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Demands And Challenges For SME Regarding The Human-Centered Implementation Of Innovative Technologies And AI

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Abstract

Digitization is constantly affecting the working world and is of enormous interest in many fields of science. But to what extent are innovative technologies actually being applied in regional SMEs and what are the obstacles to their introduction? From a psychological point of view, it is essential to consider the employee's health and the effects of innovative technologies on their everyday work. The aim of using innovative technologies should not be to completely replace human labor or to dequalify employees, but to relieve the workforce and free up working time for more meaningful activities. One concept that should be included in the human-centered design of human-machine interaction in artificial intelligence is the HAI-MMI concept [1], which offers starting points for high-quality collaboration at various levels.

To reduce the gap between science and industry, this paper focuses on the actual demands of SME in the Aachen region in Germany referring to a requirements analysis within the research project AKzentE4.0 (N = 50 SME) and discusses how appropriate innovative technologies of the Industry 4.0 and AI can be implemented and deployed in a human-centered way. Moreover, the establishment of a Human Factors Competence Center for Employment in Industry 4.0 is outlined, which is meant to be used for the dissemination of research results and should narrow the gap between science and industry in the long run.

Keywords

Digitization; Industry 4.0; AI; Human-centered work design; SME

1. Introduction

Significant structural changes are taking place in the Aachen region due to the energy transition. The region has a unique mix of high technology and production expertise, which is mainly supported by small and medium-sized enterprises (SMEs) and prestigious universities. Industry 4.0 technologies and concepts, especially AI-based applications, have been used by only a few companies in the region so far. When introducing as well as developing these innovative technologies, some companies face obstacles such as human-centered introduction and implementation. These obstacles are analysed and addressed in the project "AKzentE4.0" (German acronym: Arbeitswissenschaftliches Kompetenzzentrum für Erwerbsarbeit in der Industrie 4.0), which is funded by the German Federal Ministry of Education and Research (BMBF). Together, multi-professional teams of the consortium develop and test precisely fitting solutions for the project-internal SMEs in consortium projects. Other companies across industries should benefit from these solutions because the AI-based potential in Germany remains mostly unutilized [2]. Particularly in SMEs, the consistent use of Industry 4.0 technologies and concepts is not widespread. For example, in a survey of 880 specialists and managers, only 7% of the respondents from SMEs and 12.6% of the respondents from large companies stated that they used AI in individual cases [3]. In a comparable survey by the Fraunhofer Institute for Industrial Engineering [4], only 16% (n = 309) of the industrial and service companies surveyed

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used a specific AI application. The reasons for this are varied: they range from a lack of AI expertise and competence in the company to be able to assess advantages and disadvantages, or a high level of uncertainty among employees in dealing with AI, to concerns about job loss or incapacitation due to AI systems.

Therefore, within the framework of AKzentE4.0, an infrastructure in the form of a mixed reality model factory is being established, through which both the exchange of knowledge by means of an open knowledge repository for work design and training offers, as well as the exchange between affected companies is being promoted. In this way, 4.0 technologies can be experienced in real and virtual terms in a mixed reality model factory and the gap between science, technology and industry could be closed a little bit more. In order to be internationally competitive, the concepts require not only a high degree of flexibility, but also an orientation towards an integrated human-centered work design [5–8], because despite the advancing automation through AI use, humans will be a decisive factor in the factory of the future with their ability to think creatively and abstractly [9]. By agreeing on these goals, this research contributes to the human-oriented as well as participatory design of work designs of the digital transformation together with the employees, as demanded by employee representatives [10], and thus to a socially sustainable and at the same time economically beneficial design of the digital transformation. On this basis, an analysis was made of how innovative Industry 4.0 and AI technologies can be implemented and used in a human-centered way.

2. Theoretical Background

In order to approach the object of research, important terminology will be theoretically classified, which will subsequently be used for the further work.

