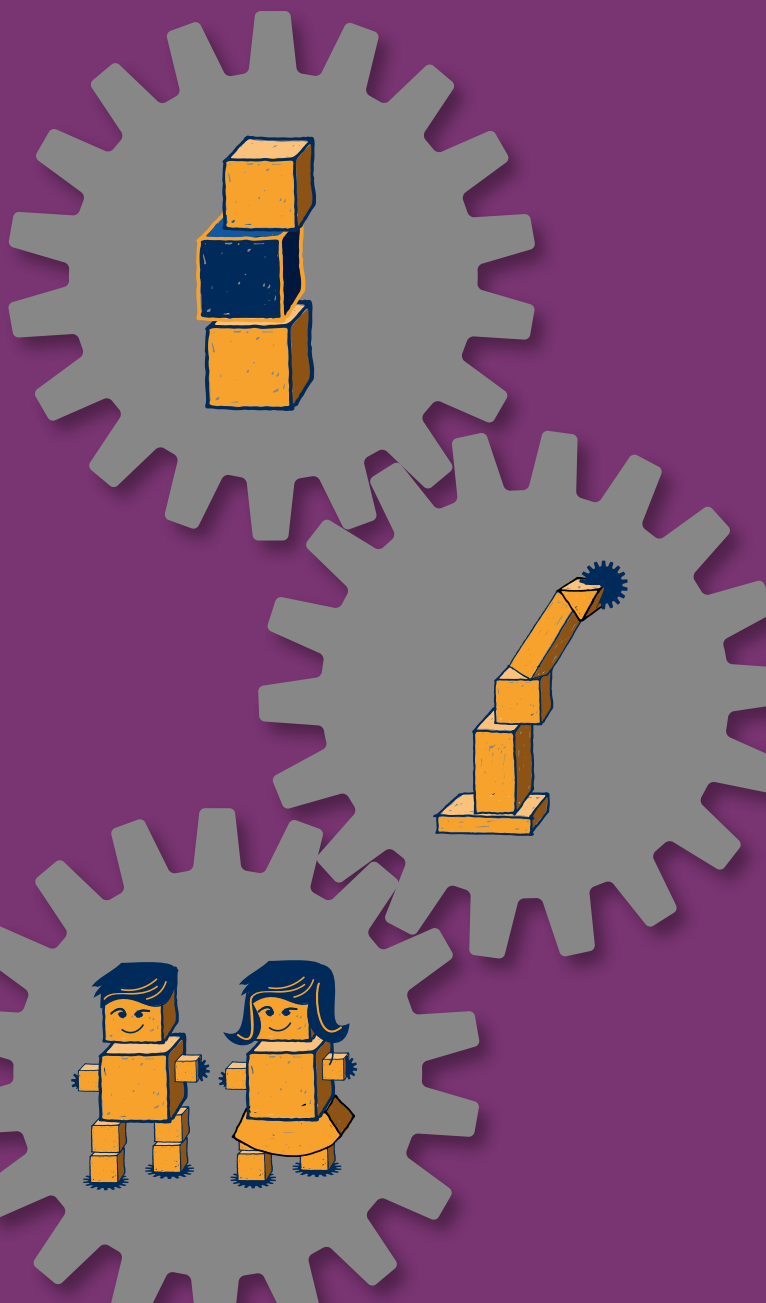
manufacturing

Annual report

2019



sfi Centre for Research-based Innovation

The Research Council of Norway

Index

Picture from Benteler
Photo: Kasper van Wallinga

Welcome to the SFI Manufacturing annual report 2019

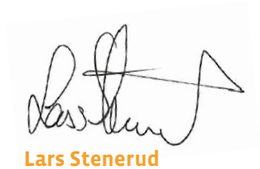
During 2019 SFI Manufacturing had its midway review, conducted by the Norwegian Research Council. This review was partly based on the review of an international panel, consisting of 4 experts from Sweden, Switzerland and the UK, and their evaluation of both the scientific achievements and the centre's activities.

We received positive feedback and the Research Council confirmed that it will continue its financing also the last 3 years. We deeply appreciate this recognition and are looking forward to further develop our centre.

As a result of the midway evaluation and internal developments, it has been decided to focus more on interdisciplinary activities. However, we do believe that the experts shall remain experts in their fields of science, and we try to address cross-disciplinary issues by utilising multi-disciplinary teams. The industry copes with multi-disciplinary issues in their day-to-day business, and for the academic partners, to be more relevant to the industry, the ability to cope with such issues is a key competence.

Sustainability has become a very important ingredient in the licence to operate for all businesses in general, and for the manufacturing industry in particular. This area of research is a good example of the need for a cross-disciplinarily approach: Material selection, processes development, product development, business models and industry models need to be aligned in order to develop sustainable industry solutions.

Hence, researchers from a wide range of sciences need to collaborate on common sustainability goals. The industry partners of SFI Manufacturing appreciate the common centre targets that are being developed with reference to the UN Sustainability Development Goals.



Lars Stenerud
CEO Plasto AS
Chair of the board, SFI Manufacturing
Raufoss, 25th of March 2020

Centre for Research-based Innovation

The Research Council of Norway

SFI: 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**
- **Recruitment of talented researchers**

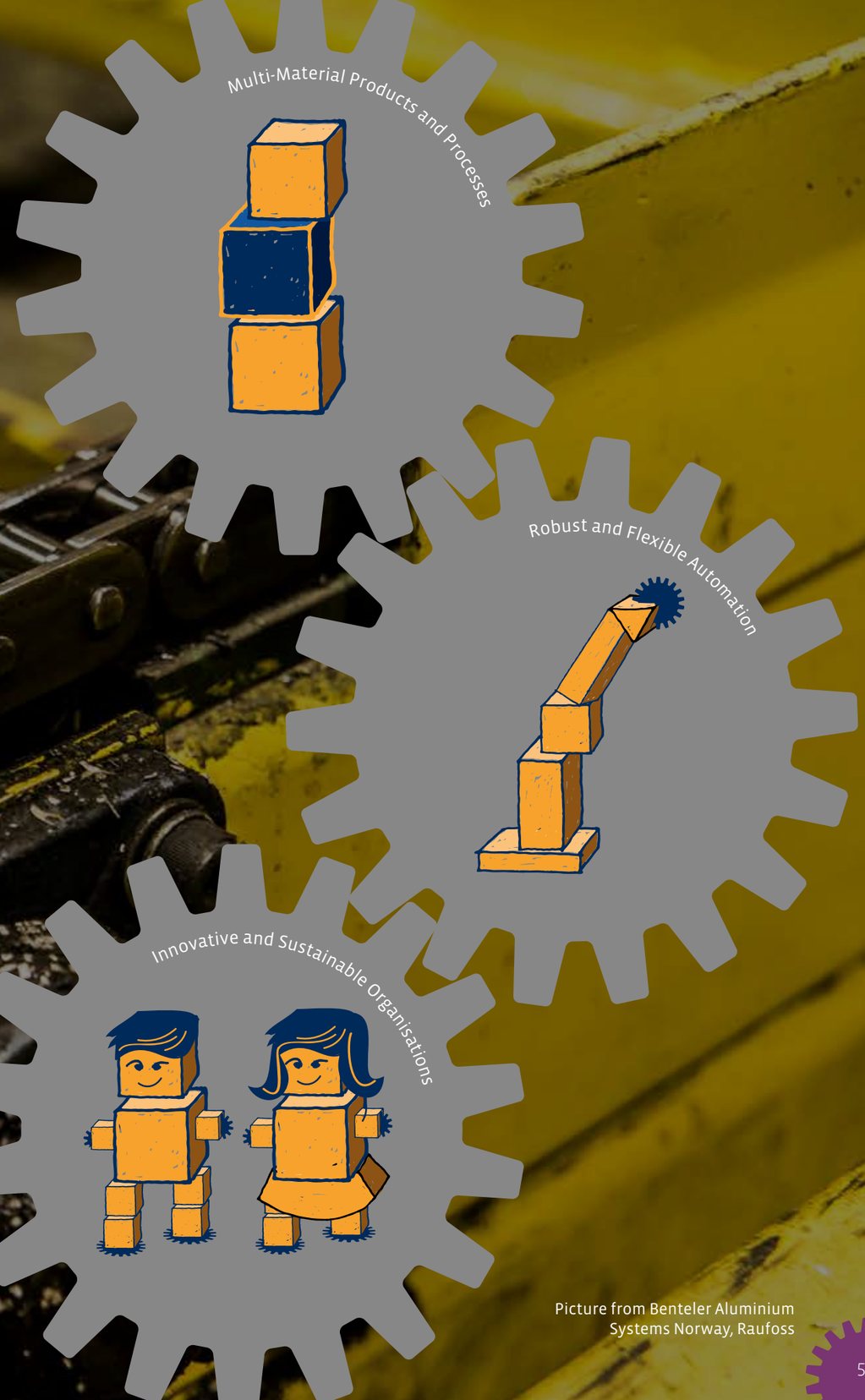
SFI Manufacturing builds on existing national capabilities and aims to strengthen the Norwegian manufacturing companies' ability to innovate. The centre seeks to mirror the inherent cross-disciplinary innovation systems in the industry and combine research on multi-material product solutions, flexible 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 crossdisciplinary interfaces, and to develop new research methods. The objectives of the SFI Manufacturing's research areas which support this vision are:

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.



