

RESEARCH REPORT

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HiFive: Meaningful industrial work in hybrid human-technology-AI teams

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Summary This is the final report of HiFive -project (BusinessFinland 5785/31/2023), which summarizes the key results and research activities as conducted by HiFive research partners (VTT, Aalto university, University of Jyväskylä) together with participating companies Konecranes (Veturi Zero4), A-Insinöörit, Elomatic, ProVerse Interactive, and Tasowheel. The HiFive project successfully investigated how hybrid human-technology-AI teams can enhance meaningful industrial work aligned with Industry 5.0 principles. Through empirical studies, proof-of-concepts, and collaborative workshops, the project developed frameworks, prototypes, and business vision supporting worker well-being, competence, and productivity. It emphasized human-centric design, preserving autonomy and relatedness alongside technological innovation. The findings serve as a foundation for future research and practical implementations ensuring that Industry 5.0 transformations foster sustainable, inclusive, and fulfilling industrial workplaces.	
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1. Introduction

HiFive (BusinessFinland 5785/31/2023) was a two-year project (2024-2026). Total budget of the Business Finland funded co-innovation project was ~4.7M€.

The project consortium included Konecranes (Veturi Zero4), A-Insinöörit, Elomatic, ProVerse Interactive, and Tasowheel. The research partners were Aalto University, University of Jyväskylä, and VTT Technical Research Centre of Finland Ltd, which coordinated the project. This report summarises the research activities of the research partners.

The HiFive project has addressed the interlinked challenges facing European and Finnish manufacturing in the context of the twin green and digital transition: rising technological complexity (artificial intelligence (AI), robotics, extended reality (XR) and cyber-physical systems), increasing environmental requirements, and a growing shortage of skilled workforce. Emerging technology is set to transform industrial work and the role of human operators within it. Building on the Industry 5.0 (European Union, 2021) vision of a sustainable, human-centric and resilient industry, the project has focused on how manufacturing can remain competitive while simultaneously improving the attractiveness, inclusiveness and well-being of industrial work.

A central premise of HiFive was that successful industrial renewal requires more than deploying advanced technology: it requires designing work that people want to do. The project therefore examines meaningful industrial work in hybrid human–technology–AI teams, where work may be distributed across on-site and remote contexts, physical and virtual environments, and varying levels of automation. The project expands the concept of human-centered design by going beyond the traditional perspectives of safety, ergonomics, usability, and user experience, into work meaningfulness. By meaningful work, this project refers to the subjective experience of one's work as purposeful, valuable, and significant (e.g., Hackman & Oldham, 1976; Pratt & Ashforth, 2003), fostering both employee and organizational wellbeing.



Figure 1. Towards meaningful industrial work

Against this background, HiFive investigated how to design future industrial work roles, interactions and operational concepts so that intelligent technologies can support productivity and sustainability while also fostering workers' agency, trust and sense of purpose. The project responded to key research needs related to hybrid collaboration, multimodal human–machine interaction, task division between humans and AI, and implementation practices that ensure transparent,

beyond the obvious

trustworthy and usable systems. Ultimately, the anticipated impacts span (i) societal and work-life outcomes through more meaningful tasks and improved well-being, (ii) environmental benefits enabled by AI-driven optimisation and new operating models, and (iii) business value through new product and service concepts, and emerging business models in increasingly networked industrial ecosystems.

This document compiles the research conducted by the research partners within the project. The companies had their own research projects, but the consortium's research was carried out through active collaboration. This enabled researchers to receive real practical use cases from the companies, interview industrial employees, and participate in joint activities such as workshops where knowledge was actively shared. This human-centered approach, which emphasises a holistic perspective and active involvement of employees/users in the collaborative research project, can be described through the framework presented below (Aromaa et.al. 2026a).

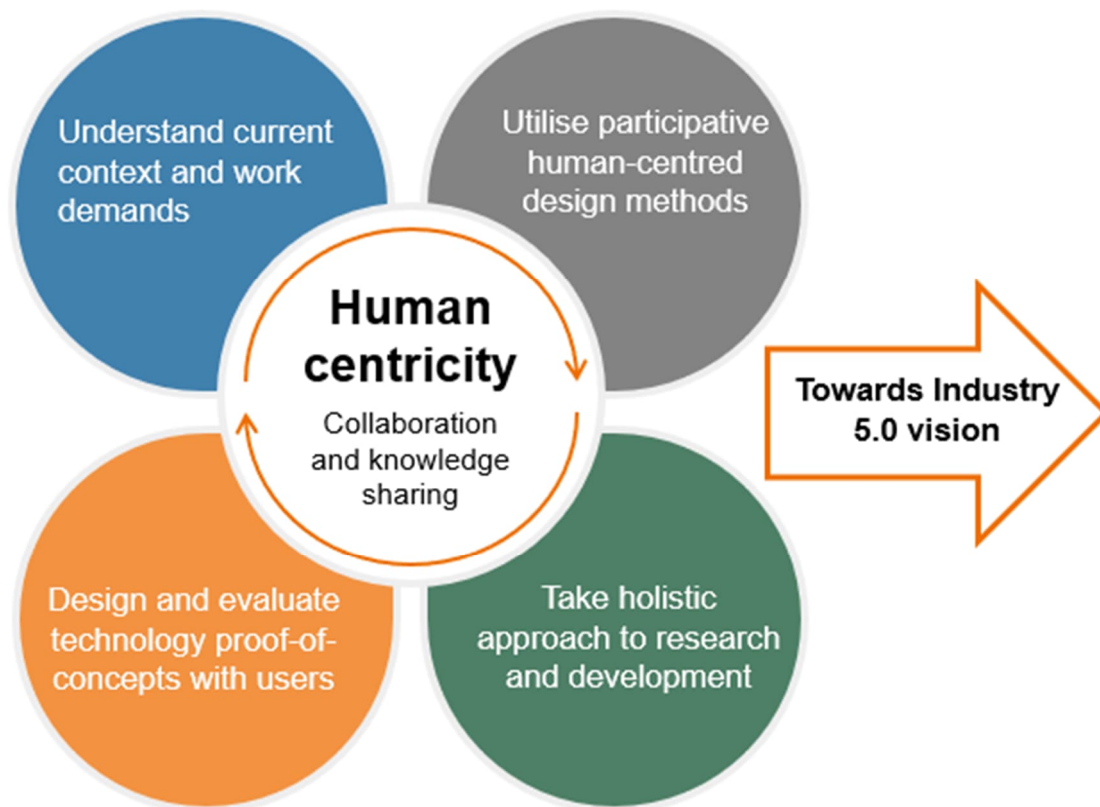


Figure 2. A human-centric framework that emphasises a holistic approach and active user involvement in collaborative research projects when pursuing the vision of Industry 5.0 (Aromaa et al., 2026a).

2. Methodologies used¹

The HiFive project used a multi-method, human-centered research approach to study meaningful industrial work and the design of hybrid human–technology–AI teams. The methodologies combined empirical workplace studies, participatory co-creation, conceptual and literature-based analysis, and proof-of-concept development and evaluation. This combination enabled the research partners to connect theoretical perspectives on Industry 5.0, meaningful work, cognitive ergonomics, human digital twins, and AI adoption with practical industrial needs identified together with participating companies and employees.

Qualitative workplace research formed the empirical foundation of the project. Researchers conducted semi-structured interviews with factory-floor workers, experts, managers, and company representatives across different industrial contexts. These interviews were used to understand current work practices, information needs, perceived challenges, sources of meaningfulness, technology expectations, and future business implications. In selected studies, the interviews were complemented with workplace observations, factory visits, contextual familiarisation, and documentation of work environments. The interview data were generally recorded, transcribed, anonymised, and analysed using thematic, content-analytical, abductive, or data-driven approaches depending on the specific research question.

Several studies used participatory and co-creative methods to ensure that research results were grounded in industrial practice. Workshops with consortium companies and researchers were organised to validate preliminary findings, discuss future work scenarios, explore human digital twin concepts, identify AI adoption pathways, and define future research agendas. These workshops used methods such as facilitated group discussions, scenarios, personas, active listening exercises, roadmap building, and structured reflection tasks. The workshop material was analysed to identify shared themes, concerns, opportunities, and practical implications for future industrial work.

Design-oriented and experimental methods were applied through proof-of-concept and prototype studies. These included AI assistants, smart glasses, virtual AI assistants for human-cobot assembly, crane AI assistant concepts, storyboard evaluations, and prototype feedback sessions. The evaluations typically combined task execution, observation, interviews, questionnaires, and participant feedback. In some studies, mock-ups, storyboards, mobile interfaces, local large language models, vision-language models, speech interfaces, and collaborative robot systems were used to make future work concepts concrete and assess their usability, perceived usefulness, trustworthiness, and implications for work meaningfulness.

The project also applied cognitive and conceptual research methods to examine human information processing and future human–AI collaboration. This included protocol analysis, think-aloud methods during work tasks, stimulated recall based on video recordings, conceptual engineering, content-based cognitive ergonomics, human digital twin modelling, and analysis of mental representations and information contents. These methods were used especially to understand how workers perceive, reason, decide, and act in complex industrial tasks, and how such understanding can inform the design of intelligent technologies and future work systems.

Finally, business and dissemination-oriented methods were used to examine the broader industrial relevance of the research. These included literature reviews, analysis of previous research results,

¹ This summary of methodologies presented in this report was created by Microsoft co-pilot and reviewed by authors.

business interviews, business visioning, scenario development, competence and skills analysis, and evaluation of service processes from cost-benefit and adoption perspectives. Across the project, the methodological approach was therefore integrative: empirical insights from workers and companies were combined with theory, design experimentation, technology prototyping, and collaborative validation to support both scientific understanding and practical application of Industry 5.0 principles.

3. Goals

This project aimed to ensure that Finnish industry companies remain attractive (inclusive of all generations), up-to-date (in digitalization and the use of metaverse technologies), and efficient (fluent material flows). The purpose was to develop and utilize novel technologies and practices that support smooth collaboration in hybrid human cyber-physical systems and to provide meaningful workplaces in industry.

Three research partners took part to the research project: VTT Technical Research Centre of Finland Ltd. (VTT), University of Jyväskylä (JyU), and Aalto University, School of Arts, Design and Architecture (Aalto). Their goals in this research project are (1) to make Finnish industrial work more meaningful for ensuring future human resources, (2) to increase Finnish industries' export related to metaverse technologies, and (3) to ensure industrial productivity and employee well-being. These were achieved by developing and applying novel technologies (e.g., AI, XR, digital twins, and robotics), improving ways of working in hybrid teams and workplaces, and creating new offerings and services related to technology-enhanced efficient and meaningful industrial workplaces.

Given the aims and goals outlined above, this project addressed the following interrelated research questions:

- RQ1:** What is meaningful in industrial work and how does that match with the values of potential new workers (the new generation especially)?
- RQ2:** How to design new industrial work tasks and roles that are meaningful and attractive (in addition to being justified through task-specific aims)?
- RQ3:** How to design intelligent and connected technological solutions by means of studying human workers?
- RQ4:** What is the division of tasks between people and intelligent machines, given their respective cognitive capabilities, task requirements and the possibilities for networked and remote work?
- RQ5:** What could be the new industrial work tasks and roles, allowed by intelligent and connected technology solutions, that are meaningful and attractive (in addition to being justified through task-specific aims)?
- RQ6:** How to implement intelligent and connected technology solutions to industrial jobs in a manner such that the new work tasks are meaningful for the workers (in addition to addressing the generic aims of safety, ecological sustainability, quality, efficiency, and economic competitiveness)?
- RQ7:** What are the future business concepts and models, given the work transformations envisioned in the project (as addressed in RQ1-6)?

Following table presents the research questions, research methods and their relationships in WPs. Results are presented in chapter 4 and in conclusions.

Table 1. Research questions, methods and related work packages

Research questions	Research methods	Related WPs
RQ1: What is meaningful in industrial work and how does that match with the values of potential new workers?	Workplace research; Co-creation and Workshops	WP1
RQ2: How to design new industrial work tasks and roles that are meaningful and attractive?	PoCs & Prototypes	WP1, WP3, WP4
RQ3: How to design intelligent and connected technological solutions by means of studying human workers?	Info-practice map; think-aloud + stimulated recall; content-based cognitive ergonomics; HDT/CDT methods	WP2
RQ4: What is the division of tasks between people and intelligent machines, given their respective cognitive capabilities, task requirements and the possibilities for networked and remote work?	Workplace research; PoCs and interviews	WP1, WP3, WP4
RQ5: What could be the new industrial work tasks and roles, allowed by intelligent and connected technology solutions, that are meaningful and attractive?	Workplace research; Co-creation and Workshops; PoCs and prototypes	WP1, WP3, WP4
RQ6: How to implement intelligent and connected technology solutions to industrial jobs in a manner such that the new work tasks are meaningful for the workers?	Workplace research; Co-creation and Workshops; PoCs and prototypes	WP3, WP4
RQ7: What are the future business concepts and models, given the work transformations envisioned in the project (as addressed in RQ1-6)?	Workplace research; Co-creation and Workshops;	WP5

Next section describes in more detail the key results which aimed at answering the main research questions. Research results described in the following section are also described in more detail in numerous scientific publications, section 6.2 lists the key publications.

4. Results

This section covers main research results divided by Work Package and main research conducted.

4.1 WP1: Meaningful work in hybrid human-technology-AI teams

The aim of WP1 was to study meaningfulness in industrial work and design how hybrid, technology-enhanced teams can foster work meaningfulness going beyond usability to support agency, learning, and resilience. In response to increasingly complex AI-driven, connected systems, WP1 emphasized intelligible system models that enable worker autonomy and growth, and demonstrates how technology solutions can enhance meaningful practices and systemic understanding. Through user research, interviews, workshops, and scenarios, WP1 co-created new design methods with companies, delivering practical frameworks, toolkits, and prototypes while building user-centered design capability and improving engagement, adaptability, and performance of participating organizations.

Interview data was collected as a co-effort by researchers from Aalto University, VTT and University of Jyväskylä. A total of 36 people were interviewed across nine manufacturing companies in the study during 2024 and 2025. In 2024 researchers participated in planning and conducting interviews of 20 factory floor workers working in different industrial sectors. The data

was collected using semi-structured interviews. A joint interview protocol was created to discover blue collar workers' (i) job contents and workflow; (ii) technology and automation needs and opportunities, and (iii) enablers and barriers for perceived work meaningfulness and employee well-being. The data collected served the differing research objectives: University of Jyväskylä studied information contents and processes, thinking, knowledge and learning; Aalto studied how to support technology adoption while strengthening work meaningfulness; VTT studied current work practices, task-related challenges, meaningful work factors, and knowledge and information needs.

Joint data collection continued in 2025, when researchers participated in 16 factory workers interviews. This time researchers conducted their own data collection in four factories. Researchers from the University of Jyväskylä interviewed four factory floor workers to collect information on what they really think and act by using thinking out loud while performing a task and stimulated recall (video) as a method. They also included questions related to Aalto University's and VTT's research focus areas. Researchers from the Aalto University interviewed six factory floor workers to study the current and future roles of AI in fostering employee flourishing. Researchers from VTT interviewed six factory floor workers to study information workers need in daily tasks.

4.1.1 Challenges in industrial work hindering perceived work meaningfulness

As previously described, the foundation of this project was interviews conducted with industrial workers. One key perspective in analysing these interviews was the question of current work challenges. Understanding these challenges is particularly important when aiming to introduce new technologies to enhance work efficiency and meaningful work. Building on empirical findings, the challenges were examined both from the employee's own viewpoint (Aromaa et al., 2026b) and from the organisational perspective (Viljakainen et. al., 2026).

The table below provides synthesis of both. Employee's viewpoint of challenges provides quotes from the people who are working in factories. Organizational challenges look at areas that constrain or disrupt prevailing social structures, diminishing perceived (i.e., individual level) work meaningfulness.

Table 2. Challenges hindering perceived work meaningfulness from employee and organisational viewpoints.

Organisational perspective	Individual employee perspective
Siloed information structures Data siloes; Lack of data feedback loops; Poor information systems; Information unavailability; Over-reliance on tacit knowledge. Communication breakdowns Organizational hierarchies; Departmental siloes; Lack of information flow; Language barriers; Withholding information Chronic time pressure Work interruptions; Continuous multitasking; Improper tools; Faulty components or orders; Unpredictability of work; Scheduling problems; Work overload; Worker negligence Operational challenges Workforce scarcity; Time constraints amplifying challenges; Human errors; Cognitive overload; Reduced physical ergonomics; Continuous cost-cutting Work unpredictability Mechanical challenges; Machine malfunctions; Material shortages; Work delays; Over-reliance on individuals Complexity of work Mixed work practices; Large component and product portfolio; Constant technology changes; Complexity of systems; Lack of work instructions; Increased quality and documentation demands Misalignment in managerial coordination and feedback Lack of work planning or scheduling; Lack of feedback, clear targets and KPIs; Reluctance to management control Nature of work Underutilization of skills; Monotonous work tasks; Outdated practices or technology; Lack of competence	Individual employee • “If you’re tired or have no energy and suddenly some really heavy task comes up. You still feel like, ‘Well, I guess I just have to do it anyway.’ [...] Personally, I’ve often had to do Saturday shift basically without any sleep. It was really tough.” (Welder in assembly) • “Old days you were given time to learn the job—time to work alongside a more experienced coworker, pick things up properly, and do everything safely so that the different tasks became routine. [...] These days people just aren’t given that time anymore. [...] It creates challenges that you can see in the workers as tiredness and a kind of general strain.” (Machinist in assembly) Work tasks, tools and environments • “Learning the movement paths of the machine is tough because the positions and all the hoses are so complicated. Even now I still have to stop and check carefully to make sure everything is actually installed the right way.” (Assembler in assembly) • “I see it as a real problem when an air hose doesn’t quite reach somewhere. Or the welding torch won’t reach because the piece is long and you have to move around a lot. The torches are only 16 meters at most, and that’s really annoying.” (Welder in assembly) Organisational practices and processes • “Working in shifts is probably the hardest part of this job. The changing schedule means that just when you start getting used to the rhythm at the end of the week, it switches again the next week. For me, that’s the biggest challenge.” (Assembler in assembly) • “I’d say the biggest challenge right now is communication — it causes the most problems. It really feels like every issue comes down to poor communication.” (Assembler in assembly)

4.1.2 Workstream 1: Study on information practices and knowledge retention in industrial manufacturing work

4.1.2.1 Study description

This study led by VTT examined how information is accessed, shared, and retained in industrial manufacturing work, with particular attention to the implications for knowledge retention,

beyond the obvious

professional competence, and human agency. The study was motivated by the observation that industrial work is currently shaped by two major trends: an aging workforce and increasing digitalisation, including automation and AI, which both raise concerns about how critical shop-floor knowledge is preserved and transferred when experienced workers retire and work systems become more technologically complex.

