

Appendix 2 summarises: collected findings, L = literature reference, I = interview reference, requirement rising from the finding, suggested actions / design guidelines / responsibilities

PRE-DESIGN ACTIONS				
Finding	L	I	Requirement	Actions
Collaboration goals influence task design, interaction design, performance expectations, and evaluation criteria	13, 15, 20, 30	-	Define the collaboration goal before designing the collaboration	Define the collaboration goal, expected benefits, and evaluation metrics
Collaboration goals may target process outcomes, human outcomes, or team-related outcomes	11, 20, 30	P1	Identify the intended outcomes and expected benefits of the collaboration	
Success criteria and quantitative and qualitative evaluation metrics should align with collaboration goals and expected benefits	13, 30*	P1	Define success criteria and evaluation metrics before deployment	
Human-AI collaboration should address a genuine work-related need or task		P1	Design collaboration around clearly identified operational problems and work tasks	
The manufacturing environment shapes collaboration opportunities and constraints	11, 13, 16, 22	P8	Analyse the deployment context before making design decisions	Understand the manufacturing context and select fitting technologies and interaction methods
Environmental factors may influence technology choices, interfaces, displays, alarms, and interaction methods	11, 13, 16		Select technologies and interaction methods that fit the operational environment	
Human-AI collaboration design should prioritise worker needs, capabilities, and well-being	16, 22, 25	P5, P6, P8	Adopt a human-centred design approach throughout development	Adopt a human-centred design approach throughout development
Understanding users' expertise, work practices, challenges, and AI familiarity is essential before design		P5, P6, P8	Conduct user, task, and context research prior to design activities	Conduct user, task, and context research prior to design activities
Workers possess valuable experiential knowledge about tasks, tools, and work practices		P4, P5, P6	Capture and utilise worker expertise during design	Involve users and stakeholders in design
Users and stakeholders should be involved throughout the design process	7, 16, 22	P5, P6	Involve workers and relevant stakeholders from the earliest design stages	
Human-centred design and iterative development are essential for collaboration design		P6, P8	Employ iterative design, prototyping, testing, and refinement	Use HCD approach throughout the collaboration design and deployment
Human-AI collaboration should be approached as a sociotechnical design challenge rather than a purely technical one	16, 22	P1, P8	Consider human, organisational, technical, and task-related factors jointly	
Human-AI collaboration design requires expertise from multiple disciplines		P1	Establish multidisciplinary design teams including technical, domain, and user representatives	
Understanding organisational capabilities, experiences, and current processes supports successful implementation		P1	Assess the current organisational state before implementation.	Assess organisational readiness
Maturity assessments provide valuable information about organisational and workforce readiness		P1	Conduct a maturity and readiness assessment prior to design and deployment	
Ethical concerns should be considered before implementation rather than after deployment	6, 22		Address ethical considerations during the early design phases	Address ethics and human values in the design
Human values should be treated as design requirements	31, 42		Incorporate human values into design and implementation decisions	
AI utilisation raises concerns related to bias, privacy, surveillance, and accountability		P4, P8	Identify and assess ethical risks before deployment	
AI solutions should operate fairly and minimise bias		P8	Assess and mitigate bias throughout the collaboration	

DESIGN DIMENSION: Task configuration				
Finding	L	I	Requirement	Design guideline
Task require a defined structure and allocation	12, 13		Collaboration tasks should be clearly structured, including	GL1: Clearly define and communicate