Picture from Benteler Aluminium Systems Norway, Raufoss

SFI Manufacturing and its innovation potential

During 2019 SFI Manufacturing has passed the midway review with good results. An independent evaluation of the centre's innovation potential has been presented as well. In this annual report both results will be presented, and I would like to focus on the innovation potential during this introduction.

During the development of the centre's concept, the partners agreed upon the importance of an efficient system for the creation of spin-off projects on higher Technology Readiness Levels (TRL). A system that would focus on the innovation activities of the industry partners, rather than the centre's activities itself.

SFI Manufacturing focuses on TRL 1 to 3, but several research results have been developed during, or contributed to, innovation projects on TRL 4 to 7. During the period of 2016 to 2018, 21 innovation projects connected to the centre were started.

Impello Management has conducted an independent evaluation of SFI Manufacturing's innovation potential and its spin-off projects. This evaluation concluded with a potential economic impact of more than 20 billion NOK over a 10-year period.

A contribution to this is the investment in SFI Manufacturing and the associated spin-off projects, where the partners invest approximately 460 million NOK and the Norwegian Research Council 340 million NOK. If the projects succeed, the return on investment is regarded to be very good.

I hope you will find the results presented in this annual report interesting.

Sverre Gulbrandsen-Dahl
Centre Director
Raufoss, 25th of March 2020

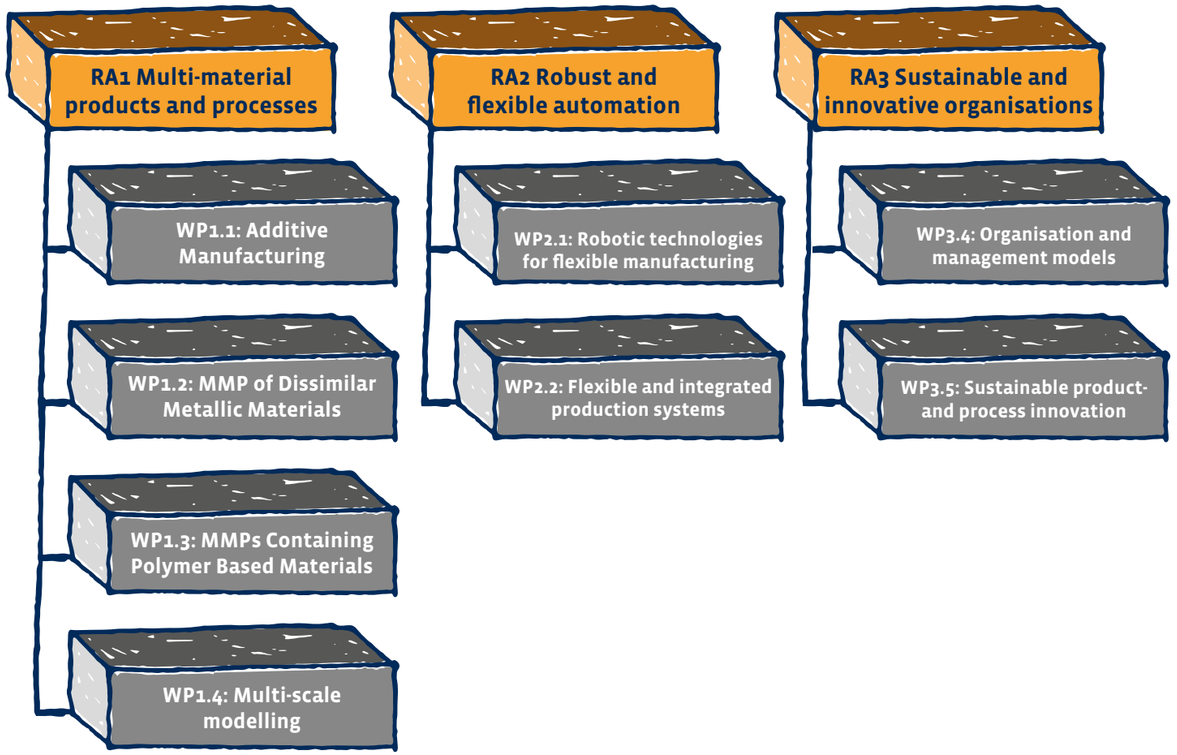
Research and industrial partners

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

Host institution: SINTEF Manufacturing
Research: SINTEF Manufacturing, SINTEF Industry, SINTEF Digital

Organisation
Centre structure

Organisation
Centre structure



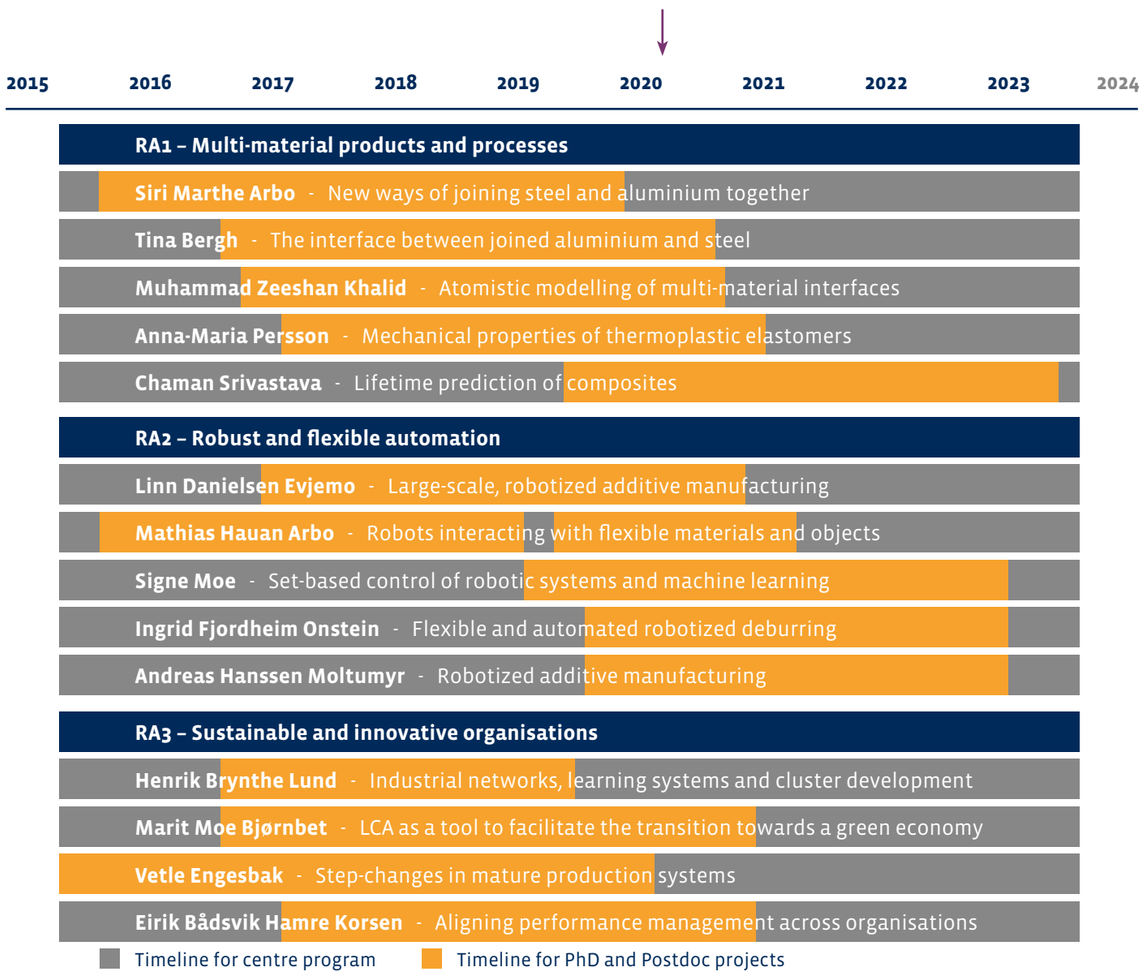
Meet the next generation scientists

Mathias finished and defended his PhD in 2019, and Ingrid, Andreas and Chaman started their PhD in 2019. You can read more about their studies below.

Mathias Hauan Arbo
Robots interacting with flexible materials and objects
During my PhD I looked at robotic assembly and optimization-based control of industrial manipulators. Primarily for robust, flexible, constraint-based robot programming systems performing assembly tasks. During my Postdoc I will be working on high-level planning and control of articulated robots for assembly, exploiting expert knowledge and CAD information. I started my SFI Manufacturing Postdoc Spring 2019.