The study asked what kinds of knowledge are important in industrial manufacturing work, what information workers need in practice, what information is missing or difficult to access, and how these conditions influence knowledge continuity. These questions were approached from the perspective of maintaining skilled personnel, resilient operations, and human-centred technological development. The analysis focused on how knowledge is enacted in everyday work through access to information, collaboration with colleagues, and embodied engagement with tools, machines, and materials.

4.1.2.2 Participants

28 semi-structured interviews were conducted with blue-collar workers from multiple industrial sectors representing a broad range of occupations from fitters to assemblers and warehouse operators. The workplaces spanned heavy machinery manufacturing, steel, automotive and heavy equipment, construction, maintenance in the energy sector, general manufacturing, and maritime manufacturing. This variation made it possible to compare information practices across different industrial settings while still focusing on common shop-floor dynamics.

The material was collected in two phases. The average age of participants in Phase 1 was 37, with a range from 21 to 53 years. In Phase 2, the average age of interviewees was 42 with an age range of 24 to 57. The data combined all 20 interviews from Phase 1 and eight selected interviews from Phase 2.

4.1.2.3 Data collection methods and analysis

The study was conducted in two phases. Phase 1 provided a broad overview of current work practices, task-related challenges, meaningful work factors, and knowledge and information needs across various industries. Phase 2 then deepened the analysis by concentrating more specifically on the information workers need in daily tasks, where they obtain it, how it circulates on the shop floor, and what gaps hinder onboarding and independent work. The second phase also revisited related themes such as technology use, future changes in work, and workers' views on how workplace technologies should be designed to better support their tasks.

All interviews were conducted face-to-face at the participants' workplaces and lasted approximately one hour. The interviews were recorded, transcribed, anonymized, and translated from Finnish into English. For analysis, a data-driven thematic approach was used where themes were allowed to emerge from the data and were then coded and grouped to identify recurring patterns in how information and knowledge are accessed, used, and shared.

4.1.2.4 Results

The results showed that information in industrial manufacturing is obtained from three main sources: paper-based physical documentation, digital systems, and colleagues. Of these, colleagues emerged as the most important and trusted information source, seeming to form an "organic information system" that supports troubleshooting, interpretation, and learning, especially in situations where documentation is incomplete or digital systems are difficult to use. Paper documents remained central to recording and passing on information in daily work because they are durable, portable, and practical in harsh industrial environments, whereas digital platforms

were valued for searchability and broader information storage when the systems were well designed.

The analysis further identified four interrelated knowledge domains that underpin effective work: technical, holistic, relational, and ergonomic knowledge. We also identified five recurring information gaps: communication gaps, documentation gaps, system usability problems, onboarding-related knowledge gaps, and poor capture of tacit knowledge. These findings suggest that the central issue is not only what workers know, but whether they can access, share, and further develop relevant knowledge under changing technological conditions. The results also indicate that resilient production depends heavily on preserving peer-based knowledge exchange while improving the usability, accessibility, and contextual relevance of formal information systems.

4.1.3 Workstream 2: Proof-of-concept on AI-assistant for novice workers

4.1.3.1 Study description

This proof-of-concept led by VTT examined how a GPT-based AI assistant could support novice workers in a concrete industrial assembly task. The study was motivated by a broader workplace challenge in which retiring experts leave with valuable practical know-how that is not fully captured in manuals, diagrams, or formal instructions. In assembly work, this includes omitted steps, troubleshooting tips, explanations of why certain actions matter, and judgments based on “feel” rather than written rules. The proof-of-concept therefore explored whether AI could function as a supplementary learning tool that makes some of this otherwise implicit knowledge more accessible for novice workers, while still preserving the central role of human expertise in onboarding, guidance, and skill formation. The study was conducted at the premises of Tasowheel during Spring 2025 (data collection) and August 2025 (testing).

The purpose was not to develop a finalized deployable system, but rather to explore how such an assistant might feel to use in practice, how accurate and reliable its guidance could be, and what kinds of source material are required for building an assistant that provides useful and understandable support.

4.1.3.2 Participants

The testing phase involved five participants selected by Tasowheel: three novices and two experts. The novice participants represented the intended target users of the AI assistant, and their participation made it possible to assess whether the assistant could provide understandable guidance, support task learning, and increase confidence during unfamiliar work. Novices were defined as workers with little or no prior experience with the selected assembly task and for whom the task was not part of their primary work role.

The expert participants were workers who regularly performed the assembly task as part of their main occupation and possessed extensive practical proficiency. Their role was to evaluate the technical correctness, completeness, and practical relevance of the assistant’s instructions. They were also asked to test the system more critically by intentionally making mistakes in order to assess whether the assistant could identify and correct errors. None of the participants had previous first-hand experience of using AI systems.

4.1.3.3 Data collection methods and analysis

To develop the proof-of-concept, task-related source material was collected from one expert worker selected by the company together with a manageable but sufficiently complex assembly task (the assembly of a lead screw).

First, the expert performed and narrated the assembly process while being recorded on video. This material was later converted into a work instruction document containing screenshots and captions for each phase of the task. Second, the expert participated in a semi-structured interview focusing on task challenges, required knowledge and skills, tool use, assembly order, cleanliness, fragility of components, and troubleshooting. Relevant parts of the interview were then refined into structured question-and-answer material suitable for retrieval-based use by a large language model. Overall, the assistant's knowledge base consisted of work instructions based on the video recording and the interview notes, exploded-view images, photographs taken of the assembly process, and additional notes made during the interview.

The assistant was implemented as a closed-environment custom GPT using OpenAI models and was operated via mobile phone. Testing was conducted over two consecutive days, first with novice participants and then with experts. Each session lasted about one hour and included an introductory interview, the assembly exercise, interaction with the AI assistant through written prompts and photographs, and a post-test interview. The analysis focused on usability, accuracy, completeness of guidance, error detection, and the assistant's perceived role in learning, problem-solving, and knowledge transfer.



Figure 3. Test set-up. The test was recorded with a mobile phone in a manner that respected the anonymity of the participants. The AI assistant was accessed using the other smartphone on the desk.

4.1.3.4 Results

The results suggest that the AI assistant was able to support novice workers in completing the assembly task and to provide generally correct step-by-step guidance. The novice participants successfully assembled the part with AI support, although the extent to which they relied on the assistant varied. Expert participants confirmed that the overall process logic was correct, but they also identified missing details, minor inconsistencies, and areas where the system's guidance remained incomplete. In particular, the assistant was stronger when users formulated precise questions, whereas more open-ended or ambiguous situations produced weaker results. The assistant was also limited in recognizing errors from photographs and could not replicate the experiential dimension of manual work.

The AI assistant demonstrated several clear strengths. The assistant could explain work steps in accessible language, provide follow-up clarification, and make some tacit knowledge more explicit by combining formal instructions with expert commentary on how, why, and when tasks should be performed. Participants also regarded the system as relatively easy to use after brief familiarization. Overall, the findings suggest that such an assistant may have value as a supplementary tool for onboarding, reminders, and problem-solving in unfamiliar tasks, provided that it is developed further through improved instructions, richer visual support, and continued integration with human expertise rather than as a substitute for it.

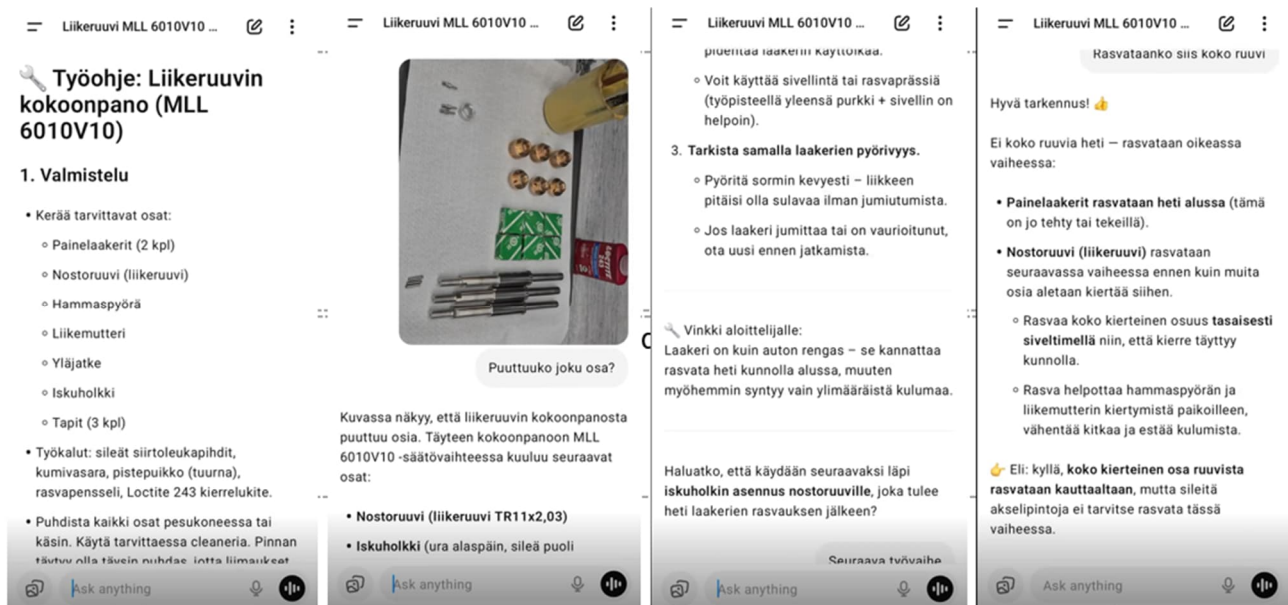


Figure 4. Collection of screenshots showing various functions of the AI Assistant.

These screenshots show functions such as work instructions and list of parts (leftmost screenshot), image recognition (centre left), additional tips derived from background material (centre right), and giving more detailed answers to user questions (rightmost screenshot).

4.1.4 Workstream 3: Study the sources of meaningful experiences in industrial work

4.1.4.1 Study description

The aim of this study led by Aalto University was to form a holistic understanding on employee well-being and work meaningfulness to help design future workplaces, where both user experience and system performance are significantly enhanced. Research has shown that enhancing employee wellbeing and perceived work meaningfulness is associated with increased human and corporate performance (e.g., Lu & Roto, 2015; Lips-Wiersmam & Morris, 2009). Despite its importance, current models offer limited guidance on how meaningful work is supported—or threatened—during the implementation of emerging technologies in industrial settings. Therefore, the study focused on three main areas of research: (1) What makes blue-collar work meaningful—defined as the degree to which workers experience their work as purposeful, worthwhile, and intrinsically valuable (Hackman & Oldham, 1976); (2) How technologies should adopted to affect both the availability of meaningful work and employees' perceptions of its meaningfulness, and; (3) How individuals and organizations can cultivate and sustain meaningfulness during periods of technological transformation.

This study first synthesized the theoretical underpinnings of work meaningfulness to better understand how to foster employee experience to move beyond satisfaction to flourishing. Literature review on meaningful work was executed across multiple disciplines, such as philosophy and psychology, management theories, and sociology, as each discipline offers various conceptual definitions, with limited consensus on the dimensions of the construct. Thereafter, a qualitative study of blue-collar work in Finnish industrial settings was performed to explore how emerging technologies intersect with everyday work practices, perceptions of meaningfulness, and institutional conditions. Central aim was to better understand how the shift towards Industry 5.0 ensures that emerging technologies enhance rather than diminish the human role in manufacturing, by reconfiguring the taken-for-granted rules, values, norms, and practices, (i.e., institutional arrangements), that shape how work is structured, experienced, and made meaningful.

4.1.4.2 Data collection methods and analysis

The study adopted an abductive research process integrating deductive and inductive reasoning (Timmermans & Tavory, 2012) to better understand how blue-collar workers experience meaningfulness in their daily work. The empirical data were collected between Fall 2025 and Spring 2026 from nine large Finnish manufacturing companies. These firms represent key segments of heavy manufacturing, including the assembly of high-value investment products ($n = 5$), remanufacturing of professional-class vehicles ($n = 1$), and handling and refining of building materials ($n = 3$). Data were gathered through semi-structured interviews with factory-floor workers ($N = 31$), holding roles within material handling, assembly, and remanufacturing. Interviews (60—90 minutes) were conducted in person at the companies' production facilities by one or two researchers from Aalto University, Jyväskylä University and/or VTT. Prior to interviewing, the researchers toured work cells and production environments to gain contextual familiarity of the lived realities in industrial settings. The empirical data were collaboratively analyzed using thematic analysis by two Aalto researchers. The resulting data structure integrated theory-driven dimensions with inductively generated subthemes, enabling robust and empirically grounded theory refinement (Timmermans & Tavory, 2012).

4.1.4.3 Results 1: A Conceptual framework for AI's role in enhancing employee experience from satisfaction to flourishing

The study explored how AI can elevate the employee experience in future industrial settings by advancing well-being and meaningful work. It bridged complementary theoretical lenses and schools of thought to conceptualize an ongoing phenomenon for broadening the scope of our thinking. The work draws on Motivation–Hygiene Theory, Human Factors and Ergonomics, Self-Determination Theory, and eudaimonic perspectives, to propose a three-tier framework for AI integration to enhance employee satisfaction, engagement, and flourishing (*Figure 5*).

Employee Experience Levels	Theoretical Background	Design Approach	Role of AI
Flourishing	Eudaimonia	Positive design	Coach
Engagement	Self-Determination Theory Motivation-Hygiene Theory	Experience design	Teammate
Satisfaction	Holistic Ergonomics	Human-centred design	Assistant

Figure 5. Theories, design and role of AI in supporting employee experience (Viljakainen et al., 2025)

This study's practical contribution was to highlight how AI can reshape future work experiences and why we must design adaptive human-machine relationships to ease current skill shortages and attract talent to sectors often seen as lacking meaningful work. The findings indicate that AI can help create workplaces that are safe, productive, and deeply fulfilling, opening the door to a new era of industrial progress and human flourishing. As an assistant, AI can reduce physical strain and enhance the physical environment (physical ergonomics), streamline mental processes in human work (cognitive ergonomics), and improve organizational processes and systems (organizational ergonomics). As a teammate, AI can strengthen the sense of belonging and relatedness, build the skills and competences needed to meet job demands, and enable employees to exercise autonomy and agency in their work. As a coach, AI can support self-actualization, personal growth, and the pursuit of one's highest potential (eudaimonia). These roles translate into three design levels for the evolving employee experience: Level 1 (human-centred design) deploys AI to alleviate pain points and raise employee satisfaction; Level 2 (experience design) uses AI to cultivate relatedness, competence and autonomy to enhance employee engagement, and; Level 3 (positive design) leverages AI to promote flourishing by supporting self-realization, personal development, and living in accordance with one's values.

The study offered organizations a framework to outline employee experience as a progressive continuum, where AI is positioned to play distinct roles. The interdisciplinary perspective underscored the necessity of adopting AI by not only addressing the physical and cognitive requirements of workers but also their emotional needs. The framework illustrated how AI design can profoundly transform the manufacturing landscape by supporting holistic ergonomics, positive emotional experiences, and human flourishing wherein employees feel valued, motivated, and engaged, ultimately leading to enhanced performance and well-being both at the individual and corporate levels. The outcomes of the study were conceptualized to industrial work, yet the outcomes were not specific to this domain showing promising avenues also to other research settings.

4.1.4.4 Results 2: Transitioning toward Industry 5.0 by reshaping institutional arrangements

This study explored the transition to Industry 5.0 by centering the distinct facets of work meaningfulness and the influence of institutional arrangements—the norms, values, roles, beliefs, rules, and practices that served as the “rules of the game” in work communities—on shaping meaningful blue-collar work. Although the Industry 5.0 discourse increasingly highlights human-

centricity, resilience, and sustainability, we still lack empirical insight into how these arrangements intersect with workers' lived experiences.

Institutional arrangements can both enable and impede progress toward Industry 5.0. Therefore, the study adopts a multi-level, systemic lens, to recognize that humans are central to successful technology adoption. It investigates how micro-level subjective experiences of meaningful work drive meso-level shifts in institutional arrangements, which, in turn, catalyse macro-level transformations toward Industry 5.0. Drawing on a comprehensive literature review and empirical evidence, this study reframes six micro-level dimensions how work is perceived meaningful in industrial blue-collar contexts (*Figure 6*): Competence (i.e., developing and applying skills), Autonomy (i.e., independence and self-efficacy at work), Embodiment (i.e., physical engagement, manual effort, and creativity), Relatedness (i.e., meaningful social connections), Beneficence (i.e., orientation towards serving others), and Identity (i.e., coherence between one's work and sense of self).