2.1 Innovative technologies

This paper makes several references to innovative technologies and AI. AI is seen as a form of innovative technology. Innovative technology means "new or improved product[s] or process[es] whose technological characteristics are significantly different from before" [11]. It is important that the innovation brings advantages over the status quo in the company or market. The introduction of these technologies requires preparation of the employees as well as the hardware, for example the digitization. Since both the companies in the AkzentE4.0 project and the companies throughout Germany require many preparations for the introduction, these preliminary stages are also included in this paper in the term innovative technologies. One example for such a preliminary stage is the installation of sensors that generate data which an AI can use later in the first place.

2.2 Artificial intelligence (AI)

Artificial intelligence has emerged as a subfield of computer science and is, at its core, a system that can perform certain procedures more or less autonomously. The traditional definition of AI, which is considered to be a "simulation of intelligent human thought and action" [12], is not used here because it interprets human thinking as absolute intelligence and does not take into account that technology has already been able to solve some capabilities in a different way, even partially overtaking human intelligence as a result [12]. This research is based on the understanding of Mainzer's [12] working definition, "A system is called intelligent if it can solve problems independently and efficiently. The degree of intelligence depends on the degree of autonomy, the degree of complexity of the problem, and the degree of efficiency of the problem-solving procedure" [12]. There are two kinds of interpretations in the scientific discourse about which goal AI would pursue: the "strong AI" pursues the goal to imitate human cognition. The "weak AI" pursues the goal to provide a technical solution for application problems in society and economy, in which incomplete controllability or incomplete knowledge would be unavoidable [13]. Since AI systems do not control their environment, the systems must be able to react flexibly, for example, by evaluating sensor data. Learning procedures (machine learning) can be used to optimize the behavior of the AI [13].

2.3 Comparison of previous needs assessments with the present study objectives

There are numerous surveys that focus on the state of digitization in general or specifically on the use of AI in companies. The studies each focus on various aspects and perspectives, which means that there basically is an overview of the status in companies. For the most part, it was ascertained what is understood by Industry 4.0 and what advantages arise from the fourth industrial revolution, furthermore in which areas of the company AI has already been introduced or where it is planned and what opportunities and advantages have been achieved and are expected as a result. In some cases, the evaluation of the use of AI was considered at the organizational or individual level. Furthermore, factors were surveyed that would inhibit or prevent the introduction of AI [15–23]. When reviewing these studies, it became clear, that none of them can provide sufficient information about regional needs and capabilities. There are various platforms on which best-practice examples are presented, most of which were created in the direct environment of (model) projects, which makes the interaction between projects and companies apparent. It is difficult to apply the individual projects to other companies. As a result of AKzentE4.0, therefore, adaptable best practice examples for digitization in companies are to be developed and made available in the competence center, which can be easily used as role models by other companies. Therefore, innovative technologies will be implemented exemplarily at the project partners of AKzentE4.0. Through this universal applicability, a sustainable closing of the gap between science and industry is to be achieved and no further simple listing of best practice examples is to be generated. For a successful, i.e. both socially sustainable and economically beneficial, introduction of AI, the human being has to be put in the center [9]. Thus, the labor science perspective of digitization is a dominant factor of the human-centered implementation of digital structures. However, this is strongly neglected in most surveys. Instead, the focus is placed primarily on the strategic benefits, such as cost reduction and increasing process quality and efficiency, opening up new market and customer segments, or agile and flexible management [24]. In the answers to the potentials of digitization or the introduction of AI, the relief of employees is considered, but the benefits for a humane work design are mentioned only marginally, if at all [18]. On the contrary, the use of AI is even perceived as a burden on work design [23]. This study takes up precisely this point and highlights the advantages of introducing AI and digitization, which, in addition to the above-mentioned benefits such as increased flexibility or process improvement, also pushes the improvement of human-centered work design using the Aachen region as an example.

