printing and self-learning systems, provide a professional environment to design, implement and test industrial product and process innovations. Selected design work and industrial assembly case studies were conducted in the Learning Factory.

The **Center for Mechatronics and Automation Technology gGmbH (ZeMA)** in Saarbrücken is an industry-oriented research and development partner with the goal of industrialisation and technology transfer into economic operations. The centre and its adjacent Mittelstand 4.0 Kompetenzzentrum offer an excellent platform for practice-oriented exchange and shop-floor investigations. Thus, the realistic exploration of operating concepts was accelerated in the context of the assembly case study.

The **Mittelstands-Digital Zentrum in Hanover** supports SMEs in strengthening their competencies in digitalisation and Industry 4.0. The digitalisation factory located at the Hanover trade show presents industrial solutions and their networking in a showcase production line. The digitalisation factory provided the appropriate setting for the assembly case study. The extension of the case study with camera technology and AI could thus be investigated in a realistic production line.

The **HealthCare Lab of the Karlsruhe Institute of Technology (KIT)** hosts scientists from different research disciplines and cooperates with hospitals, medical practices, and companies from the healthcare sector. The HealthCare Lab focuses on healthcare planning, simulation and optimisation. The collaboration was of great help in radiotherapy process analysis and modelling.

The **Software and Digital Business Group** of the **Technical University of Darmstadt** pursues interdisciplinary research in information systems to understand the impact of digital technologies and software solutions on business. The collaboration is a continuation of the work conducted with the

KIT. The scope was expanded to interactive chatbots, natural user interfaces, and operations research supporting radiotherapy design cycles.

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10. Appendix

Abbreviations

AAS .... Asset Administration Shell
AI .... Artificial Intelligence
AIS .... Association for Information Systems
BCM .... Business Continuity Management
BIM .... Building Information Modelling
BISE .... Business and Information Systems Engineering
BPMN .... Business Process Modelling Notation
COVID-19 .... Coronavirus Disease 2019
CPS .... Cyber-Physical-System
CSUQ .... Computer System Usability Questionnaire
CT .... Computer Tomography
DES .... Discrete Event Simulation
DHES .... Digital Health Ecosystem
DICOM .... Digital Imaging and Communications in Medicine
DNA .... Deoxyribonucleic Acid
DP .... Design Principles
DR .... Design Requirements
DSR .... Design Science Research
DSS .... Decision Support System
DT .... Digital Twin
DTO .... Digital Twin of an Organisation
EC .... European Commission
EDT .... Explanatory Design Theory
EHR .... Electronic Health Record
ERP .... Enterprise Resource Planning
EU .... European Union
FGRP .... Fibre-Glass Reinforced Plastic
GDT .... General Design Theory
GFRP .... Glass Fibre Reinforced Plastic
GUI .... Graphical User Interface
HCPS .... Human Cyber-Physical System
HDT .... Human-Digital Twins
HIC .... High Income Countries
HIM .... Health Information System
HIS .... Hospital Information System, Healthcare Information System
HL7 .... Health Level 7
HMI .... Human-Machine-Interface
HRC .... Human-Robot Collaboration
IAB .... Institute for Employment Research
ICIS .... International Conference of Information Systems
ICT .... Information Communication Technology
IGRT .... Image Guided Radio Therapy
IoS .... Internet of Service
IoT .... Internet of Things

IPE .... Individual Protection Equipment
IS .... Information System
ISDT .... Information System Design Theory
ISO .... International Organization for Standardization
IT .... Information Technology
IVR .... Interactive Voice Response
KPI .... Key Performance Indicator
LIC .... Low Income Countries
linac .... Linear Accelerator
LLWI .... Later Life Workplace Index
LMIC .... Lower Middle Income Countries
m2m .... machine-to-machine
MCPS .... Medical Cyber Physical System
meCUE .... modular evaluation of key Components of User Experience
MES .... Manufacturing Execution System
MIS .... Management Information System
ML .... Machine Learning
MRT .... Magnetic Resonance Tomography
MTRA .... Medizinisch-technische/r Radiologieassistent/in
NUI .... Natural User Interface
OAR .... Organs-at-Risk
OECD .... Organisation for Economic Cooperation and Development
OEE .... Overall Equipment Effectiveness
OIMS .... Oncology Information Management Systems
OM .... Operations Management
PACS .... Picture Archiving and Communication Systems
PIACC .... Programme for the International Assessment of Adult Competencies
PLC .... Programmable Logic Controller
QA .... Quality Assurance
QFD .... Quality Function Deployment
QoS .... Quality of Service
RAMI 4.0 .... Reference Architecture Model Industrie 4.0
RCIS .... International Conference on Research Challenges in Information Science
RDS .... Responsible Data Science
RM .... Risk Management
RT .... Radiotherapy
RTT .... Radiotherapy Technologists
SaaS .... Software as a Service
SARS .... Severe Acute Respiratory Syndrome
SCPS .... Social Cyber-Physical System
SDG .... Sustainable Development Goal
SEM .... Structural Equation Modelling
SGRT .... Surface Guided Radio Therapy
SLR .... Systematic Literature Review
SME .... Small Medium Enterprise
TAM .... Technology Acceptance Model
TDP .... Technical Data Package
TPB .... Theory of Planned Behavior

TPM .... Total Productive Maintenance
TPS ....Therapy Planning System
TRA ....Theory of Reasoned Action
UML .... Unified Modelling Language
UN...United Nations
UTAUT...Unified Theory of Acceptance and Use of Technology
UX ....User Experience
VSD ....Value Sensitive Design
WAA..World Assembly on Ageing
WF .... Workflow
WIS ....Web Information System

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e. Grey literature

Within the scope of this dissertation, the following bachelor's and master's theses were supervised by the author either academically or as a representative of LAP GmbH Laser Applications.

Berwanger, F. (2018), Development of a laser assistance system and its integration into the control level of the digital factory. Bachelorarbeit, Lüneburg, Leuphana Universität.

Brach, L. (2019), Erstellung und Bewertung eines Digitalen Zwillings für ein laserbasiertes Montageassistenzsystem. Bachelorarbeit, Lüneburg, Leuphana Universität.

Feger, J. (2021), Assistance systems for patient positioning in radiotherapy in the hospital 4.0. Masterarbeit, Lüneburg, Leuphana Universität.

Gärtner, S. (2017), Entwicklung und Aufbau eines flexiblen, laserprojektionsbasierten Montageassistenzsystems. Bachelorarbeit, Lüneburg, Leuphana Universität.

Jambor, E. H. M. (2021), Entwicklung einer ereignisdiskreten Simulation zur Analyse und Bewertung von Prozessen in einer Strahlentherapie-Einrichtung. Herausragende Masterarbeiten am DISC, Kaiserslautern, Technische Universität Kaiserslautern.

Meyer, L. P. (2018), Analyse und Auswertung des Marktes hinsichtlich vorhandener Schnittstellen und Standards zur Integration des LaToMo (Laser-To-Mount) Demonstrators in Manufacturing Execution Systeme einer Smart Factory der Industrie 4.0. Bachelorarbeit, Lüneburg, Leuphana Universität.

Schmidt, R. (2019), Analyse und Bewertung von Potentialen zur Effizienzsteigerung durch Informations- und Assistenzsysteme in der Strahlentherapie 4.0. Bachelorarbeit, Karlsruhe, Karlsruher Institut für Technologie KIT.

f. Research data

The extensive qualitative and quantitative empirical data and results are documented in the scientific publications of the individual design cycles. They are also available for download for selected publications. The corresponding sources are referenced in the bibliography.

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h. Plagiarism and citation statement

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