Tasks consist of activities performed individually or collaboratively	15, 18		activities, responsibilities, and interactions between collaborators	collaborative task structures and collaborators' roles and responsibilities in it
Different collaboration structures may exist, ranging from AI as a tool to AI as a teammate		P5, P7, P8	Explicitly define the intended role and level of autonomy of the AI collaborator	
Task allocation is a key design decision in human-AI collaboration	11		Allocate tasks according to collaborator capabilities	GL2: Allocate work according to task requirements and collaborator capabilities
Task allocation should improve ergonomics, safety, and worker well-being.	11, 20, 22, 23		Prioritise worker well-being in task allocation	
Task allocation should be done based on the collaborators' skills	11, 9, 12, 15		Allocate tasks according to collaborator capabilities	
Humans are commonly expected to retain responsibility for oversight and evaluation of outcomes	22, 23	P5, P8	Ensure that human responsibility, oversight, and decision authority remain clearly defined.	
AI should reduce monotonous, hazardous, and physically demanding work	2, 16, 20, 42		Utilise AI to ensure human workers wellbeing and safety.	
AI should compensate for human cognitive, physical, and sensory limitations.	4, 41, 12, 15, 18, 20		Task allocation should utilise AI to complement human capabilities and compensate for cognitive, physical, or sensory limitations	
Human workers should remain meaningfully involved in work processes	11	P2, P3, P7, P8	Ensure workers retain meaningful responsibility and involvement in the collaboration	GL3: Maintain meaningful human involvement and agency
Poorly designed collaborations may place excessive cognitive demands on workers, particularly during unexpected situations.	16	P7	Avoid task designs that overload workers with monitoring, troubleshooting, or exception handling responsibilities	
Task allocation should adapt to changes in the manufacturing environment	11, 13		Task allocation should be continuously adjustable to accommodate changes in tasks, collaborators, and manufacturing conditions.	GL4: Design for adaptive task allocation

DESIGN DIMENSION: Collaboration team				
Finding	L	I	Requirement	Design guideline
Human-AI collaboration team consists of one or more human and AI collaborators working towards a shared goal	9, 10, 15, 18, 16, 30, 34		Define the collaborating actors and establish a shared collaboration objective	GL5: Build collaboration teams by matching task requirements with complementary human and AI capabilities
Human and AI collaborators contribute different but complementary capabilities to the collaboration	8, 15; 1, 2, 16, 18, 20	P2, P5, P8	Utilise the complementary strengths of human and AI collaborators	
AI collaborators are particularly suited for repetitive, scalable, data-intensive, and analytical activities	1, 2, 36, 38, 40	P2, P5	Assign AI collaborators tasks that benefit from computational capabilities and automation	
Humans contribute contextual knowledge, expertise, creativity, flexibility, and judgement in unexpected situations	2, 16, 18	P2, P8	Preserve and utilise human expertise, judgement, and contextual understanding within the collaboration	GL6: Support cooperative and mutually beneficial teaming
Human-centred collaboration should augment rather than replace human capabilities	4, 11, 12, 15, 20	P2, P5, P8	Design AI collaborators to enhance and support human capabilities rather than replace them	
Effective collaboration is based on cooperation and mutual support between collaborators	15, 30, 34	P2, P5, P8	Foster collaborative relationships based on mutual support and shared contribution to goals	
Team should adapt and learn	7, 18, 23; 32, 33, 34	P2	Design collaboration teams that can adapt to changing tasks, technologies, and operational conditions	

DESIGN DIMENSION: Skills and skill development				
Finding	L	I	Requirement	Design guideline
Successful human-AI collaboration depends on the skills, knowledge, and	15, 16, 17, 19,	P2	Ensure that collaborator capabilities are aligned with	GL7: Ensure collaborators possess