2.4 HAI-MMI-Model

During the introduction of these innovative technologies, the human-oriented design of work is central. The working human being with his individual and social relations to the technical elements of the work systems is considered [25] in order to reduce stress and to positively increase job satisfaction and performance. For the future-oriented, user-centered design of collaboration and interaction between humans and AI-driven systems, criteria have been developed that address the protection of humans, the guarantee of trustworthiness of AI, and the creation of supportive working conditions [26].

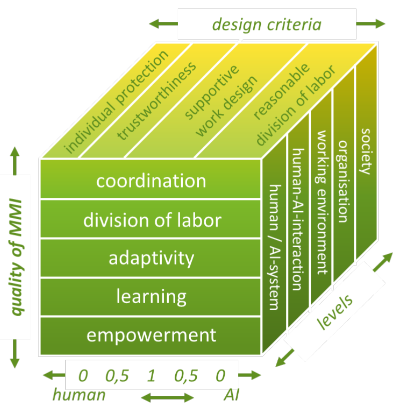

Figure 1: HAI-MMI model

A reflection and design tool for the complementarity between employees and AI is the HAI-MMI (Humanizing Men-Machine Interaction Model with AI) model developed by Huchler [1], shown in figure 1. This model can be used firs to evaluate concrete situations of collaboration between AI and humans regarding the quality of collaboration, and second to evaluate the design criteria of work as well as, in a third step, to estimate the consequences at various levels.

The Quality of MMI on the left side behaves on a scale, which can be seen below the graphic, between the two poles of sole dominance of human action and AI-supported full automation of work processes. In the middle there is the ideal, high-quality form of cooperation between AI and human. In the extreme poles, a lower quality of work occurs, as it can be read from the heading "0". No step-by-step full automation is aimed at as the highest form, but rather a complementary form of work that combines the advantages of humans with those of AI. On the vertical level, the various situations of "*interactive collaboration* with learning AI systems [emphasis in original]" [1] are presented. The extent to which there is coordination of labor, how the division of labor is designed, the extent to which a mutual learning process is present and possible, who adapts to whom in the work process, and whose interests are reinforced in the work process are still evaluated [1]. The different qualities of the work forms are outlined as examples for "Coordination" and "Learning" in table 1. The illustration is shortened so that the MMI of medium quality (at 0.5) was not shown due to space constraints. The complete description can be found in Huchler [1].

Table 1: Qualities of MMI

Human ← Human & AI → AI

	Low Quality	High Quality	Low Quality
Coordination	*One-sided Coordination* • System only works in background • No interaction	*Interactive Coordination* • Transparent and interactive distribution of control-/decisionpower • System proactively offers tasks that it can take on	*Compensating Coordination* • Human only involved in error correction/avoidance
Learning	*Separate Learning* • Human learns separately from technical system • Quality of machine learning is not improved by MMI	*Interdependent Learning* • System and human support each other in learning • High learning quality	*Prevented Learning* • System learns invisibly • Human becomes dequalified at the same time
...			

The design criteria therefore describe the conditions of human-machine interaction under which a human works in an organization. These can be seen in figure 1 above. The individual protection means the protection of human health and safety. In addition, it includes data protection and responsible performance recording, as well as sensitivity to diversity and thus freedom from discrimination. Trustworthiness means that the data is available in high quality and that it can always be explained transparently. This can create system trust and responsibility. A supportive work design means having scopes of action that enable learning and the experience of rich work. In addition, communication as well as cooperation and the promotion of social integration are prerequisites. Reasonable division of labor has the aim to create a work environment full of support, adequacy, and relief. In addition, it includes a setting in which mistakes are tolerated and tasks can be adapted as well as individualized. [1]. Based on these qualities, various levels can be considered, which can be seen on the lower right side of figure 1. With these, the focus is placed on the micro level on the impact assessments of the work both on the person and the technology itself as well as on outside persons or processes, on the meso level on the organization and on the macro level on the society [1].

