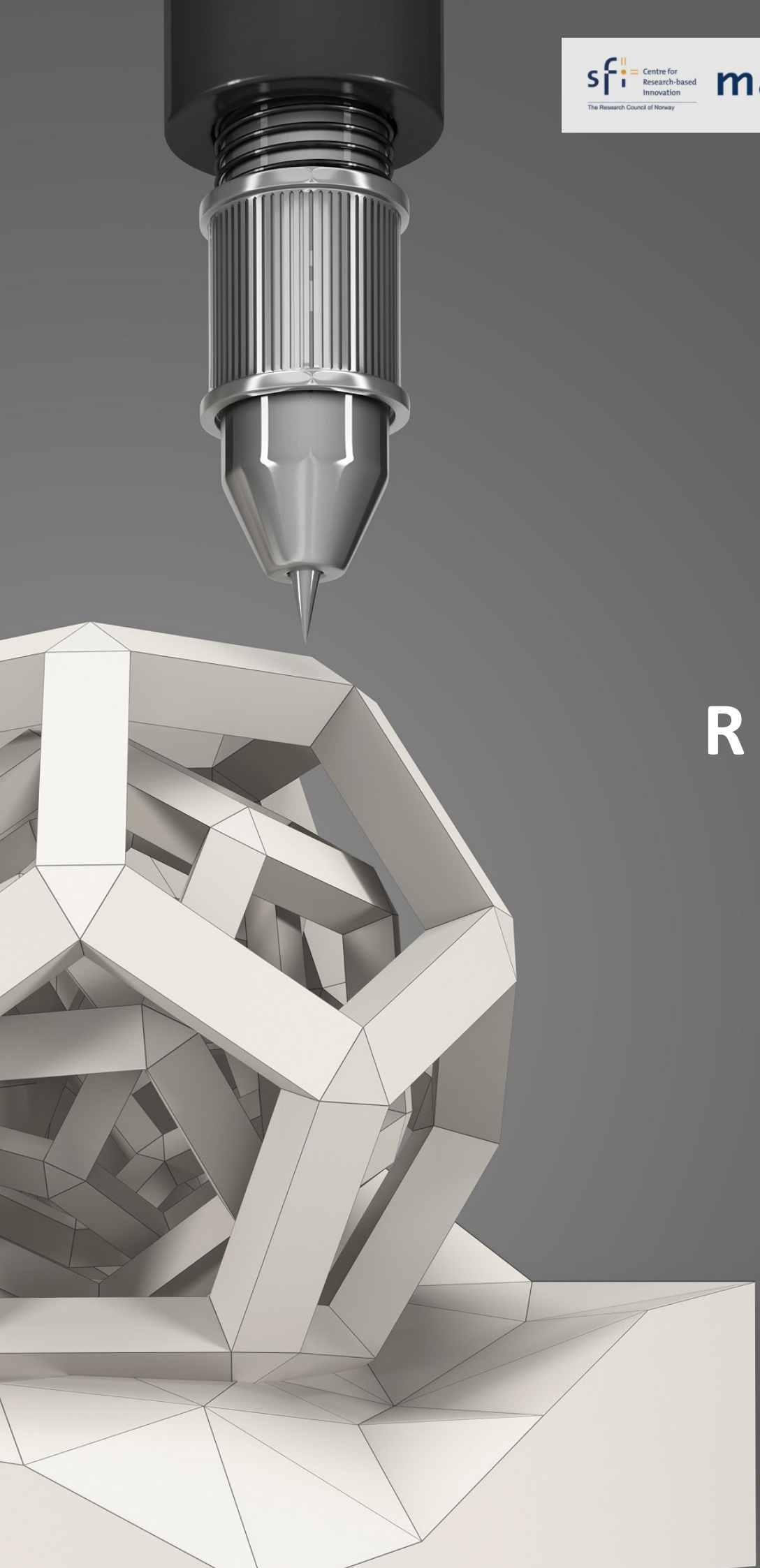
sfi Centre for Research-based Innovation
The Research Council of Norway

manufacturing



ANNUAL REPORT

2022

Welcome to the SFI Manufacturing annual report 2022

A message from the Chairman of the board

One year ago, I was writing in the introduction to the annual report 2021 that we are facing “a number of crises simultaneously.” That statement is for sure still valid and we as a consortium has been able to develop even in these hard times – or perhaps we are developing due to the challenges?

The manufacturing industry has shown during 2022 that we are an integrated part of the national security and our ability to adapt to upcoming challenges is one of our key assets. This ability is based on long term investment in company internal skills and robust networks. In this sense the collaborative research activities of SFI Manufacturing have been a vital input. Building of robust networks is based on multiple levels of collaboration – on institution/company level, on individual engineer/researcher level etc. In order to maintain the role of as an integrated part of national security it is also required that manufacturing is on the national political agenda. It is our intention that SFI Manufacturing, and the continuation of the centre, will contribute to this.

- Lars Stenerud

In this report

What is SFI Manufacturing?

The SFI program

An SFI is a program for industrially oriented research in active cooperation between innovative companies and prominent research groups.

- High potential for innovation and value creation
- Active cooperation between innovative companies and prominent research groups
- High scientific quality of research
- Bridgehead for international cooperation

SFI Manufacturing

SFI Manufacturing builds on existing national capabilities. Our aim is to strengthen the Norwegian manufacturing companies' ability to innovate.

The centre seeks to mirror the inherent cross-disciplinary innovation systems in the industry and combine research on multi-material product solutions, flexible automated manufacturing and organisational processes.

The innovation process itself is a core research topic and SFI Manufacturing strives to be a basis for unleashing innovation potentials and research challenges embedded in the cross disciplinary interfaces, and to develop new research methods.

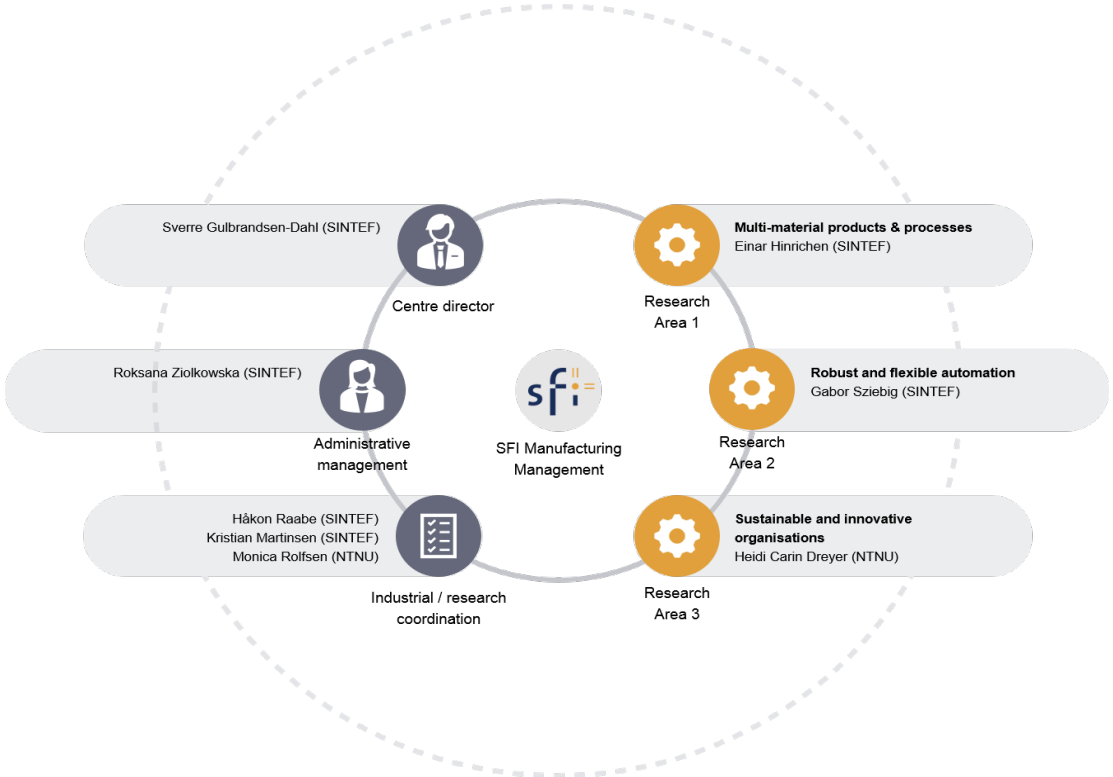
Research and industrial partners

Education and Research: Physics, Materials Science, Cybernetics, Industrial economics and technology management, Geography, Manufacturing