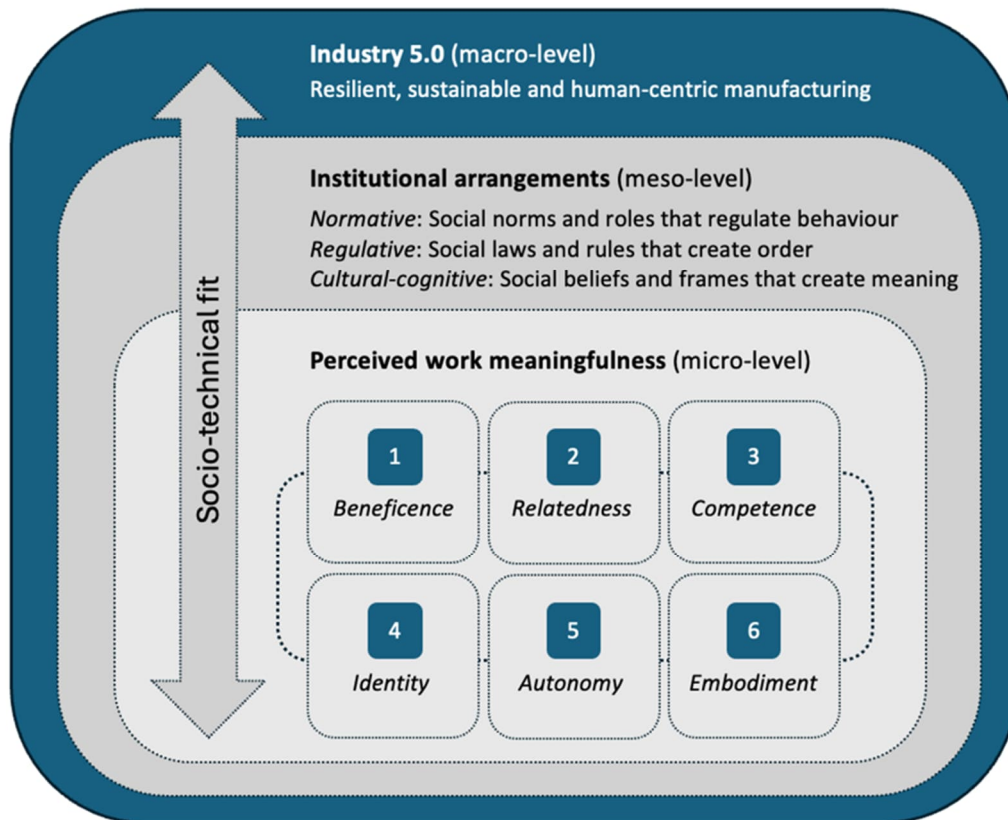


Figure 6. Multi-level perspective to foster socio-technical fit in the transition towards Industry 5.0. (Viljakainen et al., 2026)

Extending beyond individual experience, the study further delineated twelve meso-level institutionalized social structures that both enabled and constrained the experience of meaningful work. Four are normative: Stewardship (knowledge sharing to help colleagues grow), Collectivism (collaborative problem-solving and collective responsibility), Solidarity (trust, collegiality, and mutual care in dynamic factory work), and Ingenuity (creativity and cleverness in tasks and practices). Three are regulative: Entitlement to learn (active, ongoing skills development), Safeguarding (rule-governed practices that ensure safety and collective wellbeing, reinforced through everyday responsibility rather than formal enforcement), and Flexibility (mutual support and adaptive reallocation of work to maintain operations and enable job crafting). Five are cultural-cognitive: Synchronicity (tacitly coordinated teamwork and shared practices), Harmony

(respect for individuality, inclusion, and diverse working styles), Achievement (striving for excellence and surpassing expectations), Fellowship (trust-based autonomy and communal responsibility), and Respect (recognition of competence and tacit expertise that builds esteem and responsibility). Together, these structures explain how meaningfulness is enabled or constrained at the organizational level and why aligning technologies with existing norms, rules, and shared meanings is critical for sustaining human-centric Industry 5.0 transformations.

The study further introduced operational frictions that erode meaningful work in industrial workplaces, by constraining collaboration and learning, and ultimately weakening the social structures that make shop-floor work feel purposeful and valuable. These challenges are presented in the following table:

Table 3. Identified organizational challenges in blue-collar work and practical implications for technology adoption to foster meaningful work (adapted from Viljakainen et al., 2026)

Organizational challenges	Example challenge areas	Practical implications
Siloed information structures	Data siloes; Lack of data feedback loops; Poor information systems; Information unavailability; Over-reliance on tacit knowledge.	Support tacit-to-explicit knowledge transfer. For example, enforce peer learning via AR / VR technologies to simulate real-world scenarios.
Communication breakdowns	Organizational hierarchies; Departmental siloes; Lack of information flow; Language barriers; Withholding information	Enhance collaborative problem solving and group-level competence building. For example, transfer tacit knowledge into digital manuals.
Chronic time pressures	Work interruptions; Continuous multitasking; Improper tools; Faulty components or orders; Unpredictability of work; Scheduling problems; Work overload; Worker negligence	Improve work planning while making progress visible. For example, introduce haptic devices to support decision-making under pressure.
Operational challenges	Workforce scarcity; Time constraints amplifying challenges; Human errors; Cognitive overload; Reduced physical ergonomics; Continuous cost-cutting	Enforce worker and collective wellbeing. For example, use wearables to enhance ergonomics and safety.
Work unpredictability	Mechanical challenges; Machine malfunctions; Material shortages; Work delays; Over-reliance on individuals	Reinforce in(ter)dependence and autonomy to preserve quality under time pressure. For example, use VR to simulate hazardous environments.
Complexity of work	Mixed work practices; Large component and product portfolio; Constant technology changes; Complexity of systems; Lack of work instructions; Increased quality and documentation demands	Support daily task execution and the development of trust-based relations. For example, use AI powered chatbots to sustain work practices.
Managerial misalignment	Lack of work planning or scheduling; Lack of feedback, clear targets and KPIs; Reluctance to management control	Emphasize clarity, purpose and goal setting for flexibility. For example, use performance dashboards to highlight achievements.
Nature of work	Underutilization of skills; Monotonous work tasks; Outdated practices or technology; Lack of competence	Enforce creativity, craftsmanship, innovation and dedication. For example, enhance precision of manual work with robots.

This study highlighted that Industry 5.0 is a socio-technical transformation, where successful technology adoption depends on how they align with the organizations shared structures that govern work. The interplay between employee perceptions, organizational-level social structures, and the macro-level pressures should be made visible, to allow the design of solutions that foster meaningful work. This multi-level alignment reduces resistance, enhances human roles in manufacturing, and builds resilience to disruptions, advancing the human-centric, sustainable, and robust vision of Industry 5.0.

4.1.5 Workstream 4: Validation of two industrial crane AI-assistant concepts

4.1.5.1 Study description

This study validated two AI assistant concepts with factory workers who use industrial cranes in their daily work. Conducted by Aalto University at Konecranes' premises in Hyvinkää in March and May 2025, the study aimed to collect design-oriented feedback on users' expectations and concerns, and to connect experiences of meaningfulness with usability.



Figure 7. Crane AI assistant storyboard visualisation (Source: Aalto Experience Design-course team, 2025)

4.1.5.2 Data collection methods and analysis

Research team from Aalto University made two separate visits to Konecranes crane factory at Hyvinkää. Agenda of the first visit in March 2025 included interviews with 2 factory workers to understand their current work process and challenges involved when using the crane to move components. Team recorded the interviews and documented factory environment which were later analysed to formulate journey map where each work phase was identified with challenges and requirements pinpointed. Analysis indicated that most prominent areas of improvement were related to rigging of the load and safe movement with load while using the crane. Based on the findings from first visit the team formulated AI assistant prototype on mobile device including two features to address the requirements: 1.) Assistant for efficient and safe load rigging, and 2.) Assistant for safe load moving.

Research team created a mock-up version of AI assistant prototype on mobile device which was validated on second visit to same factory in May 2025. The prototype included two features to help factory workers in their work: Assistant for efficient and safe load rigging was used to determine load's centre of gravity by using mobile device camera with AI algorithm to detect suitable attachment points of the component. The aim of the concept was to alleviate the stress which operators feel when rigging a demanding load to hook with lifting accessories like slings and chains.

Assistant for safe load moving was a concept to utilise machine-vision cameras in crane with intelligent software. The purpose of the concept was to detect possible objects which could cause a collision with the load on its current trajectory, thus helping an operator to maneuver safely with load in factory.

The prototype was created for testing purposes only and utilised only limited functions with device camera and user interface with no real intelligent software included. Validation session was arranged with same factory workers who were interviewed during the first visit.

Workers were asked to use the mock-up version on mobile device like it was intended to be used and at the same time to describe how the prototype features would help them in their work. The criteria for evaluation were features usability and possible benefits it would provide in their work.

4.1.5.3 Results

Both factory workers provided positive feedback to two prototype concepts: based on their validation rigging assistant would make load rigging easier, faster and more pleasant by reducing the number of test lifts needed to find an optimal lifting point for complex components, whereas safe load moving assistant would reduce the need for operators to manually observe surroundings of lifting area in case of collisions, thus reducing the stress and anxiety associated with working large objects. Participants also commented that such assistant in lifting work would reduce possible feelings of uncertainty when working with large components, boosting the experiences of competence and autonomy. Results are in line with findings concerning sources of work meaningfulness in factory work reported by Viljakainen et al., (2026).

4.2 WP2: Human (cognitive) digital twin in future hybrid work

The aim of WP2 was to focus especially on human cognitive processes and capabilities. The idea was to develop a systematic process to analyze human intellectual work and to automatize and autonomize it. Key tools were cognitive mimetics, i.e., imitation of human information processing and human digital twins (HDTs), i.e., modelling internal processing in work. The objectives of WP2 were to develop a design methodology for how human work can be replaced or supported by AI-systems in future industry, to study industrial workers' mental representations and intellectual processes related to the context and function of current task and to free people from steering and control tasks by developing AI systems capable of carrying out such work processes automatically in the future. In addition, the objectives included to create generic enough but sufficiently detailed models of the intellectual process and HDT of the worker, transform the outcomes modelling into prototypical solutions for intellectualizing the work, and to create new design theoretical models and theoretical paradigms, concepts and methods to understand and model HDTs.

4.2.1 Acceptance of conceptual models for new technologies

Industry 5.0 envisages integrating intelligent technologies such as artificial intelligence (AI), Virtual Reality (VR), Augmented Reality (AR), metaverse, robots and cobots, into human work, which impose new challenges for design. This requires creating new models and concepts of work, technologies and interaction, which also opens new ways to think and to innovate. However, new models are not always easy to accept and adopt, thus, it is good to consider how people accept new kinds of conceptual models created by means of conceptual engineering (Chalmers, 2020; Floridi, 2011; Nefdt, 2024). This way it is possible to get an idea about how the acceptance of conceptual models progresses in the minds of people who meet a new conceptual model of technology such as HDTs for the first time (Myllylä, Salo-Pöntinen & Saariluoma, 2026).

4.2.1.1 Study description

Two workshops were organized in autumn 2024 and spring 2025 in Finland with HiFive-project participants to collect their views and questions regarding meaningful industrial work and HDTs. In the first workshop we presented our preliminary ideas of HDTs and joint cognitive systems in industrial processes. We then collected participants' thoughts and concerns about HDTs. In the

second workshop we continued to investigate how industry's representatives think about HDTs in an HDT-specific exercise. The goal was to reflect and discuss further on the thoughts, questions, uses and designing.

4.2.1.2 Data collection and analysis

The first workshop participants included 22 representatives from five industrial companies, five researchers from a research organization and six researchers from academia. There were 34 participants in total in the first workshop. In the second workshop, the HDT exercise participants included eight industry representatives from the same five industrial companies as in the first workshop (with job titles ranging from senior designers to design and development managers and technology chief officers). The second workshop HDT exercise was facilitated by two researchers from the University of Jyväskylä.

The first workshop included a HDT presentation, an active listening exercise and collecting the active listening exercise key takeaways. In the second workshop, participants joined a group work, where each of the formed four groups discussed on seven key HDT-related themes. Themes were based on the analysis of the key takeaways from the active listening exercise (Table 4. HDT themes).

Table 4. HDT themes (Myllylä, Salo-Pöntinen & Saariluoma, 2026, p. 854).

Themes	Elaborated questions
Theme 1: HDT applications	Why should there be a HDT in industrial work?
Theme 2: HDTs in industrial work	What are the core tasks for people and for AI? What is the goal of HDT? (in industrial work)
Theme 3: HDTs in design	What are the core tasks for people and for AI? What is the goal of HDT? (in design)
Theme 4: Research methods	How to access people's tacit knowledge and how to identify relevant information for building HDT's?
Theme 5: HDTs and meaningfulness of work	What is the link between modelling human cognitive process and meaningfulness of work?
Theme 6: Risks and data privacy	What is the role of risk management in HDT? What is company's or worker's own tacit data, how to achieve desirable transparency and legality?
Theme 7: User experience (UX)	What is UX design in HDT?

Data from workshops were analysed by using a thematic content analysis (Krippendorff, 2019) and responses were categorized into main themes and subthemes.

4.2.1.3 Results

Results suggested that acceptance of HDT as a new conceptual model needs to consider at least issues linked to the following four themes:

1. Understanding possibilities for HDT application and design
2. Identifying perceived value conflicts
3. Information collection, communication, and sharing underlying HDT design
4. HDT's relation to work meaningfulness, experience and learning

The results showed that with the case of HDT, some of the thought patterns of the workshop participants were highly interconnected by the themes of understanding application, value conflicts

and meaningfulness of jobs. According to the prevailing pattern, the main idea in HDT involves replacing people, the tasks that people are replaced in are likely to be a source of meaningful experience for the worker, thus HDT's are likely to impede meaningful workplaces, if not restricted to the 4D tasks. This thought pattern is an obstacle for the acceptance of HDT as an important design solution and may prevent people from considering HDT from the holistic perspective. According to that view, HDT should be always understood as part of designing the whole system, where having meaningful job tasks is one important factor. (Myllylä, Salo-Pöntinen & Saariluoma, 2026, p. 855–858)

4.2.1.4 Conclusions

To engineer new technology concepts such as HDTs and increase their acceptance, it is vital to discuss and create holistic and well-informed narratives of their meaning and possible implications now and in the future together with designers, developers and users. Making individual and social forms of thinking explicit in an microinnovation level (Saariluoma et al., 2011) makes it possible to discuss about imagined and previously unthought challenges and possibilities related to new technology's practical applications and design, recognize potential value conflicts and how to resolve them, and agree how to manage information and ensure that it is used fairly. Reflective discourses also reveal how human-centricity is fundamental in technology design, as it is important to ensure experiences of positive emotions and meaningfulness during technology interaction. This necessitates that communication with technology and its training happen in ways that are as natural and flexible as possible for humans. (Myllylä, Salo-Pöntinen & Saariluoma, 2026)

4.2.2 Job crafting and intellectually stimulating industrial work

Future industrial work will leverage intelligent technologies and human-machine/ cyber systems, where physical and virtual spaces are integrated to enhance operations through hybrid environments and digital twins, including HDTs. Collaboration will occur in human-technology-AI teams and joint cognitive systems (JCSs; Woods & Hollnagel, 2006). Simultaneously, Industry 5.0 aims to renew European industries by focusing on resilience, sustainability, and human-centricity—including focus on wellbeing that can be supported by technology. Meaningfulness, satisfaction, and psychological richness (i.e. intellectual stimulation) are complementary dimensions of wellbeing, which construct good working life and can be attractive aspects of work. An imperative step for achieving well-functioning human-technology interaction, JCSs and wellbeing at work is to understand how job crafting and intellectually stimulating work are experienced by industrial workers (Myllylä et al., 2026).

4.2.2.1 Study description

It is important to understand how emerging technologies, new ways of working, and job design could empower employees in job crafting, where workers themselves making adjustments to working conditions and work quality, and thus fulfil their psychological needs such as sense of meaning, relatedness, autonomy and competence building (De Bloom et al., 2024; Demerouti, 2014; Le Blanc, Demerouti & Bakker, 2017; Napier et al., 2024). Competence related job crafting is associated with a psychologically enriching work environment and working life (Zacher & Baumeister, 2025), which can also be coined as intellectually stimulating work. However, there is lack of research on how job crafting and intellectually stimulating work relate to each other and to the meaningfulness of work in different work domains. Therefore, we examine how competence-enhancing and challenge-seeking job crafting and intellectually stimulating work emerge in industrial factory floor workers' daily experiences (Myllylä et al., 2026).

4.2.2.2 Data collection and analysis

To explore how competence related job crafting and intellectually stimulating work emerge in the daily experiences of 20 Finnish industrial factory floor workers, we conducted a qualitative empirical study. Data was collected with semi-structured interviews during autumn 2024 and spring 2025 in 9 Finnish industrial companies of various fields.

Data was analysed using a combination of content analysis (Krippendorff, 2019) and abductive analysis (Tavory & Timmermans, 2014). Content analysis was used to categorise interview data into meaningful themes and with abductive analysis empirical data was related with existing theories and concepts, also allowing the creation of new hypotheses and models.

4.2.2.3 Results

According to the results (Myllylä et al., 2026, p. 4–7), elements of job crafting and intellectually stimulating work can be categorized into three main categories that fulfil psychological needs: (1) Versatility of work; (2) Agency and embeddedness, and (3) Competence building. Additionally, there are tensions between pursuing psychological needs from the position of the self and considering needs and interdependencies reflected on others – i.e. position of others (see e.g., Abele & Wojciszke, 2007; Ryan & Deci, 2017). Autonomy discusses the capacity to organize one's work in a manner that allows individuals to utilize their thinking, judgement and decision-making skills, thereby recognizing the significance of these abilities (Rosso et al., 2010; Smids et al., 2022). Relatedness refers to the building of a shared sense of agency and purpose in relationships with others (Lysova et al., 2019; Rosso et al., 2010). Categorisation of different elements, psychological needs and positions are presented in the following table.

Table 5. Job crafting and intellectually stimulating work categories and related psychological needs. References in parenthesis refer to earlier literature on the concepts. (Myllylä et al., 2026, p. 4–5).

Job-crafting categories	Psychological need and position	
	Autonomy, self	Relatedness, others
Versatility of work	Self-worth (sense of accomplishment from commanding and executing tasks; Bailey et al., 2019; Rosso et al., 2010) Self-efficacy (sense of free choice to shape work related activities; Smids et al., 2022; Rosso et al., 2010)	Contribution to community (effect positive change; Martela & Riekk, 2018; Rosso et al., 2010; Ryan & Deci, 2017) Solidarity (shared sense of agency; Lips-Wiersma & Morris, 2009; Smids et al., 2022; Viljakainen et al., 2026)
Agency and embeddedness	Self-guidance (independence in job crafting; Saari et al., 2022; Smids et al., 2022) Self-connection (consistency to own values; Bailey et al., 2019; Pratt & Ashforth, 2003)	Recognition (feedback from others; Lips-Wiersma & Morris, 2009; Saari et al., 2021) Social, i.e. intersubjective sensemaking (constructing a perception of a collectively meaningful environment; Pratt & Ashforth, 2003; Rosso et al. 2010)
Competence building	Self-development (developing new skills and competences; Bailey et al., 2019; Saari et al., 2021) Creativity (utilizing one's skills to solve challenging tasks; Rosso et al., 2010; Smids et al., 2022)	Resilience at work (adaptation and flexibility to changing work demands; Viljakainen et al., 2026) Joint problem solving and learning (engaging the work community; Kaasinen et al., 2020; Viljakainen et al., 2026)

4.2.2.4 Conclusions

Our research (Myllylä et al., 2026) illustrates, how job crafting and intellectually stimulating working life are highly connected concepts. Factory work may seem routine, but in fact, people perform tasks that are intellectually complex, varied and that require competence and creative problem-solving skills even on daily basis. People must be able to craft their ways of working and working environments to make their own work smoother and easier, but also to foster the productivity and quality of work carried out by their own team or organization. Versatility of the work, agency and embeddedness, and competence building, from the viewpoint of oneself and as fulfilling the psychological need of autonomy, and from the position of others and as fulfilling the need for relatedness, are important for having a meaningful, motivating and engaging industrial work.