In the implementation phase of the subprojects of the application companies, the HAI-MMI model provides a scientific basis for designing the introduction process of innovative technologies in a human-centered way. The following phases must be taken into account and awareness needs to be created in the companies in this regard: 1. goal setting and impact assessment, 2. planning and design, 3. preparation and implementation, 4. evaluation and adaptation. First, the objective and purpose of the AI system must be determined. For this purpose, the modes of operation must be uncovered. A potential analysis and operational impact assessment must be carried out in the company. Based on this, the participations are clarified and the contributors are mobilized on the basis of the corporate culture. In the second phase, the design of the human-machine interaction must be planned and the transparency of the data usage and the load profiles must be worked out. In the third phase, the experimentation phase, participants are qualified for new requirements at an early stage and the work organization and upcoming tasks are distributed. In this phase, processes are introduced across the board. In the final phase, the processes are reviewed, evaluated and adjusted. The empirical values are used for this and other innovation processes [27].

3. Method

To reach as many companies as possible an online survey was conducted in the middle of 2022. The survey had the aim to provide an overview of the digitization status of the companies as well as of initial information about the expectations and wishes the companies have regarding a regional competence center. Based on the preceding analysis, duplications of results were to be avoided, so that this survey explicitly considered the economic region of Aachen and especially included human-centered work design. In addition, the survey was intended to sensitize companies to the topic of innovative technologies and to arouse their curiosity.

3.1 Survey and data analysis

The link to the survey which was conducted via Unipark was distributed through the Chamber of Crafts, the VUV-Vereinigte Unternehmerverbände Aachen and especially addressed to the companies from the project consortium. The questionnaire consisted of three main parts which were, first, required general information about the company, second, questions about the status quo of the company (e.g. regarding the AI ability, data quality) and third, wishes and needs that should be addressed in the competence center. Afterwards, data were analyzed descriptively via the software SPSS.

3.2 Sample

A total of 50 representatives from manufacturing companies took part in the survey. Of these, 31 belonged to the craft, 9 to industry, and 10 categorized themselves as other but subsequently allowed themselves to be assigned to industry (therefore total n industry = 19). 44% of those companies (n = 22) had between 1 and 9 employees, 28% of the companies (n = 14) had 10-49 employees, 14% (n = 7) of the companies had 50-249 employees, 12% of the companies (n = 6) had between 250 and 499 employees, and one company (2%) had between 500 and 999 employees. In terms of AI enablement, on average, companies ranked themselves very midway between the poles of analogue (0) and autonomous (10) (M = 4.54, SD = 1.99, Range = 0 - 8). The range illustrates the need to focus not only on AI, but also to include innovative technologies in general.

4. Results

First, the needs of the participating companies were surveyed regarding existing hardware that should be used more intensively and digital hardware that should be purchased. Some kinds of innovative technologies are available in the companies, particularly in the very basic form of smartphones or tablets, and are to be used more intensively. This can be seen in the blue bars in Figure 3. Approximately 60% (n=30) of the companies surveyed use these technologies. Moreover, sensors on machines already exist in 18% (n =9) of the companies surveyed and are planned to be used in more detail. The green bars represent the planned acquisitions of technologies that are not available at all in the company at the moment. Especially the acquisition of data glasses (30%, n=15) as well as AR systems (26%, n=13) and VR systems (22%, n=11) is planned.