Ingrid Fjordheim Onstein
Flexible and automated robotized deburring
I finished my master at the Department of Engineering Cybernetics (NTNU) in 2018. During my master, I worked with Linn Danielsen Evjemo on robotized additive manufacturing. I started working as an IT consultant after my master but realized after a few months that I was missing working with robots. As a result, I decided to take a PhD in manufacturing instead. In my PhD I will focus on flexible and automated robotized deburring. I will try to automatically remove burrs with a robot manipulator using input from CAD and vision.

Andreas Hanssen Moltumyr
Robotized additive manufacturing
I received my master's degree from the Department of Engineering Cybernetics at NTNU, summer 2019. In my master thesis, I explored the topic of fractional-order control and tested it for control of an Atomic force microscope. In my PhD I will focus on on-line monitoring and quality control of robotized additive manufacturing. Using computer vision, I will attempt to monitor the printing process, detect print defects and do corrective action with the printing robot.



Chaman Srivastava
Lifetime prediction of composites
I started to work on my PhD from June 2019 at the group of sustainable composites, Department of Manufacturing and Civil Engineering at NTNU Gjøvik. I have a master in Materials Engineering from KU Leuven, with specialization in polymeric composites. I was also working as a Marie Curie fellow for 2 years in an EU project on crashworthiness of composites. In my PhD, I will focus on the lifetime prediction of composites by developing accelerated aging protocols and predictive modelling tools to estimate long term structural performance of polymer composites.

Picture from Benteler
Photo: Kasper van Wallinga

Report from the research areas 2019

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 that has been done in 2019. In the newsletters, available on the website www.sfimanufacturing.no, more information can be found.

3 research areas
The research area Multi-Material Products and Processes concerns the design and manufacturing processes of multi-material products, and the overall objective is to develop the ability to optimize material choice, multi-materials geometry and processes simultaneously.

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.

The research area Sustainable and Innovative Organisations 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.

RA1 Multi-material products and processes

Additive manufacturing:
- Powder properties is a hot topic in additive manufacturing. We continued our work on powder layoutmethods in multi-material processes relevant for the consortium.

- Process parameters affect product behaviour. How this affection looks like and how to model it, is complex and depends on the material and production method. We have started to investigate and model these multi-physical processes.

Multi-material products of dissimilar metallic materials:
- PhD student Siri Mathe Arbo submitted her PhD thesis on the joining of steel and aluminum alloys. She defended her thesis January 2020. In the next annual report, more information will follow.

- We developed a novel one-sided accessible mechanical joining with hollow rivets, which potentially can be used for joining of dissimilar metallic materials, as well as joining of metallic and non-metallic materials.

- We performed nanomechanical testing of intermetallic phases of Al-Fe joints for the first time in the centre.

- Successful collaboration between RA1 and RA2 was promoted regarding optimal deposition patterns in terms of minimized residual stresses and distortion in wire arc additive manufacturing (WAAM).

Multi-material products including polymer:
- We updated the SOTA of multi-material technologies for scientific and popular literature. This was also presented during the RA1 workshop in 2019.

- Chaman Srivastava started his PhD on the lifetime prediction of composites, see also page 11.

Multi-scale modelling:
- We updated the SOTA on interoperability and multi-scale modelling concepts, including an online* report on design and implementation of metadata schema for syntactic and semantic interoperability.

- PhD candidate Zeeshan Khalid finalized his first principles calculation of joining aluminium and steel. He also calculated on the separation and elastic constants within and between different intermetal lic phases.

- In December three EU-proposals were submitted related to the work on ontologies.

RA2 Robust and flexible automation

Robotic technologies and flexible and integrated production systems:
- We investigated the state-of-the-art on 3D quality control and pose estimation, as well as human-robot collaboration.

- We defined a use-case for Mjøs Metallvarefabrikk for 3D quality control and deburring.

- A collision free path planning in bin picking operations, with a 3D-camera and gripper on a robotic end-effector, was demonstrated.

- A method for rapid robot cell calibration using virtual reality gaming hardware was developed.

- PhD candidate Mathias Hauan Arbo submitted and defended his thesis, see also page 10.

- We had several publications and presentations on for example rapid robot cell calibration and robotic bin-picking under geometric end-effector constraints.

RA3 Sustainable and innovative organisations

Literature study as basis for a survey:
- We analysed 37 global trends described in major international and national reports, such as World Economic Forum, OECD, the European Commission and the Norwegian Ministry of Trade and Industry.

- We analysed technological trends, market trends, environmental trends and labour trends.

- The results of the literature study were used for our Mentimeter-survey.

- 41 respondents from both the industry and academia in SFI Manufacturing were asked to evaluate how likely and important the trends are for their organisation.

- The trends that were evaluated as most certain and important are: Cybersecurity, eco-products, robotization, lifelong learning and artificial intelligence. These trends were expected to occur regardless future development and organisations should consider them in their strategic plans.

- The survey will be repeated with all industry partners in 2020, as well as with a Japanese cluster. The results will be compared, and thereafter we are planning to organise workshops with the individual partners to further validate the scenario building method, and to assist them in developing their own scenarios and drafting long-term strategies.

PhD research activities:
- Eirik Hamre Korsen does research on performance measurement and management in complex organizations. He published a chapter in Fjordantologien and also organized a seminar sharing and discussing performance management practice. Eirik aims to deliver his PhD by summer 2021.

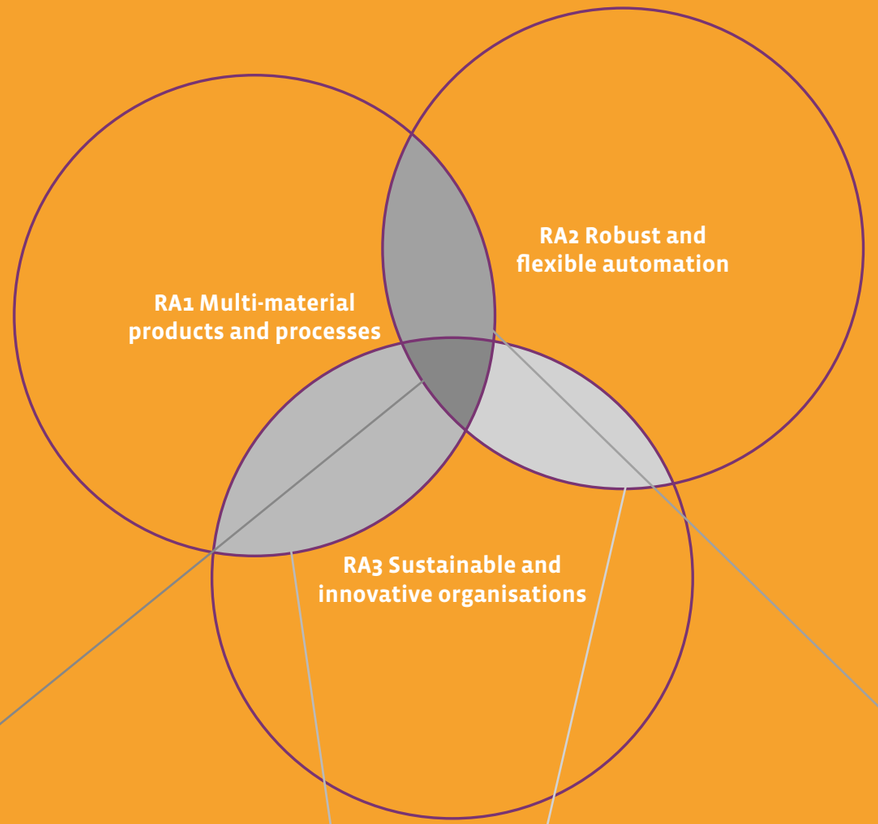
- December 2019 Henrik Brynthe Lund submitted his thesis on the development of technology and knowledge capabilities in Norwegian manufacturing industry, particularly in the manufacturing clusters at Raufoss and Kongsberg. In the next annual report, more information will follow.

- Vetle Engesbak does research on step-changes in mature production systems. He published an article** on parallel organizations and achieving impact in operating organizations. Another article on organizational learning and bureaucracy will be published in 2020, as well as a final article on learning processes during technology implementation.

* https://emmc.info/emmc-documentation-on-design-and-implementation-of-metadata-schema-for-syntactic-and-semantic-interoperability/
** https://www.emerald.com/insight/content/doi/10.1108/TPM-01-2018-0007/full/html

Increased Multi-Disiplinarity Through Focus on Research

Thematics that are on, or close to, the intersection of the RA's



Develop scenarios for future manufacturing organization and related stakeholders that can be used as roadmaps for strategic choices within the participating companies and the multi-disciplinary research in the consortium.

Demonstrate the integration of the UN Sustainable Development Goals in business model development, with emphasize on circular material streams

Develop adhesive joining technologies to reduce manufacturing costs, increase product quality or ease end-of-life disassembly.