Host institution: SINTEF Manufacturing

Research: SINTEF Manufacturing, SINTEF Industry, SINTEF Digital

Centre Structure



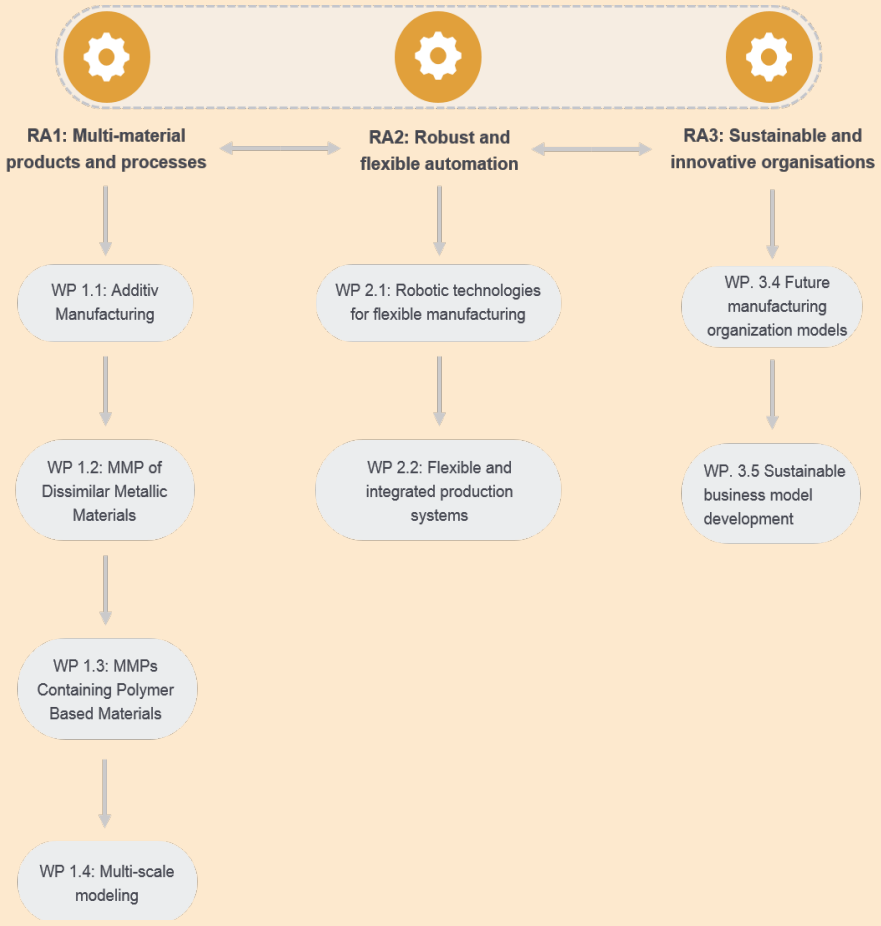
Our research areas

Objectives of the Research Areas

Multi-material products and processes
To develop the ability to optimise material choice, multi-materials geometry, and processes simultaneously.

Robust and flexible automation:
To further develop and link novel technologies and methodologies within automation to support innovation processes and advanced work systems in the manufacturing industries.

Innovative and sustainable organisations
To develop advanced work systems enabling utilisation of new technology and flexible and automated processes to manufacture sustainable multi-material product solutions.



SFI Manufacturing

- Deep in the second half of centre period

During 2022 the activities in SFI Manufacturing have been more back to normal after the most severe pandemic period. However, also this year suffered from hinders on mobility and contact between people in the centre. I will express may sincere gratitude to all industrial partners, students and researchers that have kept a strong spirit during this challenging period.

In spit of the challenges 2022 have been a good year for SFI Manufacturing activities. 3 of our PhD candidates have defended their theses this year – congratulation with your PhD's Linn, Eirk and Anna-Maria. Your work is part of the core of SFI Manufacturing.

Furthermore, with have been back with physical 1-1 meetings with all industrial partners and 2 industrial work-shops in Åndalsnes and Kongsberg. Thank you to the host companies Plasto and Kongsberg Maritime for making this possible and to all the participants for contributing to the activities of the work-shops.

Finally, in 2022 SFI Manufacturing have been active on the political arena regarding support to collaborative industrial research. In April members from the board and administration of SFI Manfuacturing had a meeting with Minister of Trade and Industry Jan Christian Vestre addressing the effect of collaborative industrial research and the need for predictable and strong national support scheme. This topic was followed up on an event during Arendalsuka with members from The Standing Committee on Business and Industry of the Storting (The Norwegian Parliament). The development with the Research Council on 2022 implies that we need to follow these activities also in 2023.

I hope that you will find the 2022 annual report interesting and that we can use the nice results for a strong wrap up of the centre in 2023.

Sverre G Dahl

Report from the Research Areas

SFI Manufacturing aims to strengthen the Norwegian manufacturing companies' ability to innovate, by doing research on multi-material product solutions, flexible automated manufacturing, and organizational processes. In this part of the annual report, we will give an insight into the research highlights that has been done in 2022. In the newsletters, available on the website www.sfimanufacturing.no, more information can be found.

Research Area 1

Multi-material products and processes

In this research area we work towards an integrated understanding of multi-material product design and production processes by focusing on selected scientific challenges in the chain: Material – Process – Structure – Property – Performance. The overall objective is to develop the ability to optimize material choice, multi-material geometry and processes simultaneously. In this work we use a methodology where we combine advanced experimental characterization, experimental studies of production process and both physical simulation and numerical modelling of these.

Up until 2020 the two main topics for this research area have been challenges in joining of dissimilar materials with a special focus on interface region and adhesion, and additive manufacturing of metals and polymers. Based on input from both the Scientific Advisory Board and Mid-term evaluation there has been a focus towards identifying activities in cross-disciplinary topics both between work packages in RA1 and between the other research areas.

The global trend towards sustainability and circular economy thinking will have an increasing influence on product design, including choice of materials. Solutions to this important challenge depends on innovations in all three research areas. Many of the spin-off projects established the resent years, based on the work and challenges discovered in RA1, have sustainability as an important part of the research.

Additive manufacturing highlights

Additive manufacturing (AM) is an important key enabling technology in which the SFI is focusing much research on. However, since AM share many fundamental building blocks with adjacent research areas, -such as materials technology that has much in common with joining technology, and steering and process control have much in common with automation technology, the Ph.D.-, and Post-Doc. -projects related to these topics have been shared between the AM research group and the research group for each relevant topic. In addition to the ongoing Ph.D.-, and Post-Doc. -projects key efforts on AM in SFI Manufacturing have been directed at supporting the adoption of AM technology in Norwegian manufacturing industry. Some of the highlights in this area in 2022 are described in the following.

Developing a Norwegian additive manufacturing interest group: „Norwegian AM Hub“

While there have been many impressive breakthroughs on numerous application areas for AM around the world, the prevailing opinion has been that Norway still is lagging behind the international development, both in Europe and in other Nordic countries. Norway is a small country where AM expertise traditionally has not been regarded as a key priority, and consequently there have been limited access to AM expertise and capabilities in most Norwegian companies. While there is ample access to publications on various aspects on this technology available through internet, the extraction of high-quality information from this requires some level of expertise, or a significant work effort, and finding the right resources is a critical steppingstone for small and medium sized companies as they are beginning to investigate the possibilities of AM technology.

AM technology is in several aspects ground-breaking and could be highly disruptive for product development and design as well as for the entire value chains. A widespread exploitation of the many possibilities of AM requires the development of an entire ecosystem that covers a wide area of competencies and services as well as technical skills and capabilities.

Norwegian AM
ADDITIVE MANUFACTURING CLUSTER, NORWAY

Since it was evident that the lack in coordination and collaboration in this field was hampering the adoption of AM in Norwegian industry, there was a clear consensus that a national business organization and network for AM, -something similar to the Danish AM Hub was needed also in Norway. The initiative for this has to a large extent been driven by Equinor, who has experienced great benefits of AM since they started to study and find applications for the technology in 2017. A conservative estimate from Equinor's "Centre of AM Excellence" in 2021, had concluded that using AM for sourcing and supply of spare parts could save the company around NOK 470 million in 2022, with a potential for much more in the coming years. The planning and discussions on the organization of the Norwegian national interest group for AM started in 2021 and in 2022 the "Norwegian Additive Manufacturing Cluster" (Norwegian AM) was established with members from SFI Manufacturing in the board. A key objective for Norwegian AM is to build networks and disseminate quality information on AM. One important activity for this is the arrangement of an annual national conference on AM, and in March 2023 NTNU and SINTEF will host the first National Conference for Additive Manufacturing arranged by Norwegian AM in Trondheim.

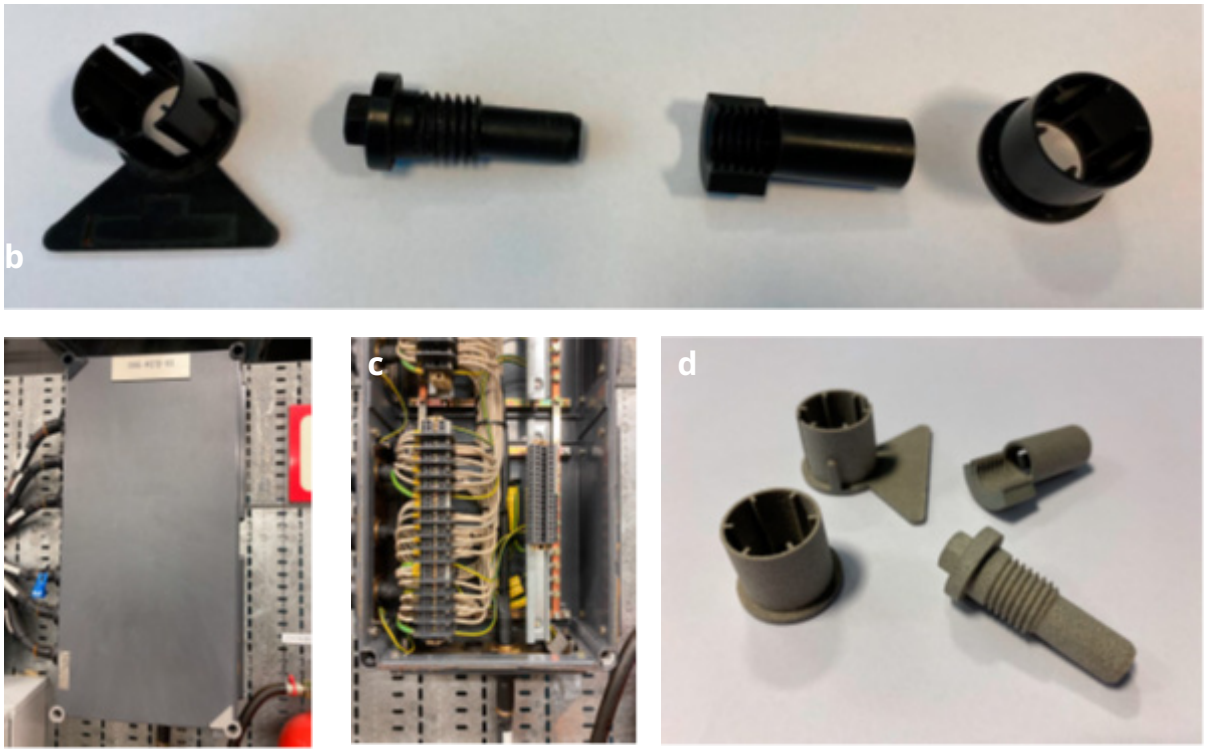


Figure 1: Spare parts for a switch cabinet: the original locking screws (a), positions in the cabinet (b & c), and the spare parts, manufactured by PBF-LB/PA12 (d). (Images provided by courtesy of Equinor and Karsten Moholt)

Dissemination activities: Publication of information material on AM for industrial need

In order to address the difficulties to find and identify good quality information on AM in an industrial context for people with limited experience, SFI Manufacturing in collaboration with dedicated internally funded projects, has published a 32-page brochure, “Additiv tilvirkning for norsk industri” (in Norwegian) and a 15-page report on „Smart spare parts management“ (ISBN 978-82-14-07909-8, in English).