In the future people and intelligent technologies, such as artificial intelligence and industrial robots, will collaborate even more in different forms of JCSs. Implementing intelligent technologies in industry and work life should be thought as an emerging social challenge. To meet the necessary renewal process, workers, designers and managers alike should be actively involved in designing new work processes and, for example, think how to support job crafting. This can also help to develop more accurate and more relevantly focussed intelligent technologies.

4.2.3 Workshop for the ECCE 2025 conference

As part of the HiFive-project's researcher collaboration, JYU, Aalto University and VTT planned for a workshop that was going to be held as part of ECCE 2025 conference (October 7–10 2025, Tallinn, Estonia). The researchers created a Call for Workshop to invite contributions to an interactive workshop that will explore how cognitive ergonomics and human-centered design can enhance the meaningfulness of work in hybrid environments where humans collaborate with automation, AI, VR, and other remote technologies. The extended abstract for the Call for Workshop was published in the ECCE 2025 Conference proceedings, although the workshop itself was not held.

4.2.4 Future research: Content-based cognitive ergonomics and methodology for human digital twins

JCS is a helpful concept to understand the strengths and limitations of human and machine information processing and reasoning. To operate in the real world, the JCS must represent the relevant actions, agents, goals, and context. However, machine representations represent the world in terms of meaningless symbols. Such formal machines must be interpreted, otherwise they cannot function in a meaningful way in the real world. Interpretation and meaning-making are a consequence of human information processing and thinking.

Information content enables to ask and answer new kinds of questions, for example about truth and validity. Information content and its relevance thus form the human part of intelligent JCS. The problem of information content, its relevance and truth form the standpoint of a new kind of ergonomic thinking. The field of ergonomics that focuses on the content of relevant information can be called content-based (Saariluoma, 2022; Saariluoma, Cañas and Myllylä, 2024). Analysis and design processes in content-based cognitive ergonomics are based on the properties of the information content involved in human-machine interaction. As a paradigmatic approach, content-based cognitive ergonomics provides tools to construct AI and other intelligence-based technological solutions. Human thinking can be imitated and supported by intelligent technologies, and they can be modelled in HDTs. However, it necessitates that we have knowledge what the existing processes and their contents are like. Thus, focusing on and continuing developing the content-based cognitive ergonomics further is imperative for the future research and design of intelligent technologies.

New technologies make it possible to support or replace human tasks and operations with intelligent technologies such as AI. Thus, it is important to develop methods to analyse and model human information contents and processing during those actions and to engineer the concepts of intelligent technology systems, such as HDTs (see e.g., Myllylä, Salo-Pöntinen & Saariluoma, 2026; Saariluoma et al., 2024). The key question in this work is what are the existing information processes like? To investigate the human thinking during a task in industrial factory floor work, we conducted user study in Konecranes in November 2025. There were four participants: two novices and two experts in crane operating. The objective was to investigate crane operators' HDT (mental models, thinking and actions during operation). This information could help in the design of control equipment in a dynamically changing environment, where the crane operator must perceive space, movement and orientations of objects against environment during manual operation. The empirical material was collected by using a protocol analysis as a method, comprised of thinking-aloud while operating a crane and followed by a retrospective video analysis. In practice the participants were given a task to operate a crane where they had to lift a weight and move it through a simple track. The task was also videotaped. After the task, each participant went through the video with a researcher, where they explicated their thoughts and actions further. From the collected empirical material, it is possible to analyse and extract information contents and processes that are essential and relevant in that task and also to find differences in thinking between people with varying levels of skills and experiences.

To answer the question of what are the existing human information processes like requires analysis, mapping and describing them through content-based cognitive ergonomics and HDTs. This way it is possible to develop technologies and work processes that can provide solutions for the recognised needs and requirements based on what and why humans think and act as they do. Designing, implementing and using new technologies and ways of working require also training and its development. Consequently, the future research should also focus on development of the methodologies for analysing and describing human mental information processes and contents into models of HDTs, or more broadly, into cognitive digital twins (CDTs). During the HiFive-project we have started this work, but the research on methodological issues of HDTs / CDTs is still ongoing.

4.3 WP3: New technological enablers and solution concepts for hybrid teams

4.3.1 New technological enablers and solution concepts for hybrid teams

4.3.1.1 Study aims and description

The study explored how the diffusion (adoption and spread) of virtual AI assistants can be enhanced within the manufacturing industry. As artificial intelligence technologies - particularly Large Language Models (LLMs) and multimodal AI - rapidly evolve, companies are increasingly interested in leveraging them for competitive advantage. However, despite strong technological potential, adoption in industrial contexts remains uneven and insufficiently understood. The aim of this study was therefore to identify the key factors that influence the successful adoption of AI assistants in manufacturing environments.

The study applied the Diffusion of Innovations theory (Rogers et al., 2014), focusing on attributes such as relative advantage, compatibility, complexity, trialability, and observability, as well as organizational and user-related factors. To ground the research in practice, VTT developed a proof-of-concept (PoC) virtual AI assistant designed for human-cobot assembly work. This PoC serves as a concrete example of an industrial AI solution and allows to evaluate how such innovations are perceived by industry professionals.

Additionally, the study sought to identify broader and future use cases for AI assistants across manufacturing operations, extending beyond the PoC scenario. Overall, the research bridged the gap between technical AI development and real-world industrial adoption by providing empirical insights into both benefits and barriers.

4.3.1.2 Study execution

The study employed a Design Science Research (DSR) methodology, which is particularly suited for developing and evaluating technological artifacts in real-world contexts. The developed PoC solution represented the artifact developed in this study. The research approach combined system development with empirical investigation. This chapter bases on two publications in which the study results were reported (Hakanen et al, 2025; Tikka et al., 2025).

4.3.1.3 PoC Development

VTT designed and developed a virtual AI assistant PoC solution to support human operators working alongside collaborative robots (cobots) in gear assembly tasks. The system integrates multiple advanced AI components:

- LLMs provide real-time, natural language-based instructions to operators through speech and text.
- Vision-Language Models (VLMs) enable safety monitoring by detecting whether workers are using required protective equipment.
- A 3D virtual assistant interface (developed using Unity) visually represents the AI assistant and assembly process.
- A speech-based interface allows hands-free interaction, which is critical in manufacturing environments.
- A cobot system delivers components automatically to the worker based on AI-generated instructions.

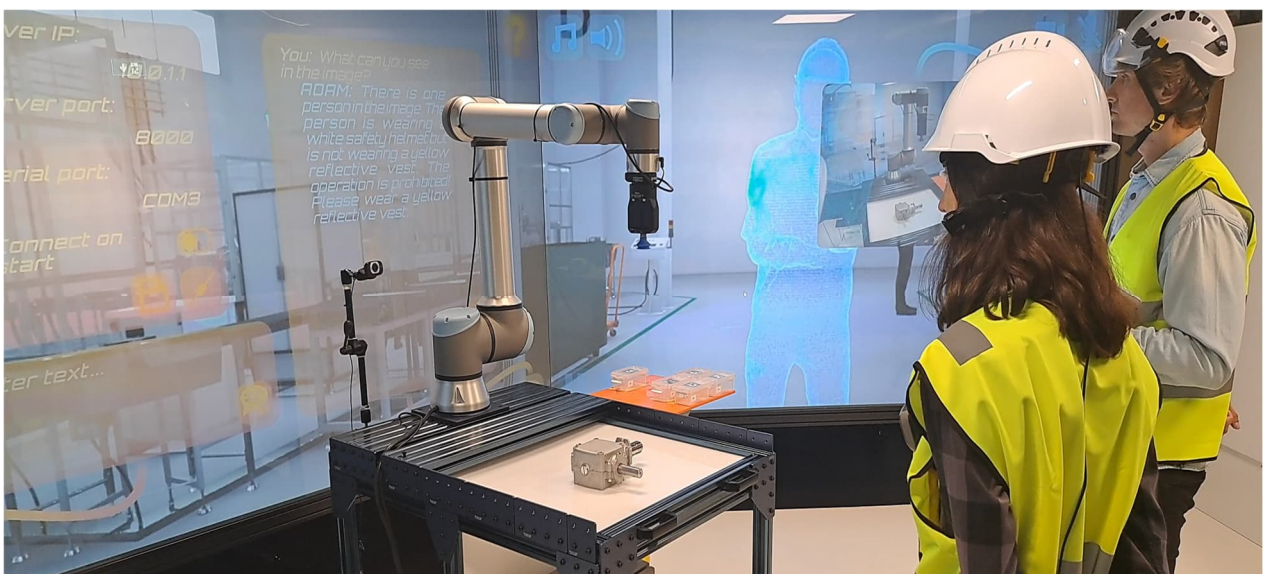


Figure 8. PoC solution setup (Hakanen et al, 2025).

In the development work, offline Qwen2.5-32B (LLM) as a conversational agent and Qwen2.5-VL-3B (VLM) as an image interpreter for safety were utilized. Both models were run on a local PC with 24 Gb of vRAM, and they had their own use-case specific contexts provided for scope. VLM was used for analysing image feedback from a camera. Camera was triggered by a YOLO11 detection model as the number of people changed around the defined worksurface. VLM detected required safety equipment (safety vest and optional helmet) from the image and informed workers accordingly about the usage of safety equipment.)

LLM on the other hand, was presented as a virtual assistant on the VTT power wall screen (*Figure 9*). The assembled components and interaction interface with settings were also visualized on the screen. Interaction between operator and the assistant was based on speech with OpenAI faster_whisper for speech-to-text and Kokoro for text-to-speech. Additionally, LLM communicated with a cobot via a socket to provide necessary components for the assembly. The cobot informed the LLM of its progress, which the LLM then articulated to the operator, thus providing interim information about the overall progress.



Figure 9. VTT Power Wall UI of the AI assistant system (Hakanen et al, 2025).

The system operated locally on high-performance hardware, ensuring data security and minimizing risks related to sensitive industrial information. The architecture connected multiple components (AI models, cameras, cobots, and user interfaces) through a centralized AI server that processed multimodal inputs (text, speech, images, video) and coordinates outputs. The following figure presents the system architecture of the PoC solution:

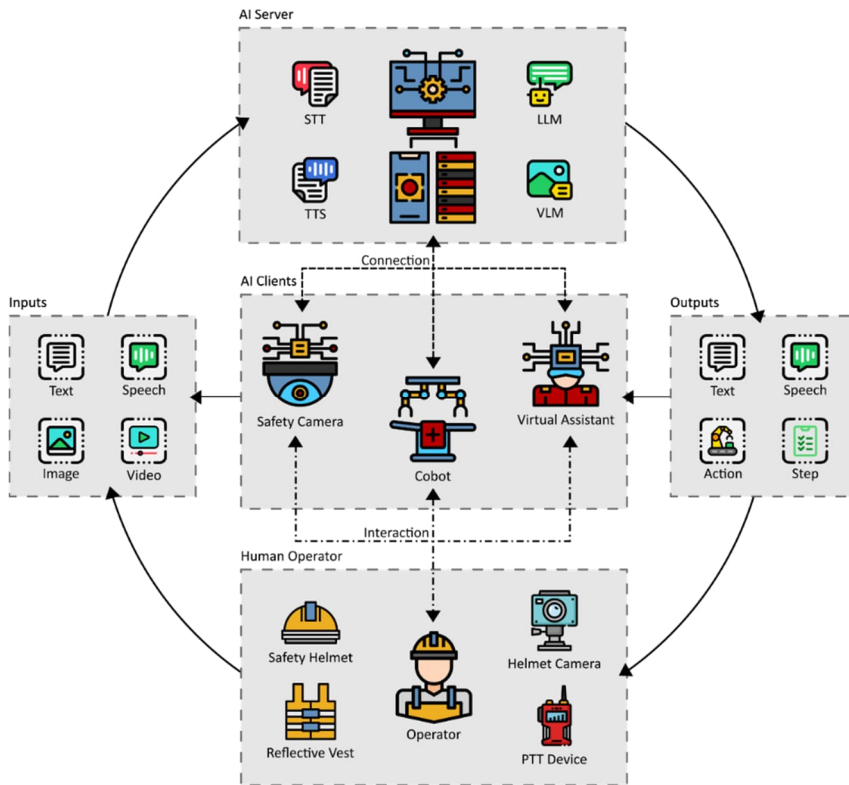


Figure 10. System architecture of the PoC solution (Hakanen et al, 2025).

4.3.1.4 Empirical Study Design

The empirical part of the study was conducted through qualitative research:

- **Participants:** 10 experts from six organizations, including manufacturing firms, engineering companies, and research institutions.
- **Data Collection:** Semi-structured, in-depth interviews (30–60 minutes each), where participants were presented with the PoC and asked to evaluate it.
- **Focus Areas:** Perceptions of benefits, usability, compatibility, challenges, and future applications, aligned with innovation diffusion factors.
- **Analysis:** Interview data were analysed using qualitative content analysis and condensed into key themes and insights.

4.3.1.5 Study Results and Conclusions

This section describes the key findings and conclusions from this study.

As a result of the study, the following innovation factors were identified and elaborated: Benefits and relative advantage, compatibility, complexity, trialability, and observability. The AI assistant was perceived as delivering significant practical benefits:

- Improved efficiency and productivity in assembly tasks

- Reduction in errors, mistakes, and operator hesitation
- Hands-free, flexible interaction through natural language
- Continuous availability (24/7 support).

Running the system locally was seen as a major advantage for data security. The solution aligns well with current manufacturing needs and trends, particularly as product complexity and customization continue to increase. It also addresses workforce shortage and the growing need for productivity improvements, while responding to rising demand for effective training and onboarding tools in environments with multilingual and diverse workforces. Importantly, the PoC was perceived as easy to integrate into existing production systems without requiring major changes. That said, compatibility with organizational culture varies, as attitudes toward AI adoption differ across individuals and companies.

The system itself was generally seen as easy to use, largely due to its natural language interface. Speech-based interaction further lowers the barrier to adoption, making the solution accessible even for non-technical users. AI assistants are also relatively easy to test and deploy. However, more complex integrated systems that combine AI with collaborative robots and sensors still require further development before they can be considered fully plug-and-play.

The benefits of AI assistants, particularly in terms of time savings and efficiency improvements, are often quickly observable. These applications are particularly valuable in knowledge-intensive environments where information is fragmented across systems. Despite these, many organizations remain in the early stages of adoption and do not yet have extensive experience with these types of systems.

4.3.1.6 Potential Future Use Cases

As a future development idea, the system could support quality assurance by detecting incorrect actions and ensuring proper task execution. It could also enable knowledge capture and sharing, particularly valuable as experienced workers retire.

The study identifies a wide range of promising applications for AI assistants beyond the PoC:

- Training and onboarding: Personalized guidance and simulation-based learning
- Production planning: Optimizing machine settings and workflows
- Production operations: Error detection, task guidance, and process optimization
- Product documentation: Automatic generation and management of documentation
- Knowledge management: Capturing and sharing tacit knowledge and best practices
- Internal logistics: Warehouse picking and routing optimization
- Maintenance and repair: Instructional support and diagnostics
- Product design: Feedback loops from production and usage to improve designs
- Sales support: Drafting technical proposals and offers.

4.3.1.7 Conclusions

The study demonstrates that virtual AI assistants have strong potential to transform manufacturing work, particularly by enhancing human-machine collaboration in line with Industry 5.0 principles. The PoC highlighted how AI can support workers through intuitive, natural interaction while improving efficiency, quality, and knowledge utilization. However, widespread adoption depends on overcoming several key challenges:

- Ensuring AI reliability and minimizing errors (e.g., hallucinations)
- Addressing cybersecurity and data privacy concerns
- Maintaining up-to-date and accurate data for AI systems
- Integrating solutions with existing processes and technologies
- Building user trust and aligning with organizational culture.

Future research should focus on deploying and testing such systems in actual industrial environments to get further insights. In the future, individuals and companies may have several AI assistants in use and research can expand the scope to team-level AI collaboration. Overall, we recommend that companies begin with targeted use cases, develop roadmaps for AI adoption, and experiment with PoC solutions to validate benefits. With proper development and implementation, virtual AI assistants could become a key enabler of more efficient, flexible, and human-centered manufacturing systems.

4.4 WP4: Proof-of-Concepts for industrial work in hybrid human-technology-AI teams

4.4.1 PoC 1: Smart glasses and AI assistant supporting meaningful industrial work

4.4.1.1 Study description

This proof of concept (PoC) study investigated how new digital technologies - smart glasses enabling remote expert support and a generative AI assistant - can be integrated into factory floor work. The study was conducted by VTT at Konecranes premises in May 2025, where factory employees performed a gearwheel lifting task using two different technological configurations. The purpose of the study was to gather workers' feedback and practical experiences as well as to assess the suitability of these technologies for industrial tasks.

The technological setup consisted of two assistance systems. First, a see-what-I-see smart glasses solution Iristick.G2 Pro (Iristick) was connected to Microsoft Teams, enabling a remote expert to provide real-time visual guidance, troubleshooting, and operational feedback. The glasses included e.g., an integrated camera with a wide field of view, speaker and microphone, supporting continuous expert monitoring during the task.

Second, a generative AI assistant (ChatGPT 4o) was configured to provide step-by-step instruction based on background materials such as lifting plans, crane safety regulations, and legal requirements regarding work equipment use. Interaction with the AI assistant was possible via both speech and text, and the system automatically generated a report summarizing the task execution.



Figure 11. Smart glass and AI assistant tasks (Aromaa 2026c)

The figure shows both the smart glasses and AI assistant tasks. In the AI assistant task, the test participant first interacted with the AI assistant using the keyboard, followed by verbal communication via the speaker.

4.4.1.2 Data collection methods and analysis

Five factory workers participated in evaluation of the PoC, each completing the lifting task twice - first with smart glasses and remote expert support, and then with the AI assistant. Five factory workers, aged 36 to 63 (average 53, all male), used smart glasses and an AI assistant while operating a crane to lift a gearwheel. They presented a range of work roles including two technicians, a machinist, an electrician, and a reliability engineer. Most were experienced with cranes but had little familiarity with generative AI or smart glasses, and only moderate experience using remote collaboration tools like Teams.