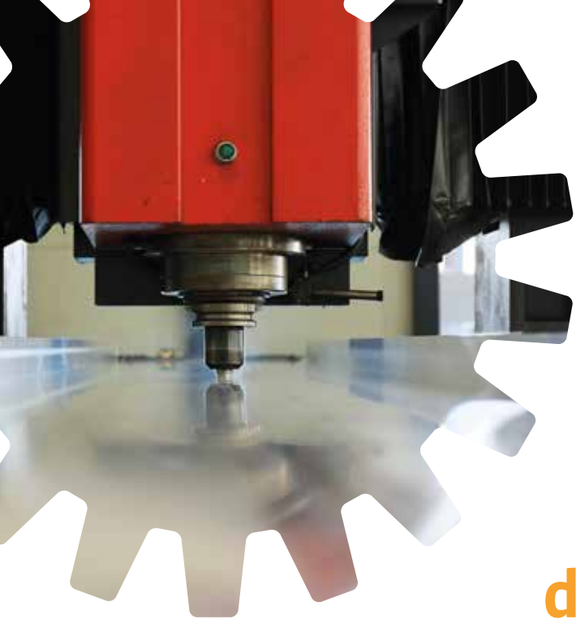
Additive manufacturing with robot

Systems for in-line monitoring of processes and quality control of products based on novel automated cognitive processes to increase robustness, mass customisation, enabling first-time-right manufacturing and reduced ramp-up time.

Human-oriented automation through man-robot cooperation, intuitive programming methods and virtual reality immersion

Competitive interaction between digital work and the Norwegian model

Socio-technical approach for integration of emerging technologies into existing and future manufacturing systems in order to test for maturity and applicability.



Nammo signs its largest ever space development contract

In April 2019, Nammo has been awarded a €19 million development contract in the ESA VEGA-E program, to provide the next generation of Roll and Attitude Control System.

Roll and Attitude Control Systems (RACS) are used to help spacecraft position itself accurately in orbit, which is crucial when deploying its payload, such as satellites.

Under the terms of the contract, Nammo will develop a new RACS for VEGA-E using Hydrogen Peroxide (H_2O_2), a green propellant for which Nammo currently is world leader. H_2O_2 is a green environmental friendly alternative to the toxic and highly dangerous Hydrazine, which currently is the industry standard propellant for RACS applications.

– With our Hydrogen Peroxide technology, you have all the ingredients needed for an extremely attractive system, says Morten Brandtzæg, CEO of the Nammo Group.

Aluminium tank

The tank itself has represented a particular challenge, one where Nammo has used its long-standing experience and expertise in aluminium alloys to ensure successful qualification.

– Aluminium is the preferred metal to work with H_2O_2, says Turi Røyne Valle, RACS project manager at Nammo.

– It has excellent compatibility properties, giving the system a very stable and long lifetime. It is also very light weight, which is always an advantage within aerospace systems, and as well ensuring that the VEGA RACS can be deorbited at the end of its service life.

SFI Manufacturing's role

Through 2018 and 2019, in addition to Hexagon Ragasco, SINTEF Manufacturing has supported Nammo with the establishment of an orbital friction stir process, which will be used for welding the propellant tank.

– Friction stir welding is the best suited process for aluminium tank production as the structural integrity will remain at a satisfactory level after welding, explains Jo Aunemo in SINTEF.

The period of process establishment has mainly been focused towards the exit hole, which is the welding process' biggest drawback, and numerous trials have been performed to find the best exit solution.

– A wedge, which will be installed while orbital welding is being performed, will act as a sacrificial part of the tank, solely with purpose of forcing the welding tool out of the orbital plane. As the propellant tank does not have any internal structural support, the main backing potential is a cross-section with a self-bearing design.

This is something that previously has not been performed with success: Friction stir welding of thin cross section in aluminium using a wedge while welding as exit hole strategy.

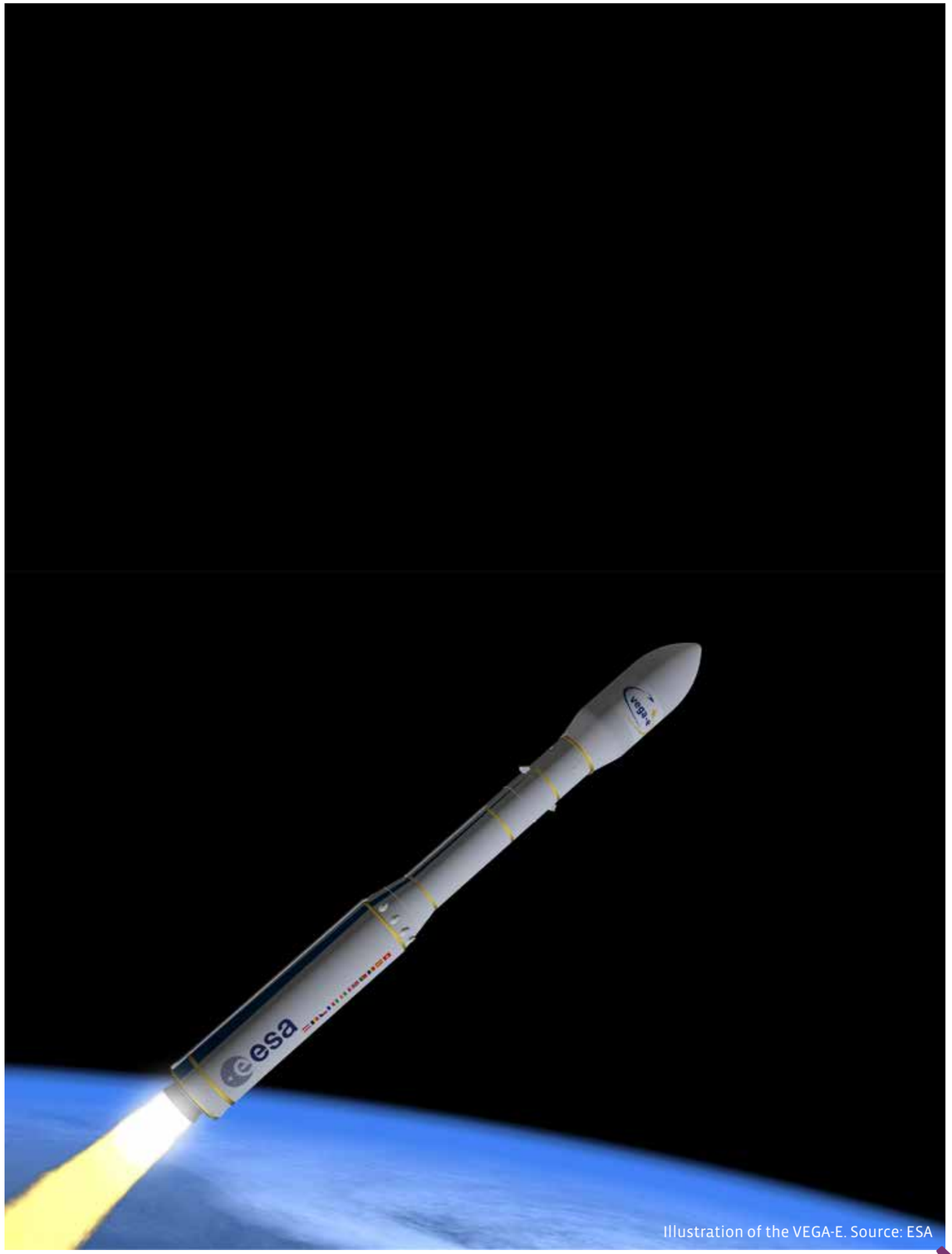


Illustration of the VEGA-E. Source: ESA

Midway evaluation of SFI Manufacturing

Last year 17 Centres for Research-based Innovation (SFI-III) had their “Midway evaluation”, arranged by the Norwegian Research Council. Each centre got evaluated by a panel of international experts.

This evaluation had two purposes:

1. **It gave advice to the centre on aspects that could be improved**
2. **And it formed the basis for a decision about whether to continue the centre’s financing the following three years**

March 2019 the Norwegian Research Council visited SFI Manufacturing at Raufoss. The centre’s research activities were discussed, and PhD students were met, as well as representatives of the industry partners and host institution.

Well-organised research centre

The evaluation shows that SFI Manufacturing is a well-led and organised research centre that has created a strong national community in manufacturing and is delivering results of real value to its partners. “The centre is particularly successful in creating spin-off projects”, writes the Norwegian Research Council in its report.