The „Additiv tilvirkning for norsk industri”“ brochure covers an overview of key advantages and considerations for metallic AM processes for industrial applications, together with examples of successful use-cases and various aspects regarding industrialization. The “Smart spare parts management“ report focus on the use of AM for sourcing of spare parts with respect to the digital basis and inherent flexibility and versatility of this technology.

Initiation of a joint effort to develop an ontology for additive manufacturing technology

The ongoing activity in development of international standards in AM has brought the publications of the second edition of the international standard for AM terminology: ISO/ASTM 52900:2021 Additive manufacturing – General principles – Fundamentals and vocabulary. Based on a unique collaboration between the two largest organizations for international standards development, the first edition of this standard was the first standard that has been jointly developed between ISO and ASTM International.

It is also accepted by CEN/CENLEC as a European standard and thus by default the national standard for all member countries, -including Norway. This document is thus globally recognized as the source of authority for reference of terms and definitions as well as fundamental concepts for AM technology.

To make this standardization effort accessible and interpretable by machines as well as humans will be an important step towards the development of an AM-enabled digital manufacturing workflow.
Therefore, a joint activity between WP1.1 “Additive manufacturing” and WP1.4 “Multi-scale modelling” in SFI Manufacturing have expressed this standard in the form of a Domain Ontology for Additive Manufacturing (DOAM). The concepts in the ISO/ASTM 52900 standard are categorised thematically (as sub-sections) and grammatically (adjective/noun/participle/verb).

The ontology introduces a new categorisation based on what these concepts are. For example, the concept AdditiveManufacturing is a subclass of Process. In total, 7 new generic concepts, so-called bridge concepts, were introduced, including: Data, Equipment, EquipmentPart, Material, Process, Property and Role. These bridge concepts are well defined in an existing top-level ontology for applied sciences, the Elementary Multiperspective Material Ontology (EMMO)1.

This connection to the EMMO top-level ontology has several benefits.

Most importantly it provides a sound theoretical foundation based on first order logics that is shared with other domain ontologies for materials. This allow connecting modelling of AM processes with the modelling of alloys in physical metallurgy. This has brought the initiation of a cross-disciplinary collaboration between the expertise in AM fundamentals and terminology and the expertise in ontologies and multi-scale materials modelling with the intention to develop the basis for a generic ontology for processing and materials in AM technology.

The first version of the DOAM ontology has been released publicly available on GitHub2.

Framework for design in multi-material additive manufacturing

In a SINTEF internal project, we have developed a framework for process and material design for multi-material additive manufacturing based on a combination of experimental and numerical modelling methods.

In a SFI Manufacturing workshop in 2022, we presented this framework with the title „High-throughput materials discovery – A framework towards sustainable material development“, which will be valuable for sustainable material development and is becoming more and more important for circular economy and green manufacturing.

The flowchart of the developed framework is shown in Figure a:

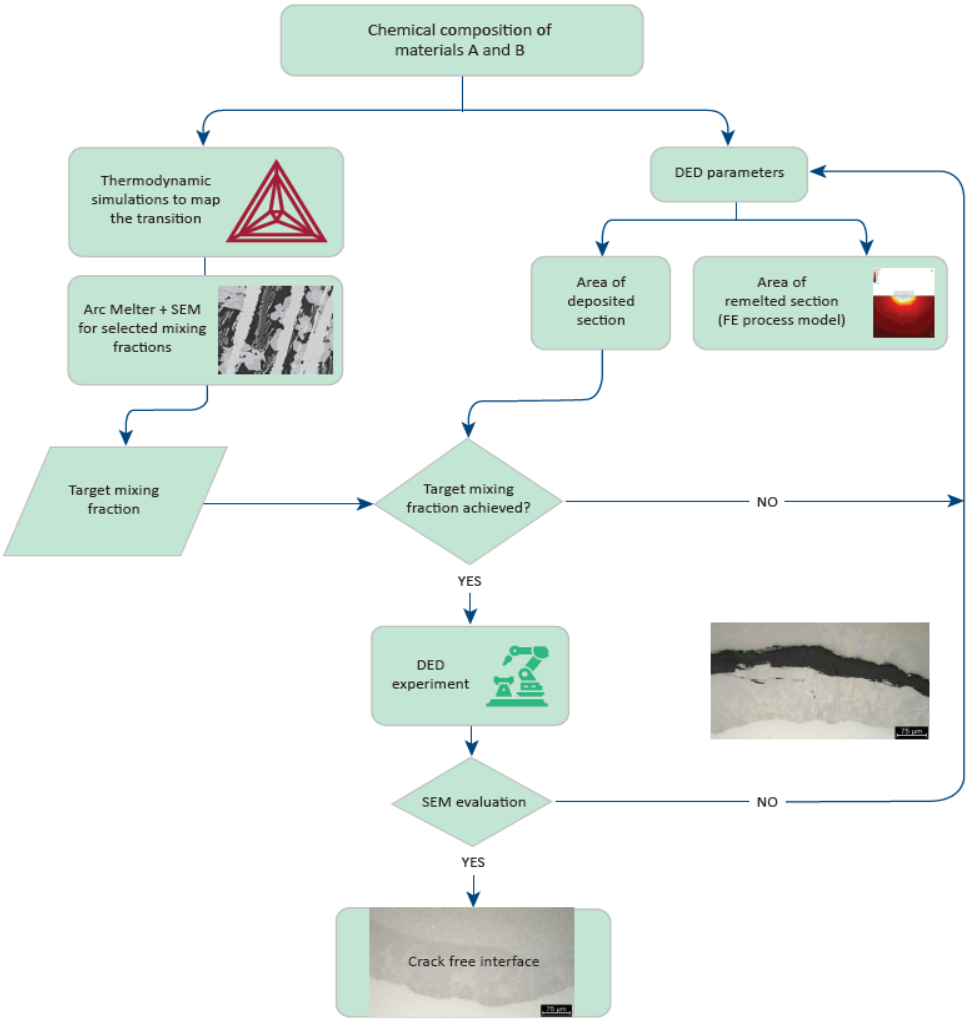


Figure a: The flowchart of the developed framework

Joining of dissimilar metallic materials

Joining, as a key enabling technology for manufacturing of multi-material products, has been focused from the very start of SFI Manufacturing. Different welding methods for joining of dissimilar materials have been in focus of our research, e.g., roll bonding method, cold metal transfer (CMT) welding and the HYB technology. In 2022, AM for joining dissimilar materials has been focused, mainly through PhD and Postdoc work.

Postdoc Ding Peng has completed his work in the SFI Manufacturing center on additively manufactured multi-material components. We are now working on a manuscript to publish the results from his work.
PhD student Håkon Linga focused on microstructure and in-situ microtomography of interface between additively manufactured aluminium bronze and H13 tool steel.

The results have been published in the proceeding of the Risø Symposium on Material Science. An interesting work on laser beam remelting of scrap stainless steel for cladding and its comparison with the CMT welding process has been submitted for publishing.

The paper contains extensive study on process parameter development, numerical simulation, microstructure investigation and corrosion testing. The paper is expected to be published in 2023.

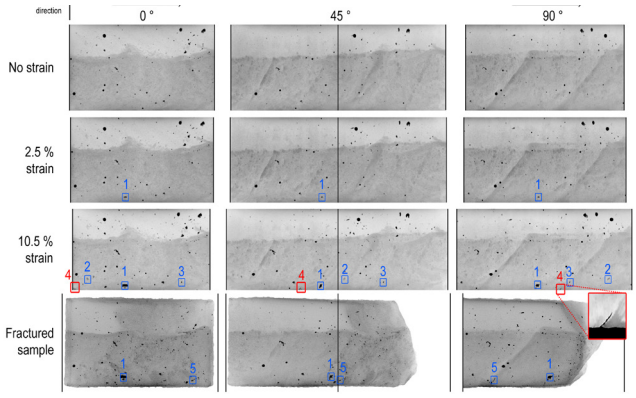


Figure. Minimum intensity projections at various strains and projection angles. X-ray microtomography can clearly show evolutions of pores and initiation of defects with increasing loading.