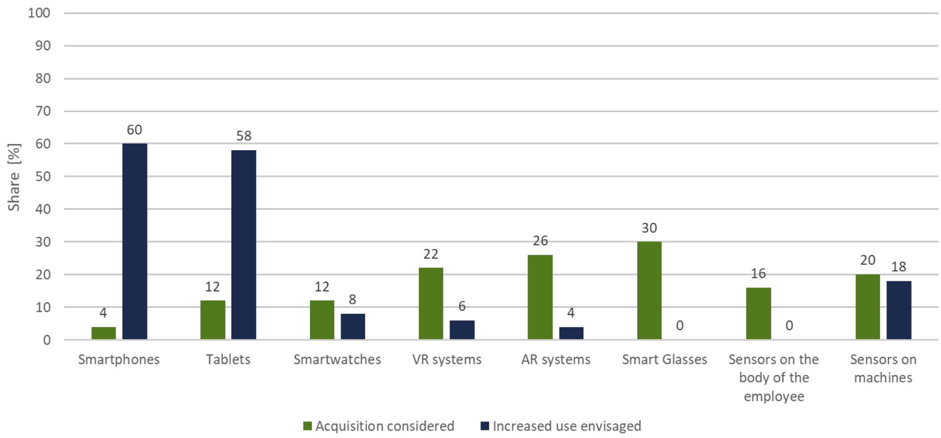

Figure 2: Usage of and need for innovative technologies

The introduction of innovative technologies is currently mainly carried out by the companies themselves. 70% (n = 35) of the respondents state that the introduction takes place in-house. Overall, employees would tend to co-operate with this introduction (M = 4.09; SD = 1.5; possible range = 1 - 6) and be actively involved (M = 4.18; SD = 1.42; possible range = 1 - 6). The average response to the question of whether further training would be offered in the company for the use of these technologies was "tend not to agree".

The survey asked which offerings companies would like to see for the digital transformation (see figure 3). These primarily include qualification offerings (72%, n=36) and networking offerings (62%, n=31)). 54% (n=27) each would like to receive an expert advice and a toolbox with various methods. Only 12% (n=6) would like to participate in conferences. The low interest in the mixed reality model factory can at least partially be explained by a lack of understanding of what is behind the term. This illustrates the importance of properly promoting the factory and creating awareness that encourages potential customers to engage with the issue. What seems to be most important are interactive exchange formats. What is noticeable about the results of the different responses is that the participants in the survey prefer different offerings depending on the branch of industry. This shows the need for a broad variety of offerings in the competence center.

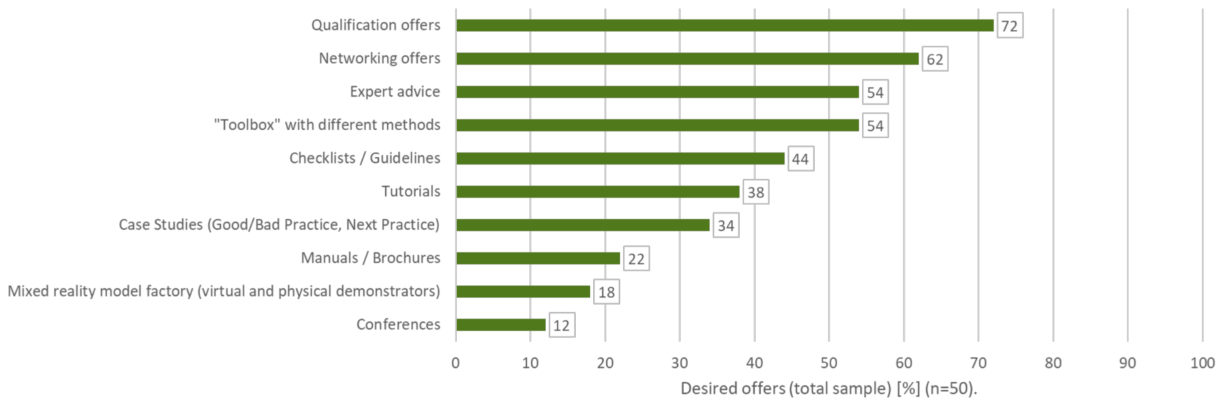

Figure 3: Desired offers

More detailed questions were asked about the desired networking offers. To this end, nine offerings were to be ranked in descending order of importance (1 = the most important, 9 = the least important). Overall, the offers through which companies with similar cases network with each other were prioritized. These include, for example, contact with other companies with the same/similar problems (M = 3.42; SD = 1.95) or networking with partner institutions (M = 3.90; SD = 2.61).

