Metadata of the chapter that will be visualized in SpringerLink

Book Title	Advances in Production Management Systems. Production Management Systems for Responsible Manufacturing, Service, and Logistics Futures
Series Title	
Chapter Title	Industry 5.0 and Manufacturing Paradigms: Craft Manufacturing - A Case from Boat Manufacturing
Copyright Year	2023
Copyright HolderName	IFIP International Federation for Information Processing

Corresponding Author	Family Name	**Henriksen**
	Particle	
	Given Name	**Bjørnar**
	Prefix	
	Suffix	
	Role	
	Division	
	Organization	SINTEF Digital
	Address	Trondheim, Norway
	Email	bjornar.henriksen@sintef.no
Author	Family Name	**Thomassen**
	Particle	
	Given Name	**Maria Kollberg**
	Prefix	
	Suffix	
	Role	
	Division	
	Organization	SINTEF Digital
	Address	Oslo, Norway
	Email	maria.thomassen@sintef.no

Abstract	Industry 5.0 is emerging as a novel approach in manufacturing, with focus on sustainability, resilience, and human centricity. This study investigates the complex and comprehensive Industry 5.0 concept, its relevance for the craft manufacturing paradigm and the role of technology in the industry transition towards Industry 5.0. Findings are based on empirical data from a research and development project with Norwegian leisure boat manufacturers, and results of previous research projects within the boat building industry. The boat building industry is a traditional hand-craft industry with high degree of manual labour. Findings show that this industry have several suitable conditions for developing strong capabilities related to sustainability, resilience, and human centricity. The investigated case companies, characterized as craft manufacturers, seem to have limited knowledge of both Industry 4.0 and Industry 5.0. Despite that previous research projects have included technological elements, advanced technologies are still scarce in production processes.

Keywords (separated by '-')	Industry 5.0 - Technology Maturity - Craft Manufacturing

Industry 5.0 and Manufacturing Paradigms: Craft Manufacturing - A Case from Boat Manufacturing

Bjørnar Henriksen[1](✉) and Maria Kollberg Thomassen[2]

[1] SINTEF Digital, Trondheim, Norway
bjornar.henriksen@sintef.no
[2] SINTEF Digital, Oslo, Norway
maria.thomassen@sintef.no

Abstract. Industry 5.0 is emerging as a novel approach in manufacturing, with focus on sustainability, resilience, and human centricity. This study investigates the complex and comprehensive Industry 5.0 concept, its relevance for the craft manufacturing paradigm and the role of technology in the industry transition towards Industry 5.0. Findings are based on empirical data from a research and development project with Norwegian leisure boat manufacturers, and results of previous research projects within the boat building industry. The boat building industry is a traditional hand-craft industry with high degree of manual labour. Findings show that this industry have several suitable conditions for developing strong capabilities related to sustainability, resilience, and human centricity. The investigated case companies, characterized as craft manufacturers, seem to have limited knowledge of both Industry 4.0 and Industry 5.0. Despite that previous research projects have included technological elements, advanced technologies are still scarce in production processes.

Keywords: Industry 5.0 · Technology Maturity · Craft Manufacturing

1 Introduction

Manufacturing companies must deal with increasingly complex business environments and challenges that require novel approaches. European policymakers and organizations have therefore introduced Industry 5.0 on the agenda. This is driven by severe implications of unforeseen events and crises such as the pandemic, war in Europe, disruptions in supply chains, the climate and environmental crisis, and the urge to put people at the centre. Industry 5.0, which provides a future vision for the European industry, is gaining increased attention. Still, its impacts and practical implications on industries, companies, people and society are to be defined and exploited [1].

Since companies are still engaged in Industry 4.0, or in earlier industrial revolutions, it can be questioned whether Industry 5.0 should be positioned on a timeline of "Industrial Revolutions" based on innovations from technology, Industry 1.0 (mechanization from

Published by Springer Nature Switzerland AG 2023
E. Alfnes et al. (Eds.): APMS 2023, IFIP AICT 689, pp. 1–15, 2023.
https://doi.org/10.1007/978-3-031-43662-8_21

water- and steam power) and to Industry 4.0 (Cyber physical systems from internet of things, artificial intelligence, etc.) [2]. Instead, innovations that push manufacturing towards Industry 5.0 are not solely limited to technological ones, but rather within social- or human–machine system-sphere [3]. Furthermore, according to Kraaijenbrink [1], the idea of Industry 5.0 is not limited to industry only, but applies to a wide range of sectors and organizations. This means that its applicability is significantly wider than Industry 4.0.

Manufacturing paradigms may be related to and even overlap with industrial revolutions. The development of paradigms is associated with changing customer needs [4], but also changing capabilities such as enabling technology. However, manufacturing paradigms are not necessarily a function of time or technology. Thus, "low tech" manufacturing could still meet market requirements and imply relevant approaches for companies.