Recommendations

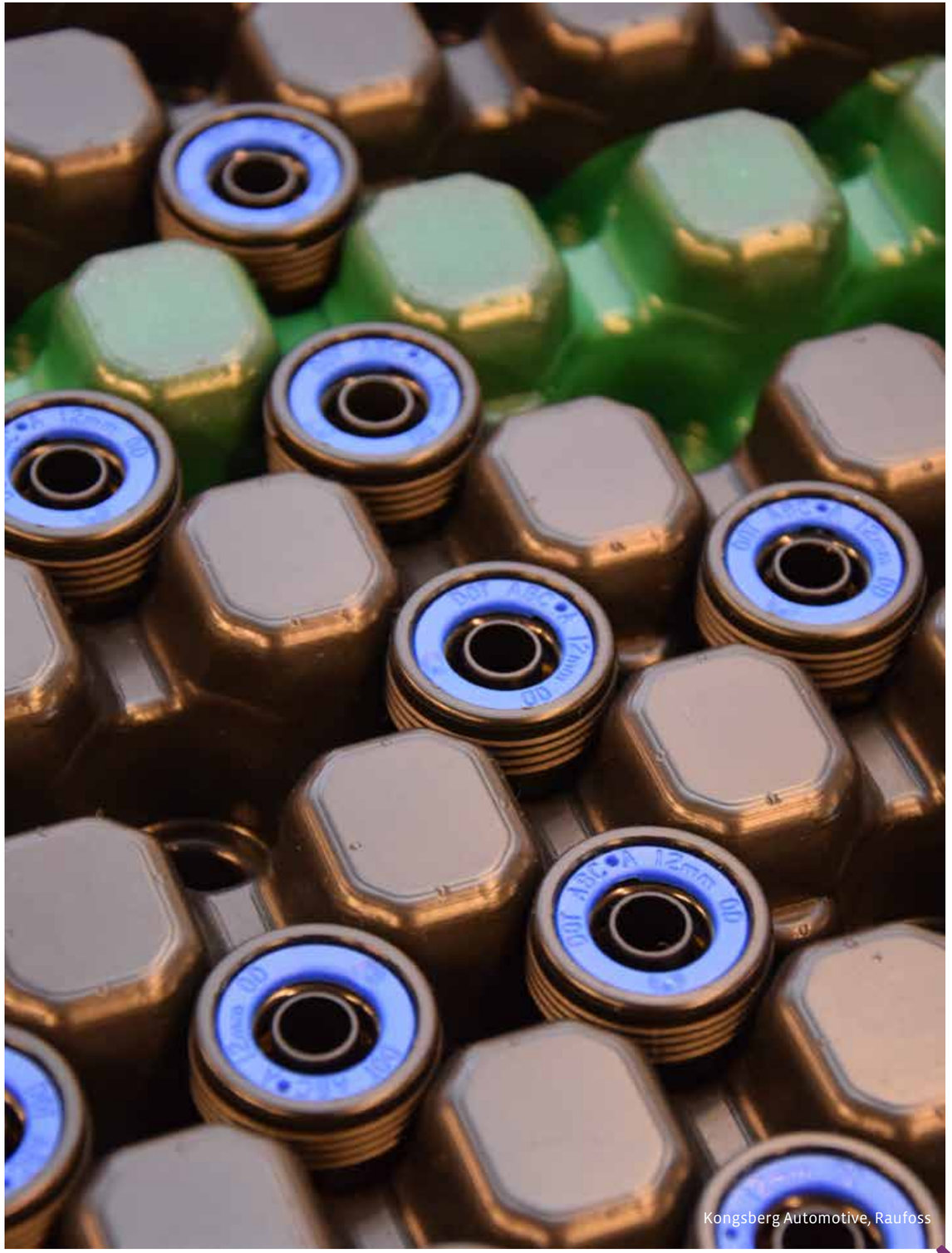
The report also shows several opportunities for improvement. “SFI Manufacturing could consider the direction of RA2 to ensure it has long term value to the industry partners. The centre could also grow its activities in environmentally driven issues, for example those driven by material mixtures in both metals and polymers.”

When it comes to PhD research, more training on for example project management and intellectual property could be offered. The centre could also work on the closeness between the students and industry.

September 2019 SFI Manufacturing received good news from the Research Council. “We would like to let you know that the centre will receive its three-year financing, provided that the centre will take a look at the opportunities for improvement.”

Improvement activities

SFI Manufacturing has reviewed the recommendations and integrated most of them in the work plan for 2020. The international scientific advisory board has been invited to compare the recommendations with their own recommendations. The results of this comparison will be taken into account when formulating the work plan for 2021. The recommendations regarding RA2 will need a more comprehensive review, as they deviate somewhat from the recommendations of the advisory board.



Kongsberg Automotive, Raufoss

Cybersecurity seminar at Fornebu

In December 2019 SFI Manufacturing was co-organizer of 'Cybersecurity for the Industry', an industry's own seminar together with Kongsberg Innovasjon and the main organizer Telenor.

The seminar was held in Telenor Expo at Fornebu as a result of cybersecurity being mentioned as an important topic during the SFI Manufacturing 1-1 meetings and having accelerated into a common initiative, gathering around 100 participants during a full day.

Black screens

One of the speakers was Torstein Gimnes Are. The 19th of March 2019, Torstein was relatively new in the Chief Information Security Officer role at Hydro. He quickly realized that he would face a rough start the night he received a phone call from one of the employees, saying "I believe we are under attack". The morning after, everyone's computer had a black screen and it was advised to leave it alone. The following hours – until the press conference at 3 pm – passed quickly, as the picture of the serious situation became clearer. The whole global organisation was affected and went over to manual operation and procedures wherever possible. During his talk, Torstein described this experience, the sleepless nights and a story about a digitalization skeptical guy who had printed the order book, who became the cybersecurity hero.

Cybersecurity and innovation

Torstein's story left no one in the room questioning their participation at the seminar. Ole Hoen, Head of Research and Technology at GKN, and Peder Arvidsson, R&D center manager at Sandvik, answered the question: 'Is cybersecurity a barrier for industrial innovation?', sharing their companies' focus on cybersecurity and how they are internally handling the balance between protective measures and cutting edge innovations. Telenor, Kongsberg Defence & Aerospace, CISCO, Escio and NTNU among others shared their experiences and knowledge, in parallel with research results on industrial IT-security.

Roadmap for companies

Anja Solheim at SINTEF Manufacturing presented the Manufacturing Technology Norwegian Catapult Centre and its ongoing projects on cybersecurity, such as the development of a cybersecurity course at Lean Lab. Furthermore, she presented a project where she, together with Norsk Industri and NTNU IIK, is developing a roadmap for Norwegian companies, an initiative SFI Manufacturing is supporting by taking a disseminating role. Afterwards more than one company exclaimed their interest in participating in the project, something that will keep on adding to the acceleration effect that evolved around the topic.

Anja Solheim, SINTEF Manufacturing

Ole Hoen, GKN

Industry 4.0 in practice

The spin-off project Intelligent machining – Intellma – finished in 2019 and resulted in both interesting scientific data and a concrete product. This is Industry 4.0 in practice.

The Intellma project has developed a new product range for optimization, monitoring and control of advanced machining processes. In the aircraft and oil & gas industry, the machined components are often made of very expensive materials and with strict tolerance requirements for the machined surfaces. This means that the margin of error is small, and the cost of errors is high. In a previous project, it has been shown that integrated sensors in the tool can provide the operator with a good means of monitoring the process in a much more detailed way and with a better result.

A tool that communicates with the operator and machine
The Intellma project has taken this a big step further, with the development of solutions and hardware for the tool to communicate with the operator and the machine. The system can now present information on the machining process during the process, so that critical parameters are reached. Should a critical situation occur, a “cancel” command could be sent to the machines.

Several partners of Sandvik Teeness are now using and testing the technology in their CNC machines. It has been shown at trade shows, under the name Silent Tools Plus, and new products have been launched as well. The software is downloadable from the Microsoft Store and has an intuitive user interface.

Project period:
2015-2019

Partners:
Sandvik Teeness, NTNU, SINTEF

Scientific articles:
https://app.cristin.no/results/show.jsf?id=1587409
https://app.cristin.no/results/show.jsf?id=1619109

Potential economic impact of SFI Manufacturing

An independent report of Impello Management shows that SFI Manufacturing potentially can have an economic impact of >3 billion NOK per year in the Norwegian manufacturing industry.

SFI Manufacturing has been awarded 30 IPN projects in the period of 2016-2019. The analysis of Impello Management is based on 15 of these projects started in 2018, and statements of the industry partners in relation to these projects.

In addition to the >3 billion NOK per year the next coming years, the report shows more potential economic impact of the IPN projects: Reduced operating costs, increased profits and reduced investments.

These results are based on 8 use cases linked to both the IPN projects and research areas of SFI Manufacturing – Multi-material products and processes, Flexible and robust automation, and Sustainable and innovative organizations.

The use cases are covering the fields of:
- New joining methods for high-performance aluminum-steel products
- Additive manufacturing of elastomer products
- Robust robotic motion planning for manufacturing
- Software architecture and tools for «batch size one» robotic assembly
- 3D vision: Deep learning for robotic grasping
- Benchmarking enterprise development maturity
- Modernization of vocational education and training
- Alignment of management tools

It is in these fields where the potential economic impact of SFI Manufacturing lies.