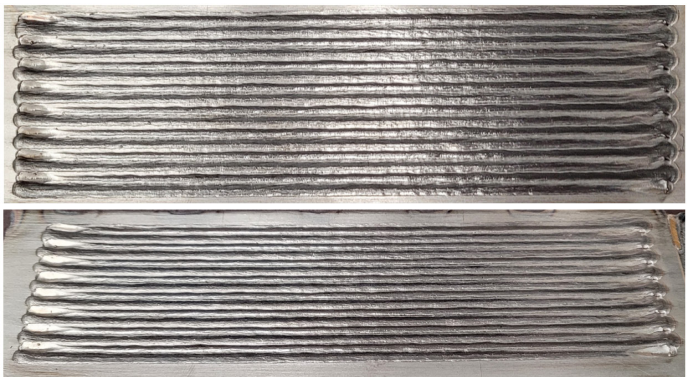


Figure: An example of melt track appearance by laser.

Degradation and ageing of composite products

PhD candidate Chaman Srivastava (NTNU, 2019-2023) continues his work on analysing the degradation processes which occur during the aging of composites products.

Chaman has focussed on physical and chemical characterisation of composites which have been exposed to a number of different environments which real composite parts might be expected to experience during their service life, such as extremes of temperature, cycles of strong sunlight and hot and cold water exposure.

These environmental factors may affect the polymer matrix of fibre reinforced composites, resulting in a reduction in the fibre matrix interface strength, and so reducing composite performance over time.
By collecting data on a range of variables and characterising the changes in performance of large numbers of samples, models are developed to predict failure processes of composite parts in real environments

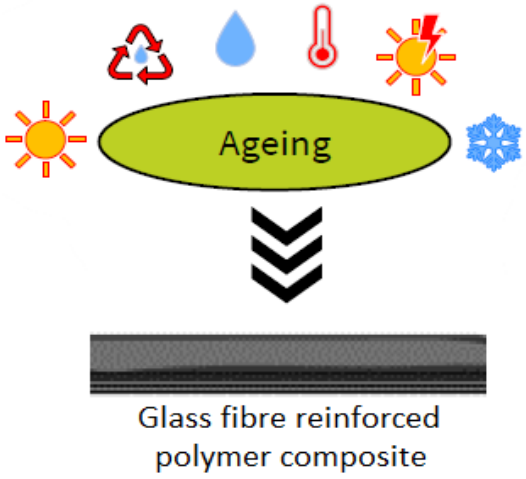


Figure: Chaman Srivastava has investigated the effect of different aging parameters on the properties of glass fibre

Additive manufacturing of composite parts: Continuous Filament Fabrication

Continuous Filament Fabrication (CFF) (or AM with continuous fibres – CFAM) is a process that fuses continuous fibre filaments encased in a thermoplastic matrix to create complex-shape composite parts, including hybrid designs with fibre reinforced features and thermoplastic-only infill. This is a new and promising technology for Norwegian industry targeting the production of complex-shapes, high-performance components previously relegated to metals (e.g. mounting brackets, production tooling, customized medical devices). Thermoplastics reinforced with continuous fibres (e.g. glass, carbon or Kevlar) render possible properties that far exceed those of the unreinforced polymers and surpass the stiffness- and strength-to-weight ratios of lightweight alloys.

Thermoplastic composites are also far more recyclable than composites based on crosslinked thermosets, since they can be melt processed at end of life. However, the technology also faces challenges that must be address: The AM process can generate various material defects, namely poor fibre-matrix bonding, porosity, fibre waviness and polymer rich regions that are aggravated by increasing geometric complexity. We have studied this process in detail to develop experimental

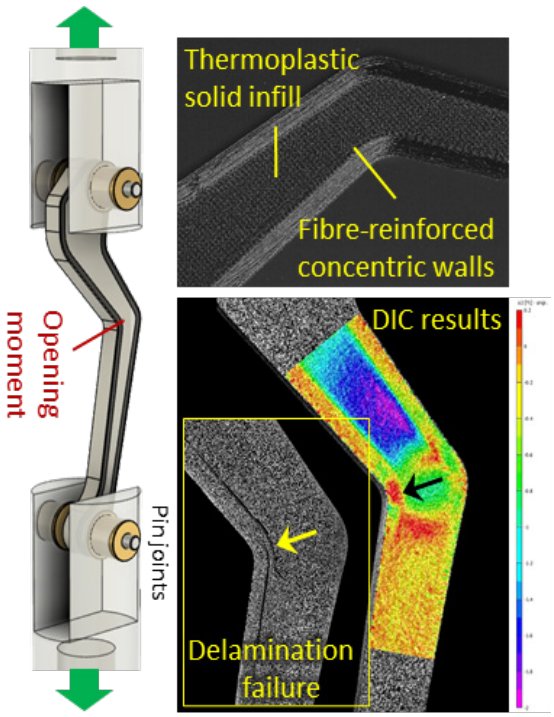


Figure: Lever demonstrator test testing properties of a complex shaped product.

Mechanical performance of thermoplastic elastomers for two-component injection moulding

PhD candidate Anna-Maria Persson (NTNU 2017-2021) passed her defense in November 2022. Anna-Maria has researched the performance of multimaterial components comprising an injection mouldable thermoplastic elastomer, combined with a harder thermoplastic substrate.

PhD candidate Anna-Maria Persson (NTNU 2017-2021) passed her defense in November 2022. Anna-Maria has researched the performance of multimaterial components comprising an injection mouldable thermoplastic elastomer, combined with a harder thermoplastic substrate. Since both components can be melt processed, this enables two component injection moulding – complex multimaterial parts can be manufactured in a single automated process, reducing manufacturing time and costs. their service life, such as extremes of temperature, cycles of strong sunlight and hot and cold water exposure.

Being able to melt these polymers also opens up more routes for recycling, simplifying the end of management of the materials at the end of the application life. One possible drawback of these melt-processable materials is that they can be sensitive to temperature, and so the mechanical properties of these materials was investigated at different temperatures; as with most polymers, the higher the temperature, the softer they become (see figure). Therefore, it is important to understand how this softening affects applications which might experience high temperatures (for example in automotive applications)

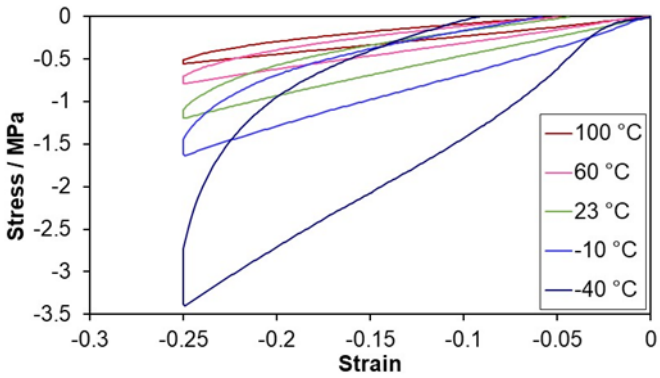


Figure: The effect of temperature on the compressive stiffness of one of the elastomers in Anna- Maria Persson's PhD study. As temperature increases, the elastomer becomes softer.

Research Area 2

Robust and flexible automation

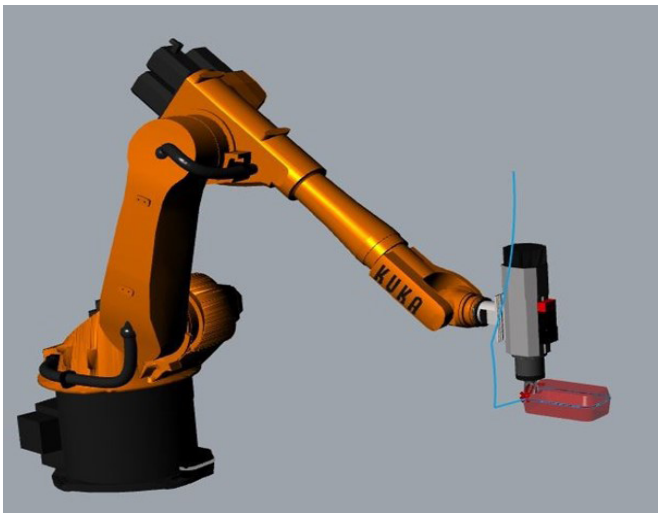
The research area Robust and Flexible Automation concerns new ways of automation and robotics in manufacturing systems. The overall objective is to further develop and link novel technologies and methodologies within automation to support innovation processes and advanced work systems in manufacturing industries.

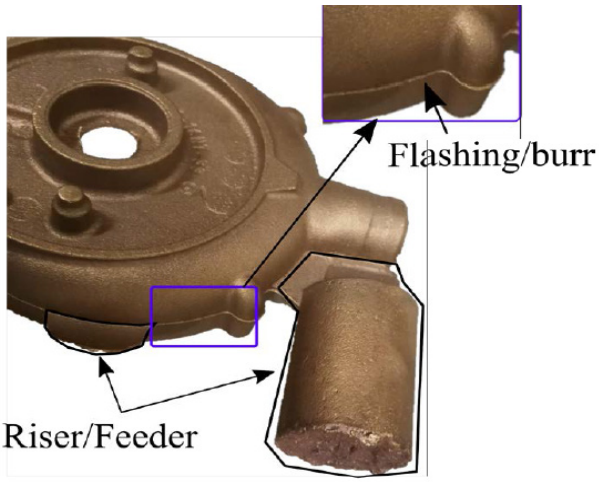
Novel automations technologies and methodologies, and smart integration of those, open new ways to use automation and robotics in manufacturing systems. Within this research area we focused on bin-picking, safe and efficient motion planning in dynamic environments, „batch size one“ robotic assembly, robotic flexibility in additive manufacturing, and effective and safe development of robotic assembly processes. Several of these challenges also link to the other research areas within the SFI.