With a starting point in the view that Industry 5.0 is a complement to the Industry 4.0 technological paradigm, this transition is technology dependent and emphasizing the importance of technology for the Industry 5.0 transition. It can thus be assumed that significant technological investments are required if companies are to make the transition towards Industry 5.0. However, the Industry 4.0 transition has been mainly aligned with the optimisation of business models and economic thinking, supporting the current digital economy, based on a winner-takes-all model that creates technological monopoly and giant wealth inequality [5]. This may question to what extent existing technologies that were once implemented with purposes of increasing productivity and economic benefits only, may be utilized to support the new transition. The Industry 5.0 vision suggests that the traditional financial objectives of technology investments, such as productivity and profitability, should be replaced with goals related to resilience, sustainability, and human-centricity.

Even though Industry 4.0 has been well known in many industries for several years, its adoption rate still is slow. Moreover, manufacturing companies may be close to the Industry 5.0 vision, without major investments in new digital technologies. This means that companies may have developed strong sustainable, resilient, and human-centric abilities independent of heavy technological investments. Thus, the starting point for this research is that the Industry 5.0 vision does not necessarily have to rely on enabling technologies and that technology advancement should not be a goal. There is a need for a more nuanced picture of the role of technology for the Industry 5.0 transition.

This study investigates sustainability, resilience, and human centricity to bring further understanding the relevance of the Industry 5.0 vision for manufacturing paradigms with a technology maturity level different from we find in Industry 4.0. It seeks to bring further understanding of the complex and comprehensive Industry 5.0 concept, and to the specific role of technology in the industry transition towards Industry 5.0. Findings are based on empirical data from case companies in the boatbuilding industry, which is a traditional hand-craft industry with high degree of manual labour.

2 Theoretical Perspectives

2.1 Industry 5.0 – A Vision for the European Industry

According to the European Union (EU) [5], the Industry 5.0 concept provides a vison of industry that look beyond efficiency and productivity as the sole goals, and reinforces the role and the contribution of industry to society and a particular focus on the wellbeing of the workers. The use of modern technologies should provide prosperity beyond jobs and growth while respecting the production limits of the planet. The concept further promotes the transition towards a sustainable, human centric and resilient European industry.

The Industry 4.0 technological paradigm is mainly centred around cyber-physical objects, promising enhanced efficiency through digital connectivity and artificial intelligence [5]. In order to Industry 4.0 often refers to the fourth industrial revolution, with focus on digital transformation in the manufacturing industry for faster delivery times, more efficient and automated processes, higher quality and customised products [6]. However, this paradigm does not fit in the context of climate crisis, planetary emergency, and deep social tensions. Industry 5.0 complements the existing Industry 4.0 paradigm by highlighting research and innovation as drivers for a transition to a sustainable, human-centric and resilient European industry [7]. It moves focus from shareholder to stakeholder value, with benefits for all concerned, and attempts to capture the value of new technologies, providing prosperity beyond jobs and growth, while respecting planetary boundaries, and placing the wellbeing of the industry worker at the centre of the production process [7].

Industry 5.0 moves the focus from shareholder to stakeholder value, with benefits for all concerned. Industry 5.0 is about interaction between people and technology, with the employee as a positive driver for development of company, but where the objectives go beyond company profit, heading for sustainability and positive contribution to society. According to the European Union [7], Industry 5.0 is defined as follows;

> *"provides a vision of industry that aims beyond efficiency and productivity as the sole goals, and reinforces the role and the contribution of industry to society." and "It places the wellbeing of the worker at the centre of the production process and uses new technologies to provide prosperity beyond jobs and growth while respecting the production limits of the planet." It complements the Industry 4.0 approach by "specifically putting research and innovation at the service of the transition to a sustainable, human-centric and resilient European industry.*"

Industry 5.0 has three key pillars: human-centric, resilient, and sustainable, but with a comprehensive approach these pillars are seen in context and building culture, principles, technology, and solutions, so that these elements are intertwined and create synergies.

- *Human centricity*: Places essential human needs and interests at the centre of the manufacturing and is a shift from seeing people as means (e.g., as in human resources) to seeing people as ends. Or, in other words, a shift in perspective from people serving organizations, to organizations serving people.

- *Sustainability:* The company must face the challenges (and opportunities) outside the factory. Aiming for positive societal development beyond purely (short-term) business targets (profit). Rather than only reducing a company's negative impact, sustainable companies focus on increasing their positive impact.
- *Resilience:* Manufacturing systems should have the ability to withstand demanding situations and to accommodate disruptions without significant additional costs.

2.2 Enabling Technologies

There are a wide range of Industry 4.0 technologies enabling this digital transformation, including for instance additive manufacturing, augmented and virtual reality, automation and industrial collaborative robotics, big data analytics, blockchain, cloud data and computing, cybersecurity, cyber-physical systems, internet of things, artificial intelligence, and simulation and modelling (see for instance literature reviews by [6] and [8]). These technologies can also have a wide range of applications in various processes in manufacturing companies, including product life cycle management, supply chain management and production and operations management [6]. Also, similar enabling technologies are recognized within the Industry 5.0 concept [9].