In addition to looking at the needs regarding the offers of the competence center, the focus was placed on the conditions of health as well as occupational safety and the human-centered introduction of the innovative technologies, since this has been neglected in previous studies. The question regarding the impact of innovative developments on the conditions shows that the respondents assume that especially competence and quality requirements of the employees as well as the transparency of work and performance behavior would increase with the introduction of innovative technologies (see figure 4). The individual dimensions from figure 4 are examined in more detail below, from bottom to top.

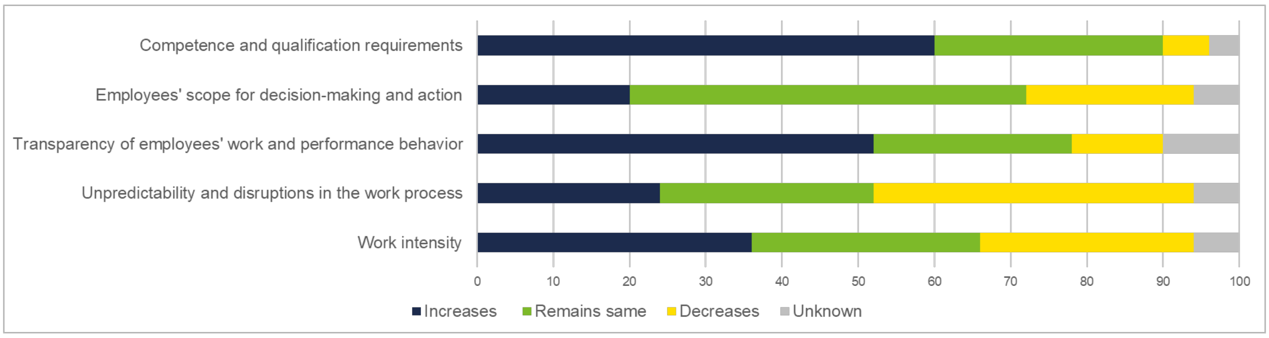

Figure 4: Impact of innovative developments

The effects on labor intensity were examined in more detail. Here, 36% (n = 18) of respondents assume that labor intensity will increase with the use of innovative technologies, while 28% (n = 14) expect it to decrease. This means that the increase in labor intensity is estimated to be lower than previous studies suggest, such as in the Innovation Barometer [23], in which 52% (n = 515) of respondents report an increase in labor intensity and only 8% (n = 42) a decrease. The comparison of respondents from the craft and industry shows that the effects in the craft were to be assessed as more severe from the respondents' point of view, but statistically significant differences could not be determined.

Regarding the increase or decrease in disruptions and imponderables, 42% (n = 21) of respondents assume that the use of innovative technologies will reduce disruptions and imponderables in the work process. This is predicted in particular by respondents from industry and other occupational groups (52.6% (n = 10)). In the craft, 35,5% (n = 11) expect this. Here, again, the results are contrary to previous findings, according to which 42% (n = 416) of the respondents see an increase in disruptions in work processes and only 11% (n = 109) speak of a reduction [23].

The transparency of work and performance behavior is assessed in line with the results of previous studies, which see a strong increase in the transparency of employees' work and performance behavior due to AI [23]. More than half of all respondents to this survey (52% (n = 26)) forecast an increase in the transparency of employees' work and performance behavior using innovative technologies, while only 12% (n = 6) forecast a decrease using innovative technologies.

In previous studies, 60% (n = 594) of the respondents expected the scope for decision-making and action to decrease. Only 31% (n = 307) would expect the scope for decision-making and action to remain unchanged. In the present study, more than half of the respondents (52% (n = 26)) stated that they did not expect any changes in employees' scope for decision-making and action as a result of the use of innovative technologies. Notable differences in this result emerged regarding occupational groups. While 63.2% (n = 12) of respondents from industry and other occupational fields forecast no changes, only 45.2% (n = 14) of respondents from the crafts occupational field did.