The research area 2 has been focusing on publishing journal articles, which are highly renowned in the manufacturing discipline. One article has been published in Journal of Intelligent Manufacturing (IF: 7.136, Level 2 in NSD) and another one in Systems Engineering (IF: 2.034, Level 2 in NSD). Researchers, PhD‘s and Postdoc‘s has been active on all industrial workshop hold in 2022, where the research area 2 has contributed to all workshops.

3D vision-based registration and burr detection

Ingrid F. Onstein, Marianne Bakken, Ahmed Kedir Mohammed.





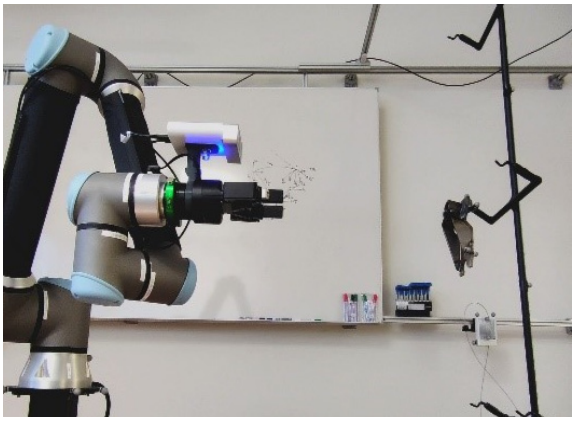
RGB-D scanning and reconstruction have advanced significantly in recent years, thanks to the growing availability of commodity range sensors like the Zivid, Microsoft Kinect, and Intel RealSense. State-of-the-art 3D reconstruction techniques can now capture and recreate real-world objects with astonishing accuracy, spawning a slew of possible applications including manufacturing artifact detection, content production, and augmented reality.

Due to geometric incompleteness, noise, and uneven shrinkage and deformation during the production process, such breakthroughs in 3D scan reconstruction have remained limited to certain usage situations.

In particular, there is a notable limitation in matching 3D scans to clean, sharp 3D models for quality control.

Ingrid F. Onstein is working on automatic deburring of cast parts with industrial robots. The first step in this process is to get a 3D representation of the actual workpiece to be deburred, represented as 3D mesh. This mesh will be used in an automatic tool path planning system for robotic deburring that has been developed. An initial test of the system has been performed on an industrial robot.

Tracking, loading- and unloading of overhanging trolleys, Martin Brandt, Klaus Ening, Esten Ingar Grøtli



Loading and unloading of overhanging trolleys are common tasks for instance at spray painting facilities. They are often manual and can therefore constitute a large cost to the manufacturing industry in Norway.

Furthermore, the tasks are tedious and can pose significant health-related issues. Our automated solution consists roughly of 1) object pose prediction and velocity estimation, 2) real-time trajectory generation for the robot manipulator arm, and 3) robot trajectory tracking and gripper commands execution. The current solution uses a marker-based real-time motion capture system to measure the position and orientation of the objects but we will in future work aim to replace this with a CAD-based object-tracking method.

Ongoing RA2 PhD/post-docs:

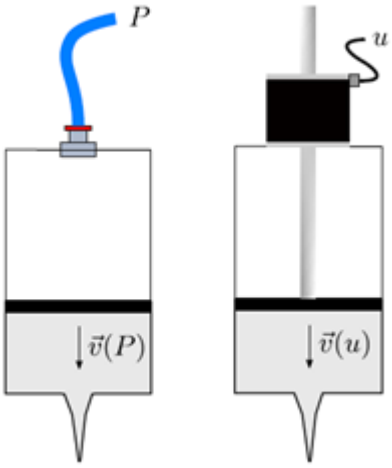
PhD: Ingrid Fjordheim Onstein (started August 2019)

„Deburring Using Robot Manipulators“,

Glue dispensing

Morten Lind

The main problem is the formation of bubbles embedded in the sealant. Some gas inclusions (bubbles) are large enough that they leave stretches depleted of sealant in the laid string in the joint. In today's manufacturing process the string is inspected and re-worked manually by a dedicated operator. The origin of the bubbles is not known.



Mobile, robotized assembly

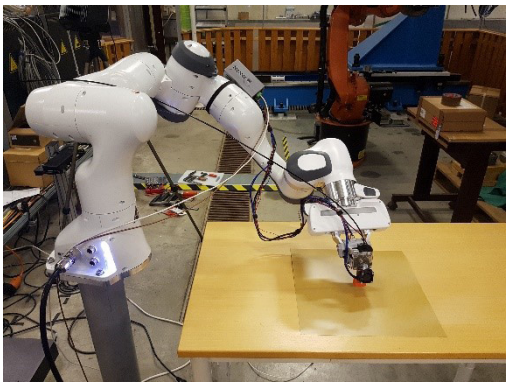
Eirik Njåstad

Handling and towing winches for vessels are typically manufactured in only a few variants but several hundred units per project. The logistics involved are considerable for each project, with components being sent around the world to undergo various assembly operations and processing. Together with Kongsberg Maritime, we are conducting an introductory study on the feasibility of modular and robotic production lines for winch assembly that can be transferred and put into operation for production and automated assembly at yards worldwide.

The production lines are packed down and sent to the next yard when a project is completed. Such a manufacturing concept requires robotic production lines that easily can be configured and set up quickly, with just as easy and quick disassembly. The motivation is to reduce the considerable amount of logistics, reduce the lead times, the cost of tied-up capital, and reduce the impact on the environment.

Plastic 3D print, robotized additive manufacturing

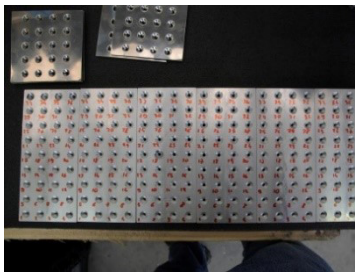
Mathias Huan Arbo, Alexander Waller Johnsgaard

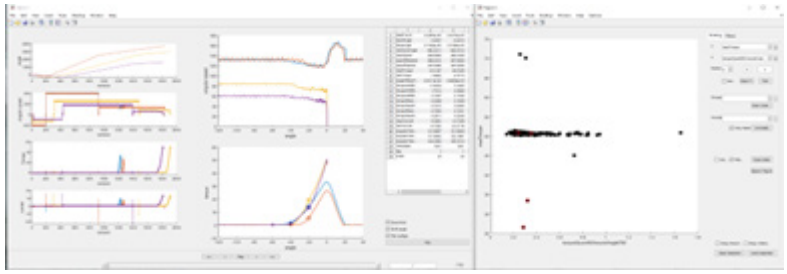


The research on additive manufacturing with robot manipulators is continued by Alexander Waller Johnsgaard, a master student working on fused filament deposition using the Franka Emika cobot. With the new hybrid manufacturing lab at Valgrinda, we will also explore direct energy deposition and feedback control with summer students that will continue with a master thesis on the topic.

Learning based evaluation of robotic screwing

Andrej Cibicik, Johannes Tjønnås





Identify the physical parameters and the main mechanisms of the screwing process. The main questions to be answered by the experiments: Can the knowledge be used in an online setting to predict „optimal“ target torque/ clamping force based on the estimates of the particular screw yield point? Can the knowledge be used to identify new features and quality measures for the screwing process?

Research Area 3

Sustainable and Innovative Organisations

This research area concerns organisational and innovative sustainability aspects of advanced manufacturing companies. The overall objective is to develop knowledge and solutions for advanced work systems that are able to utilize new technology and flexible and automated processes to manufacture sustainable multi-material products.

“Industry 4.0 and circular economy – what’s really going on in the Norwegian manufacturing industry?”

The aim of the study was to dig deeper into how the two concepts, Industry 4.0 and circular economy, influence the strategies and decisions of Norwegian manufacturers and how they navigate a landscape which from the outside seems to undergo substantial change, both in terms of the implementation of new technologies and increased focus on sustainability. To understand the journey that Norwegian manufacturers have been and still are on, we were eager to understand what manufacturers have done in the last decade, what they currently were doing, and what they aimed to do concerning technology investments and efforts to improve the environmental impact of their production and products. The study has resulted in to book chapters.

The first chapter titled “Phasing the barriers to Industry 4.0: Linking implementation stages and barriers”, aims to provide a better understanding of the different implementation barriers that manufacturers face when moving towards the Industry 4.0 vision. While earlier studies have listed different barriers, this chapter uses the different stages of a digitalization process as a framework for further detailing how different barriers are prevalent at different phases. Using data from the interviews, a total of 62 phase-specific barriers are presented in the chapter. We argue that by focusing on phase-specific barriers, rather than more generic barrier groups, more understanding of the potential challenges can be obtained, and manufacturers can be better prepared to face these and develop effective roadmaps and strategies for digitalization.

The second chapter entitled “Environmental upgrading and the notion of power: a case study of Norwegian manufacturers”, digs into the topic of environmental upgrading, meaning how companies in global value chains can reduce the ecological footprint of their operations. The paper argues that the studied Norwegian manufacturers’ possibilities for environmental upgrading are shaped by existing power relations within the global value chain they are part of, and their relationship with their suppliers and customers.

We find that Norwegian manufacturers, most of whom are suppliers in global value chains, have limited possibilities to improve the environmental footprint of their products and how these products are handled at the end-of-life, as they are not in a position to change the design of and/or the material inputs that go into the products manufactured. However, environmental upgrading concerning production processes, e.g. through reducing energy consumption or recycling of in-house scrap, is possible as these can be done without the involvement of other value chain actors.

Preparing manufacturing clusters for grand challenges

A study on manufacturing cluster development from various perspectives. One study focused on the role of vocational education in preparing for technology upgrading in manufacturing clusters. A more recent study pays attention to the role of intermediaries in enhancing cluster absorptive capacity. A more longitudinal study focuses on the role of state agency in path development or the same manufacturing clusters.