However the abilities of technologies as co-drivers in producing resilience and sustainability on a wider scale are often uncertain and context-dependent [10]. Today's technologies are primarily designed and used with a focus on maximizing organizational/operational performance instead of human well-being and societal growth and prosperity, prioritizing full automation of tasks per se, that sometimes creates trust issues rather than empowering the human in the task [11]. However, researchers have started to investigate how technologies such as for example digital twins and artificial intelligence may help to improve worker situations and enhance human centricity [12, 13].

2.3 Manufacturing Paradigms

As the focus and perspectives in manufacturing have developed over time, the changes have often been described as shifts in paradigms, "a set of beliefs that guides action" [14]. These paradigms are not absolute in terms of complete frameworks for how to conduct business or organize manufacturing. What they represent are more coherent sets of principles and methods that inspire companies. Strategies will often have elements from different paradigms even if it is claimed they have adopted only one.

Defining paradigms is not an exact science; rather, to a considerable extent it is a question of choosing a set of criteria supporting the purpose of categorization. Paci et al. [15] have presented criteria in what they call a "Production Paradigms Ontology" (PPO) which focuses on knowledge- and innovation. PPO is based on the NEST (Nature, Economy, Society, Technology) context defined by Jovane et al. [16]. Jovane et al. use these criteria to identify and describe five manufacturing paradigms. While industrial revolutions as described above mainly focus on innovations, technology, and other enablers for radical shift in manufacturing, manufacturing paradigms are more about what you want to obtain, purpose and focus areas in manufacturing, described as "Society needs." Although it is tempting to challenge this list of paradigms from 2003, referring to many changes and innovations, we consider that these paradigms are basically those we can identify in the broad context [14]:

- *Craft Manufacturing*—which means to make exactly the product that the customer asks for, usually one product at a time in a "pull-type business model": sell (get paid)—design-make-assemble. The processes have a low level of automation, but use skilled and flexible workers
- *Mass Manufacturing*—means to manufacture high quantities of identical products, selling them to customers and markets that will absorb what is manufactured. High volume means low costs and cheaper products, thereby increasing the market, which implies a "push-type business model". The moving assembly line is an enabler for this paradigm, requiring standardized processes and specialized workforces
- *Flexible manufacturing*—has been the answer to the increased complexity and uncertainty in the business environment. In the 1970s overproduction and the demand for more diversified products resulted in decreased lot size and the requirement for shorter time-to-market. The manufacturing still followed principles from mass manufacturing but more module-based to meet the demand for variation.
- *Mass customization and personalization*—is a society driven paradigm due to customers asking for greater variety in products, and because of globalization creating a huge excess of production capacity. This situation has put customers in power and the manufacturer aims to manufacture a variety of almost customized products at mass production prices.
- *Sustainable manufacturing*—is based on societies' needs for 'clean' products and product-life-cycle management related to clean products. Nano-, bio- and material technology are regarded as enablers for sustainable manufacturing.

All the above listed manufacturing paradigms are more-or-less relevant today. It all depends on products- and market requirements and the context within the companies operates. And there is not a clear cut between them so we will see a myriad of combinations for example related to "sustainable manufacturing."

2.4 Industry 5.0 Maturity

A company seeking to realize the Industry 5.0 vision, may consider its capabilities regarding human-centric, resiliency, and sustainability. The development of Industry 5.0 capabilities in industry requires a thorough understanding of the concept as well as relevant guidelines and showcases for practitioners [17]. However, since Industry 5.0 is a fairly new concept, models for measuring and assessing Industry 5.0 maturity or advancement are still lacking [18]. In contrast, a wide range of maturity assessments models and tools have been developed recently for measuring advancements related to Industry 4.0 (see literature reviews by [19–21] and [22]). Even though industry 4.0 maturity assessment models may serve as an important starting point for assessing Industry 5.0 maturity, these models rely heavily on technology and are to a considerable extent focused on measuring the digital readiness in companies.

Yet, digital readiness and Industry 4.0 maturity models may be relevant for companies to support digital transformation and the transformation process towards Industry 5.0 [18]. Moreover, several digital maturity models include Industry 5.0 aspects related to human-centricity, sustainability and resilience [18]. This means that the Industry 5.0 maturity level of a company can be assessed based on measures related to the three basic elements of Industry 5.0. However, if considering the interdependencies between ongoing shifts, of both Industry 5.0 transformation and digital transformation, it may be relevant to investigate opportunities for combining human-centric, resiliency and sustainability maturity measures with digital measures that specifically reflect the digital readiness in accordance with these three elements. An assumption for this research is that despite that Industry 4.0 is considered technology-driven and digital enablers are recognized within Industry 5.0, the technology-dependency of the Industry 5.0 transformation can be questioned.

3 Methodological Considerations

This research is applied research, conducted in collaborative manner with three case companies. It is based on a mixed methods approach, combining empirical data collected by a questionnaire and literature studies, as well as information from previous research projects involving companies in the Norwegian boatbuilding industry. Most research conducted in various previous projects in this industry has been based on a combined approach involving action research and case research strategies. This has implied an extensive understanding of this industry and in-depth insights to several of the companies, among involved researchers.