capabilities of both human and AI collaborators	21; 15, 20, 30, 33		the requirements of the task and collaboration	the skills required for the task
Task demands should match capacities, skill levels, and cognitive resources	7, 11, 21, 19; 16	P7	Align collaboration demands with human capabilities to support performance, trust, and well-being	
Human collaborators require both domain expertise and AI-related competencies to collaborate effectively with AI	1, 21, 30	P5, P6, P8	Support the development of domain-specific and AI-related competencies among workers	
Workers must understand AI capabilities, limitations, and appropriate use contexts	1, 21, 30, 12	P5, P6, P8	Provide workers with sufficient understanding of AI capabilities, limitations, and intended use	GL8: Support AI collaboration literacy
Human collaborators should be capable of interpreting, evaluating, and critically assessing AI-generated outputs	1, 21, 30	P5, P8	Design collaboration processes that support critical evaluation of AI recommendations rather than passive acceptance.	
Workers benefit from practical guidance on how to use AI systems, collaborate with them, and avoid misuse.	1, 4, 15, 23	P5, P6	Provide clear instructions, guidelines, and support materials for effective collaboration with AI.	
AI literacy is necessary for effective collaboration	12, 35		Provide workers with sufficient understanding of AI capabilities, limitations, and appropriate use	
Training is a critical for successful human-AI collaboration.	15, 21, 19; 1, 4, 15, 23	P5, P6	Provide structured training before and during human-AI collaboration.	GL7: Ensure collaborators possess the skills required for the task
Skill development is a continuous process due to evolving technologies, tasks, and work environments	15, 33	P5, P6	Support continuous upskilling, and reskilling	
Learning in human-AI collaboration is bidirectional: humans learn from AI, and AI learns from human expertise and feedback.	4, 12, 15, 19; 30, 34	P2	Design mechanisms that support bi-directional learning and knowledge exchange between human and AI collaborators	
Human expertise and feedback contribute to improving AI performance over time.	30, 34	P2	Enable AI collaborators to learn from human feedback, corrections, and domain expertise	
Overreliance on AI may reduce human engagement and contribute to skill degradation.	16, 33	P7	Design collaborations that maintain human engagement, expertise, and active participation in decision-making.	GL9: Design collaboration to preserve and develop human expertise

DESIGN DIMENSION: AI agent characteristics				
Finding	L	I	Requirement	Design guideline
AI collaborators should adapt to the needs, capabilities, pace, and working conditions of human collaborators.	13, 34	P5	Enable AI collaborators to adapt their behaviour to human capabilities, preferences, and work contexts.	GL11: Design adaptive AI collaborators
AI should adapt to users, tasks, and environments (adaptive)	43		Design AI agent that adapt to individual workers, tasks, and changing operational conditions	
AI should understand human intentions and goals	22, 13		Enable AI to interpret human goals, actions, and intentions relevant to the collaboration // ability to model human intentions and needs // ability to interpret human intent	GL12: Design proactive AI collaborators
AI should communicate limitations and uncertainty	33, 34		Ensure AI explicitly communicate uncertainty, confidence levels, and capability boundaries	GL10: Design AI collaborators that are understandable to human collaborators
Transparency supports trust and human oversight (trans)	33, 34		Provide transparency regarding AI capabilities, reasoning, actions, and current state	

Transparency should be understandable and actionable	34		Tailor transparency mechanisms to user needs, expertise, and context	
AI should provide explanations for decisions and recommendations	12, 13, 18, 43		Provide explainability mechanisms that allow users to understand AI outputs and actions	
Explanations should match user expertise and context	11, 27		Adapt explanations to users' knowledge levels and situational requirements	
Users should be able to request additional explanations when needed		P5	Support interactive explainability through user-driven requests for clarification or rationale	

DESIGN DIMENSION: Communication and interaction				
Finding	L	I	Requirement	Design guideline
Communication is a central element of human-centred collaboration.	7, 19		Communication should support appropriate information exchange	GL13: Design communication to support coordination and collaboration
Successful human-AI collaboration depends on effective bidirectional communication between collaborators	7, 19, 13, 15, 33		The collaboration should support bidirectional communication between human and AI collaborators.	
Appropriate information exchange contributes to trust and successful collaboration.	1, 3, 9, 12, 18		Communication mechanisms should support trust-building and cooperative collaboration.	GL14: Support mutual understanding between collaborators
Communication supports feedback and relationship building between collaborators	3, 12, 19			
Communication supports task execution by conveying instructions, warnings, recommendations, status updates, and task-relevant information	3, 12, 19, 13		The collaboration should provide mechanisms for communicating task-relevant information.	
Communication enables feedback, coordination, alignment of actions, and adjustment of behaviour during collaboration.	13, 20, 21		The collaboration should support reciprocal feedback and coordination between collaborators.	
The information conveyed, channel used, and level of detail should be carefully considered	1, 3, A9, 12, 18		carefully considered how and which way to present information	GL15: Design information delivery to be timely, context-aware, and actionable
Proactive communication supports cooperation and team performance		P5	The collaboration should support proactive information exchange when relevant to the task and situation	GL12: Design proactive AI collaborators
AI should actively communicate problems, causes, and potential solutions when issues occur		P5	AI should proactively communicate relevant information, problems, and corrective actions	
Monitoring AI can create additional cognitive workload when system behaviour is unclear or unexpected		P5	Minimise monitoring effort by making AI behaviour understandable and transparent	
AI should understand human intentions, environmental conditions, and task situations in order to provide effective support		P5	AI should be capable of interpreting human intentions and situational context during collaboration	
AI should proactively communicate problems, status changes, causes, and possible solutions	33	P5	Enable proactive communication that supports awareness, troubleshooting, and decision-making	