All these studies give insights into how manufacturing cluster could develop and enhance their knowledge and technologies, so the cluster firms are able to stay competitive and prepare for grand challenges. These insights are particularly relevant for the twin transformations of digitalization and sustainable development in manufacturing industry.

Realising zero-waste value chains through digital twin-driven S&OP

Nearly one-third of the world's food supply is wasted every year because it is not sold in time. Predictions put the annual amount of food wasted around the world at 1.6 billion tons, with that number expected to rise to 2.1 billion tons by 2030. While food waste occurs throughout the value chain, it is most easily prevented and managed at the retail level in developed countries. Sourav and Heidi's research advocates proactively preventing and reallocating food surplus rather than reactive waste management and circular approaches like landfilling, incinerating, or recycling waste as byproducts.

The research introduces and elaborates on the notion of digital twin technology-driven S&OP to predict and detect variabilities across the value chain and, in turn, to prevent and reallocate food surplus and balance demand and supply with an emphasis on zero waste. Digital twins enable supply and demand visibility, real-time planning ecosystem monitoring, and what-if analysis to predict variations and consequences. The research builds on the concepts and strategies of zero-defect manufacturing and extends this zero-waste mindset to food value chains. This paves the way for a new line of research at the intersection of zero-defect manufacturing, value chain variability, waste management, and Industry 4.0 technologies.

The role of adaptable S&OP in the era of Industry 4.0

A study which explore employing the dynamic capabilities perspective, the concept of adaptable S&OP is introduced as a response to the persistent and growing uncertainties stemming from shifting sources and amplified by disruptions that contribute to planning nervousness. The research reveals how the facilitative and empowering roles of I4.0 technologies can be leveraged for adaptable S&OP in both a developmental and transformative manner.
As a result, an integrative framework was developed to classify industry 4.0 functionalities in planning as „low hanging," „immersive," „pioneering," and „far-fetched."

The future need of shop floor competence

A study about the future need of competence at shop floor - enabling intelligent machines, products, and human being exchanging information with each other in a successful way. In short, the future focus should be closely related to the link between a digital strategy prioritizing forthcoming digital technologies for the company and the respective need for reskilling and upskilling for technical professions and operators at shop floor level

Workshops series

A workshop series has been performed this year. The first workshop in February was held by Eirik Bådsvik Hamre Korsen hosted at NTNU Gjøvik with the main topic - business management, digitalizing, and sustainability. The second workshop was arranged in November with a collaboration with the national research project Smartlog and iKuben Molde.

A presentation about Human Centric Operations and digital enhanced operator was held by Emrah Arica. The last workshop was held at Orkanger in desember and hosted by Thamsklyngen and Thams Innovation. The main topic was about circular economy in Norwegian Industry. Two business cases were tested with the aim to deepen and explore circular proposition with use of a circular business model proposition canvas.

PhD school activity

The Ph.D. school forms an essential part of SFI manufacturing with PhDs and Postdocs from diverse research backgrounds and interests. After being nominated as a coordinator for the Ph.D. school, I conducted a survey in May 2022 to gauge what activities would be of interest and relevance to the PhDs and Postdocs in the school. The survey result pointed out several interest areas including “learning more about the wicked problems in the industry”, “developing soft skills and creative research presentations”, and “Podcasts and cross-research area discussions”.

After a follow-up meeting during the SFI workshop, we organized our first formal engagement in August taking up the most popular response - “the wicked problems”. This involved a socializing dinner on the 18th of August followed by an engaging half-day seminar on the 19th by Ole B Hoen on (a) wicked problems in the industry – around robotics, circular economy, and digitalization, and (b) overcoming challenges in industry-academia collaborations. business model proposition canvas.

Sourav Sengupta

Postdoc, SFI Manufacturing (2020-2023) Norwegian University of Science and Technology

I started my postdoc position at SFI Manufacturing in August 2020, in the midst of the Covid 19 pandemic. My research naturally turned to a major problem that most companies were having, which was the emerging and growing uncertainties and challenges in effective supply chain planning. I mostly look at how sales and operations planning (S&OP) powered by industry 4.0 technologies can help businesses deal with the growing uncertainty and sustainability problems of today.

In one of my ongoing studies with Heidi, we introduce the notion of adaptable S&OP to address the continuous and growing uncertainties against the traditionally rigid and efficiency-focussed S&OP and thereby, point to a need for a paradigm shift in S&OP research. The study employs a novel research approach in which managers from six partner companies participate in an integrative review process that includes three reflective workshops. The methodology developed in this research contributes to the emerging discussions on industry-academia knowledge cocreation, review research, and engaged scholarship.

The research findings indicate a need to develop an adaptable S&OP where looser constraints on resources and capacities are made possible by the smart categories of industry 4.0 enablers contributing to the interaction of the dynamic S&OP capabilities of acquisition, assimilation, and accommodation. What differentiates adaptable S&OP from traditional is the ability to manage the planning paradox of stability and dynamics by combining the rigid and formal tactical level S&OP approach with dynamic industry 4.0-enabled capabilities as one integrated multi-level planning system. Problematizing the assumptions and boundaries, we further look to elaborate on future research directions within the new paradigm of adaptable S&OP.

Meet the next generation scientists

Research area	Name
RA1 - Multi-material products and processes	Siri Marthe Arbo Tina Bergh Muhammad Zeeshan Khalid Anna Maria Persson Chaman Srivastava Håkon Linga Ding Peng
RA2 - Robust and flexible automation	Mathias Arbo Linn Danielsen Evjemo Ingrid Fjordheim Onstein Andreas Molturmyr Signe Moe Tamal Ghosh
RA3 - Sustainable and innovative organisations	Henrik Brynthe Lund Marit Moe Bjørnbet Vetle Engesbak Eirik B. Korsen Assiya Kenzhegaliyeva Amalie Lystrup Østhassel Sourav Sengupta

Industrial Coordination

Three physical workshops

Finally seeing the end of restrictions due to the Covid-19 pandemic, we were able to host all three workshops in 2022 as physical meetings.

The first in April was held at Sanner Hotel at Hadeland with Hapro as host industrial partner. Close to 60 participants – nearly half from industry – got started the first evening with two thought-provoking presentations from Nammo and Hexagon on the geopolitical changes and consequences for industry. The main day addressed planning and logistics in global supply chains (RA3) and flexible, adaptive robotic production and assembly (RA2). Hapro gave us an introduction to their operations before a thorough factory tour provided prime insight on flexible and efficient electronics manufacturing. Group discussions and feedback to host partner Hapro concluded the workshop.

The second workshop in June saw close to 60 participants gathering in Åndalsnes with Plasto (and invited company Wonderland who shares top manager with Plasto as host partners. The evening session included a discussion around "life after SFI Manufacturing" and a "Green Platform" project as a possible way forward. A breath-taking ride with 'Romsdalsgondolen' took us up to Nesaksla for a 'dinner with a view'. Some even hiked down again in beautiful early summer evening light. The main day comprised lectures on circular manufacturing and business models (RA3) including researchers' perspectives on Plasto's 'circular journey in the aquaculture and other sectors.

Next up was the topic of sustainable, recyclable materials and products (RA1) before we got introductions to the two factory visits. Plasto shared their story on innovation and research that is increasingly driven by sustainability improvements. Wonderland shared input from their ongoing sustainability project aiming to reduce the environmental footprint of a continental bed by 50%. We got to see both factories as well as the Wonderland showroom before a brief wrap-up session concluded the workshop.

In late September we gathered at Kongsberg with Kongsberg Innovasjon and Kongsberg Group (KOG) as hosts. 40 participants – again close to half from industry – heard about Smart Spare Part Management before discussions continued at a joint dinner at the 1624 Restaurant. The main day first centred on different aspects of additive manufacturing (AM), including presentation from both RA1 and RA2. We got two industrial presentations on AM from Equinor and Kongsberg Innovasjon, before we moved on to 'Arsenalet', the site for aircraft components manufacturing in Kongsberg Defence & Aerospace (KDA). A very interesting tour of the factory was followed by short presentations from KOG and KDA and a Q&A session.

The effects of the pandemic slowing down was followed by Russia's invasion of Ukraine in February causing even more disruptions in manufacturing supply chains. Effects for our industrial partners vary a lot. Standing out is the sharp rise in demand for defence products as seen by Nammo as well as KDA and these companies were presented at the first and last workshop this year. So far, we now have had 25 industrial workshops with more than 1400 participants in the project period.

1-to-1-meetings and case work for the industrial

The 1-1 meetings with the industrial partners in the first half of 2022 were again held as physical meetings at our partners' home locations. In SFI Manufacturing we think this is a key activity to understand the challenges facing our industrial partners.

Several companies had ideas/needs for new spin-off projects and despite a drastically reduced rate of granted vs applied projects from the Research Council in 2021, several applications were filed in 2022 and some new projects approved as well.

Furthermore, the SFI carried out follow-up activites with several of the companies with respect to case work or other centre activities. Topics has included testing of AM for customer specific dissimilar materials, automated assembly, movable and modular production/assembly lines and LCA considerations, to mention some – in sum spanning all

Plenary session at Sanner Hotell, Hadeland, April -22

Nammo presentation by Fredrik Tangeraas at Sanner Hotell, Hadeland, April -22

Hexagon presentation by Skjalg Stavheim at Sanner Hotell, Hadeland, April -22

Hapro presentation by Jens A. Martinsen at Sanner Hotell, Hadeland, April -22

View from Nesaksla over Romsdalen and Øran industriområde, Åndalsnes, June -22

Active discussions during workshop at Åndalsnes, June -22

Runar Stenerud showing aquaculture products made from recycled material at Plasto, June -22

Automated mattress assembly line at Wonderland, June -22

Visit at the Wonderland showroom, June -22

Kongsberg Innovation presentation by Ole Hoen, Kongsberg, Sept. -22

Smart Spare part Management presentation by SINTEF Manufacturing, Kongsberg, Sept. -22

Equinor presentation by Petter Grue, Kongsberg, Sept. -22

International research collaboration

International collaboration in the SFI has been hampered by the global Covid-19 pandemic in 2022 as well although less than previous year. The activities have mainly been in the INTPART international partnership projects, attending CIRP and Manufuture meetings.

