Towards Industry 5.0: Developing Knowledge and Skills in a Research and Innovation Lab

Irina-Emily Hansen, Ola Jon Mork, Paul Steffen Kleppe and Lars Andre Langøyli Giske
Department of Ocean Operations and Civil Engineering, Norwegian University of Science and Technology, Aalesund, Norway

irina-emily.hansen@ntnu.no
ola.j.mork@ntnu.no
paul.s.kleppe@ntnu.no
lars.a.l.giske@ntnu.no

Abstract: The challenging global environmental, economic, and societal transformations urge Norwegian industry to capitalize on all value creation from the manufacturing processes. For many companies, this implies taking manufacturing back to Norway. However, high labour costs do not allow Norway to compete in the global market, and therefore industry needs to take advantage of state-of-the-art technologies. Norwegian society is experiencing a steep learning curve: the acquisition of new knowledge and skills for engineers and managers in companies, while simultaneously transforming and aligning educational programs in universities with Industry 4.0 and Industry 5.0. This research presents a knowledge management perspective of the Industry 5.0 competence platform from the viewpoint of Manulab, a research and innovation lab specializing in Industry 4.0 technologies for the small-scale production of customized products. Located at the Norwegian University of Science and Technology in Ålesund, Manulab collaborates closely with regional industries, including marine, maritime, furniture, and food production, as well as suppliers to these sectors. While Industry 4.0 concepts developed in Manulab have significant potential for value creation, companies and stakeholders have yet to fully capitalize on them. To address this issue, the research adopts Nonaka and Takeuchi's organizational knowledge creation model and applies it to the competence building processes in Manulab, investigating the contribution from different knowledge workers to each phase. The term "knowledge workers" refers to individuals with specialized knowledge and expertise who create value for their organization. The study shows that involving additional knowledge workers in various phases of the Manulab competence building process is crucial for successful implementation of research projects in industry. Furthermore, this human-centric approach can assist companies in transitioning to the Industry 5.0 paradigm. The research is a collaborative effort among researchers, students, and employees holding various positions within industrial companies

Keywords: Knowledge management, Industry 5.0, industry-university, Research laboratory

1. Introduction. A new Vision for Norwegian Industry

The tremendous global environmental, economic, political changes have pushed everyone into looking beyond the conventional emphasis on technology and economic-driven growth that characterizes the current production and consumption-based economic model. Instead, the global community now promotes a more transformative approach that prioritizes human progress and well-being. This approach is a new paradigm Industry 5.0 (i5.0)(Renda *et al.*, 2022). It entails reducing and shifting consumption towards sustainable, circular, and regenerative economic value creation, and promoting equitable prosperity. Industry 5.0 does not merely represent a technological advancement but rather builds upon the Industry 4.0 (i4.0) approach to provide a regenerative purpose and direction for industrial production (Huang *et al.*, 2022). This shift focuses on creating value for people, the planet, and prosperity, rather than solely benefiting shareholders through value extraction.

But what knowledge and skills are needed for the transition to Industry 5.0?

Researchers at the Norwegian University of Science and Technology have used industry-university projects conducted in a research and innovation laboratory to find an answer to this question. The laboratory, known as Manulab, is equipped with Industry 4.0 technology and has been a valuable arena for exploring and using knowledge about Industry 4.0 technology in research, education, and industry. Some of the industrial cases conducted in Manulab have revealed the challenges of implementing Industry 4.0 technology in companies. This led the researchers to question how companies can benefit more from Industry 4.0-advantages and become ready for Industry 5.0. Since the knowledge and its application in organizations were central for the study, the researchers took Nonaka and Takeuchi's organizational knowledge creation model and applied it to the competence-building processes in industry-university projects in Manulab (Nonaka and Takeuchi, 1995). Furthermore, the researchers investigated how different knowledge workers contributed to competence building processes within i4.0 and i5.0.

"Knowledge workers" refers to individuals who possess specialized knowledge and expertise that they use to create value for their organization (Drucker, 2011). These workers are involved in knowledge creation, dissemination, and application, and are critical for organizations that rely on knowledge-intensive processes. Nonaka and Takeuchi argue that knowledge workers are not just passive recipients of information, but active participants in the knowledge creation process, constantly synthesizing and transforming information to generate new knowledge. They also emphasize the importance of socialization and interaction among knowledge workers, as knowledge is often created through dialogue and collaboration.