The study employed a multi-method qualitative approach. Data were collected through observation of the task execution, semi-structured interviews immediately after the task completion, and an online questionnaire capturing participants' experiences with both technologies.

The qualitative analysis of the gathered data focused on workers' perceptions regarding both positive and negative perspectives of the experience, development ideas, knowledge sharing, and meaningfulness of work. Particular attention was paid to meaningful work from five perspectives – purpose, belonging, development, confidence, and autonomy – reflecting the themes on meaningfulness identified by Smids et al. (2020).

4.4.1.3 Results

The results of the study indicate that AI assistants and smart glasses show significant potential especially in assisting novice workers within industrial environments. The study participants responded generally positively toward both technologies; smart glasses were particularly appreciated for enabling real-time remote expert support and enhancing collaborative interactions among employees. The AI assistant provided valuable structured guidance and was valued particularly for its rapid report generation, though its speech interface required greater user adaptation and occasionally resulted in misunderstandings.

These findings imply that digital tools can be integrated effectively into industrial workflows; however, optimal adoption will require targeted user training and well-defined communication protocols. Overall, the results provide a strong foundation for further development and scaling of digital assistance tools in industrial environments. The comprehensive description and results of the study are detailed in Aromaa et al. (2026c, in review).

4.4.2 PoC 2: Storyboard feedback study on industrial work in hybrid human-technology-AI teams

4.4.2.1 Study description

This proof-of-concept evaluated how to leverage AI to foster skills development and factory workers' sense of competence, by designing and testing alternative AI system concepts in real-world factory settings. The study was designed and conducted by Aalto University. The following sections present the study's methodology, results, and practical implications.

4.4.2.2 Methodology

The study was carried out using storyboard evaluation (Van Den Hende & Schoormans, 2012) as the data collection method. Altogether six storyboards were developed by analyzing interview data from factory workers (n=31; for further detail, see chapter 3.1.4.2). Each storyboard presented a unique mechanism through which a personal, employee-only AI assistant might strengthen workers' perceived work meaningfulness and competence. Altogether nine trolley and electricity factory workers were interviewed in-person at two Finnish industrial sites in Spring 2025. Each interview lasted 45-60 minutes and were audio recorded. Participants were recruited via factory managers, and they attended the sessions during working hours without compensation.

Each storyboard was described verbally while participants followed the texts. The interview sessions focused on respondents' experience and familiarity with GenAI tools, open prompts ("What are your thoughts on using GenAI in this type of work scenario?"), more specific questions related to opportunities, challenges, and additional use cases in each storyboard, and a Likert-scale questionnaire on how the respondents perceive AI could help them develop professional skills in each scenario. Using inductive thematic analysis for each storyboard, the analysis was focused on codes highlighting perceived meaningfulness of work and merged them into higher-level themes capturing how workers see AI assisting skill and competence growth.

In the following, the results from three storyboards are introduced.

4.4.2.3 Results

In the case of using AI as a co-worker to train novices (Storyboard A, *Figure 12*) the results suggest clear opportunities by making on-the-job learning more systematic, speeding up onboarding by creating job aids from existing materials, reducing time spent searching across systems, and drafting instructions for experts to review. When employees are given a personal AI space for private learning, it may support their sense of competence. To manage risks, human reviewers should be kept for AI-generated content limiting it to approved sources and keeping personal coaching data private. Furthermore, the results emphasize to restrain from using AI data to monitor or punish individuals and pair AI feedback with regular human check-ins in on-the-job learning. The implications of this survey emphasize that AI tools as co-workers should be adopted

with small pilots, integrating the tool with existing processes, training supervisors and users, and setting up an easy way to report and fix issues.



Pete is training a new employee, Max. Pete asks Max to record the training session on his phone.



AI monitors Pete and Max's training simultaneously through recording.



AI turns the recording into instructions for Max in text, image, and video format.

Figure 12. Storyboard A on AI serving as a co-worker substitute for novices, prompting task execution details after training (Roto et al., 2026)

In the case of using AI as a “serviceperson” that provides on-demand performance information (Storyboard B, Figure 13), the results suggest the tool will resonate most with workers already motivated to develop their skills. The tool design should focus on supporting employee autonomy by making use voluntary, letting workers set goals and metrics, controlling notifications, and pausing or turning the tool off. The tool should be kept strictly personal and private, reframing from rankings or cross-worker comparisons, and prohibiting use of the data for monitoring or punitive evaluation. Because participants were uncertain about how performance is defined, clear and transparent criteria with supervisors and workers should be co-created, to make the metrics transparent, and allowing workers to add context notes. The data should be used primarily for coaching, with regular human check-ins to interpret results. The implications of this survey emphasize that AI tools as servicepersons should be first piloted with volunteers, clearly verify privacy and transparency in practice, train users and supervisors, and provide a simple channel to report issues.



Pete builds a component part.



Pete gets the work done and confirms the work completion to the AI.



The AI provides a summary of Pete's performance, e.g. time and interruptions, and creates visuals of Pete's work performance.

Figure 13. Storyboard B on post-task AI feedback (Roto et al., 2026)

When AI is used as a coach that provides guidance and structured learning (Storyboard C, *Figure 14*), the results suggest the tool can strengthen competence by offering step-by-step support, clear goals, and AI-generated summaries of achievements and progress for use in supervisor check-ins and performance reviews. The design should emphasize trust and privacy, making use voluntary, keeping data personal and private (a personal app or phone), allowing workers to choose if/when to connect the tool to workplace systems, and letting them decide what summaries to share with colleagues or managers. The tool should ensure transparency in how tasks and performance are interpreted, prohibiting rankings, cross-worker comparisons, and any monitoring or punitive use of coaching data. The implications of this survey emphasize using AI as a coach should be piloted with volunteers with regular human check-ins, training both users and supervisors to use summaries for supportive coaching, and providing a simple channel to report issues and revoke consent.

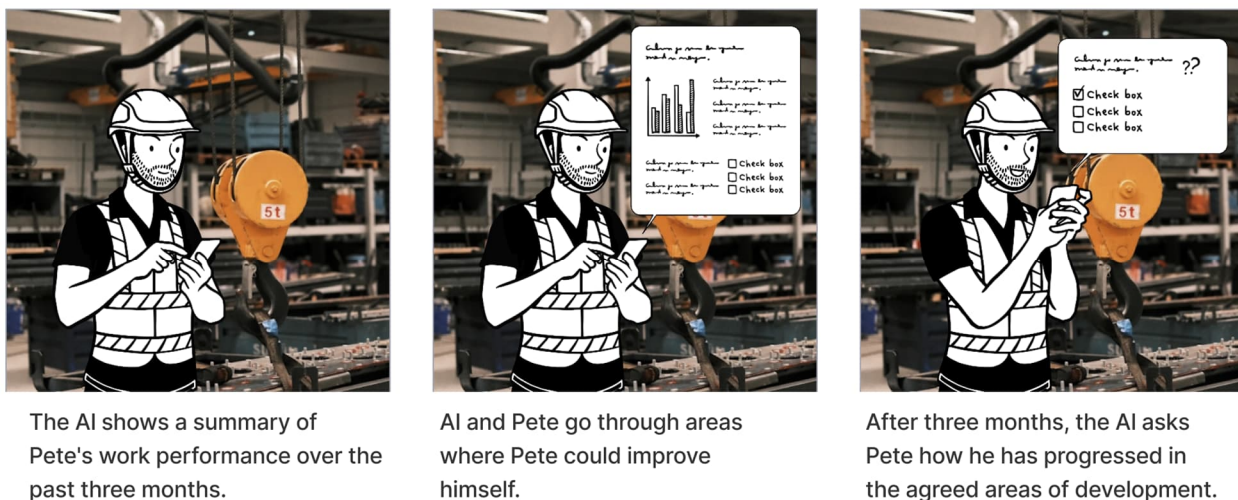


Figure 14. Storyboard C on personal AI coach (Roto et al., 2026)

4.4.2.4 Practical implications of the study

The deployment of personal AI should be voluntary, privacy-first support for onboarding, on-the-job learning, performance insight, and coaching, always accompanied with human oversight. These tools should be designed for fostering autonomy by letting workers set goals, choose guidance levels, control notifications and opt in to any links with workplace systems. Data used in these tools should be personal and private by default, letting employees decide what to share and when. Reliability and trust through expert review of operational content should be ensured, with clear definitions of performance, transparent sources and metrics, and advice constrained to approved knowledge bases. The results also suggest outputs should be primarily used for supportive coaching, avoiding surveillance harms using rankings, cross-worker comparisons, and punitive use of data. Personal tools should be implemented via small volunteer pilots integrated with existing systems, while training supervisors and users, providing simple feedback and issue-reporting channels, and measuring impact on time saved, learning progress, adoption, trust, and well-being.

4.4.1 PoC 3: AI prototype feedback study on industrial work in hybrid human-technology-AI teams

4.4.1.1 Study description

Following the storyboard evaluation sessions, a prototype evaluation was conducted to examine participants' interactions with a functional Generative AI (Gen AI) tool. The prototype consisted of a web-based application integrating an AI chat interface (see *Figure 15*) alongside additional functionalities, including AI-assisted reporting, support for skill development, assistance in communication with colleagues, and the generation of work-related summaries. These features were designed to reflect the scenarios presented in the storyboard evaluations.

The prototype enabled participants to gain concrete, hands-on experience with how the envisioned system could operate in a workplace context, thereby uncovering insights that may not have emerged through storyboard scenarios alone. The prototype evaluation served three primary purposes: (1) to validate or challenge the perceptions identified during the storyboard sessions, (2) to generate insights through practical interaction with the system that may otherwise have been overlooked, and (3) to explore how direct interaction with the system shaped participants' attitudes toward Gen AI.



Figure 15. AI chat interface

4.4.1.2 Methodology

Recruitment for the prototype evaluation sessions began by contacting factory managers at four industrial facilities in Finland. Factory managers were asked to identify and recruit employees who were interested in participating in the study. Ultimately, five participants (male, 2 to 26 years of experience) from one Trolley factory agreed to take part in the prototype evaluation. Participation was voluntary, and no financial or other compensation was provided.

The prototype evaluation interviews were conducted individually, with each session lasting between 35 and 60 minutes. All interviews took place in person in designated meeting rooms at the factory facilities, arranged in advance for the study. Each session was audio recorded for subsequent analysis.

At the beginning of each session, participants were given approximately five minutes to independently explore the prototype and familiarize themselves with its interface and functionalities. Following this initial exploration, participants were guided through specific features of the system, including the AI assistant and AI coach functionalities, AI-supported reporting, AI-assisted skill development tracking, AI support for communication with colleagues, and AI-generated work-related summaries.

4.4.1.3 Results

The prototype evaluation sessions revealed both opportunities and concerns regarding the use of Gen AI in industrial work contexts. Some participants found the prototype intuitive and easy to use (n=2), with particular value identified in features supporting work progression (n=3) and completed task tracking (n=2), which were perceived as enhancing a sense of accomplishment. AI-assisted documentation and reporting were also seen as beneficial for reducing repetitive tasks and enabling greater focus on meaningful work (n=4). In addition, the AI coach feature was positively received, as participants valued its ability to encourage deeper thinking and personal development rather than simply providing direct answers (n=4). AI-supported communication features were also viewed favourably for their potential to save time (n=2).

At the same time, participants raised concerns related to data governance, privacy, and transparency (n=3), particularly regarding what data the system accesses, how it is processed, and who controls it. Practical concerns also emerged around device ownership and system integration, with participants expressing a preference for company-owned devices and AI tools embedded within existing organizational systems (n=3). Overall, while participants recognized the potential value of the AI tool, concerns related to trust, transparency, and integration were identified as important barriers to workplace adoption.

4.5 WP5: Future business concepts and models for the industrial metaverse

This section summarizes main activities conducted from business perspective relative to work transformations conducted during the HiFive project.

4.5.1 Goals

The objectives of WP5 were to

- create a business vision and scenario for future factory operations utilizing metaverse technologies

- create understanding of Finnish manufacturing industries Industry 4.0 transition towards Industry 5.0 by defining new operational scenarios like Sustainable factory floor operation model, Location free factory employee model, and Multi-site factory floor operation model.
- realize business vision through development of new operation and service processes.
- employee competence portfolios in the future for ensuring safety, productivity and technology utilization

4.5.2 Study description

Activities in this work package were mainly conducted via literature studies, utilizing research results from previous research projects and conducting industrial interviews. Feedback was collected in the workshops organized during HiFive project.

Industrial interviews were conducted based on the following thematic interview frame:

- o What are the future business concepts and models, given the work transformations envisioned in the project:
- o How the change in operational environment and workers' daily routines will change the business?
- o How Finnish industries are able to move towards Industry5.0, and what are the main benefits and challenges?
- o How to create value and what are the earning models in the future?

Altogether six people were interviewed from four Finnish manufacturing and engineering companies. Interviews were recorded and the analysis followed a thematic approach. The case data were analysed by one researcher, and a research colleague reviewed the results of the analysis. Public findings were presented in Business Model Conference 2026 (BMC2026) conference paper in June, 2026. (Vierimaa & Käärinen 2026)

For each company, analysis was done on interview findings, their future roadmap/vision and based on the analysis it was presented how to realize business scenarios in practice.

4.5.3 Results

Based on the interviews, when utilizing I5.0 work transformations companies expect faster and more transparent design and production, particularly due to AI, which is seen as a strategic asset. Data assets provide clear value and they need to be monetized. Revenue models will change over time from hour-based to value-based, in short term hybrid models may also emerge. New opportunities will emerge for advanced smaller companies such as technology SMEs.

As customers expect more comprehensive approach and life-time services, companies will evolve from product providers to strategic digital lifecycle partners. Hybrid teams (human + AI) are likely to form the basis of operations and human work focuses on expert work. Remote monitoring and expert guidance can support several sites simultaneously, safety will continue to improve, immersive training advances and blue-collar maintenance will become increasingly analytics driven.

Interviews and pilot experiences pointed out that when realizing the value of emerging technologies in Finnish manufacturing users and other related personnel needs to be involved. In particular, human ability, willingness, and structured, continuous training are essential to keep “human-in-the-loop” control, ensure safe adoption, and translate work transformations into successful operational change. AI-enabled twins, simulations, and AR workflows promise step-changes in efficiency and responsiveness, yet they also introduce uncertainty through data quality gaps, integration complexity with legacy systems, and unresolved questions around accountability and compliance.

Business-model innovation also lags the speed of technological development. Although value-based monetization (e.g., outcome- or performance-linked pricing) in data-driven ecosystems is attractive to many organizations, they are not easy to implement in large ecosystems due to uneven digital maturity, unclear value capture logic, and the need for shared incentives and standards. Finally, data sharing and transparency are viewed as prerequisites for interoperable metaverse platforms and cross-firm optimization, but remain complicated by IP protection, trade secrets, regulatory constraints (e.g., data protection and emerging EU data rules), and the practicalities of governance, trust, and common schemas. Overall, the findings point to a need for robust data-space approaches and clear partnerships.

Business Vision workshop was organized at Tasowheel (April 2025) where draft version of business vision was presented. Workshop was organized on discussing and further defining business targets for future factory operations. Based on the workshop and literature studies, business vision has been created. It includes main challenges, HiFive business statements, example scenarios and business targets.

Business vision and WP5 work was presented at Konecranes zero4 seminar (October 2025). Business vision was updated in 2026 based on the results of business scenarios.



Figure 16. WP5 presentation at Konecranes Zero4 seminar.

Two business scenarios were studied, namely “sustainable factory floor operation model and location free / multi-site factory floor operation model. Scenarios were built to two manufacturing companies and two service providers. Main challenges, benefits and business impact with specific section on AI were analysed from the literature.

During the course of HiFive project, VTT developed remote assistance solution to assembly. The developed service process was evaluated from business perspective considering costs and benefits.

Main findings based on the interviews and related to envisioned work transformations are described in the BMC2026 paper “Business impact of industry 5.0 in a meaningful work context”.

In addition, literature analysis was conducted based on the selected business scenarios and competences/skills required during the era of I5.0.

Following publications and presentations were made:

- “Digital twins benefits, challenges and future prospects from intelligent motion control point of view.” Vierimaa, M., Heiskanen, M., Kuppens, H., Islam, A. T., Khan, R. & Mohamed, S., 2026, In: Microprocessors and Microsystems journal. 122, 105271.
- “Business impact of industry 5.0 in a meaningful work context”. Vierimaa M , Kääriäinen J. BMC2026 conference, June 2026, Italy.
- Presentation of business vision at Tasowheel workshop on WP5 (April 2025).
- Presentation of WP5 results and vision at Konecranes Zero4 seminar (October 2025).
- Presentation of WP5 related business interviews (see task 5.3) to participating companies. (January 8th, 2026).
- Publication on A-insinööri case under work. To be published after project has ended.

5. International and national collaboration

HiFive project organised five workshops during the course of the project:

- “Foundations of Meaningful Blue-Collar Work” at Konecranes, December 2024
- “Solving the Challenges of Hybrid Industrial Work” at Tasowheel, April 2025
- “HiFive Demo Session with Vera Liao” at Aalto University, May 2025
- “Solutions for Future Hybrid Teams” at Turku UAS, November 2025
- “Future Research Agenda”, online workshop, February 2025

These workshops are described in more detail in chapter 6.

In addition to conference papers and journal articles, described in the Chapter 6.2, HiFive project was presented in the following events:

- Poster “LLM based virtual assistant for human-robot interaction” FCAI, AI-DAY, Helsinki 21.10-22.10. 2024
- Zero4symposium at Konecranes October 9, 2025. Several presentations from HiFive project including HiFive project presentation by Susanna Aromaa and research sessions

organized by Juho Silmukari, Mari Myllylä and Antti Tammela. In addition, Matias Vierimaa presented HiFive Business WP in demonstration session.

- Poster “Offline LLM for assisted assembly process and safety observation” FCAI, AI-DAY 2025.
- Poster “Comparison of human and AI analyses in an AI assistant and remote expert field trial”, FCAI, AI-DAY 2025.
- HiFive project was presented in EFFRA Human Group online meeting 22.5.2025 and Operator 4.0 Symposium at Chalmers University of Technology 27.-28.5.2025
- “HiFive-project final webinar – key results and insights” was organised on 19.03.2026 from 13-14.30 by Susanna Aromaa. Final webinar contained the following sections.