DESIGN DIMENSION: Collaboration infrastructure				
Finding	L	I	Requirement	Design guideline
Collaboration infrastructure acts as the coordinating mechanism connecting collaborators, tasks, goals, and the manufacturing environment.	1, 6, A9, 11, 14, 18, 15, 19, 33		The collaboration infrastructure should support coordination between collaborators, tasks, goals, and the surrounding manufacturing environment	GL17: Design infrastructure that enables coordinated and informed collaboration
Collaboration tasks and interactions are carried out through the enabling/collaboration infrastructure	9, 11, 13, 16, 17			

The collaboration infrastructure acts as a coordinating mechanism between collaborators	9		Provide context-aware interaction mechanisms - Interaction methods should be selected according to task requirements, environmental constraints, and operational context	
Human-AI collaboration is enabled through socio-technical and cyber-physical infrastructures that integrate digital and physical systems.	6, 11, 13, 16, 17, 19, 22		The collaboration infrastructure should integrate human, AI, physical, and digital components into a coherent collaboration environment	
Manufacturing environments are dynamic, requiring infrastructures that can adapt and evolve alongside changing tasks, technologies, and user needs.	1, 11, 15, 16, 17, 2, 6, 14, 36, 22		The collaboration infrastructure should be adaptive, resilient, and capable of evolving with changing operational requirements	
Infrastructure should support communication between the collaborators	1, 6, 11, 14, 18			
Infra should support understanding of collaborators, roles, and collaboration status	1, 6, 11, 14, 18			
Infra should support learning of the collaborators	1, 11, 15, 16, 17		Support learning and knowledge sharing: The collaboration infrastructure should facilitate learning, knowledge exchange, and continuous development of collaborators	
Infra should support situational awareness of tasks, collaborators, and environment	1, 6, 11, 14, 18		The collaboration infrastructure should promote situational awareness	GL18: Support situational awareness and human oversight
Human operators require awareness of AI actions, intentions, and behaviour to determine when intervention is necessary	19, 22, 33		The collaboration infrastructure should support human oversight by making AI activities, status, and interventions visible.	
Situational awareness depends on access to information about tasks, roles, system status, environmental conditions, and collaboration progress	15, 16, 33, 34		The collaboration infrastructure should support situational awareness by providing visibility into task, system, collaborator, and environmental states.	
Shared displays, dashboards, visualisations, alarms, and confidence indicators help operators maintain awareness and oversight	33		The collaboration infrastructure should provide mechanisms for sharing and visualising collaboration-relevant information.	
Information-rich manufacturing environments create a risk of information overload.	19, 33		The collaboration infrastructure should prioritise relevant information and minimise unnecessary cognitive workload.	
Information should be presented in accessible, understandable, and salient forms.	19, 33	P4	The collaboration infrastructure should present information in ways that are understandable, accessible, and actionable for users.	
Multimodal interfaces, shared displays, and context-aware interaction mechanisms support effective decision-making and collaboration.	2, 11, 19		The collaboration infrastructure should support multimodal and context-aware interaction mechanisms.	GL19: Design multimodal and adaptive information infrastructures
The collaboration infrastructure should support interaction methods that match the skills, preferences, and needs of different workers.			Accommodate user differences by designing a collaboration infrastructure that support interaction methods that match the skills, preferences, and needs of different workers	
Effective collaboration requires access to relevant and timely information	1, 6, 11, 14, 18,		The collaboration infrastructure should provide	

regarding tasks, system state, collaboration progress, and environmental conditions.	15, 19, 33		timely, relevant, and context-specific information to support decision-making and collaboration	
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