This study unveils the vital roles of specific knowledge workers in the distinct phases of the competence building process within i4.0 and i5.0. The application of these findings does not only enhance the adoption of Manulab i4.0 concepts by industry but also facilitates companies in transitioning to the new Industry 5.0 paradigm. The results are of significant interest to researchers and companies worldwide who are engaged in innovation projects within i4.0 and i5.0.

This article covers the following topics: an introduction to the Manulab i4.0 concept, a brief overview of Nonaka and Takeuchi's organizational knowledge creation model, a detailed description of the Manulab-industry competence building process, and the findings and conclusions.

2. Manulab i4.0

The Norwegian University of Science and Technology, campus Aalesund, opened the Manufacturing laboratory, (Manulab), in 2020 (Kleppe *et al.*, 2022). The lab was developed as a collaborative effort between the campus and local industries, with a prominent presence from the marine and maritime sectors such as shipbuilding and aquaculture (Madappilly and Mork, 2021). Additionally, the district boasts a strong representation by the furniture industry.

Despite broad variation in types of products, the industrial companies had shared manufacturing goals which became a foundation for the design of the Manulab, as shown in Figure 1 . To respond quicky to evolving customer needs, companies had to transform their manufacturing approach from producing big batches of a narrow range of products to producing a wider range of products at lower volumes. Furthermore, Norwegian companies recognized the importance of transitioning from manual or semi-automated to fully automated production to decrease production costs and remain competitive in the global market. Keeping these industrial goals in mind, the Manulab was created as a small-scale factory that used Industry 4.0-technology - Manulab-i4.0 concept. The concept involves both creating and developing technological products, as well as designing and assessing adaptable and automated manufacturing processes for these products. The Manulab equipment includes 3d-printers, laser-cutters, collaborative, mobile and industrial robots that communicate with each other through sensors, cameras and IoT technology. The equipment incorporates simulation software, machine learning, virtual reality, and artificial intelligence to enhance the functioning of Manulab (Kleppe and Bjelland, 2022).

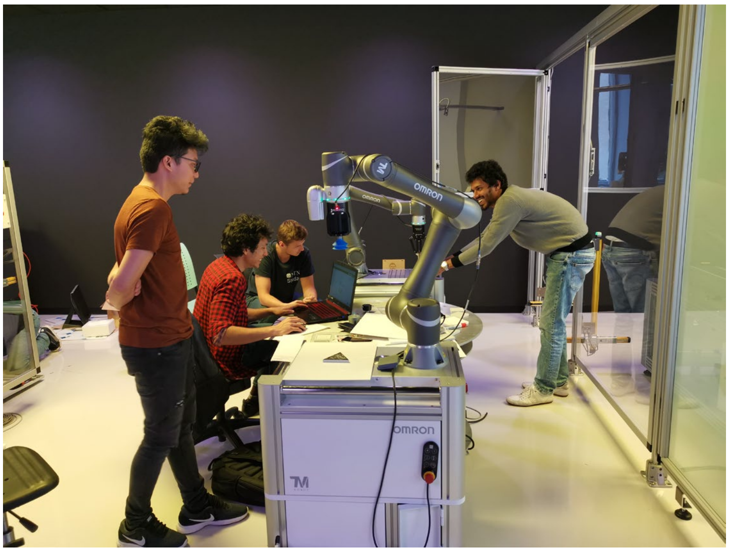

Figure 1: Students Working on the Industrial Case in Manulab Using Industry 4.0 Technology

From the day it opened, Manulab has been actively used for research, education, and industrial innovation projects. These activities intersect in the laboratory. For example, industrial cases can be elaborated in engineering courses. In addition to PhD students doing research, there are bachelor and master students, who are working as research assistants on research and innovation projects. Thereby, Manulab has emerged as a potent platform for building competencies by fostering collaboration among students, researchers, and industrial companies. However, not all industrial cases have yielded successful outcomes, as some of the industry 4.0 concepts developed in Manulab have encountered obstacles for their implementation in the industry. To tackle these challenges, the four authors of this article used a knowledge management approach to analyze industry-university cases in Manulab. All four authors are researchers, three of them are associated with the university while one is the head of research and development in an industrial company. The researchers employed the Nonaka and Takeuchi's organizational knowledge creation model on competence building process in Manulab, a brief introduction to which is given below.