The results of this survey regarding expectations of competence and quality requirements are similar to the results of previous studies. 60% (n = 30) of the respondents expect competence and quality requirements to increase with the use of innovative technologies, and only 6% (n = 3) expect them to decrease. This distribution is evident across all subgroups surveyed.

The potentials, which could result from the introduction of innovative technologies, regarding the influence on healthy working, are estimated rather moderately. Thus, 56% (n = 28) rather or completely agree with the support of a better work-life balance through time- and location-flexible working, made possible by innovative technologies. Taking over cognitive activities, e.g., filtering information flows using innovative technologies, is rated best (M=3.81, SD=1.54). 60% (n = 30) of respondents somewhat or fully agree that cognitive relief will occur.

56% (n = 28) of respondents assume that no physical relief at all or rather no physical relief for employees will result from the use of AI. Only 46% (n = 23) assume that the safety of employees will be improved as a result of AI taking over dangerous activities. Overall, these findings show that respondents are aware of at least some of the potential opportunities and risks of using innovative technologies.

5. Discussion and outlook

The results of the literature analysis and survey show a clear need for a Human Factors Competence Center for Employment in Industry 4.0 in the Aachen region, which enables companies to introduce innovative technologies in an employee-centered way and contributes to the networking of local actors. Through contact with regional companies, specific needs became apparent, which will be incorporated into the development of the business model. However, the relatively small sample must be mentioned as a limitation of the study at this point. For this reason, additional needs assessments and more intensive discussions with potential customers of the competence center are planned for the further course of the project. It is also necessary that the HAI-MMI model is applied in practice and that this is evaluated in order to highlight the merits and practicality of the model.

In the form of value proposition canvas and business model canvas workshops, a start has already been made on setting the guard rails for the strategic orientation of the competence center. In this context, the structures of the competence center will be consistently aligned to be able to work on topics of labor research and work design relevant for industrial production systems in an agile manner, to build up competencies and to make them available for operational practice. The implementation strategy includes elements of infrastructure, networking and methods. The infrastructure consists of the mixed reality model factory with distributed virtual and real hub locations, whose main function is to draw attention to innovative technologies and arouse the enthusiasm of potential customers. This is intended to lower the inhibition threshold for the acquisition of innovative technologies as much as possible. In addition, the infrastructure is to include an open knowledge repository through which companies can access practically prepared research findings and training units on the topic of digitization for various target groups. Above all, networking with other companies with similar problems or best practice companies through a regional map with contact information, events in regulars' table format and working groups is a central task of the competence center. Methods include occupational science evaluation procedures and work design strategies, and companies are advised on how to implement them. The overriding goal is to develop the competence center into the central point of contact for the topic of work design in the region.

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Biography

Annika Franken (*1999) is a psychologist and project manager in the department Smart Work at FIR e. V. at the RWTH Aachen University and is primarily involved in projects in the context of health-promoting work design and resilience. Previously, she worked on projects in the field of health psychology at RWTH Aachen University in the context of vocational rehabilitation and mental health of students.

Christine Manthei (*1997) is a childhood educator, social worker, and adventure pedagogue and is currently studying empirical educational research. Since 2021 she has been working in the department Smart Work at FIR e.V. at RWTH Aachen University as a junior project manager.

Roman Senderek worked as project manager in several German and Latin American companies before taking up his position as project manager at FIR e. V. at the RWTH Aachen University. In 2019 he founded the research group New Work, which eventually grew in 2021 into the department Smart Work at FIR, which focusses on the design of customized teaching and learning solutions as well as human-oriented design that promotes learning in the digitized world of work.

Prof. Dr.-Ing. Volker Stich is head of FIR e.V. at the RWTH Aachen University since 1997. Prof. Dr.-Ing. Volker Stich has been working at the St. Gobain-Automotive Group for 10 years and led the management of European plant logistics. His research focuses on operations management, logistics and business applications systems.