The 2019 workshops

Every year, SFI Manufacturing organises three workshops at three different places in Norway. These workshops are one of the most important cross-functional activities of the year. Researchers and industrial partners connected to the centre come together in order to learn from each other and discuss relevant topics. In 2019, the workshops took place at Raufoss with Hybond and the Manufacturing Technology Norwegian Catapult Centre as host, in Bergen and Osterøy with Mjøs Metallvare as host, and in Ålesund and Sykkylven with Ekornes as host.

From evening to evening
The – typically between 40 and 60 – participants gather in the evening, to become up to date with trends and activities in the different environments connected to the SFI, and to have time to chat during the following dinner and social activities. Some go to bed early and some end up discussing all too interesting topics until break of day. After a good night sleep and breakfast at the hotel, the participants look forward to the exciting workshop activities.

Visits to Norwegian world class industries
In 2019 we had interesting visits to the production sites of world-leading companies, showing ground-breaking applications of new technology and breath-taking Norwegian environments.

In March, the participants visited the catapult centre at Raufoss, where RA3 presented their new work packages: “Future manufacturing organisation models” and “Sustainable business model development” in the form of possible scenarios followed by a discussion around the tables. The main day focused on RA1-presentations followed by presentations and discussions of Hybond and their new technology for joining of metals such as aluminium and steel.

In Bergen and Osterøy in June, the workshop kicked off at Flesland airport hotel with presentations on circular manufacturing and megatrends in the automotive industry, followed by group discussions on implications for the SFI partners. The main day started with presentations from RA2 on robust and flexible automation, before we entered the bus and got to know the technologically impressive facilities of Mjøs Metallvare, a leading CNC machining company producing a wide range of parts in small series, and with a high degree of automated solutions and many robots in use.

In Ålesund and Sykkylven in October, we started Monday evening at Norwegian Maritime Competence Centre in Ålesund with presentations of the ‘Blue Innovation Arena’ and ‘DigiCat’ as well as an updated presentation of Kongsberg Maritime CM (formerly Rolls-Royce Marine), before RA3 took us through an interactive scenario building workshop based on manufacturing trends. Tuesday morning started on the bus before we crossed the fjord with a ferry and arrived at Ekornes in Sykkylven. RA3 had academic presentations before Ekornes took us through the company, the technology and their activities within sustainability. The Stressless chair is a truly ‘multimaterial’ product! The Ekornes main factory is an impressive facility spanning several production departments with different technologies, and – not the least – heavily automated and robotized.

Inspirational research briefings
During the workshops we have been inspired by the latest discoveries from the research areas of Multi-Material Products and Processes (RA1), Robust and Flexible Automation (RA2) and Innovative and Sustainable Organisations (RA3), during the presentations given by the highly motivated PhD students and Postdocs. We have learned about additive manufacturing, multimaterial products containing polymer based materials, knowledge frameworks for manufacturing (workshop 1), wire-arc AM, vision-based robot path planning, robotic assembly ontology, machine vision, efficient robotic assembly programming (workshop 2), and life-cycle analysis and circlar economy in manufacturing, performance measurement versus performance management, and innovation processes (workshop 3).

Vivid group discussions
With the production site visits and research briefings in mind, the participants take active part in the group discussions towards the end of the workshop days. The group discussions are focused on solving problems and discussing topics related to the host, combined with the research area in focus: Hybond and RA1, Mjøs Metallvare and RA2, and Ekornes and RA3. After vivid discussions, the results are presented to the audience, with the host representatives hurriedly taking notes in order to be able to bring back the valid comments to the organisations.

The first workshop of 2020 will be organized at Kongsberg Automotive at Raufoss in June. We will strengthen the host company’s relevance even further by focusing on specific cases and linking the research briefings from the relevant research areas to these cases.

International collaboration 2019

In 2019, SFI Manufacturing has been involved in Manufuture work, as well as the international project INMAN: Intelligent circular manufacturing research and educational collaborate on with Japan and India. We have had a physical meeting with the Advisory Board as well.

Manufuture
A document describing a strategic research and innovation agenda (SRIA) for European manufacturing, called, has been developed in the European Technology Platform: Manufuture. The document can be downloaded from Manufuture.org*

The document describes the Manufacturing Research and Innovation Ecosystem and its unique characteristics, and presents an integrated strategy for linking basic science to applied research in Manufacturing, cutting across the different stages of research and development, i.e., from basic science, fundamental and applied research to market uptake, including education and training, entrepreneurship, and innovation infrastructures that are necessary to address the dimension and complexity of research challenges in Manufacturing. Furthermore, describing the most relevant Science and Technology Challenges, namely: Adding value in the system of manufacturing, Horizontal and vertical integration and The Road to Circular Economy and Decentralised Technical Intelligence. Research and Innovation Priority Domains, which is the first Building Block are proposed, and how to reach our vision for 2030. Ten Research and Innovation Priority Domains for successful European Manufacturing are presented: Manufacturing technology and industrial equipment; Digital Transformation; Robotics and flexible automation; Nanotechnologies and materials; Biological transformation; Customer-driven manufacturing; Human-centred manufacturing; Agile manufacturing systems design and management; Circular economy, New business models and logistics networks. The document is also describing the needs for innovation and Entrepreneurship and Education and Training.

International academy for production research – CIRP
SFI Manufacturing has been represented at the at selected CIRP conferences. Several of the papers in SFI Manufacturing are published in Elsevier Procedia CIRP and Procedia Manufacturing which are journals based on CIRP peer review.

Intelligent circular manufacturing
SFI Manufacturing was successful in a proposal to the INTPART program of the Norwegian Research Council. The project is called INMAN: Intelligent circular manufacturing research and educational collaboration with Japan and India. Our main motivation is to strengthen the quality of our research and education by creating long-lasting international links with key research institutions in Japan and in India. Partners are NTNU (host institution), SFI Manufacturing and NCE Raufoss, Waseda University in Tokyo, National Institute of Advanced Industrial Science and Technology (AIST) in Tsukuba and Indian Institute of Technology in Hyderabad. The project goals are:

- Common research agendas and funding applications for all INMAN-institutions
- Open online course (MOOC) on circular manufacturing
- Joint PhD supervision and seminars
- Framework for a joint master degree program and joint PhD school
- Mobility of students, researchers and industry partners in Norway, Japan and India

International scientific Advisory Board
The following persons are recruited to our international scientific Advisory Board:

- Dr. Martin Kuhlman from the Soziologisches Forschungsinstitut (SOFI) in Göttingen, related to the Georg-August-Universität. His research is within organisation and work systems including lean and industry 4.0, and he has a lot of experience from German industry.
- Dr. Gerhard Goldbeck from university of Bristol. His main research area is numerical modelling of materials, including crystallography, polymers and complex fluid dynamics.
- Dr. Günther Hörcher is strategic research manager at the Fraunhofer Institute for Manufacturing Engineering and Automation (IPA) in Stuttgart. He is central in the development of the German strategy for Industry 4.0.

We had a physical meeting with the advisory board in the SFI consortium workshop at Hydro Karmøy in April.

EU project proposals
There has been sent a number of EU proposals with origin in the SFI Manufacturing to calls in Horizon 2020.

* http://www.manufuture.org/wp-content/uploads/ManuFUTURE_SRIA_2030_Vfinal.pdf

Recruitment and communication

We are according to our plan with our PhD education. In 2019, SFI Manufacturing had 12 PhD candidates, and 2 Postdocs. We are pleased to inform that 50% of our candidates is female, and that all candidates are equally distributed over the different research areas.

Our website, **www.sfimanufacturing.no**, includes updated information on the centre, partners, research areas, PhD candidates and publications. The website includes a blog as well, with news about mainly the workshops, PhD candidates and partners. We are sharing all blogposts on Twitter, and most of the blogposts on SINTEF Manufacturing's social media as well. We are using Twitter actively during conferences, workshops, meetings and other gatherings where the centre is involved. SFI Manufacturing has tweeted 173 times until now, and has 272 followers.

We have published three newsletters last year, prior to each workshop. Its aim is to keep the community up to date with the current research that is being carried out within and related to the centre. The newsletters can be found at: **www.sfimanufacturing.no/newsletters**. In addition to the newsletter, we published the annual report of 2018 in the start of 2019, including a summary of the main scientific results, and link to the newsletters as appendix as well.

We are communicating internally about the centre's activities as well. Besides email, eRoom and OneDrive, information is being shared on the info screens. These screens are placed at SINTEF Manufacturing's locations at Raufoss and in Trondheim, and are accessible to both employees and guests. SINTEF's intranet Yammer, accessible to all employees of SINTEF, is being used for sharing information as well.

At last, in our communication, we try the make use of both text, photography and video, and we are using our communication channels cross medial.