Empirical data on enabling technologies are collected through a questionnaire filled out by representatives of three companies. The companies are selected because they participate in a research project, the TEL project. The questionnaire is developed by the authors based on a brief review of relevant literature on digital enabling technologies and Industry 5.0. It includes thirteen questions. For twelve of the questions, ratings are conducted by a 5-point Likert scale ranging from "Strongly agree" to "Strongly disagree", in addition to the alternative "Don't know". One of the questions, related to prioritization of the key qualities and expertise, involves six suggested response alternatives to choose from. Respondents could also add open comments in a dedicated text box after each question. SINTEF researchers evaluated the questionnaire before it was distributed to the companies. It was sent as an attached word document by e-mail to the main contact person of each case company. Answers were returned from all the companies.

To further investigate the relevance of enabling technologies and Industry 5.0 in the Norwegian boat building industry, a mapping of previous relevant R&D projects is conducted. The mapping is based on information collected from the final reports of the research projects. Project research results and innovations are mapped in relation to digitalization and Industry 5.0 key dimensions. The projects were selected since researchers and case companies were previously involved in these projects.

3.1 The TEL Research Project and Case Companies

This research is conducted as part of a four-year research project, Transformation to electric propulsion (TEL), which is partly funded by the Norwegian Research council. The project focus on electrification of boats, but also has on production efficiency. Environmental and sustainability aspects for leisure and professional boats are recognized to have major potential for improvements. The main objective of the TEL-project is to realize this potential. By evaluating and testing user demands, industrial fabrication standards, available technology and several other aspects from a commercial standpoint, development of fabrication, new flexible hulls, propulsion, and electrification/hybrid technologies will be conducted. The use of electrification is presently the most promising technology to achieve environmental and sustainability potentials.

The automotive industry has taken immense electrical innovation leaps over a brief period, and now the marine industry is expected to achieve the same. There is however a major difference in requirements, demands and solutions. For example, the laws and regulations for the implementation of electric propulsion in the maritime industry are not available and clear. Therefore, the project also will collaborate closely with the authorities on this topic. To provide the knowledge needed for a new industry standard, there is a push from the project to present products that may be the start of a new generation of boats. New drivelines, a lower speed range and technology advancement will provide new hull designs. The project also addresses the relation between range, speed and use-profiles will affect the user demands and how this influences commercial alternatives.

The TEL project includes three boatbuilders Ibiza Boats AS, Viknes Båt og Service AS and Nor-Dan Composites AS. In addition, the project includes the technology providers Farco AS and SeaDrive AS, and the R&D-partners SINTEF Digital and Inventas Kristiansand AS. The boat companies produce boats between 20 to 37 feet to customers in different market segments. One of them focuses on professional boats, primarily coastal fishing, while the others focus on the private leisure boat segments. The companies are SMEs and are all companies with a history that goes back several decades. Several TEL-project partners have participated in larger R&D projects, both national with co-funding from the Research Council of Norway and the European Union (EU) research funding programs. The most relevant projects are shown in Table 1.

3.2 Craft Manufacturing

The leisure boat manufacturers and production of small workboats are competing on global markets that are very fluctuating, vulnerable for the financial situation and priorities among households. Traditionally, these companies have been small or medium sized (SME) but the last two decades there has been a tendency towards larger more industrialized operations with larger production volumes and reduced costs. This has to some extent rugged the industrial structure, increased competition and challenged traditional craft manufacturing principles [23].

The Norwegian leisure boat industry has long traditions and a broad culture for quality products. The design, production and after sales activities have been characterized by craft manufacturing and to a large extent based on tacit knowledge in development, improvement and design [24]. However, several research and development projects have to some extent changed that bringing in elements from new technologies, digitalization and modularization [25]. The craft manufacturing of leisure boats is characterized by engineer-to-order manufacturing and projects. Even though the design and production of boats is characterized by wide number of quite demanding requirements, processes are manual. However, a wide variety of digital tools and equipment are used in boats and in manufacturing processes in this industry.

One of the main advantages in craft manufacturing is that the employees have a strong ownership to their products and put a lot of effort in finding good ad-hoc solutions to problems. For example, when a supplier has delivered a part with minor quality problems, the craftsmen can often fix the problems themselves instead of initiating administrative processes. The craftsman represents a capability for adjusting and practical solutions in line with customer expectations. This also tends to create a customer relationship that are appreciated and could lead to "loyal" customers. A general characteristic of quality and quality improvement in leisure boat companies is that their employees constantly work to optimize quality.

4 Empirical Findings

4.1 Industry 5.0 and Enabling Technologies in the Case Companies

The TEL-project aims at developing transfer leisure boats (and small craft vessels) to more environmentally friendly propulsion solutions, which also includes hydro dynamics and material technology. Putting all these elements together has required application of new simulation methods and digital tools. As these electric and hybrid solutions are more expensive, an important part of the project has been focusing on cost reduction and novel approaches to production.