INTPART international partnership projects

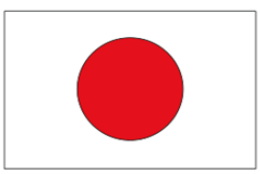
SFI Manufacturing has been a partner in a International Partnership (INTPART)-project CIRMAN ; Circular Manufacturing research and educational collaboration with India and Japan. Read more at the project website: https://www.ntnu.no/ivb/cirman1.

The CIRMAN -project is a continuation of the previous INTPART-project called INMAN: Intelligent Circular Manufacturing research and educational collaboration with India and Japan, with the same partners:

- NTNU, SFI Manufacturing (Norway)
- Waseda University and National Institute of Advanced Industrial Science and Technology (AIST) (Japan)
- And Indian Institute of Technology (IIT) (India)

On the Norwegian side also SFI Norwegian Centre for Cybersecurity in Critical Sectors (NORCICS) is added as partner. CIRMAN build upon INMAN with the main objective of the to develop world-class research and education in Norway within the area of Circular Manufacturing through long-term international partnerships. The plans include developing common research agendas and research funding proposals, joint seminars and educational programs, mobility of students and researchers and cooperation with businesses in Norway, Japan and India. Research topics will focus on circular manufacturing, remanufacturing, and the establishments of life-cycle digital twins useful for EOL-decisions.

The CIRMAN-project will broaden and deepen the strategic collaboration established in INMAN, and integration of business enterprises such as the SFI consortium is an important asset, both for research activities, to foster exchange of research results and technology transfer as well as to link Norwegian industry with the industry in Japan and India. The mobility program in the project will be offered industry partners as well as academic partners. Yearly summer schools alternating between the three countries will be open for students from all countries.

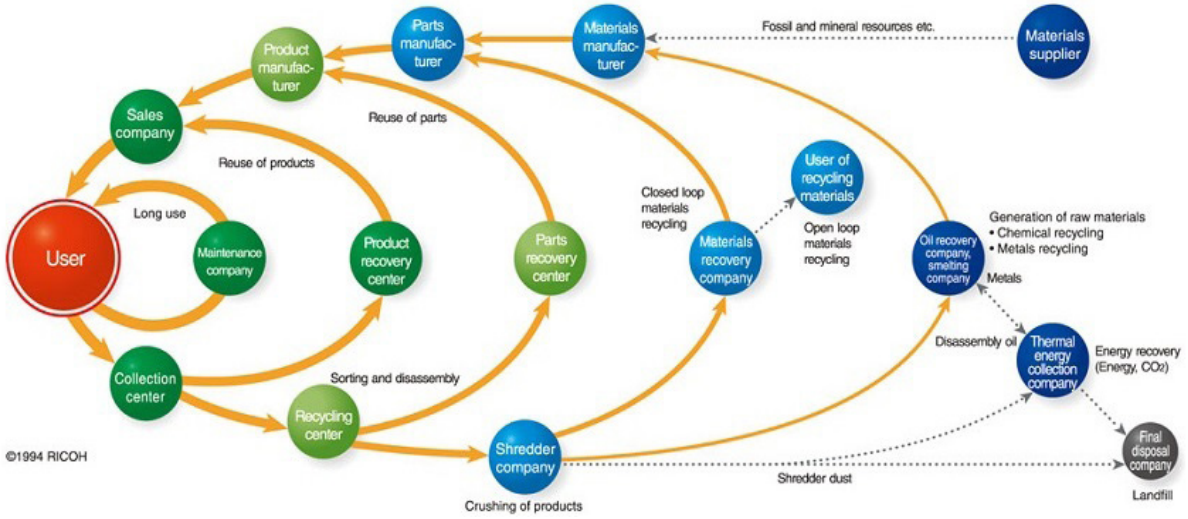



Figure 1. The Ricoh comet circle. www.ricoh.com

Furthermore is SFI Manufacturing partner in an other INTPART project called MAVIS: Industry 4.0 and Management of Variations in a Sustainable manufactured product life cycle.

This proejct has similar main goal as INMAN and CIRMAN: To develop world-class research and education in Norway, through long-term international partnerships. MAVIS focus on how digitalization can be useful, create better products and contribute to UN SDGs, industry 4.0 and how IoT and cyber-physical systems can be useful to manage the inevitable variations in manufacturing of products, the product life cycle and at the end-of life/ reuse / remanufacturing.

The MAVIS Partners are:

University of Stuttgart, Fraunhofer IPA and IAO in Germany and Grenoble INP, University of Technology of Compiègne and IRT Jules Verne in France

CIRP meetings

IN 2022 CIRP meetings has been both digitally and hybrid. We participated in the General Assembly in August. For SFI Manufacturing the most interesting is perhaps the new keynote papers published in 2022 with the following titles:

- Sami Kara et al.: Closed-Loop Systems to Circular Economy: A Pathway to Environmental Sustainability?
- Roberto Teti et al.: Process monitoring of machining
- Daniel Brissaud et a.l: Designing Value-Driven Solutions: The Evolution of Industrial Product-Service Systems
- Paulo Bartolo et al.: 3D bioprinting: materials, processes and applications
- J. Yanagimoto et al.: Simulation of metal forming – Visualization of invisible phenomena in the digital era
- Anthony Beaucamp et al.: Advances in Grinding Tools and Abrasives
- Erhan Budak et al.: Mechanical interfaces in machine tools
- Aydin Nassehi et al.: Daydreaming Factories
- Wim Dewulf et al.: Advances in the metrological traceability and performance of X-ray computed tomography
- B. Mullany et al.: The Implication and Evaluation of Geometrical Imperfections on Manufactured Surfaces

All of these published in the CIRP Annals, Volume 71, Issue 2, 2022 https://www.sciencedirect.com/journal/cirp-annals/vol/71/issue/2

Manufuture meetings

Also Manuture meetings has been both digital and hybrid in 2022. SFI Manufacturing personell has been taking part in the formation of a working group on human centered manufacturing.

SFI Manufacturing International

There was no interaction with the ISAB in 2022.

Communication

PhD student videos

In the last 6 months, four former Ph.D. students from SFI Manufacturing have taken part in a video series. The videos provide a 5–7-minute overview of their dissertations. The goal is to share these video summaries with partners and professionals interested in learning more about our Ph.D. work. The videos will be shared on the SFI website. To this day, all participants are actively involved in the Norwegian manufacturing sector; some work for NTNU, while others work for SINTEF and the SFI.

Despite the challenge of condensing a comprehensive doctoral dissertation into 5-7 minutes, we hope viewers enjoy and learn from these short videos. We will continue publishing more SFI Ph.D. videos in the coming months.

PhD videos, in the photo: Muhammad Zeeshan Khalid

Key Researchers, Publications & KPIs

Key researchers

RA	Name	Institution	Main research area
1	Ida Westermann	NTNU-NV-IM	Joining aluminium to steel
1	Bjørn Holmedal	NTNU-NV-IM	Joining aluminium to steel
1	Vegard Brøtan	SINTEF Manufacturing	Additive manufacturing, Multi material products cont. polymers
1	Klas Boivie	SINTEF Manufacturing	Additive manufacturing
1	Olav Åsebø Berg	SINTEF Manufacturing	Additive manufacturing
1	Erik Andreassen	SINTEF Industry	Additive manufacturing
1	Per Erik Vullum	NTNU-NV-IF	Multi material metallic products
1	Randi Holmestad	NTNU-NV-IF	Multi material metallic products
1	Sotirios Grammatikos	NTNU-IV (Gjøvik)	Multi material products cont. Polymers
1	Are Strandlie	NTNU-IV (Gjøvik)	Multi material metallic products, Multiscale modelling
1	Per Harald Ninive	NTNU-IV (Gjøvik)	Multi material metallic products, Multiscale modelling
1	Xiaobo Ren	SINTEF Industry	Multi material metallic products, Multiscale modelling
1	Ivan Bunaziv	SINTEF Industry	Multi material metallic products
1	Magnus Eriksson	SINTEF Industry	Multi material metallic products
1	Ragnhild Aune	SINTEF Industry	Multi material metallic products
1	Odd M. Akselsen	SINTEF Industry	Multi material metallic products
1	Bård Nyhus	SINTEF Industry	Multi material metallic products
1	Dirk Nolte	SINTEF Industry	Multi material metallic products
1	Hoang Hieu Nguyen	SINTEF Industry	Multi material metallic products
1	Gaute Gruben	SINTEF Industry	Multi material metallic products
1	Ben Alcock	SINTEF Industry	Multi material products cont. Polymers
1	Afaf Saai	SINTEF Industry	Multi material products cont. polymers, Multiscale modelling
1	Christian Karl	SINTEF Industry	Multi material products cont. Polymers
1	Jesper Friis	SINTEF Industry	Multi material metallic products, Multi material products cont. polymers, Multiscale modelling
1	Ole Martin Løvvik	SINTEF Industry	Multiscale modelling
1	Einar Hinrichsen	SINTEF Industry	Multi material
1	Sverre Gulbrandsen-Dahl	SINTEF Manufacturing	Multi material
2	Jan Tommy Gravdahl	NTNU-IE	Senor fusion
2	Esten Ingar Grøtli	SINTEF Digital	Robotic handling of flexible objects, Flexible and integrated production systems
2	Marianne Bakken	SINTEF Digital	Robotic handling of flexible objects
2	Helene Schulerud	SINTEF Digital	Robotic handling of flexible objects