Research exchanges were arranged by HiFive project:

- Bastian Tammentie from VTT visited Tallinn University's School of Digital Technologies in October, 2026
- Mikael Wahlström from VTT visited the Stockholm Technology & Interaction Research (STIR) group at Stockholm University in March, 2025
- Mari Myllylä from the University of Jyväskylä visited University of Granada, Faculty of Psychology for three months in February-May 2026.

6. Dissemination and exploitation

6.1 Participatory Co-creation & Validation

Throughout the HiFive project, empirical findings from the various studies were disseminated via a series of co-creation workshops that brought together participating organizations. In each session, we synthesised the main findings to validate interpretations, surface tacit knowledge, and jointly prioritize opportunities. This approach ensured the findings were immediately actionable, fostered a shared understanding across different stakeholders, and built commitment to next steps. As a result, partners were able to align on HiFive problem framing, define pilot concepts and ideas, and agree on next steps, which accelerated the path from research to implementation and increasing the likelihood of adoption across the partner network. In the following sub-section, we will introduce each workshop organized during the 2-year project.

6.1.1 Workshop 1: Foundations of Meaningful Blue-Collar Work

This 4-hour workshop was organized in December 2024 at Konecranes, Hyvinkää. Aalto University acted as the main organizer and workshop facilitator. The workshop was designed to share empirical research findings (*Figure 17*) with participating organizations and to cultivate a shared understanding of what makes industrial work meaningful.

 Beneficence	 Relatedness	 Competence	 Identity	 Autonomy	 Embodiment
Belonging Being part of something larger than oneself Calling Doing something with greater meaning Worthy cause Doing positive things for others / society Contribution Serving a greater cause Purpose Anticipating positive future events	Solidarity Positive social relationships and work experiences Unity / Belongingness Shared values, identity, sense of agency, meaning of value Recognition Positive feedback from others Unification People in harmony Self-efficacy Sense of having a capacity to effect positive change for coworkers / organization / society Equality Being a valued member of a team	Self-development Exercise or develop skills Self-esteem Use skills to overcome challenges Self-worth Find own contributions valuable for others Becoming self Expressing full potential, staying true to oneself Resilience Adapt to changing demands of work Feedback Get good feedback from others Learning Development focused work climate	Social recognition Others recognizing one's contributions Self-esteem Feedback from others as a source of self-esteem Self-connection Act in accordance with one's authentic self Accomplishment Accomplished tasks increase motivation and self-worth Sensemaking Build desired sense of self Consistency Uniformity between roles, tasks, and identity / self-perception	Job craft Ability to shape work activities and task Decision-making Use of own judgement Individuation Take action to become competent, autonomous and valuable Self-efficacy Sense of free choice to effect desired change and make a difference Agency Craft the job and environment to match personal goals/values Independence Cope without supervisory control	Manual work Capacity to use handicraft skills Physical labour Tasks that involve physical strength and effort Problem solving Tasks that involve ideation to build innovative solutions

Figure 17. Interview-informed view on the state-of-the-art of meaningfulness of industrial work

The workshop was opened with research partners presenting key insights, which served as inputs for collaborative activities. Participants then formed four teams to explore future-factory use cases (including assembly, repair, and material handling) envisioning opportunities for the adoption of emerging technology (Figure 18). Using design methods such as scenarios and personas, the groups build a shared and tangible view of the future of industrial work and translated that view into concrete priorities and set of topics that were advanced in subsequent project phases.

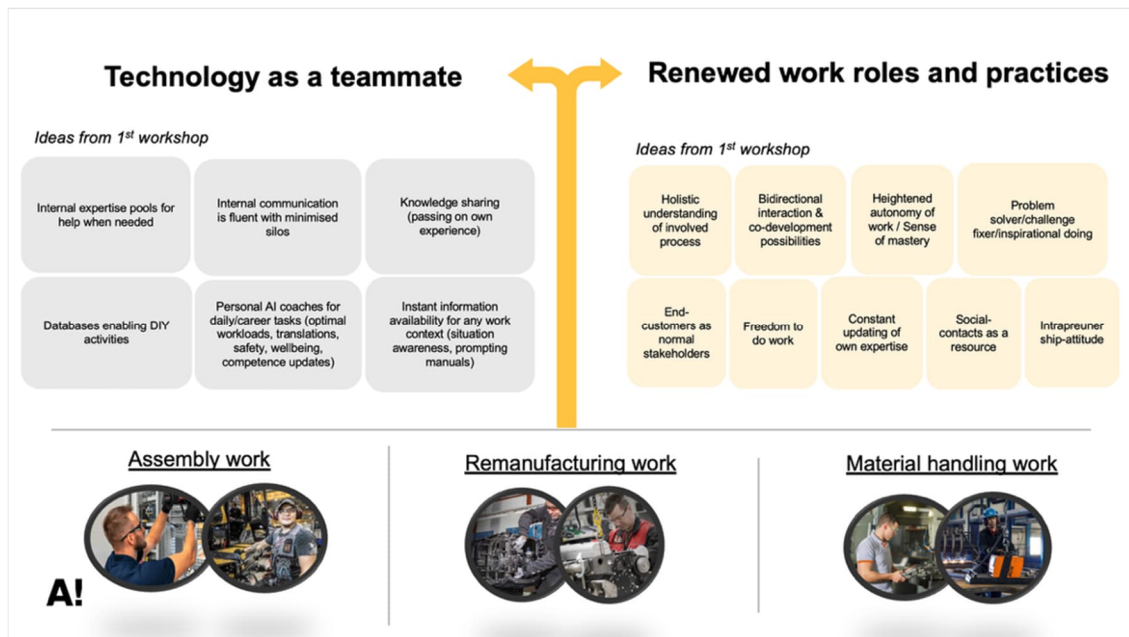


Figure 18. Example results from WS1

6.1.2 Workshop 2: Solving the Challenges of Hybrid Industrial Work

This 4-hour workshop was organized in April 2025 at Tasowheel, Tampere. VTT acted as the main facilitator, with Aalto University and Jyväskylä University as co-organizers.

VTT's facilitated discussion on two groups, one was focused to introducing a pathway tool for supporting AI adoption, and other for disseminating business vision and discussing business targets and needs for updates in the business vision.

For AI adaptation, two objectives were presented, namely:

- 1) Desire for a clear pathway focusing on how to move toward implementation: can the problem be approached from other angles? E.g., employees and processes may matter more than the technical features of AI and employees don't need to personally understand what happens "inside the box" as long as the organization has the required expertise
- 2) Leverage existing technologies and capabilities. The goal is to develop work practices; the service is built around technologies that already exist. Would it be more effective to focus on one specific customer domain, learn from it, and use it as a foundation for developing the pathway?

Company interests were collected and future steps for adoption were discussed. Focus was on practical testing. What stumbling blocks or successes have other companies had? Which benefits can be validated and calculated: e.g. AI's effectiveness, employee feedback etc. Methods for company participation were discussed; whether it could be related to knowledge if no financial investment could be made. Information security and value preservation were seen important. Verification via case study was seen useful. Examples of existing services were seen as an example: a company offering AI + onboarding service including training and monthly follow-ups. Concrete contents was required to be added to the case study. Business targets of work transformations were discussed, based on the discussions safety was added as one business target.

Aalto University's facilitation disseminated empirically grounded challenges (Chapter 3.1.4.2) and generated a roadmap for solution development and future research avenues. The results indicate that future work should explore holistic AI integration that augments human teams by capturing and sharing tacit knowledge, prioritizing tasks, and reducing cultural and communication barriers, particularly in complex, safety-critical domains like construction. Key opportunities include AI-mediated communication that builds trust and transparency; chatbots that unlock siloed information and enable rapid expert consultation; and targeted tools for minimizing design errors, bridging language gaps via real-time translation, and systematically incorporating worker input. As AI agents and robots increasingly operate as team members in factories, future research must address cognitive load, role allocation, and dynamic adaptation to changing requirements, while leveraging AI for sustainability analytics and end-to-end data collection across project lifecycles. Complementary advances in VR- and AI-enabled training, troubleshooting, and competence development can support the shift from traditional craft work to information-centric, remote operations. Finally, responsible deployment should examine how pervasive chatbot mediation reshapes human interaction, identity, and the meaningfulness of work, ensuring that efficiency gains do not erode autonomy, connection, or purpose.

The University of Jyväskylä's goal of the workshop groupwork was to continue joint reflection and take discussions forward on the thoughts, questions, uses and designing related to HDT and intelligent technologies. The goal of the groupwork was to support and guide participants' thinking, find different perspectives, identify additional questions, and build shared understanding of HDTs and their relevance in the industrial context. The design of the groupwork at Tasowheel was based on the key takeaways from the first workshop and knowledge from previous research literature. In

the group work each of the formed four groups discussed on seven key HDT-related themes. Themes were based on the analysis of the key takeaways from the active listening exercise conducted in the first workshop (see also 3.2.1.2). The discussion was compiled, analysed and summarised into four main themes: 1) HDT applications and their design, 2) perceived value conflicts, 4) information collection and sharing, and 4) meaningfulness, experience, communication and learning. HDT applications can expand to tasks that go beyond 3D or 4D types of work, such as covering sectoral activities where they are based on extracted high-level tacit knowledge. Value conflicts can emerge when facing questions related to things such as sense of professional pride or future human-AI teams. Information collection requires trust, transparency and dynamic methods. Interaction with technology should be in a form that is natural to humans and support positive experiences and learning for different people and situations (the results and conclusions from the second workshop groupwork are elaborated also in subchapters 3.2.1.3. and 3.2.1.4., respectively).

6.1.3 Workshop 3: HiFive Demo Session with Vera Liao

Aalto University organized another workshop in May 2025, featuring Vera Liao (Principal Researcher at Microsoft Research and incoming Associate Professor at the University of Michigan). During this session, consortium companies and researchers exchanged insights on AI-related developments and discussed preliminary findings from the first wave of interviews.

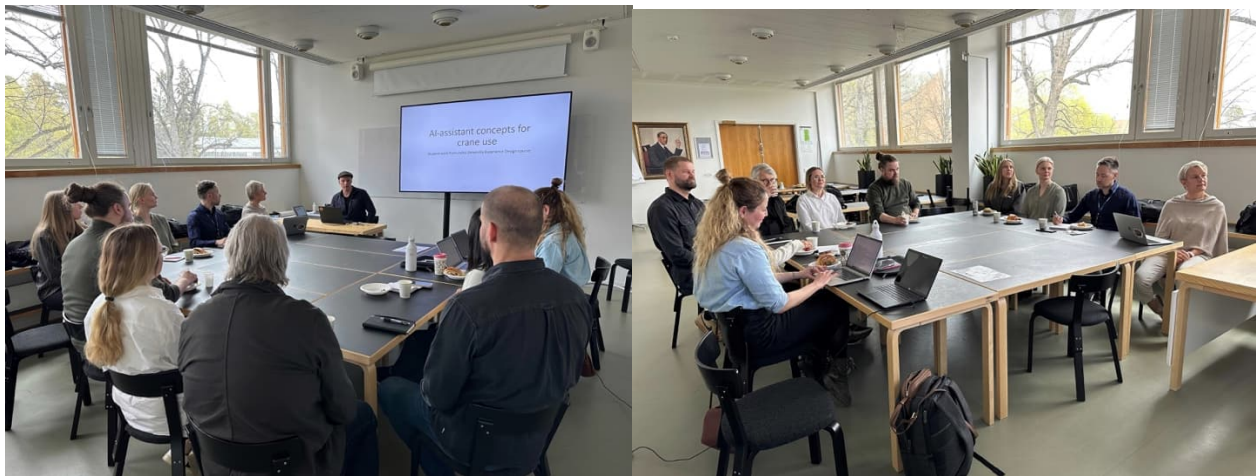


Figure 19. Workshop with Vera Liao

Aalto University presented findings and early design concepts on AI-assisted competence development and meaningful work. Presentation included two design concepts, 1.) AI-assistant for rigging the load, and 2.) AI-assistant for safe moving of the load. Purpose of the design concepts was to find out how can AI enhance daily crane usage and support blue-collar workers in material handling tasks. Objective was to develop an AI-powered assistants which would enhance work safety, efficiency, and strengthen meaningful human-AI collaboration. Concept creation included a facilitated visits to Konecranes production site at Hyvinkää to collect on-site observations and to interview factory workers. Based on this knowledge team produced user scenarios, task-flow maps and personas. Key findings from site visits were importance of visibility and intuitiveness of solutions, safety criticality of complex load handling, role of personal experience and anticipation, and general openness to test AI-based support features in crane usage.

The presentation by the University of Jyväskylä addressed the topic of sharing tacit information, knowledge and skills, and the future role of experts in industrial work. The availability, sharing and utilization of information is essential for the successful operation of companies and employees. Expertise of employees also becomes a competitive advantage, both for the person themselves and for the company where the person works and utilizes their unique expert competence, i.e. their knowledge and skills. However, various questions may raise regarding expert knowledge and experts themselves. Is workers' knowledge their own capital or company's data? What data should or should not be collected, needs to be collected, what is necessary and adequate for company and intelligent information systems and other intelligent technologies to do their job? What will be the role of human experts in the future industrial work? Will experts become redundant in the future, or will there always be some knowledge and skills that cannot be made explicit and turned into data and machine use? These topics were discussed together with all workshop participants.

6.1.4 Workshop 4: Solutions for Future Hybrid Teams

This 4-hour workshop was organized in November 2025 at Turku University of Applied Sciences (Turku UAS). Jyväskylä University acted as the main facilitator, with Aalto University and VTT as co-organizers. For the groupwork, participants were divided into two groups.

VTT and Aalto facilitated the groupwork that was focused on solving two challenges: A) information and communication problems and B) amount of complexity that is seen increased in work. In (A) future vision included personal AI agent and knowledge that has been collected to a single place. In that way access to essential details of the work is available when work starts and it would even be possible to get that information on your way to work. This would require two changes in thinking: First, information should not be withheld, one's work will no vanish if information is shared and second, new roles may emerge, for example person with high experience on specific issues could train others. In (B) work complexity could be eased by providing personal assistant that would remind of necessary tasks and provide skills development. Skills development could offer better opportunities for task switching. AI could also set limits and offer guidance, for example in proper language used in work context.

University of Jyväskylä's groupwork focused on designing and utilizing the metaverse. The participants were given a following scenario:

"Imagine it's 2035 (ten years from now). Agree on an equipment whose assembly on the factory assembly line you want to examine. You are the operational management team of the factory. Your task is to plan the work process that takes place on the assembly line of the device or its component. You have a metaverse at your disposal where the work process is simulated."

Participants were then asked to consider and discuss how the metaverse can be used to design the work process of device assembly. What roles do they see in the work process of assembling a device with humans, artificial intelligence and robots? Group 1 discussed about Ship hull production. They noted how there may be challenges related to material, complexity, robotics and practical issues such as welding requirements, safety, locations or storage space, but also due to the fact that shipping industry typically moves quite slowly. Group 2 discussed about Assembly of the lifting trolley. While humans have flexibility and creativity for doing more specific tasks, AI could be used to support and augment humans, for example in checking, customizing, training, safety, and for controlling robots. AI can also enable new ways of working. Summarising both group discussions, metaverse could be useful in tasks such as supervising and maintaining the system, measuring, inspecting and estimating risks, design, planning, simulation, training, recruiting, and supporting remote work. However, it is important to ensure that issues related to data protection, reliability of the metaverse and diversity of people are also addressed adequately.

6.1.5 Workshop 5: Future Research Agenda

A 2-hour online workshop was organized in February 2026. Turku University of Applied Sciences and ProVerse Interactive hosted Metaverse demonstrations. Aalto University acted as the main organizer and workshop facilitator. The workshop was designed to identify, prioritize and concretize future R&D opportunities on the future of industrial work and employee wellbeing. Prior to the workshop, a questionnaire was sent to HiFive participating organizations (N=7). This survey sought to gather signals from operational environments about the transforming manufacturing sector. It also prioritized the post-HiFive R&D agenda by identifying near-term (1–3 years) and long-term (3+ years) focus areas.

Overall, four overarching themes with specific focus areas were identified (*Figure 20*):

1. **Human augmentation and automation:** Research should investigate how to ensure employee mental and physical well-being amid increased automation, focusing on: human-centric, adaptive user interfaces that optimize human–machine interaction; the design principles and governance of dual-use technologies that reflect diverse generational values and skill levels; and the efficacy, ergonomics, and long-term impacts of exoskeletons and other physical augmentation tools. Parallel lines of inquiry should address methods to manage rising complexity and safety risks in automated, digitalized environments—covering robust system design, workflow engineering, continuous training, and real-time monitoring—to determine how these interventions can enhance capability without compromising health, dignity, or safety.
2. **AI integration in the workplace:** Research should investigate how AI can support industrial processes while elevating human roles and preserving meaningful work, emphasizing improvements in employee experience and mental stimulation alongside efficiency. Priorities include: designing and evaluating cognitive digital twins to model information flows and reduce cognitive workload; developing methods to balance increased automation with job redesign, feedback loops, and skill development that sustain engagement; creating metrics to assess work meaningfulness and human capability; and conducting technology roadmapping to identify where quantum computing offers task-specific advantages and when generative AI will surpass conventional approaches in specialized domains. These lines of inquiry should ensure technology choices enhance human purpose and performance.
3. **Workforce development and education:** Research should investigate how to design and evaluate educational programs that prepare workers for future technologies and practices; develop innovative workforce strategies to recruit and retain scarce skills (e.g., machinists); and increase the appeal of industrial careers and Industry 5.0 technologies among younger generations. Priorities include adapting training methods to diverse employee backgrounds and learning styles; creating inclusive education and engagement models that reduce polarization and widen participation; and establishing metrics and longitudinal studies to assess skill acquisition, career entry and persistence, and the social impact of these interventions.
4. **Sustainability and societal impact:** Research should investigate how to build sustainability frameworks that integrate social and economic dimensions alongside environmental metrics; examine societal polarization and its effects on technology adoption and trust; and embed sustainability into AI development and deployment beyond conventional reporting, including lifecycle impacts, governance, and accountability. Priorities include evaluating virtual environments and the metaverse for educational and practical applications, developing methods and standards for sustainable AI across sectors,

and creating comparative metrics, audits, and longitudinal studies to track outcomes, equity implications, and real-world impact.