Key Researchers

Name	Institution	Main research area
Ida Westermann	NTNU-NV-IM	Joining aluminium to steel
Bjørn Holmedal	NTNU-NV-IM	Joining aluminium to steel
Vegard Brøtan	SINTEF Manufacturing	Additive manufacturing, Multi material products cont. polymers
Olav Åsebø Berg	SINTEF Manufacturing	Additive manufacturing
Ben Alcock	SINTEF Industry	Additive manufacturing, Multi material products cont. polymers
Erik Andreassen	SINTEF Industry	Additive manufacturing
Per Erik Vullum	NTNU-NV-IF	Multi material metallic products
Randi Holmestad	NTNU-NV-IF	Multi material metallic products
Sotirios Grammatikos	NTNU-IV (Gjøvik)	Multi material products cont. Polymers
Are Strandlie	NTNU-IV (Gjøvik)	Multi material metallic products, Multiscale modelling
Per Harald Ninive	NTNU-IV (Gjøvik)	Multi material metallic products, Multiscale modelling
Magnus Eriksson	SINTEF Industry	Multi material metallic products
Ragnhild Aune	SINTEF Industry	Multi material metallic products
Odd M. Akselsen	SINTEF Industry	Multi material metallic products
Bård Nyhus	SINTEF Industry	Multi material metallic products
Dirk Nolte	SINTEF Industry	Multi material metallic products
Hoang Hieu Nguyen	SINTEF Industry	Multi material metallic products
Gaute Gruben	SINTEF Industry	Multi material metallic products
Ben Alcock	SINTEF Industry	Multi material products cont. Polymers
Virgile Delhaye	SINTEF Industry	Multi material products cont. Polymers
Kjell Olafsen	SINTEF Industry	Multi material products cont. Polymers
Afaf Saai	SINTEF Industry	Multi material products cont. polymers, Multiscale modelling
Christian Karl	SINTEF Industry	Multi material products cont. Polymers
Jesper Friis	SINTEF Industry	Multi material metallic products, Multi material products cont. polymers, Multiscale modelling
Xiaobo Ren	SINTEF Industry	Multiscale modelling
Ole Martin Løvvik	SINTEF Industry	Multiscale modelling
Rune Østhus	SINTEF Manufacturing	Multiscale modelling
Einar Hinrichsen	SINTEF Industry	Multi material
Sverre Gulbrandsen-Dahl	SINTEF Manufacturing	Multimaterial
Jan Tommy Gravdahl	NTNU-IE	Sensor fusion

Esten Ingar Grøtli	SINTEF Digital	Robotic handling of flexible objects, Flexible and integrated production systems
Marianne Bakken	SINTEF Digital	Robotic handling of flexible objects
Helene Schulerud	SINTEF Digital	Robotic handling of flexible objects
Morten Lind	SINTEF Manufacturing	Robotic handling of flexible objects, Flexible and integrated production systems
Eirik Njåstad	SINTEF Manufacturing	Robotic handling of flexible objects
Rune K. Sandøy	SINTEF Manufacturing	Flexible and integrated production systems
Ådne S. Linnerud	SINTEF Manufacturing	Flexible and integrated production systems
Sebastian Dransfeld	SINTEF Manufacturing	Flexible and integrated production systems
Per Nyen	SINTEF Manufacturing	Flexible and integrated production systems
Tone Beate Gjerstad	SINTEF Manufacturing	Flexible and integrated production systems
Lars Tore Gellein	SINTEF Manufacturing	Robotic handling of flexible objects, Flexible and integrated production systems
Gabor Sziebig	SINTEF Manufacturing	Robotic handling of flexible objects, Flexible and integrated production systems
Eva A. Seim	SINTEF Digital	Work systems and organization
Hans Torvatn	SINTEF Digital	Work systems and organization
Pål Kamsvåg	SINTEF Manufacturing	Work systems and organization
Eirin Lodgaard	SINTEF Manufacturing	Work systems and organization, Industrial clusters and learning systems, Innovation and product development
Gaute Knutstad	SINTEF Manufacturing	Work systems and organization, Industrial clusters and learning systems, Innovation and product development
Ragnhild Eleftheriadis	SINTEF Manufacturing	Industrial clusters and learning systems
Jonas Ingvaldsen	NTNU-Økonomi-IØT	Work systems and organization, Innovation and product development
Asbjørn Karlsen	NTNU-SU-GEO	Industrial clusters and learning systems
Eli Fyhn Ullern	SINTEF Digital	Industrial clusters and learning systems
Sigurd Vildåsen	SINTEF Manufacturing	Industrial clusters and learning systems
Maria Flavia Mogos	SINTEF Manufacturing	Industrial clusters and learning systems
Johanne Sørumsbrenden	SINTEF Manufacturing	Industrial clusters and learning systems
Monica Rolfsen	NTNU-Økonomi	Work systems and organization, Industrial clusters and learning systems, Innovation and product development
Heidi Dreyer	NTNU-Økonomi-IØT	Work systems and organization, Industrial clusters and learning systems, Innovation and product development
Kristian Martinsen	NTNU-IV (Gjøvik)	Additive manufacturing, Work systems and organization

Postdoctoral researchers with financial support from the Centre budget

Name	Nationality	Period	Sex M/F	Topic
Signe Moe	Norwegiern	2017-2019	F	Flexcible and robust autmation
Mathias Hauan Arbo	Norwegiern	2019-2021	M	Flexcible and robust autmation

PhD students 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	2016-2020	F	Automatisaton of additive manufacturing
Eirik B.H. Korsen	Norwegian	2017-2020	M	Robustnes of MES and work systems
Andreas Molturmyr	Norwegian	2019-2023	M	Automatisaton of additive manufacturing
Chaman Srivastava	Indian	2019-2023	M	Liftime of polymer products
Ingrid Fjordheim Onstein	Norwegian	2019-2023	F	Sensor fusion

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	2015-2019	M	Business management, innovation and implementation of changes
Marit Moe Bjørnbet	KPN SISVI	Norwegian	2016-2019	F	Life cycle assessment as a management tool
Anna Maria Persson	SINTEF Institute funding	Norwegian	2017-2020	F	Mechanical properties of thermoplastic elastomers in injection moulded components

Master Degrees

Name	Sex M/F	Period	Topic
Audun Fjelldahl	M	2016	Knowledge sharing organizational learning
Line Larsen	F	2016	Entrepreneurship and innovation through spinn-offs
Harald Solhaug	M	2017	Thermomechanical processing of an AA6082 - IF steel cold roll bonded composite material
Peter Sjølie	M	2017	Robust and Flexible Automated Assembly of Pneumatic Couplings
Maurice Muser Iv	M	2017	Can Lean Leadership promote social sustainability in the context of the Norwegian model
Thorbjørn Midthus	M	2017	Standardized work in a work organization that is based on Lean philosophy
Torbjørn Schjelderup Leirmo	M	2017	Additive Manufacturing: An integrated methodology for optimizing part allocation
Christina Mitcheltree	F	2017	Innovation through a circular perspective - Creating shared value through networking
Cristian Livik	M	2018	Improving the deployment of tolerances through utilization of closed-loop tolerance engineering in the automotive industry
Sissel Marie Breivik	F	2018	Additive manufacturing of tool inserts for High-pressure aluminum die-casting dies
Stian Nødseth Halvorsen	M	2018	Digital visual boards for effectiveness and KPI generation
Nora Leiva Garcia	F	2018	Path Correction for 3D Printing by Robotic Manipulator
Ingrid Fjordheim Onstein	F	2018	An Additive Manufacturing Path Generation Method Based on CAD Models for Robot Manipulators
Jørgen Jackwitz	M	2018	Visual Feedback for Large Scale Additive Manufacturing Process
Erlend Sverdrup	M	2018	Investigation of bond strength and intermetallic phases in roll bonded steel-aluminium laminates at 150°C
Christopher Berg	M	2018	Industri 4.0 i norsk industri: En casestudie om adopsjon av ledelsestrender
Ingvill Korsvoll	F	2018	Industri 4.0 i norsk industri: En casestudie om adopsjon av ledelsestrender
Ida Plassen Limi	F	2018	Teknologiinnføring i praksis og bruk av Idealmodell: En casestudie i Norsk Hydro ASA
Per Torsvik Steinsvåg	M	2018	Teknologiinnføring i praksis og bruk av Idealmodell: En casestudie i Norsk Hydro ASA
Henrik Aamodt	M	2019	Pilot- og demonstrasjonsanlegg: Er det nok?
Fredrik Witzøe	M	2019	Pilot- og demonstrasjonsanlegg: Er det nok?
Lill Maria Gjerde Johannessen	F	2019	Robot Dynamics with URDF & CasADi
Morten Andre Astad	M	2019	Vive for Robotics

Visiting Researchers

Name	Affiliation	Nationality	Sex M/F	Duration
Jos Benders	Professor KU Leuven	Belgium	M	20% position

Scientific publications

Reporting year: 2018
Type: Article
Authors: H. Holstkog, L.K. Lied, G. Ringen
Title of work: *Coping with technology: A future of robots?*
Book/compendium/journal: ICoping with the Future: Rethinking Assumptions for Society, Business and Work. Routledge 2018
Page no.: 151-165