3. Five-Phase Model of Organizational Knowledge Creation Process

According to this model, knowledge creation is a spiralling process of interaction between tacit and explicit knowledge, that goes through five phases as shown in the upper segment of Figure 2 (Nonaka and Takeuchi, 1995).

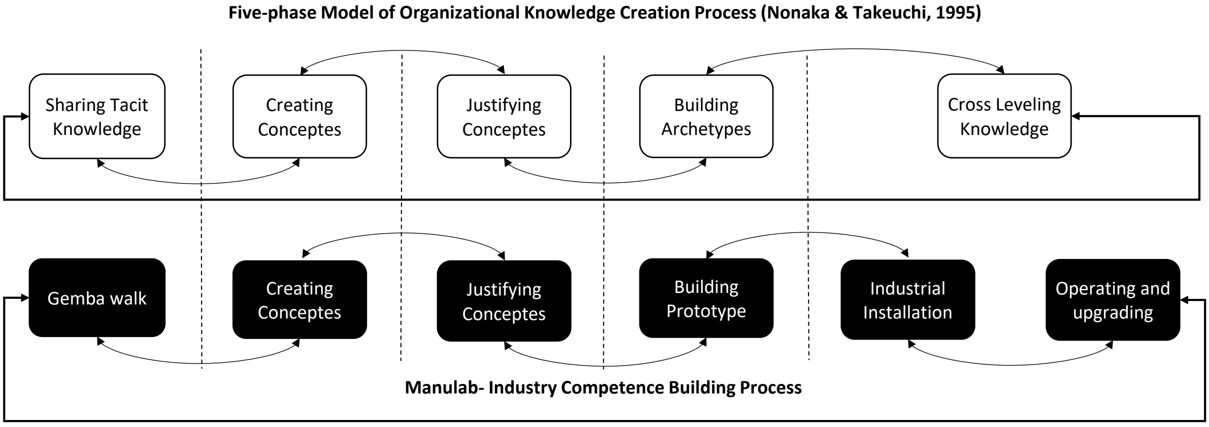

Figure 2: Nonaka and Takeuchi's Organizational Knowledge Creation Process and the Manulab-Industry Competence Building Process, Showing the Interrelations Between Their Phases

Nonaka and Takeuchi's organizational knowledge creation model describes five phases, which are:

Sharing tacit knowledge: This phase involves the sharing of tacit knowledge between individuals through interaction, observation, and communication. Tacit knowledge is difficult to articulate and is based on subjective experiences and insights.

Creating concepts: In this phase, individuals combine their tacit knowledge to create new concepts and ideas. This process involves a combination of intuition, insight, and creativity, and can lead to the development of new products, services, or processes.

Justifying concepts: In this phase, the new concepts and ideas are tested and refined to ensure their validity and usefulness. This process involves testing the concepts against existing knowledge and experience and adjusting, as necessary.

Building archetypes: In this phase, the validated concepts are used to create archetypes or models that represent the underlying principles and ideas. These archetypes can be used to guide future actions and decisions, and to communicate the knowledge to others.

Cross-leveling knowledge: In this final phase, the knowledge and insights gained through the previous four phases are shared and integrated throughout the organization. This involves creating a culture of knowledge sharing and collaboration and ensuring that the knowledge is accessible and useful to everyone in the organization, regardless of their level or position. By doing so, the organization can create a shared understanding and language around the knowledge, which can lead to ongoing innovation and improvement.

4. Manulab - Industry Competence Building Process

Guided by Nonaka and Takeuchi's model, the researchers set the phases of the competence building process in the Manulab industry projects, as illustrated in Figure 2. The process of competence building in Manulab follows the same pattern as the organizational knowledge creation process proposed by Nonaka and Takeuchi, with the exception that the Manulab process encompasses six distinct phases. The final two phases of the Manulab process, namely "industrial installation" and "operating and upgrading," are equivalent to a single phase of cross-leveling of knowledge in Nonaka and Takeuchi's model. The phases in the Manulab-industry competence building process are as follows.