The concepts Industry 4.0 and 5.0 have not been explicitly introduced to the project and its partners. So, when the companies were asked to answer a simple questionnaire, it was to get picture of their knowledge of the concepts. The aim was also to get an indication of to which extent they comply with industry 5.0 and the underlying elements and especially the technology. The knowledge of Industry 4.0 and Industry 5.0 is low when it comes to the concrete content, and what it means for a company at strategic as well as operational levels. However, when they were asked more specific on the basic elements of it the picture change:

- Sustainability is a central element in two of the company's overall strategies, plans and goals, where they also had a focus on enabling digital technology. The third company responded neutral to these questions
- Resilience is an essential element in the three companies' strategies and plans. Digital technology is an important part of it.
- Human centricity in terms of focus on the workers, involvement in improvement and development are important in all three companies. The answers vary when it comes to which skills are considered most important, but "solution-oriented" gets the highest priority followed by "structured" and "independent"
- The companies lack a clear strategy on digitalization, and they have different answers on the degree they use digital tools in production improvement and product development.

The results of the questionnaire show that there are major variations between the answers from the companies. Even though the knowledge of Industry 4.0 and 5.0 is limited, and the "digital maturity" is low, it looks different when the questions are on the underlying elements of Industry 5.0. Sustainability, resilience and in particular human centricity are by no means neglected, where enabling technologies are used by the companies.

4.2 Industry 5.0 and Enabling Technologies in Previous R&D Projects

Table 1. Overview of results of previous R&D projects

Project title and period	Description of project results
Industrialised Small Scale Boat Production, ISB (2008–2012)	Modularization, manual adjustments are minimized; Production-, product- and market-knowledge for design and production strategies; Supply chain integration for customized production; Production that addresses environmental issues and making the leisure boat industry an attractive workplace
Boat Management, BOMA (2011–2014)	Software platform for data handling, analysis, etc. tied to production / documentation /DSS mm. Intelligent Universal Marine Gateway installed that collects, analyses, transmits operating data from boat to manufacturer, service partners, and the boat owner
Planning and Management of Small Series, PLAN (2011–2014)	Better utilization of resources of partners from coordinated planning and management; Differential control based on partners' mass custom profiles; Automating logistics and technical information in the supply chain through better application of existing technology
EcoBoat MOL, EBM (2011–2015)	Technical solutions in prototypes and test solutions for data acquisition, analyses, and transmission of data/results from real-life running of individual boats; Sensors adapted to the need of the boat producer; Improvement related to actual systems data entry and use of data for product development
Marine Platform, MAP (2012–2016)	Development of flexible and standardized structural platforms as the basis for well-defined interfaces for a boat's various modules; Environmentally friendly material solutions regarding weight, reuse, and recycling
Innovative Connected Vessels, LINCOLN (2013–2019)	Methodologies and tools for the development of new vessels concepts through dynamic simulation model testing; IT customized tools to enable the acquisition and usage of field data, from an IoT platform; Introduced High Performance Computing Simulation to verify the resulting concept design of boats

(*continued*)

Table 1. (*continued*)

Project title and period	Description of project results
Robust Industrial Transformation, RIT (2018–2021)	Design dashboard that can handle the display and analysis of real test data, and critical information in product development based on new hardware for data capture from real operation of the products, and innovative algorithms that allow you to, for example, transform a measured force impact; Modularization
Radically Improve Costly Development, RADDIS (2018–2021)	Visualization technologies, i.e., virtual product and factory twins; Regulations opening new opportunities for quality development and documentation; Avatar with checklists and module based BOM solutions; Updated product and process information throughout the boat's life cycle

Table 2. Overview of linkages between results of R&D projects and Industry 5.0 elements

Project name	Industry 5.0 dimensions and elements										
	Sustainability				Resilicene				Human centricity		
	STY	PCI	PDI	DIG	STY	PCI	PDI	DIG	STY	PCI	DIG
ISB	x	x			x	x			x	x	
BOMA	x	x	x	x					x		x
PLAN		x			x	x	x	x	x		
EBM	x	x	x		x	x	x				x
MAP	x	x	x		x	x				x	
LINCOLN	x	x	x	x	x	x	x	x			x
RIT		x	x	x	x	x	x	x	x		
RADDIS	x	x	x	x	x	x	x	x		x	x

STY = Strategy, PCI = Process improvements, PDI = Product improvements, DIG = Digitalization.

Several R&D projects have been conducted in the Norwegian boat building industry since 2008 (see Table 1). These have aimed at increasing efficiency in production with linkages to product development, seeking to increase performance while keeping the advantages of the craft manufacturing tradition.

The table below (Table 2) shows an overview of the results of the previous projects in view of Industry 5.0 dimensions and elements including digitalization.

5 Is There Industry 5.0 Without the 4.0 (Digital) Maturity?

5.1 Overall Perspective and Transition

The transition of a business is the process of bringing a company into its next chapter [26]. Transition is about strategies to create new or better capabilities for major changes and improvements. A business or industry may progress in the right direction towards a major shift. However, such movements do not necessarily imply a transition.