Reporting year: 941/2018
Type: Article
Authors: M.Z. Khalid, J. Friis, P.H. Ninive, K. Marthinsen, A. Strandlie
Title of work: *A First-Principles Study of the Al (001)/Fe(0-11) Interface.*
Book/compendium/journal: Material Science Forum 2018
Page no.: 2349-2355

Reporting year: 9/2019
Type: Article
Authors: S.M Arbo, T. Bergh, B. Holmedal, P.E. Vullum, I. Westermann
Title of work: *Relationship between Al-Ni intermetallic Phases and Bond Strength in Roll Bonded Steel-Aluminum Composites with Nickel Interlayers*
Book/compendium/journal: Metals
Page no.: 2349-2355

Reporting year: 780/2019
Type: Article
Authors: H. Becker, T. Berbh, P.E. Vullum, A. Leineweber, Y. Li
Title of work: *Al-Fe-Si intermetallic phase, their intergrowth and polytype formation*
Book/compendium/journal: Journal of Alloys and Compounds
Page no.: 917-929

Reporting year: 5/2019
Type: Article
Authors: H. Becker, T. Berbh, P.E. Vullum, A. Leineweber, Y. Li
Title of work: *Effect of Mn and cooling rates on -, - and -Al–Fe–Si intermetallic phase formation in a secondary Al–Si alloy*
Book/compendium/journal: Materialia

Reporting year: 2019
Type: Article
Authors: V. Engesbak, J.A. Invaldsen
Title of work: *“Please use our ideas”: making parallel organizations work*
Book/compendium/journal: Team Performance Management

Reporting year: 52/2019
Type: Article
Authors: L.D. Evjemo, G. Langelandsvik, J.T. Gravdahl
Title of work: *Wire Arc Additive Manufacturing by Robot Manipulator: Towards Creating Complex Geometries*
Book/compendium/journal: IFAC-PapersOnLine
Page no.: 103-109

Reporting year:
Type: Book
Authors: A. Kalsen
Title of work: *Historical examples of entrepreneurial discovery: revisiting the manufacturing history of Raufoss evolving between exploration and exploitation*
Book/compendium/journal: The Entrepreneurial Discovery Process and Regional Development. New Knowledge Emergence, Conversion and Exploitation
Page no.: 288-304
ISSN/ISBN: 978-1-138-57455-7

Reporting year:
Type: Book
Authors: E.B.H. Korsen
Title of work: *Balanced Scorecard and Hoshin Kanri: Why and how they might be used together*
Book/compendium/journal: Modeller : Fjordantologien 2019
Page no.: 143-162
ISSN/ISBN: 978-82-15-03439-3

Reporting year: 81/2019
Type: Article
Authors: T. Leirmo, K. Martinsen
Title of work: *Evolutionary algorithms in additive manufacturing systems: Discussion of future prospects*
Book/compendium/journal: Procedia CIRP
Page no.: 671-676
ISSN/ISBN: 978-82-15-03439-3

Reporting year: 2019
Type: Article
Authors: H.B. Lund, A. Karlsen
Title of work: *The importance of vocational education institutions in manufacturing regions: adding content to a broad definition of regional innovation systems*
Book/compendium/journal: Industry and Innovation
Page no.: 1-20

Reporting year: Springer 2019
Type: Article
Authors: O. Ogorodnyk, O.V. Lyngstad, M. Larsen, K. Wang, K. Martinsen
Title of work: *Application of Machine Learning Methods for Prediction of Parts Quality in Thermoplastics Injection Molding*
Book/compendium/journal: “Advanced Manufacturing and Automation VIII Proceedings IWAMA 2018”
Page no.: 237-244
ISSN/ISBN: 978-981-13-2375-1

Reporting year: 7/2019
Type: Article
Authors: J. Reimann, G. Sziebig
Title of work: *The Intelligent Factory Space – A Concept for Observing, Learning and Communicating in the Digitalized Factory*
Book/compendium/journal: IEEE Access
Page no.: 70891-70900

Reporting year: 2/2019
Type: Article
Authors: O. Semeniuta, P. Falkman
Title of work: *EPypes: a framework for building event-driven data processing pipelines*
Book/compendium/journal: PeerJ Computer Science
Page no.: 1-20

Reporting year: 52/2019
Type: Article
Authors: K. Somlo, G. Sziebig
Title of work: *Aspects of Multi-pass GTAW of Low Alloyed Steels*
Book/compendium/journal: IFAC-PapersOnLine
Page no.: 101-107

Reporting year: 14/2018
Type: Article
Authors: H. Holtskog, H.C.G
Title of work: *(editorial)*
Book/compendium/journal: International Journal of Action Research
Page no.: 2-3

Reporting year: 2018
Type: Article
Authors: M. Berge, A.G. Syversen, H. Holtskog
Title of work: *Coping with globalisation: Local knowledge and multinational companies*
Book/compendium/journal: “Coping with the Future: Rethinking Assumptions for Society, Business and Work. Routledge”
Page no.: 51-68
ISSN/ISBN: 978-1-138-55932-5

Reporting year: 51/2018
Type: Article
Authors: M.H Arbo, J.T. Gravdal
Title of work: *Stability of the Tracking Problem with Task-Priority Inverse Kinematics*
Book/compendium/journal: IFAC-PapersOnLine
Page no.: 121-125

Reporting year:	9/2019
Type:	Article
Authors:	S. Thun, P.F. Kamsvåg, B. Kløve, E.A. Seim, H.Y Torvatn
Title of work:	*Industry 4.0: Whose Revolution? The Digitalization of Manufacturing Work Processes*
Book/compendium/journal:	Nordic Journal of Working Life Studies
Page no.:	39-57

Reporting year:	2019
Type:	Article
Authors:	L.M. Johannesen, M.H. Arbo, J.T. Gravdal
Title of work:	*Robot Dynamics with URDF & CasADi*
Book/compendium/journal:	Proceedings, 2019 IEEE 7th International Conference on Control, Mechatronics and Automation. IEEE
ISSN/ISBN:	9781728137865

Reporting year:	2019
Type:	Article
Authors:	I. Gravdal, K. Seel, E.I. Grøtli
Title of work:	*Robotic Bin-Picking under Geometric End-Effector Constraints: Bin Placement and Grasp Selection*
Book/compendium/journal:	"Proceedings, 2019 IEEE 7th International Conference on Control, Mechatronics and Automation. IEEE Press"
ISSN/ISBN:	9781728137865

Reporting year:	2019
Type:	Article
Authors:	M.A. Astad, M.H. Arbo, E.I. Grøtli, J.T. Gravdal
Title of work:	*Vive for Robotics: Rapid Robot Cell Calibration*
Book/compendium/journal:	"Proceedings, 2019 IEEE 7th International Conference on Control, Mechatronics and Automation. IEEE Press"
ISSN/ISBN:	9781728137865

Statement of accounts

An overview of the funding and costs is presented below. All figures are in 1000 NOK.

Funding	**2019**
The Research Council	12 186 000
The Host Institution (SINTEF Manufacturing AS)	1 316 000
Research Partners*	7 153 000
Enterprise Partners*	10 483 000
Total	**31 138 000**

Costs	
The Host Institution (SINTEF Manufacturing AS)	6 938 000
Research Partners	17 842 000
Enterprise Partners	6 385 000
Public Partners	
Equipment	
Total	**31 138 000**

Enterprise partners*

Brødrene Aa (private sector)
Benteler Automotive Raufoss (private sector)
Ekornes (private sector)
GKN (private sector)
Hexagon (private sector)
Kongsberg Automotive (private sector)
Mjøs Metallvarefabrikk (private sector)
Nammo (private sector)
Norsk Hydro (private sector)
Plasto (private sector)
Raufoss Technology (private sector)
Hybond (private sector)
Sandvik Teeness (private sector)
Kongsberg Maritime Subsea (private sector)

Research Partners*

SINTEF Digital (Research institute)
SINTEF Industry (Research institute)
NTNU IE
NTNU ØK
NTNU SU
NTNU NV
NTNU IV

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Book about MMP manufacturing - Plan 2015-2023: 1						2015-2019: 0				
Scientific paper publish in international journals and conferences with peer review - Plan 2015-2023: 112		1	7	28	32	23	2015-2019: 91			
Popular science articles - Plan 2015-2023: 16				2	1	3	2015-2019: 6			
National and international conferences and seminars/workshops - Plan 2015-2023: 2			1			2015-2019: 1				
PhD candidates - Plan 2015-2023: 17		2	7	1		3	2015-2019: 13			
Post docs - Plan 2015-2023: 3				1		1	2015-2019: 2			
MSc students - Plan 2015-2023: 100			2	6	11	4	2015-2019: 23			

SFI Manufacturing

One of the 24 SFI's in Norway

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

manufacturing

SFI Manufacturing
SINTEF Manufacturing
Enggata 40, 2830 Raufoss
www.sfimanufacturing.no