The first phase is a Gemba-walk, which corresponds to the sharing of tacit knowledge in Nonaka and Takeuchi's model. This is the phase of socialization between a company and the Manulab team. The Manulab team typically consists of three to four researchers and two to three students, all from different fields of study. These are people with knowledge within information communication technology, mechanical engineering, automation, and manufacturing design. From the industrial side, it is usually engineers that work with product design and production in the company. If the company and Manulab team do not already know each other, the collaboration starts with several Gemba-walk-visits to the factory and to the Manulab. Gemba is a Japanese term that translates to "the actual place" or "the real place". The term is often used in the context of the Toyota Production System and lean management (Womack, Jones and Roos, 2007). It refers to the place where value is created and where problems can be identified and solved by observing and engaging with the work being done. The Manulab team has had several Gemba-walks at places where industrial work is done, such as a factory floor or construction site. The industry has had Gemba-walks in the laboratory workspace to observe and engage with the Manulab team working on production cases. Gemba-walks help to build relationships, promote understanding of each other's working methods, values, and clarify the expectations for the collaboration. The Gemba walks also help to find several industrial challenges that can be solved in the Manulab workplace. Once the specific challenging case has been selected, the company and the Manulab team initiate the project to tackle the challenge. This typically involves developing and testing an Industry 4.0 production robot cell, as well as modifying the product design to suit automated flexible production.

The next phases in the Manulab-Industry competence building process are 'creating' and 'justifying the concept' and 'building the prototype'. These phases are intricately linked, with continual iteration between modifying the concept and building a prototype. Prototype building goes through many virtual and physical interactions between product- and production design concepts, before arriving at a version that is approved by the company for industrialization.

The next phase is 'industrial installation' when the technology solution is implemented in the industrial company facility. Installation of the solution in an existing manufacturing process can often take time and interrupts production activity. Industrial installation is usually the responsibility of the system integrator, another partner in the Manulab-industry competence building process. System integrator is a supplier of the industrial version of a technological prototype. In this phase, the system integrator's role also includes training operators that will use the system.

The last phase is 'operating and upgrading'. Operators and engineers in an industrial company run the system, while the system integrator's responsibility involves servicing and upgrading the delivered system.

5. Research Method

Researchers conducted a series of four workshops with four industrial companies to gain insights into how knowledge workers contribute to competence building processes within Manulab i4.0 and i5.0 projects. A separate workshop was organized for each company. The purpose of using workshops as a research method is to generate dependable and accurate information concerning forward-thinking procedures, such as organizational change and design, in order to obtain reliable and valid data about the specific field under investigation (Ørngreen and Levinsen, 2017). In each workshop, there were between two and three people from the industry. The participants were middle management with engineering backgrounds, with the exception of one CEO. In each workshop, there were also two to four researchers who had dual roles as discussion partners and researchers.

The workshops began with presentations of industrial cases and demonstrations of technology prototypes in Manulab. Next, the researchers explained these cases from the perspectives of Nonaka and Takeuchi's knowledge creation process and the Manulab-industry competence building process, drawing upon Figure 2 to illustrate the parallels between these processes. This approach facilitated in-depth discussions about the involvement of knowledge workers in the Manulab i4.0 and i5.0 projects.

Each workshop lasted for approximately one-hour during which researchers took detailed notes to capture the key points. Following the workshops, the researchers analyzed the collected data and later presented the findings to the workshop participants for final discussion and approval. The findings will be presented in the following section.

6. Findings and Discussions

6.1 Partners' Involvement in Distinct Phases of Manulab-Industry Competence Building Process

Figure 3 visualizes how industry, Manulab and the system integrator are involved in distinct phases of the competence building process.