In general, leisure boat manufacturers seem to have moved forward in line with new demands and requirements related to societal changes. Our findings show that they have also conducted a number of R&D projects that have included elements from both Industry 4.0 (technology) and Industry 5.0. (i.e., sustainability). However, it seems like Industry 4.0 and Industry 5.0 are still unfamiliar concepts in this industry. This may indicate that leisure boat manufacturers lack explicit objectives and strategies for green and digital transition. Instead, changes have implied more of inherent moves aligned with general industry expectations rather than well defined actions that are part of a long-term strategic transition plan. Still, our findings suggest that several elements of resilience, sustainability and human centricity are highly relevant for this industry, although these have limited foundation in the Industry 5.0 vision. Regarding technological progress, findings indicate that the digital technology maturity level in the industry is low, despite several previous R&D projects on advanced technologies.

5.2 Industry 5.0 Dimensions

Sustainability. Findings show that sustainability is critical for this industry. Sustainability has been linked to digitalisation. For example, data captured from boat operations may be used for analysis and simulation. Such solutions can provide more data and knowledge about a boat's life cycle and areas of use, use conditions, enabling optimization of design solutions to reduce material thickness, weight, and hydrodynamics, which affect resource requirements also in relation to propulsion.

New production methods and technology, for example the use of vacuum injection in casting, also contribute to less environmentally harmful raw materials. Another example from one of the case companies is a new digital milling machine, which is expected to have positive effects in terms of reduced waste, increased quality, and precision. In addition, leisure boat manufacturers work purposefully for recycling of plastic boats and explore possibilities for using recycled materials, for instance from plastic bottles.

Resilience. The leisure boat market face major fluctuations and is exposed to changes in the global economy that affect demand, such as economic crisis, energy crisis, as well as events like geoeconomic confrontations or pandemics. These conditions increase the need for strategies and solutions for enhanced resilience. There has been a major restructuring of the leisure boat manufacturing industry in Norway and internationally during the last decades, which has resulted in fewer companies and more challenging market competition. Despite this, the companies have had an ability to survive and adapt to these major changes in competition and business conditions. Our findings also confirm that resilience has high priority in this industry.

A specific feature of the leisure boat industry is that products and production processes are often modularized. This implies flexibility and adaptability to changes in market conditions and user requirements. Also, it enables scalability as modules can be outsourced to networks in periods of high demand or lack of own capacity, for instance. Moreover, computerized simulation has contributed to reduce costs and risks of product development. Digitalization of bills of materials, visual assistant systems, and digital twins are examples of technologies that have been explored in the industry with a positive impact on resilience. However, to enhance resilience in the industry, companies also need employees have competence capabilities that enable them to change, improvise and navigate within complex and turbulent business environments.

Human Centricity. The craft-based production of leisure boats has a strong focus on humans, especially production workers and customers (end users). This means that there is often close dialogue and collaboration between production workers, other employees, and customers. This constitutes a solid foundation for developing a strong commitment to products and the entire company among workers. Workers have high responsibility and are expected to find solutions to problems occurring in production and assembly and to product related challenges. The companies also focus on sharing tacit knowledge and involving employees in improvement and development work.

There has been an increased focus on improved working conditions the last decades with better health, safety, and environment (HSE) procedures and equipment. Also, manual casting processes of hand-laid fiberglass mats have been substituted in boatbuilding by cleaner injection moulding and vacuum processes. Investments in a new milling machine may further improve the dusty and uncomfortable cutting and grinding process at the shop floor. Even though boatbuilding companies have appreciated practical skills, there has been an increased focus on support systems, such as digitized bills of materials and visualised descriptions and procedures. Human centricity is thus considered a major element for competitiveness. However, findings indicate that human centric aspects only have had little attention in previous R&D projects.

5.3 Industry 4.0 Technology Gap

There is a large amount of literature on Industry 4.0 technologies. It typically includes descriptions of advanced cyber physical systems such as smart factory, smart machines, digital equipment, which often requires resource demanding digitization processes and/or a specific manufacturing context. Industry 4.0 technologies are more suitable for mass production and mass customization contexts, compared to craft manufacturing. This may imply that some sectors of the manufacturing industries with products, processes or scales that may be unsuitable for Industry 4.0 technologies, risk to be left behind in the digital transition. However, cognitive technologies are one exception of a type of technology that may be exploited in this industry.

Findings show a low level of utilization of Industry 4.0 technologies in boat production. This may be explained by contextual factors. Companies are typically small and medium sized enterprises (SMEs) with limited ability to make large investments in digitization. Also, small production volumes with high degree of customization and manual processes imply limited advantages of automation and digitalization. At the same time, findings show that companies have a higher digital technology level on the product side. The boats constitute advanced products with digital equipment and modern state of the art technologies, enabling data capture and analysis of condition and use. These technologies have the potential to improve processes and products, and boat builders also seem to focus more on digital support systems in product development, production and after sales.