2	Morten Lind	SINTEF Manufacturing	Robotic handling of flexible objects, Flexible and integrated production systems
2	Eirik Njåstad	SINTEF Manufacturing	Robotic handling of flexible objects
2	Ådne S. Linnerud	SINTEF Manufacturing	Flexible and integrated production systems
2	Per Nyen	SINTEF Manufacturing	Flexible and integrated production systems
2	Andrej Cibicik	SINTEF Manufacturing	Flexible and integrated production systems
2	Gabor Sziebig	SINTEF Manufacturing	Robotic handling of flexible objects, Flexible and integrated production systems
3	Eva A. Seim	SINTEF Digital	Work systems and organization
3	Hans Torvatn	SINTEF Digital	Work systems and organization
3	Pål Kamsvåg	SINTEF Manufacturing	Work systems and organization
3	Eirin Lodgaard	SINTEF Manufacturing	Work systems and organization, Industrial clusters and learning systems, Innovation and product development
3	Ragnhild Eleftheriadis	SINTEF Manufacturing	Industrial clusters and learning systems
3	Jonas Ingvaldsen	NTNU-Økonomi-IØT	Work systems and organization, Innovation and product development
3	Asbjørn Karlsen	NTNU-SU-GEO	Industrial clusters and learning systems
3	Eli Fyhn Ullern	SINTEF Digital	Industrial clusters and learning systems
3	Maria Flavia Mogos	SINTEF Manufacturing	Industrial clusters and learning systems
3	Johanne Sørumsbrenden	SINTEF Manufacturing	Industrial clusters and learning systems
3	Monica Rolfsen	NTNU-Økonomi	Work systems and organization, Industrial clusters and learning systems, Innovation and product development
3	Heidi Dreyer	NTNU-Økonomi-IØT	Work systems and organization, Industrial clusters and learning systems, Innovation and product development
1, 3	Kristian Martinsen	SINTEF Manufacturing	Additive manufacturing, Work systems and organization

Scholarships

Postdoctoral researchers with financial support from the Centre budget

Signe Moe	Norwegian	2017-2019	F	Flexcible and robust autmation
Mathias Hauan Arbo	Norwegian	2019-2021	M	Flexcible and robust autmation
Sourav Sengupta	Indian	2020-2022	M	How Digitalization Affects the Organization and Planning of Manufacturing Supply Chains
Ding Peng	Chineese	2020-2022	M	Advanced electron microscopy characterization to understand interface physics in metal additive manufacturing of multi-material products.

Postdoctoral researchers with financial support from the Centre budget

Name	**Nationality**	**Period**	**Sex M/F**	**Topic**
Siri Marthe Arbo	Norwegian	2015-2019	F	Joining aluminium to steel
Mathias Hauan Arbo	Norwegian	2015-2019	M	Sensor fusion
Henrik Brynthe Lund	Norwegian	2016-2019	M	Learning in networks
Tina Bergh	Norwegian	2016-2020	F	Advanced characterisation
Muhammad Zeeshan Khalid	Pakistani	2016-2019	M	Atomistic modelling
Linn Danielsen	Norwegian	2016-2021	F	Automatisaton of additive manufacturing
Eirik B.H. Korsen	Norwegian	2017-2021	M	Robustnes of MES and work systems
Andreas Molturmyr	Norwegian	2019-2021	M	Automatisaton of additive manufacturing
Chaman Srivastava	Indian	2019-2023	M	Liftime of polymer products
Ingrid Fjordheim Onstein	Norwegian	2019-2023	F	Sensor fusion
Assiya Kenzhegaliyeva	Norwegian	2020-2023	F	Developing sustainable supply chain based on emerging technologies
Håkon Linga	Norwegian	2020-2024	M	Material properties and geometry tolerances in additive manufacturing (AM) of multi-material metallic components

PhD students working on projects in the centre with financial support from other sources

Name	Funding	Nationality	Period	Sex M/F	Topic
Vetle Engesbak	IPN Sprangforbedring	Norwegian	2015-2021	M	Business management, innovation and implementation of changes
Marit Moe Bjørnbet	KPN SISVI	Norwegian	2016-2023	F	Life cycle assessment as a management tool
Anna Maria Persson	SINTEF insitute funding	Norwegian	2017-2021	F	Mechanical properties of thermoplastic elastomers in injection moulded components
Amailie Østhassel	NTNU-SU	Norwegian	2021-2024	F	Sustainable business models for the green economy with specific emphasis on inclusive growth and innovation systems working within the planetary boundaries

Scientific publications

Authors	Title of work	Book/compendium/ journal	Page no.	Issue/ Volume/ Year	ISSN/ISBN
Bergh, Tina; Arbo, Siri Marthe; Hagen, Anette Brocks; Blindheim, Jørgen; Friis, Jesper; Khalid, Muhammad Zeeshan; Ringdalen, IngaGudem; Holmestad, Randi; Westermann, Ida; Vullum, Per Erik	On intermetallic phases formed during interdiffusion between aluminium alloys and stainless steel	Intermetallics	107443	142/2022	1879-0216
Hekneby, Torbjørn; Ingvaldsen, Jonas A; Benders, Jos; Jenssen, Jan Inge; Lehland, Katja.	Orkestrert læring og global kulturbygging: Hvordan Elkem ASA skaper prosessforbedring i sin globale organisasjon	Magma- Tidsskrift for økonomi og ledelse	121-129	25/2022	1500-0788
Karlsen, Asbjørn; Lund, Henrik Brynthe; Steen, Markus	The roles of intermediaries in upgrading of manufacturing clusters: enhancing cluster absorptive capacity	Competition & Change	3-21	27/2022	1477-2221
Linga, Håkon; Zhang, Yubin; Brøtan, Vegard; Ren, Xiaobo; Westermann, Ida; Holmedal, Bjørn	In-situ X-ray microtomography of interface between additively manufactured aluminium bronze and H13 tool steel	IOP Conference Series: Materials Science and Engineering	1-6	1249/2022	1757-899X
Lodgaard, Eirin Anita; Torvatn, Hans Yngvar; Sørumsbrenden, Johanne	Future competence at shopfloor in the era of Industry 4.0- A case study in Norwegian industry	Procedia CIRP	961-965	107/2022	2212-8271
Lu, Xu; Ma, Yan; Peng, Ding; Johnsen, Roy; Wang, Dong	In situ nanomechanical characterization of hydrogen effects on nickel-based alloy 725 under different metallurgical conditions	Journal of Materials Science & Technology	156-169	135/2022	1005-0302

Authors	Title of work	Book/compendium/ journal	Page no.	Issue/ Volume/ Year	ISSN/ISBN
Lund, Henrik Brynthe; Vildåsen, Sigurd	The influence of Industry 4.0 narratives on regional path development	Regional Studies, Regional Science	82-92	9/2022	2168-1376
Mohammed, Ahmed Kedir; Kvam, Johannes; Onstein, Ingrid Fjordheim; Bakken, Marianne; Schulerud, Helene.	Automated 3D burr detection in cast manufacturing using sparse convolutional neural networks	Journal of Intelligent Manufacturing	303-314	34/2023	1572-8145
Onstein, Ingrid Fjordheim; Haskins, Cecilia; Semeniuta, Oleksandr.	Cascading trade-off studies for robotic deburring systems	Systems Engineering	475-488	25/2022	1520-6858
Persson, Anna-Maria Märta Ruth; Andreassen, Erik	Cyclic Compression Testing of Three Elastomer Types— A Thermoplastic Vulcanizate Elastomer, a Liquid Silicone Rubber and Two Ethylene-Propylene-Diene Rubbers.	Polymers	1316	14/2022	2073-4360
Persson, Anna-Maria Märta Ruth; Hinrichsen, Einar L; Andreassen, Erik	On the temperature dependence of the cyclic compression behaviour of a thermoplastic vulcanizate elastomer	Polymer testing	1-12	112/2022	0142-9418
Witjes, Sjors; Ahlström, Hanna; Vildåsen, Sigurd; Ramos-Mejia, Monica	Academics for sustainable development: Exploring consequences and dilemmas of transdisciplinary research approaches	Sustainable Development	289-292	30/2022	1099-1719

Key Performance Indicators

	Plan 2015-2023	Sum 2015-2017	2015	2016	2017	2018	2019	2020	2021	2022	2023
Book about MMP manufacturing	1	0									
Scientific paper published in international journals and conferences with peer review	112	149	1	7	28	32	23	25	21	12	
Popular science articles	16	14			2	1	3	3	3	2	
National and international conferences and seminars/workshops	2	2		1				1			
PhD candidates	17	16	2	7	1		3	2	1		
Post docs	3	4			1		1	2			
MSc students	100	38		2	7	11	6	4	6	2	

Statement of the Accounts

	2022
Funding	
The Research Council	11 161 669
The Host Institution (SINTEF Manufacturing AS)	948 210
Research Partners	4 933 381
Enteprise Partners	7 117 668
Total	**24 160 928**
Costs	
The Host Institution (SINTEF Manufacturing AS)	5 940 339
Research Partners	15 227 921
Enterprise Partners	2 992 668
Public Partners	
Equipment	
Total	**24 160 928**

Contact us

Contact information

Manager:	Sverre Gulbrandsen-Dahl
Phone:	+47 916 01 205
Email:	sverre.gulbrandsen-dahl@sintef.no

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Website:	https://www.sfimanufacturing.no
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