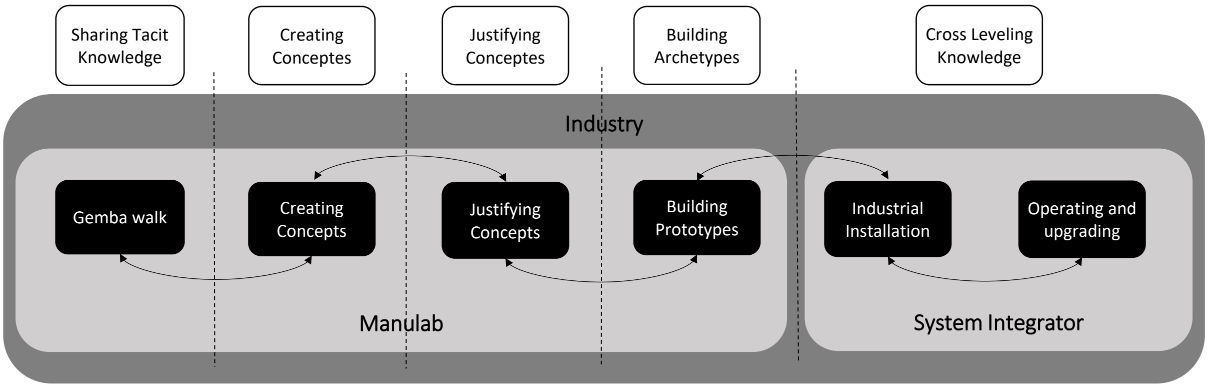

Figure 3: Involvement of Partners in Manulab i4.0- Competence Building Process and Corresponding Nonaka and Takeuchi's Organizational Knowledge Creation Process

As Figure 3 shows, the only partner that participates in the entire process is industry. The Manulab team collaborates with industry in the first four phases of the process, which involve the exchange of tacit knowledge, conceptualization, justification, and prototyping. When it comes to installation of the industrial system in a company's facility, a system integrator is typically brought in to take over. The system integrator utilizes their own concepts, often based on prior experience from other projects, to develop and install the technological solution, providing a warranty for the operating system and training for operators. Together with the system integrator, industry is cross-leveling knowledge by learning from the installation, operating and upgrading of the system. Meanwhile, the Manulab team is not involved in these last phases of the competence building process as it is today in the Manulab i4.0 concept.

While the system integrator's expertise is invaluable in the installation phase, they do not typically contribute to the Gemba, concept creation, concept justification, and prototyping phases. By involving the system integrator in the earlier phases, it is possible to create a shared Manulab-industry-system integrator concept, leading to a higher quality industrial solution.

The involvement of Manulab in the installation phase would benefit the collaborative competence building process. For instance, testing the industrial version of the technological solution in the Manulab facility can reduce the risk of new system errors that often arise during the initial stages of system usage.

Manulab can also assist in operating and upgrading systems by enabling the design and testing of enhanced systems in the laboratory before deploying them in the industrial company's facilities.

The participation of all three partners, industry, system integrator and Manulab in all phases would allow cross-leveling of knowledge by lifting the level of competence across and inside all three organizations. It would also, in accordance with Nonaka and Takechi's model, trigger a new spiral of knowledge building in organizations, which means the adjustment of organizational knowledge building strategies based on 'lessons learned' from each collaborative project.

6.2 Involvement of Specific Knowledge Workers in Different Phases of the Manulab-Industry Competence Building Process

Analyzing the Manulab competence building process from the knowledge management perspective not only highlighted the need for the participation of all three organizations along the whole competence building process, but also emphasized the importance of involving specific knowledge workers from these organizations.

Table 1 shows the knowledge workers and their involvement in the Manulab-industry competence building phases in the current Manulab i4.0 concept and how the researchers and industrial partners see knowledge workers' involvement in the Manulab i5.0 concept. The plus-symbol in Table 1 shows the need to involve knowledge workers. The higher degree of need for involvement is shown with two plus symbols.

Regarding the Manulab team, the knowledge workers, comprising of students and researchers, possess the necessary skills for both the i4.0 and i5.0 concepts. However, it is crucial to include them in the final two phases of the Manulab i5.0 competence building process.

For the system integrator, engineers are the knowledge workers needed for i5.0. However, it is necessary to involve them in the first four phases of the process.

Engineers from the industrial company have been actively involved in all phases of competence building for the Manulab i4.0 concept, and this level of full involvement will remain relevant for i5.0.

Table 1: Knowledge Workers Involvement in Manulab i4.0 and Manulab i5.0

Organiza-tions	Knowledge workers	Ind.	Gemba walk	Creating concepts	Justifying Concepts	Building Prototype	Industrial Installation	Operating Upgrading
Manulab	Students & Researchers	4.0	++	++	++	++		
		5.0	++	++	++	++	+	+
System integrator	Engineers	4.0					++	++
		5.0	+	+	++	+	++	++
Industrial company	Operators	4.0					+	++
		5.0	+	+	+	+	+	++
	Engineers	4.0	+	+	+	+	+	+
		5.0	+	+	+	+	+	+
	Decision makers	4.0					++	
		5.0	+	+	++	+	++	+
	Sales Managers	4.0						
		5.0	+	+	+	+		+

Compared to Industry 4.0, Industry 5.0 has a broader approach to value creation by promoting sustainability, human-centricity, and resilience in manufacturing (as stated by the EU). As the industry moves towards the integration of smart technologies and the cognitive skills and critical thinking of employees, it becomes increasingly crucial to involve knowledge workers such as operators, sales managers, and decision makers from the industrial company in the process.