Industry 5.0 implies a different technology perspective, where technology could enable sustainability, resilience, and human centricity. In craft manufacturing, it seems like the Industry 5.0 dimensions may be enabled by other means. Even though the investigated companies do invest in modern technology, building capabilities that enable employees to be a driving force towards Industry 5.0 may be even more important. Requirements regarding working conditions, qualification, responsibilities, organisation and involving management, but also cognitive support systems and other digital tools, therefore need further attention.

6 Conclusion

Craft manufacturing still represents an important paradigm in the manufacturing industry. The ability to adapt to customers and the flexibility through well-educated and motivated employees can provide decisive capabilities for competitiveness and survival also in high-cost countries such as Norway. The boat building companies involved in the TEL project demonstrates this ability. The low technological maturity in relation to Industry 4.0 in the investigated companies is to some extent adapted to the context of the companies. Even though the case companies lack profound knowledge of Industry 5.0 as a concept or vision, they still have strong focus on sustainability and resilience. The companies further show high focus on human centricity, which is a particularly important dimension in Industry 5.0. Hence, the companies have prerequisites for setting a course towards and working in line with the Industry 5.0 vision, especially when adopting relevant technology.

Previous revolutions in manufacturing have been based on innovative technology: Industry 1.0, mechanization from steam power and weaving loom; Industry 2.0, mass production and assembly line from electrical energy; Industry 3.0, automation from computers and electronics; Industry 4.0, cyber physical systems from internet of things (IoT) and networks. With Industry 5.0, this technological focus of revolutions may be shifting, representing a uniquely different revolution based on other perspectives than technological that drive major changes in manufacturing.

This research shows how companies in the boat building sector, representing craft manufacturing, have developed strong Industry 5.0 capabilities without adopting advanced digital technologies. These findings from the boat building sector add to the limited body of research on the Industry 5.0 concept. It contributes with further empirical insight into the role of technology and the relation between enabling technologies and the dimensions of Industry 5.0 in craft manufacturing. Furthermore, it contributes to research dealing with craft manufacturing, by a better understanding of the relation between digital technology and Industry 5.0 dimensions in this sector.

The results of this research may be relevant for practitioners, especially managers in boatbuilding companies and other companies within craft manufacturing. The study may help them to better understand the concept of Industry 5.0 and its dimensions, and the role of technological advancement in craft manufacturing settings.

Even though these results are based on limited empirical evidence from a specific industry, they may be relevant for other craft industries. Further research that involves a wider range of craft industries and contexts is however needed. Also, the questionnaire used in this research may be further developed to collect data from a larger sample of companies. The results of this study may constitute a starting point for the further development of a general framework for Industry 5.0 capabilities and digital technologies in craft manufacturing. Also, findings indicate that specific contextual aspects influence the role of digital technologies for building Industry 5.0 capabilities. Further research is therefore suggested that develop further understanding of how digital technology can help to enhance Industry 5.0 capabilities in different empirical settings of craft manufacturing.

Acknowledgements. The Research Council of Norway partly fund this research. We are grateful for the valuable contributions from the reviewers that have helped to improve the paper.

References

1. Kraaijenbrink, J.: What is industry 5.0 and how it will radically change your business strategy (2022). https://www.forbes.com/sites/jeroenkraaijenbrink/2022/05/24/what-is-industry-50-and-how-it-will-radically-change-your-business-strategy/?sh=7402650320bd
2. Lee, J., Kao, H.-A., Yang, S.: Service innovation and smart analytics for industry 4.0 and big data environment. Procedia CIRP **16**, 3–8 (2014). https://doi.org/10.1016/j.procir.2014.02.001
3. n.d.: Human-machine systems. https://encyclopedia2.thefreedictionary.com/Human-machine+systems (2002)
4. Thareja, P.: Manufacturing paradigms in 2010. In: Proceedings of National Conference on Emerging trends in Manufacturing Systems, JMIT, Radaur (2005)
5. European Commission, Directorate-General for Research and Innovation, Renda, A., et al.: Industry 5.0, a transformative vision for Europe : governing systemic transformations towards a sustainable industry. Publications Office of the European Union (2022). https://doi.org/10.2777/17322
6. Zheng, T., Ardolino, M., Bacchetti, A., Perona, M.: The applications of Industry 4.0 technologies in manufacturing context: a systematic literature review. Int. J. Prod. Res. **59**, 1922–1954 (2021). https://doi.org/10.1080/00207543.2020.1824085
7. European Commission, Directorate-General for Research and Innovation: Industry 5.0. https://research-and-innovation.ec.europa.eu/research-area/industrial-research-and-innovation/industry-50_en. Accessed 21 Mar 2023
8. Pacchini, A.P.T., Lucato, W.C., Facchini, F., Mummolo, G.: The degree of readiness for the implementation of Industry 4.0. Comput. Ind. **113**, 103125 (2019). https://doi.org/10.1016/j.compind.2019.103125
9. Müller, J.: Enabling technologies for Industry 5.0 (2020)
10. Markard, J., Raven, R., Truffer, B.: Sustainability transitions: an emerging field of research and its prospects. Res. Policy **41**, 955–967 (2012)
11. Van Kuiken, S.: Tech at the edge: trends reshaping the future of IT and business. https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/tech-at-the-edge-trends-reshaping-the-future-of-it-and-business#/. Accessed 21 Mar 2023