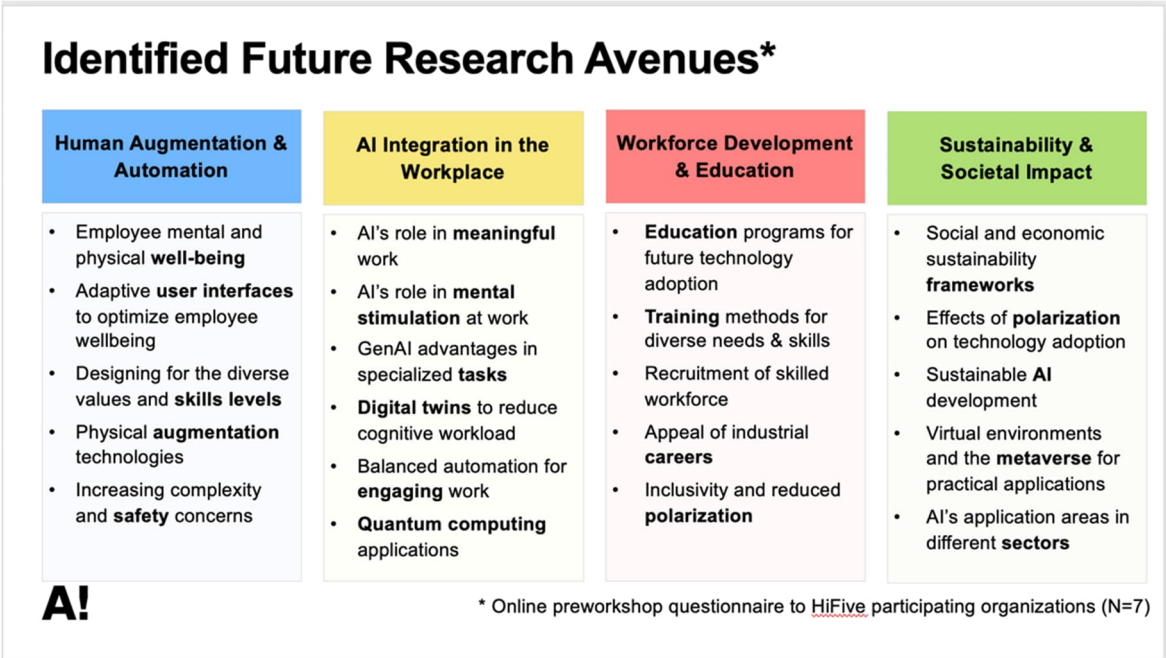


Figure 20. Mapping Future Needs in Manufacturing: A Post-HiFive R&D Prioritization Survey

Following a prioritization of the most impactful topics, two teams further translated the findings into concrete and impactful project proposals:

Table 6.Consolidated Overview of the Two Teams' Project Proposals

Project Title	Balance	Managing the dynamics of work change
Project Goal	Design human-centered work where AI augments rather than erodes human capability.	Plan, train and manage for AI-driven transformation so that organizations avoid disruption, maintain functional capacity, and keep people ready and willing for change.
Research Questions	RQ1: How to prevent information overload and loss of expertise as AI takes a larger role? RQ2: How to define sustainable levels of cognitive and physical augmentation so that people remain skilled, safe, and effective at work even as tasks and workflows change.	RQ1: How to shift worker mindsets and day-to-day practices, while recognizing that AI's rising role makes the management challenge increasingly complex
Project Tasks	Develop value-aligned guidance, tools, and operating models that clearly define AI's appropriate roles; redesign jobs and build organizational capabilities for AI-intensive environments; and enable smooth, reliable AI in production and personalized learning, alongside human augmentation (exoskeletons, AR, AI guidance) that functions as "superpowers" without eroding human competence or efficacy.	Focus on how change is designed, trained, and governed within organizations, establishing criteria to differentiate incremental from radical innovation and practical mechanisms to sustain operations during transitions. It will deliver resilient, updatable solutions and pilots for change design, training, foresight, and human augmentation that keep pace with rapid technological and contextual shifts—for example, actionable change playbooks and sequenced training programs that prevent disruptions and build worker acceptance of AI.

Project Scope	Designing humane, AI-intensive workplaces by balancing the physical, cognitive, social, and temporal dimensions of work; developing workers' skills and efficacy as tasks are redistributed between humans and AI; and supporting individualized learning at scale to sustain capability in Industry 5.0. It includes trialling technologies that improve employee experience—such as personal AI assistants—alongside remote work/operations and AI-enabled education for self-directed, employer-supported upskilling. Build transitions to digital workflows that enhance safety, quality, and wellbeing, and establish deployment guidelines for cybersecurity and privacy as critical prerequisites for trust and safe operations.	Support organizational change through comparative, cross-sectoral analysis to identify common principles and sector-specific adaptations for resilient AI adoption across manufacturing, high- and low-technology domains, healthcare, and creative project industries. Emphasize developing domain-specific language models—rather than relying solely on universal systems—to solve contextual problems previously lacking answers, and design work methods and training so that new processes, responsibilities, and tools become part of daily operations (e.g., foresight methods to forecast genuine future talent needs and approaches for training robots). Examine economic and social sustainability, define evolving human roles and appropriate levels of human augmentation, reduce physical workload, and enable effective hybrid and remote work.
Project Outcomes	Keep humans at the center of technologically advanced work by reducing cognitive overload through role-relevant information flows; preserve and enhance skills via explicit task division and continuous learning; ensure safer, less taxing work through appropriate augmentation; embed practical methods for the smooth use of AI in production job designs; and deploy education models that enable employees to thrive in uncertainty.	Deliver sector-tested change playbooks and training modules that build acceptance and readiness to work with AI, alongside job design guidance aligned with AI-enabled practices and clearer understanding of entry-level needs and pathways. Create measurable impact across stakeholders and sectors, with medium-term scaling as organizations adopt the solutions, integrate them into operations, and iteratively update them over time.
Project Score	Innovativeness, brings new insights: 5/5 Changes mindsets, practices: 3/5 Creates wide impacts: 5/5 Solves a known problem: 5/5 Resources are available: 4/5 Tackles short- and long-term challenges: 5/5 Total score: 4,5 / 5	Innovativeness, brings new insights: 4/5 Changes mindsets, practices: 4/5 Creates wide impacts: 3/5 Solves a known problem: 5/5 Resources are available: 4/5 Tackles short- and long-term challenges: 4/5 Total score: 4 / 5

Work is being reshaped. Whether humans will be needed as much is debatable, but the work—and the skills we need—will change. With automation advancing, more people will end up supervising almost autonomous systems. The problem? Humans aren't built for monitoring. Against this backdrop, the identified future research opportunities in the future of industrial work place employee wellbeing—mental, physical, and social—at the center (Figure 21), organized around four overarching themes. Adoption of emerging technologies explores how AI, robotics, AR/VR, and augmentation (e.g., exoskeletons) can enhance safety, reduce cognitive load, and support meaningful work without eroding skills or autonomy. *Training and education for diversity* focuses on inclusive, personalized learning pathways that accommodate varied backgrounds, roles, and learning styles, enabling continuous upskilling and equitable access to advanced tools. *The design of change management* examines governance, job redesign, and evidence-based change efforts that build trust, prevent overload, and guide safe, phased implementation across sectors. Finally, *sustainability increases* address social, economic, and environmental dimensions, embedding responsible AI practices, data governance, and lifecycle metrics—to ensure technology adoption strengthens resilience, fairness, and long-term workforce health.

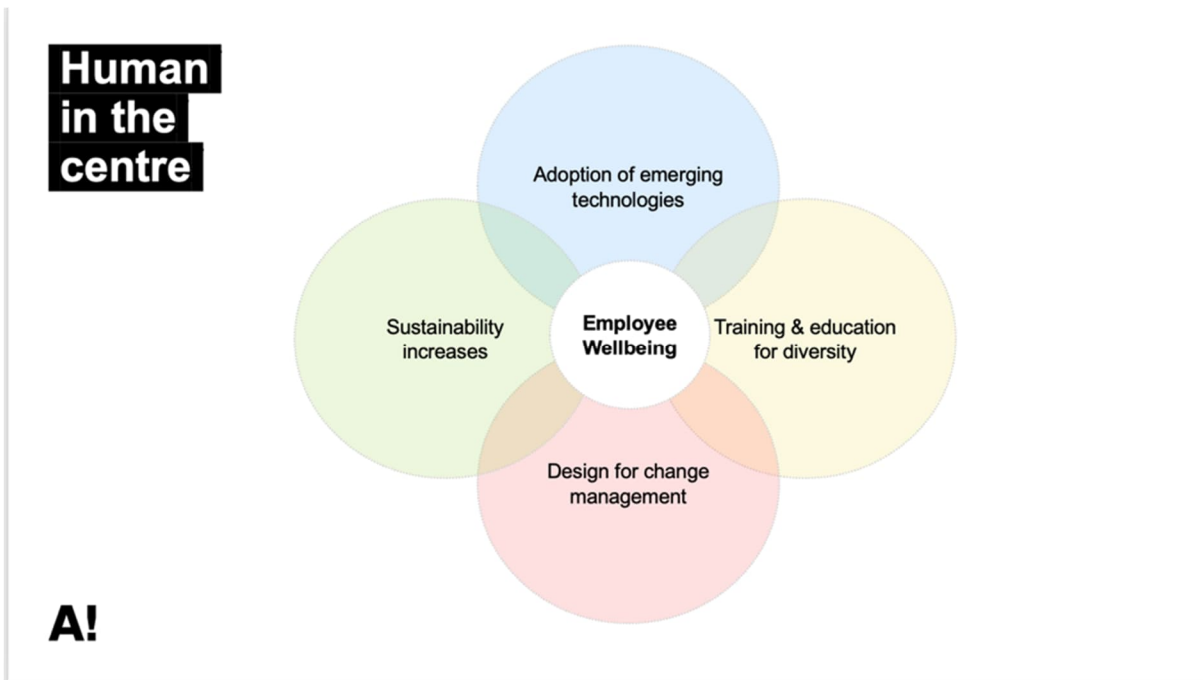


Figure 21. A Human-Centered Research Agenda for the Future of Industrial Work

6.2 List of Publications

The research partners have delivered several high-impact, peer-reviewed publications in top-tier venues advancing the state of the art across multiple domains.

No	Deliverable type	Title	Authors (1 st Author Affiliation)	Venue/Publication	Time and Location
1	Book Editor	Humane Autonomous Technology: Re-thinking Experience with and in Intelligent Systems https://doi.org/10.1007/978-3-031-66528-8	Rousi R., von Koskull, C., & Roto, V. (Aalto)	Palgrave Macmillan	October 21, 2025
2	Book Chapter	Help Me Help You: The Dilemma of Collaboration Between Expert Employees and Chatbots https://doi.org/10.1007/978-3-031-66528-8_2	Čaić, M., Ciuchita, R., & Chiorazzo, G. (Aalto)	In Humane Autonomous Technology: Re-thinking Experience with and in Intelligent Systems (pp. 15-43). Palgrave Macmillan	October 21, 2025
3	Book Chapter	Co-worker, Butler, or Coach? Designing Automation for Work Enrichment	Roto V. (Aalto)	In Humane Autonomous Technology: Re-thinking Experience with	October 21, 2025

		https://doi.org/10.1007/978-3-031-66528-8_3		and in Intelligent Systems (pp. 45-65). Palgrave Macmillan	
4	Conference Full paper	Company perspectives of generative artificial intelligence in industrial work https://doi.org/10.1016/j.procs.2025.01.085	Aromaa S., Heikkilä P., Jurvansuu M., Pehlivan S., Väärä T., Jurmu M. (VTT)	6th International Conference on Industry 4.0 and Smart Manufacturing	November 13-15, 2024, in Prague, Czech Republic
5	Journal Article	Constructing a Methodological Discourse for Using Emotion Recognition in AI Ethics—From Behaviorist to Cognitive Approaches. https://doi.org/10.1080/10447318.2025.2551049	Salo-Pöntinen, H. & Saariluoma, P. (JYU)	International Journal of Human-Computer Interaction	
6	Conference Workshop	"AutomationXP25: Hybrid Automation Experiences Communication, Coordination, and Collaboration within Human-AI Teams" https://doi.org/10.1145/3706599.3706738	Spitzer, P., Baldauf, M., Palanque, P., Roto V., Morrison, K., Zipperling, D. & Holstein, J. (Aalto)	CHI'25	27 April 2025, Yokohama, Japan
7	Conference Workshop paper	Enriching Human–AI teaming based on risk envelopment and teammates' inherent capabilities https://matthiasbaldauf.com/automationxp25/papers/AutomationXP25_CRC_2147.pdf	Salovaara A. & Roto V. (Aalto)	CHI'25	April 27, 2025, Yokohama, Japan
8	Journal Article (submitted)	Embodied Dimensions of Meaningful Work: Insights for Industry 5.0	Tammentie, B. & Wahlström, M. (VTT)	Applied Ergonomics / Special issue: E/HF for a Sustainable, Resilient, Human-Centered Future	
9	Journal Article	Designing Meaningful Industrial Workplaces: A Framework for Collaborative Research Projects	Aromaa S., Lehtovaara, J., Myllylä M., Roto V., Saariluoma P.,	Quality and User Experience	

		https://doi.org/10.1007/s41233-026-00077-w	Salonen T.-T., Salo-Pöntinen H., Tammentie B., Viljakainen A., Wahlström M. (VTT)		
10	Journal article (in review)	Artificial intelligence assistants and smart glasses supporting meaningful industrial work – a case study	Aromaa, S., Lammi, H., Tammela, A. & Heikkilä, P. (VTT)	International Journal of Industrial Ergonomics	
11	Conference Extended abstract	Design of Meaningful Work in the Transition towards Industry 5.0	Viljakainen, A.; Silmukari, J.; Čaić, M. (Aalto)	Naples Forum on Service	June 9–12, 2025 — Sorrento, Italy
12	Conference Full paper	AI and the Future of Work: A Framework for Enhancing Employee Experience from Satisfaction to Flourishing https://doi.org/10.1080/0144929X.2025.2596889	Viljakainen, A.; Silmukari, J.; Roto, V.; Čaić, M.; Aromaa, S. (Aalto)	ECCE ECCE: European Conference on Cognitive Ergonomics (ECCE2025)	October 7–10, 2025 — Tallinn, Estonia
13	Conference Full paper	User-based Evaluation of a Proof- of-Concept for a Complex Service Robot System https://doi.org/10.1145/3746175.3746176	Aromaa, S. & Lammi, H. (VTT)	The European Conference on Cognitive Ergonomics (ECCE 2025)	October 7-10 2025, Tallinn, Estonia
14	Conference Full paper	Virtual AI assistants in the manufacturing industry – innovation diffusion perspective	Hakanen, T., Goriachev, V., & Tikka, P.	International Conference on Industry 4.0 and Smart Manufacturing (ISM 2025)	November 12- 14, 2025, Malta
15	Conference Workshop paper	Designing AI Assistant for Developing Factory Worker's Competence https://matthiasbaldauf.com/automationxp26/papers/AutomationXP26_paper_2096.pdf	Roto, V.; Lappalainen, J.; Silmukari, J.; Viljakainen, A.; Čaić, M. (Aalto)	CHI 2026 Workshop on Agentic Automation Experiences	April 13— 17, 2026, Barcelona, Spain
16	Conference Panel paper	Is AI making researchers' work more meaningful?	Joseph, A.W; Viljakainen, A.; Clemmensen, T., Abdelnour- Nocera, J. & Cajander, Å. (Aalto)	NordiCHI26 Panel on Human- Computer Interaction	October 5-7, 2026, Vaasa, Finland
17	Journal	AI and the Future of Work: A Framework for Enhancing	Viljakainen, A.; Silmukari, J.;	Journal of Behaviour &	Published in

	Paper in Special Issue	Employee Experience from Satisfaction to Flourishing https://doi.org/10.1080/0144929X.2025.2596889	Roto, V.; Čaić, M.; Aromaa, S. (Aalto)	Information Technology (JUFO 2)	December 2025
18	Journal Paper in Special Issue	Making Work Meaningful in Industry 5.0: Institutional Arrangements Shaping Blue-Collar Work https://doi.org/10.1093/iwc/iwag014	Viljakainen, A.; Silmukari, J.; Čaić, M. (Aalto)	Interacting with Computers (JUFO 2)	Published in April 2026
19	Conference Workshp Extended abstract	Designing Meaningful Industrial Work for Hybrid Human-Technology Environments. https://doi.org/10.1145/3746175.3746177	Myllylä, M., Aromaa, S., Čaić, M., Salo-Pöntinen, H., Tammentie, B., & Viljakainen, A. (JYU)	ECCE 2025 (European Conference on Cognitive Ergonomics)	Oct 7–10, 2025 — Tallinn, Estonia
20	Journal Article	Digital twins benefits, challenges and future prospects from intelligent motion control point of view https://doi.org/10.1109/DSD64264.2024.00075	Vierimaa M., Heiskanen M., Kuppens H., Islam A., Khan R., Mohamed S. (VTT)	Microprocessors and Microsystems journal	
21	Conference Full paper	Acceptance of conceptual engineering models for new technologies https://doi.org/10.54941/ahfe1007146	Myllylä, M., Salo-Pöntinen, H., & Saariluoma, P. (JYU)	Intelligent Human Systems Integration (IHSI 2026): Disruptive and Innovative Technologies	Feb 11–13, 2026, Florence, Italy
22	Conference Short paper	Business impact of industry 5.0 in a meaningful work context Business impact of industry 5.0 in a meaningful work context - VTT's Research Information Portal	Vierimaa M., Kääriäinen J. (VTT)	Business Model Conference 2026	June 10-11, 2026. Ancona, Italy
23	Conference Full paper	Job crafting and intellectually stimulating industrial factory floor work https://doi.org/10.54941/ahfe1007405	Myllylä, M., Viljakainen, A., Silmukari, J., Salo-pöntinen, H., Aromaa, S., Saariluoma, P. (JYU)	17th International Conference on Applied Human Factors and Ergonomics (AHFE 2026)	July 20–24, 2026, Fenerbahçe University, Istanbul, Türkiye
24	Conference Full paper	Metascience of content-based cognitive ergonomics https://doi.org/10.54941/ahfe1008085	Saariluoma, P., Myllylä, M., Cañas, J. J. (JYU)	18th International Conference on Human Interaction & Emerging Technologies	August 25–27, 2026, Università luav di Venezia

					a, Venice, Italy
25	Journal Article	Relevance and artificial intelligence https://doi.org/10.1007/s44163-026-01936-3 https://link.springer.com/article/10.1007/s44163-026-01936-3	Saariluoma, P., Rautenberg M. (JYU)	. <i>Discov Artif Intell</i> 6 , 795 (2026)	

7. Conclusions²

The HiFive project demonstrated that the transition towards Industry 5.0 is not only a technological transformation but also a transformation of work, competence, organisation, and value creation. Across the project, meaningful industrial work emerged as a central design objective for future hybrid human–technology–AI teams. The results show that intelligent technologies can support productivity, safety, knowledge sharing, learning, and new business opportunities, but only when they are designed and implemented in ways that strengthen human agency, competence, relatedness, trust, and wellbeing.