Manufacturing operators should be involved in all phases of knowledge creation. In the context of human-centric automation in Industry 5.0, operators' knowledge and skills are essential for manufacturing processes and procedures. It is also crucial to introduce operators to new products and manufacturing technologies early on. Their input is valuable for concept creation, prototyping, and installation. Since operators are the ones who use the technological solution in the operation phase, their knowledge is essential for upgrading the solution.

The decision maker should participate in all the Manulab i5.0 knowledge process phases. The experience so far in the Manulab, is that the decision maker enters the process too late. The consequence is that the valuable early phases, like the Gemba walk, creating the concept, concept justification and prototyping, are not receiving the required attention, and neither will the project be properly funded. It is a common challenge in industrial companies that automation has too much focus on eliminating operators and less on value creation. By involving decision makers early on, the potential for industrial performance, sustainability, and value creation for society can be maximized. Decision makers can provide valuable insights into business objectives, investment decisions, and strategic planning that can inform and enhance the Manulab-industry collaboration. As such, their participation is crucial for the success of the competence building process and the realization of the Industry 5.0 paradigm.

In Industry 5.0, there is an increased emphasis on meeting customer needs through continuous improvement and upgrading of the manufacturing system to enhance the overall customer experience and make the supply chain more resilient (Renda *et al.*, 2022). As such, the role of the sales manager as a representative of the "voice of the customer" is crucial in the Manulab-industry competence building process. Sales managers should participate in the introductory phases to ensure customer preferences, wishes, and experiences are considered.

Overall, the involvement of certain knowledge workers in specific phases of the process is essential for the successful utilization of Manulab projects within the Industry 4.0 concept and can support Manulab's transition to Industry 5.0. The next section presents how the researchers used their findings to plan the Manulab-industry competence building process within the Manulab i5.0 concept.

6.3 Manulab i.5.0 – Concept: Proposing Competence Building, Learning Contexts and Tools in the Knowledge Creation Process

Based on the findings, the researchers designed the Manulab-industry competence building process to support the Industry 5.0 paradigm.

The first phase is a Gemba walk. The knowledge workers from the industrial company, the system integrator and university's Manulab meet for socialization sessions and to experience each other's learning and innovation contexts. The Manulab team arranges a Gemba walk in the Manulab with the knowledge workers who need to be involved in Manulab i5.0, that is, researchers and students from Manulab, industrial engineers from the system integrator and the industrial company, operators, decision makers and the sales manager from the industrial company. Design tools, rapid prototyping, collaborative and mobile robotics, should be demonstrated at this point. The knowledge workers can explore the design of products, jigs, fixtures, and grippers and combine it with automatic manufacturing both in simulators and in the physical Manulab factory. The industrial company should arrange a corresponding workshop with the design department and manufacturing department in their factory to explain how they work. The customers' experiences can be presented by customers if possible. The industrial company may use digital market research or IOT (Internet of Things) technology to collect and present data from customer experience and product and services performance. The operator's knowledge is important to build in the human centric approach for manufacturing systems, and therefore it is important to study the operators' work in the factory. The decision maker should participate in the Gemba walk to understand the opportunities of innovative technology. The decision maker has knowledge about the industrial company's value chain strategy and approach to sustainability. The decision maker is also the enabler of financial and human resources. Drawing a parallel between the Gemba phase and Nonaka and Takeuchi's initial phase of tacit knowledge sharing, there are several methods for exchanging tacit knowledge, including direct observation, narration accompanied by direct observation, imitation, experimentation, comparison, and joint execution (Nonaka and Takeuchi, 2019).