12. Kim, G.-Y., et al.: Human digital twin system for operator safety and work management. In: Kim, D.Y., von Cieminski, G., Romero, D. (eds.) Advances in Production Management Systems. Smart Manufacturing and Logistics Systems: Turning Ideas into Action: IFIP WG 5.7 International Conference, APMS 2022, Gyeongju, South Korea, September 25–29, 2022, Proceedings, Part II, pp. 529–536. Springer Nature Switzerland, Cham (2022). https://doi.org/10.1007/978-3-031-16411-8_61
13. Bousdekis, A., Mentzas, G., Apostolou, D., Wellsandt, S.: Evaluation of AI-based digital assistants in smart manufacturing. In: Kim, D.Y., von Cieminski, G., Romero, D. (eds.) Advances in Production Management Systems. Smart Manufacturing and Logistics Systems: Turning Ideas into Action: IFIP WG 5.7 International Conference, APMS 2022, Gyeongju, South Korea, September 25–29, 2022, Proceedings, Part II, pp. 503–510. Springer Nature Switzerland, Cham (2022). https://doi.org/10.1007/978-3-031-16411-8_58
14. Rolstadås, A., Henriksen, B., O'Sullivan, D.: Manufacturing outsourcing: a knowledge perspective. Springer (2012). https://doi.org/10.1007/978-1-4471-2954-7
15. Paci, A.M., Chiacchio, M.S., Lalle, C.: Production Paradigms Ontology (PPO): a response to the need of managing knowledge in high-tech manufacturing. In: Bernard, A., Tichkiewitch, S. (eds.) Methods and tools for effective knowledge life-cycle-management, pp. 227–240. Springer Berlin Heidelberg, Berlin, Heidelberg (2008). https://doi.org/10.1007/978-3-540-78431-9_13
16. Jovane, F., Koren, Y., Boer, C.R.: Present and future of flexible automation: towards new paradigms. CIRP Ann. **52**, 543–560 (2003)
17. Henriksen, B., Røstad, C.C., Thomassen, M.K.: Industry 5.0 – making it happen in the Agri industry. the core product service platform. In: Kim, D.Y., von Cieminski, G., Romero, D. (eds.) Advances in Production Management Systems. Smart Manufacturing and Logistics Systems: Turning Ideas into Action: IFIP WG 5.7 International Conference, APMS 2022, Gyeongju, South Korea, September 25–29, 2022, Proceedings, Part I, pp. 424–431. Springer Nature Switzerland, Cham (2022). https://doi.org/10.1007/978-3-031-16407-1_50
18. Hein-Pensel, F., et al.: Maturity assessment for Industry 5.0: a review of existing maturity models. J. Manuf. Syst. **66**, 200–210 (2023). https://doi.org/10.1016/j.jmsy.2022.12.009
19. Felch, V., Asdecker, B., Sucky, E.: Maturity models in the age of industry 4.0–do the available models correspond to the needs of business practice? (2019)
20. Mittal, S., Khan, M.A., Romero, D., Wuest, T.: A critical review of smart manufacturing & Industry 4.0 maturity models: implications for small and medium-sized enterprises (SMEs). J. Manuf. Syst. **49**, 194–214 (2018)
21. Schumacher, A., Erol, S., Sihn, W.: A maturity model for assessing industry 4.0 readiness and maturity of manufacturing enterprises. Procedia CIRP **52**, 161–166 (2016). https://doi.org/10.1016/j.procir.2016.07.040
22. Sony, M., Naik, S.: Key ingredients for evaluating Industry 4.0 readiness for organizations: a literature review. Benchmarking: Int. J. **27**(7), 2213–2232 (2019). https://doi.org/10.1108/BIJ-09-2018-0284
23. Henriksen, B., Røstad, C.: Norwegian leisure boats in front (2014)
24. Henriksen, B., Landmark, A., Røstad, C.C.: What product developers really need to know-capturing the major design elements. In: Advances in Production Management Systems. Towards Smart Production Management Systems: IFIP WG 5.7 International Conference, APMS 2019, Austin, TX, USA, September 1–5, 2019, Proceedings, Part II. pp. 447–454. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-29996-5_52
25. Henriksen, B., Røstad, C.C., von Stietencron, M.: Development projects in SMEs. In: Lödding, H., Riedel, R., Thoben, K.-D., von Cieminski, G., Kiritsis, D. (eds.) APMS 2017. IAICT, vol. 514, pp. 193–201. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-66926-7_23
26. The Bay Area Urban Manufacturing Initiative: Transition strategies for your manufacturing business (2021)