A key conclusion is that industrial work contains substantial tacit, embodied, social, and cognitive knowledge that cannot be fully captured by formal instructions or automation alone. Workers rely on colleagues, practical experience, contextual understanding, and adaptive problem solving in their daily tasks. Therefore, future AI assistants, human digital twins, metaverse solutions, smart glasses, collaborative robots, and other digital tools should be developed as support systems that make relevant knowledge more accessible and actionable, rather than as isolated technologies that replace human expertise without considering the broader work system.

The project also showed that successful technology adoption depends strongly on organisational conditions. Information silos, communication breakdowns, time pressure, fragmented systems, unclear responsibilities, and insufficient feedback can weaken both productivity and meaningfulness of work. Introducing AI or other intelligent technologies without addressing these underlying conditions may increase complexity instead of reducing it. For this reason, companies should treat Industry 5.0 implementation as a socio-technical development process that combines technology pilots with work redesign, competence development, participatory change management, ethical data governance, and continuous dialogue with employees.

The proof-of-concepts and prototype studies indicate that AI-based support can already create value in industrial contexts. AI assistants can support onboarding, task guidance, reporting, documentation, competence development, and knowledge transfer. Smart glasses and remote expert solutions can enable real-time support and collaboration. Human digital twin and content-based cognitive ergonomics approaches can help reveal the information contents and cognitive processes that should guide future system design. However, the studies also underline important preconditions: systems must be reliable, transparent, understandable, secure, and integrated with

² Part of this summary was generated by Microsoft co-pilot and reviewed by authors.

existing work practices. Human oversight, voluntary use where appropriate, privacy protection, and clear limitations of AI-generated guidance are essential for building trust.

From a business perspective, the project suggests that meaningful work and human-centered technology adoption can become sources of competitiveness. Future industrial services and business models may be built around AI-enabled support, remote operations, sustainable factory floor models, multi-site operations, knowledge management, competence portfolios, and new forms of human-machine collaboration. The business value of these solutions depends not only on technical performance but also on whether they improve safety, quality, resilience, employee experience, and the ability of companies to attract and retain skilled workers.

Finally, HiFive provides a foundation for future research and industrial development. Promising future directions include cognitive digital twins, human-centred AI adoption pathways, AI-supported competence development, sustainable and socially responsible use of industrial data, inclusive training models, remote and hybrid work concepts, and methods for measuring meaningfulness and wellbeing in technology-rich work environments. The project's overall conclusion is that Industry 5.0 should be pursued as a balanced approach in which technology amplifies human capabilities, supports sustainable and resilient operations, and helps create industrial work that people find meaningful, safe, and valuable. Our future research area workshop indicated need to focus on training and education taking into account personalized learning, designing change management that build trust and guide safe implementation and addressing sustainability issues including responsible AI, data governance and lifecycle metrics to ensure technology adoption takes these into account.

In the chapter 3, we presented the research questions, here is short summary of the findings for the research questions:

RQ1: What is meaningful in industrial work and how does that match new-generation values?

The findings of this research project propose that meaningfulness in blue-collar contexts comprises six key elements: competence, autonomy, embodiment, relatedness, beneficence, and identity. These human perceptions are shaped by normative, regulative and cultural-cognitive structures (e.g., stewardship, safeguarding, fellowship, respect) that can either foster or hinder the transition towards Industry 5.0. Our work suggests that current pain points (e.g., information silos, communication breakdowns, chronic time pressure, and complexity) should be addressed with new solutions to prevent eroding work meaningfulness. Designing meaningful work requires aligning technologies and processes with these structures and needs, to preserve agency, growth, social connection, and a sense of purpose.

RQ2: How to design new industrial tasks and roles that are meaningful and attractive?

The project co-designed roles that combine personal AI assistants, remote expert support, and safety augmentation. The results showed improved perceived competence, autonomy, and collaboration, especially for novices and cross-skilling workers. Storyboard and prototype evaluations showed strongest acceptance when tools are voluntary, focus on privacy, and use technology for coaching purposes. As implications, our study suggests that defining roles that mix task execution with learning, problem-solving, sense of autonomy, competence-building, and peer support should be prioritized.

RQ3: How to design intelligent and connected solutions by studying human workers?

Empirical methods used in this research (i.e., shop-floor interviews, observations, think-aloud/stimulated recall, thematic/abductive analysis) revealed that blue-collar workers form an "organic information system" where tacit and contextual knowledge remains central. Content-based cognitive ergonomics and HDT/CDT modelling allow designers to focus on

information contents that humans actually use and value. This implies, that information practices of humans should be the core contents for workflow modelling and participatory experiments. For example, AI should be designed around role-relevant information flows, with humans possessing an interpretive oversight.

RQ4: What is the division of tasks between people and intelligent machines?

The findings of this study suggest that people excel at tacit, embodied, social, and adaptive cognition, while intelligent systems are effective in structured guidance, monitoring, documentation, and fast retrieval. Proof-of-concepts showed, for example, that AI can coach to build efficiency, smart glasses can improve the competence of remote workers, and crane assistants can reduce physical strain. As implications, the findings suggest that machines should be assigned to routine monitoring, documentation, and just-in-time guidance, while humans should be kept in decision-making, exception handling, tacit judgement, and team coordination. A key is to ensure transparency in human-computer interaction and human override in all decisions.

RQ5: What new tasks and roles do intelligent/connected technologies enable, and how to make them attractive?

The study identified a range of new technology-enabled roles, including remote/hybrid operators, AI-augmented onboarding coaches, safety co-monitors, knowledge stewards, and metaverse-supported trainers. With these new roles, the attractiveness and increased work meaningfulness was built on growing competence and autonomy, reduced physical and cognitive strain, and strengthened teamwork of blue-collar workers. This implies that the design of new roles in the manufacturing context should specifically aim to foster employee's self-development, while recognizing and rewarding tacit-knowledge transfer.

RQ6: How to implement solutions so new tasks remain meaningful and meet broader aims (safety, sustainability, quality, efficiency, competitiveness)?

Successful adoption of emerging technologies depends on socio-technical conditions, not just technologies themselves. As such, it is essential to understand the social contexts in which technologies are introduced. On one hand, there are universal preconditions before technologies are adopted, including reliability, transparency, human oversight, privacy protection, and clear limits on AI guidance. On the other, there are institutional arrangements (e.g., norms, rules, values, beliefs) shaping the conditions for technology adoption. Therefore, as implications, the findings suggest that industry must foster co-evolving human-machine partnerships that elevate employee wellbeing, while simultaneously reshaping the prevailing social practices that shape sense-making in work communities. This kind of development emphasizes pilots, training, feedback channels, and measurement of trust and wellbeing. Accordingly, Industry 5.0 should be treated as participatory work redesign with competence development pilots and iterations to institutionalize human-centric ways of working. The adoption of new technology should reduce complexity rather than adding it.

RQ7: What future business concepts and models arise from these work transformations?

Future business concepts and models need to take into account the role of the AI in numerous positions as it becomes a strategic asset. As AI makes certain manually laborious tasks faster, monetization will shift from hour-based to value-based. Hybrid teams are likely to emerge, where AI is seen as team member rather than support tool for human worker. Advanced data platforms enable transparency and real-time collaboration across many tasks.

Overall, the findings of this study suggest that meaningful work should be a central design objective going forward towards Industry 5.0. Technology should amplify human capabilities rather than replace them. The resilience of blue-collar workers depends on preserving tacit, embodied

and social knowledge while improving access to explicit information. Emerging technologies should therefore make that knowledge more accessible and actionable. Our evidence shows that meaningful industrial work is a competitive advantage when emerging technologies are designed and deployed to strengthen human agency, autonomy, competence, relatedness, trust, and wellbeing, while delivering safety, sustainability, quality, and improved efficiency.

References

Abele, A. E., & Wojciszke, B. (2007). Agency and communion from the perspective of self versus others. *Journal of Personality and Social Psychology*, 93(5), 751–763. <https://doi.org/10.1037/0022-3514.93.5.751>.

Aromaa, S., Lehtovaara, J., Myllylä, M., Roto, V., Saariluoma, P., Salonen, T.-T., Salo-Pöntinen, H., Tammentie, B., Viljakainen, A., & Wahlström, M. (2026a). Designing meaningful industrial workplaces: a framework for collaborative research projects. *Quality and User Experience*, 11(1), 3. <https://doi.org/10.1007/s41233-026-00077-w>

Aromaa, S., Silmukari, J. & Viljakainen, A. (2026b, in review). Contemporary Challenges in Industrial Work: An Empirical Study of Blue-Collar Workers in the Era of Industry 4.0 and Industry 5.0

Aromaa, S., Lammi, H., Tammela, A., & Heikkilä, P. (2026c, in review). Artificial intelligence assistants and smart glasses supporting meaningful industrial work – a case study. *International Journal of Industrial Ergonomics*.

Bailey, C., Yeoman, R., Madden, A., Thompson, M., & Kerridge, G. (2019). A Review of the Empirical Literature on Meaningful Work: Progress and Research Agenda. *Human Resource Development Review*, 18(1), 83–113. <https://doi.org/10.1177/1534484318804653>.

Chalmers, D. J. (2020). What is conceptual engineering and what should it be? *Inquiry*, 68(9), 2902–2919.

de Bloom, J., Vaziri, H., Tay, L., & Kujanpää, M. (2020). An identity-based integrative needs model of crafting: Crafting within and across life domains. *Journal of Applied Psychology*, 105(12), 1423–1446. <https://doi.org/10.1037/apl0000495>.

Demerouti, E. (2014). Design your own job through job crafting. *European Psychologist*, 19(4), 237–247. <https://doi.org/10.1027/1016-9040/a000188>

Floridi, L. (2011). A defence of constructionism: Philosophy as conceptual engineering. *Metaphilosophy*, 42, 282–304.

Hackman, R. J. & Oldham, G. R. (1976). Motivation through the design of work: test of a theory. *Organizational Behavior and Human Performance*, 16, 2 (August 1976), 250-279. DOI: [https://doi.org/10.1016/0030-5073\(76\)90016-7](https://doi.org/10.1016/0030-5073(76)90016-7)

Hakanen, T., Goriachev, V., & Tikka, P. (2025). Virtual AI assistants in the manufacturing industry – innovation diffusion perspective. *7th International Conference on Industry of the Future and Smart Manufacturing*, 12-14 November, Valletta, Malta.

Iristick. Retrieved 10.3.2026 from <https://iristick.com/tools/Iristick.G2-PRO/>

Kaasinen, E., Schmalfuß, F., Öztürk, C., Aromaa, S., Boubekeur, M., Heilala, J., Heikkilä, P., Kuula, T., Liinasuo, M., Mach, S., Mehta, R., Petäjä, E., & Walter, T. (2020). Empowering and engaging industrial workers with Operator 4.0 solutions. *Computers and Industrial Engineering*, 139, 105678. <https://doi.org/10.1016/j.cie.2019.01.052>.

Krippendorff, K. (2019). *Content analysis: An introduction to its methodology*. 4th edition. Thousand Oaks, CA: SAGE Publications, Inc.

Le Blanc, P. M., Demerouti, E., & Bakker, A. B. (2017). "How Can I Shape My Job to Suit Me Better? Job Crafting for Sustainable Employees and Organizations", in: Chmiel, Nik, Fraccaroli, Franco and Sverke, Magnus (Eds.), *An Introduction to Work and Organizational Psychology* (pp. 48–63). <https://doi.org/10.1002/9781119168058.ch3>.

Lips-Wiersma M. & Morris, L. (2009). Discriminating Between 'Meaningful Work' and the 'Management of Meaning'. *Journal of Business Ethics*, 88 (August 2009), 491–511. DOI: <https://doi.org/10.1007/s10551-009-0118-9>

Lu, Y. & Roto, V. (2015). Evoking meaningful experiences at work – a positive design framework for work tools. *Journal of Engineering Design*, 26, 4-6 (May 2015), 99-120. DOI: <https://doi.org/10.1080/09544828.2015.1041461>

Lysova, E.I., Allan, B.A., Dik, B.J., Duffy, R.D. & Steger, M.F. (2019). Fostering meaningful work in organizations: A multi-level review and integration. *Journal of Vocational Behavior*, 110, 374–389. <https://doi.org/10.1016/j.jvb.2018.07.004>.

Martela, F., & Riekk, T. J. J. (2018). Autonomy, competence, relatedness, and beneficence: A multicultural comparison of the four pathways to meaningful work. *Frontiers in Psychology*, 9, 1157. <https://doi.org/10.3389/fpsyg.2018.01157>.

Myllylä, M., Salo-Pöntinen, H., & Saariluoma, P. (2026, to be published). Acceptance of conceptual engineering models for new technologies. *Intelligent Human Systems Integration (IHSI 2026): Disruptive and Innovative Technologies*.

Napier, A.D., Slem, G.R. & Vella-Brodrick, D.A. (2024). Crafting One's Life and its Relationship with Psychological Needs: A Scoping Review. *Applied Research Quality Life*, 19, 2063–2101. <https://doi.org/10.1007/s11482-024-10322-z>.

Nefdt, R. M. (2024). Concepts and conceptual engineering: Answering Cappelen's challenge. *Inquiry*, 67(1), 400–428.

Pratt, M. G., & Ashforth, B. E. (2003). "Fostering Meaningfulness in Working and at Work", in: Cameron, K. S., Dutton, J. E., & Quinn, R. E. (Eds.), *Positive Organizational Scholarship: Foundations of a New Discipline* (pp. 309-327). San Francisco, CA: Berrett-Koehler.

Rogers, Everett M., Arvind Singhal, and Margaret M. Quinlan (2014). "Diffusion of innovations" in *An integrated approach to communication theory and research*, pp. 432-448. Routledge.

Rosso, B. D., Dekas, K. H., & Wrzesniewski, A. (2010). On the meaning of work: A theoretical integration and review. *Research in Organizational Behavior*, 30, 91–127, <https://doi.org/10.1016/j.riob.2010.09.001>.

Roto, V.; Lappalainen, J.; Silmukari, J.; Viljakainen, A.; Čaić, M. (2026). Designing AI Assistant for Developing Factory Worker's Competence. *CHI 2026 Workshop on Agentic Automation Experiences* (April).

- Ryan, R. M. & Deci, E. L. (2017). *Self-determination theory: basic psychological needs in motivation, development, and wellness*. New York: The Guilford Press.
- Saari, T., Leinonen, M., & Tapanila, K. (2022). Sources of Meaningful Work for Blue-Collar Workers. *Social Sciences*, 11(1), 2. <https://doi.org/10.3390/socsci11010002>.
- Saariluoma, P. (2022). Mental Content and Content-Based Cognitive Ergonomics, *Ergonomics International Journal*, 6(2), 000289. <https://doi.org/10.23880/eoij-16000289>
- Saariluoma, P., Cañas Delgado, J. J., and Myllylä, M. (2024). "Problems of content-based cognitive ergonomics", in: *Human Systems Engineering and Design (IHSED2024): Future Trends and Applications. Proceedings of the 6th International Conference of the Human Systems Engineering and Design*. pp. 220-227. AHFE International. AHFE International, 158. <https://doi.org/10.54941/ahfe1005545>
- Saariluoma, P., Hautamäki, A., Väyrynen, S., Pärttö, M. & Kannisto, E. (2011). Microinnovations among the paradigms of innovation research - what are the common ground issues. *Global Journal of Computer Science and Technology*, 11(12), 12–24.
- Saariluoma, P., Myllylä, M., Karvonen, A., Luimula, M., & Aho, J. (2024). A human digital twin for the M-Machine. *Discover Artificial Intelligence*, 4, Article 61. <https://doi.org/10.1007/s44163-024-00164-x>
- Smids, J., Berkers, H., Le Blanc, P., Rispens, S. & Nyholm, S. (2024). Employers have a Duty of Beneficence to Design for Meaningful Work: A General Argument and Logistics Warehouses as a Case Study. *The Journal of Ethics*, 28, 455–482. <https://doi.org/10.1007/s10892-023-09442-9>.
- Smids, J., Nyholm, S., & Berkers, H. (2020). Robots in the workplace: a threat to—or opportunity for—meaningful work? *Philosophy & Technology*, 33(3), 503-522.
- Tavory, I., & Timmermans, S. (2014). *Abductive analysis: theorizing qualitative research*. Chicago: University of Chicago Press.
- Tikka, P., Goriachev, V., & Hakanen, T. (Ed.) (2025). Offline LLM for assisted assembly process and safety observation. Poster session presented at FCAI AI Day 2025, Espoo, Finland.
- Timmermans, S., & Tavory, I. (2012). Theory Construction in Qualitative Research: From Grounded Theory to Abductive Analysis. *Sociological theory*, 30(3), 167-186. <https://doi.org/10.1177/0735275112457914>
- Van Den Hende, E. A., & Schoormans, J. P. (2012). The story is as good as the real thing: Early customer input on product applications of radically new technologies. *Journal of Product Innovation Management*, 29(4), 655-666.
- Vierimaa M., Kääriäinen J. (2026). Business impact of industry 5.0 in a meaningful work context. *Business Model Conference 2026*. https://cris.vtt.fi/files/138418363/BMC-short-paper_Vierimaa.pdf
- Viljakainen, A., Silmukari, J., Roto, V., Čaić, M., & Aromaa, S. (2025). AI and the future of industrial work: a framework for enhancing employee experience from satisfaction to flourishing. *Behaviour & Information Technology*, 1–13. <https://doi.org/10.1080/0144929X.2025.2596889>
- Viljakainen, A., Silmukari, J. & Čaić, M. (2026). Making Work Meaningful in Industry 5.0: Institutional Arrangements Shaping Blue-Collar Work
- Woods, D. D., & Hollnagel, E. (2006). *Joint cognitive systems: Patterns in cognitive systems engineering*. Boca Raton: CRC press/Taylor & Francis.

Zacher, H. & Baumeister, R. F. (2024). Differences among a satisfied, a meaningful, and a psychologically rich working life. *The Journal of Positive Psychology*, 20(4), 713–737.
<https://doi.org/10.1080/17439760.2024.2417102>.