Concept creation phase – here the aim is to enable tacit knowledge, and use this to develop product, process, and business concepts. It is important that the creating concept phase also includes 'high flying' ideas and thoughts. The concept creation phase must evaluate whether we have the needed knowledge and skills onboard. Do we use the right methodology to externalize tacit knowledge? Do we use creative language and metaphors? Are we able to understand tacit knowledge to its full potential? If certain knowledge is not included in the second phase, it will be absent in the concept creation phase and will not be integrated into the prototype at a later phase. Innovative product and service concepts, and automatic manufacturing concepts should be made, and combined with customer experiences. Operators' role and how to use human knowledge in combination with artificial intelligence should be elaborated in several scenarios. Manulab's facilities and features, such as design and prototyping equipment, should be effectively utilized for this purpose.

Justifying the concept phase is where the concept is tested and elaborated relating to the industrial company's short term and long-term business strategy, human centric automation, sustainability performance and value for society. The sustainability view should be elaborated and highlighted within the design, manufacturing, transport, and use and recycling of products and services. If the justification of concept does not meet the industrial companies' business advancement and strategy, there should be a low threshold for creation of a new or modified concept. Concept can include pay-back time, return on investment, costs, and profit margins. The industrial company could invite customers, suppliers, and authorities to contribute to the justification of the concept.

Building a prototype phase is where the justified concept is built into a prototype of the product and an automatic manufacturing line. This means that the concept is combined with the industrial companies' existing concepts, products, components, and manufacturing facilities. It can be useful to use CAD and CAM System for visualization and simulation of the product and the manufacturing processes. However, building of physical product prototypes and real life set up of a manufacturing line will give more insights for verification and validation.

The industrial Installation phase refers to installing the automatic manufacturing line in the industrial company's factory. The industrial installation can be related to a completely new automatic manufacturing line or an upgrading of an existing manufacturing line. The industrial installation phase can be costly and critical for the industrial company since in many cases, it is done in parallel with daily operations. The engineers from the system integrator are responsible for this phase. Their knowledge, skills, experience, and access to technological resources are vital for the performance of the industrial installation process. High complexity of the product, components and manufacturing equipment can lead to delays in manufacturing, because substantial numbers of failures must be fixed 'on the line.' This can be avoided if Manulab supports the industrial installation work, by making proof of concept and even delivering the needed products and services for a period, to the customer.

The operating and upgrading phase are the normal industrial operations where the industrial company is responsible. However, in a dynamic business world customers will continuously ask for new variants of the products and services. The price of the products and components will normally decrease by 2% to 4% every year, and this puts pressure on the industrial company to find more efficient manufacturing methods. This is done as an iterative development process aiming to lower the cost of the product and components. It is also likely that both the system integrator and Manulab can take an active role and contribute with ideas and concepts if they create a lifelong partnership with the industrial company.

The knowledge and skills required for development of Industry 5.0 concepts are intertwined among the three partners and represent a common knowledge foundation. This knowledge foundation is vital for the industrial company's performance.

Following Nonaka and Takeuchi's KM model, organizational knowledge creation is a spiral process, with each new project building on the knowledge gained from previous collaborations. Long-term collaboration, lasting a minimum of three to four years, would enhance the partners' competences and equip them to meet future industry demands. To achieve this, the three partners will establish procedures and routines for their work, with the socialization process at the foundation of all knowledge creation and application. Care, trust, and commitment are the key factors that will enable the partners to create and apply new knowledge effectively.

7. Conclusion

The research findings propose a long-term cooperation between the industrial company, the system integrator and the Manulab team. Decision makers, sales managers and manufacturing operators should participate throughout the knowledge creation process, and their participation is considered crucial for human centric automation, sustainability in product and processes, and value creation for business and society. The Manulab i.5.0 concept also bridges university and industry collaboration with students participating as knowledge workers. This is regarded as beneficial for knowledge diffusion and societal development.

The findings show that Nonaka' s five phase model can support the Manulab i.4.0 concept for a transition towards the Manulab i.5.0 concept. Involving both industry, system integrator and Manulab with all the relevant knowledge workers, throughout the Manulab-industry competence building process is likely to support enabling tacit knowledge, and more innovative product concepts, production concepts and business models. A more dedicated concept creation phase and justification of concept phase can connect and adapt products, services, and manufacturing concepts more to the industrial company's short-term and long-term business strategy.

However, the Manulab i.5.0 concept must be validated with case studies. Future research should concentrate on elaborate real-life industrial cases, collecting and analyzing qualitative and quantitative data.

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