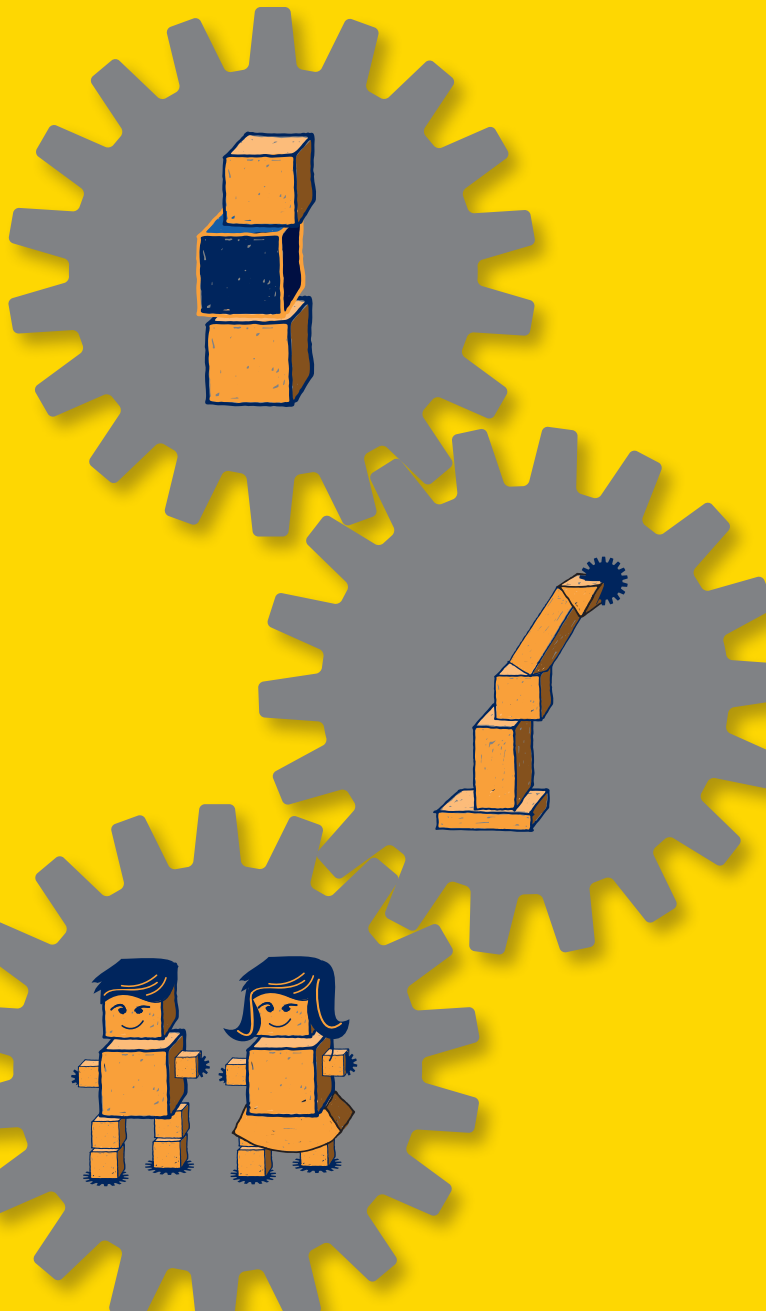
manufacturing

Annual report

2018



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

Picture from NTNU, Trondheim

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Welcome to the SFI Manufacturing annual report 2018

The manufacturing industry in Norway represents a limited part of the economy nationally, but it represents an important competence for the society.

Manufacturing is an industry that is not that dependent on natural resources, and hence is highly exposed to global competition. The Norwegian manufacturing industry's home market is limited, though exposed to international competitiveness. The industrial partners of SFI Manufacturing are all excellent representatives in their field of competence. Through continuous inhouse improvements and learning through networks, in order to prepare for step changes, the manufacturing industry develops its competitiveness based on competence development. SFI Manufacturing is developing a knowledge base to support and stimulate further development and innovation in the Norwegian manufacturing industry.

In the past 3 years, SFI Manufacturing has addressed the need for a so-called catapult centre, and the establishment of Manufacturing Technology Norwegian Catapult (MTNC) at Raufoss is one of the most substantial spin-offs from the centre. The Norwegian catapult is a result of the white paper on industry from the Norwegian Government in 2017. The vision of this white paper is: A greener, smarter and more innovative industry. MTNC has further developed this vison, which is a good illustration of the multipotential of the manufacturing industry's contribution to the society. The manufacturing industry develops its competitiveness based on the same pillars as the threefold sustainability, or the triple bottom line: People, Planet and Profit.

People: the social equity bottom line
Planet: the environmental bottom line
Profit: the economical bottom line

During the last year, SFI Manufacturing has gone through a process of revision of the research themes, and one of the adjustments has been the incorporation of circular economy topics in all the existing research areas, in addition to the relevant UN Sustainable Development Goals. This development is in good alignment with the previously mentioned threefold sustainability, and the national goals for the industry. I would like to advise the centre to continue with becoming even more relevant to the Norwegian society, and to continue with being a good addition to the industry that it represents.

This annual report will hopefully give you more insight into the relevance of SFI Manufacturing.

Lars Stenerud
CEO Plasto AS
Chair of the board, SFI Manufacturing
Raufoss, 21st of March 2019

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**

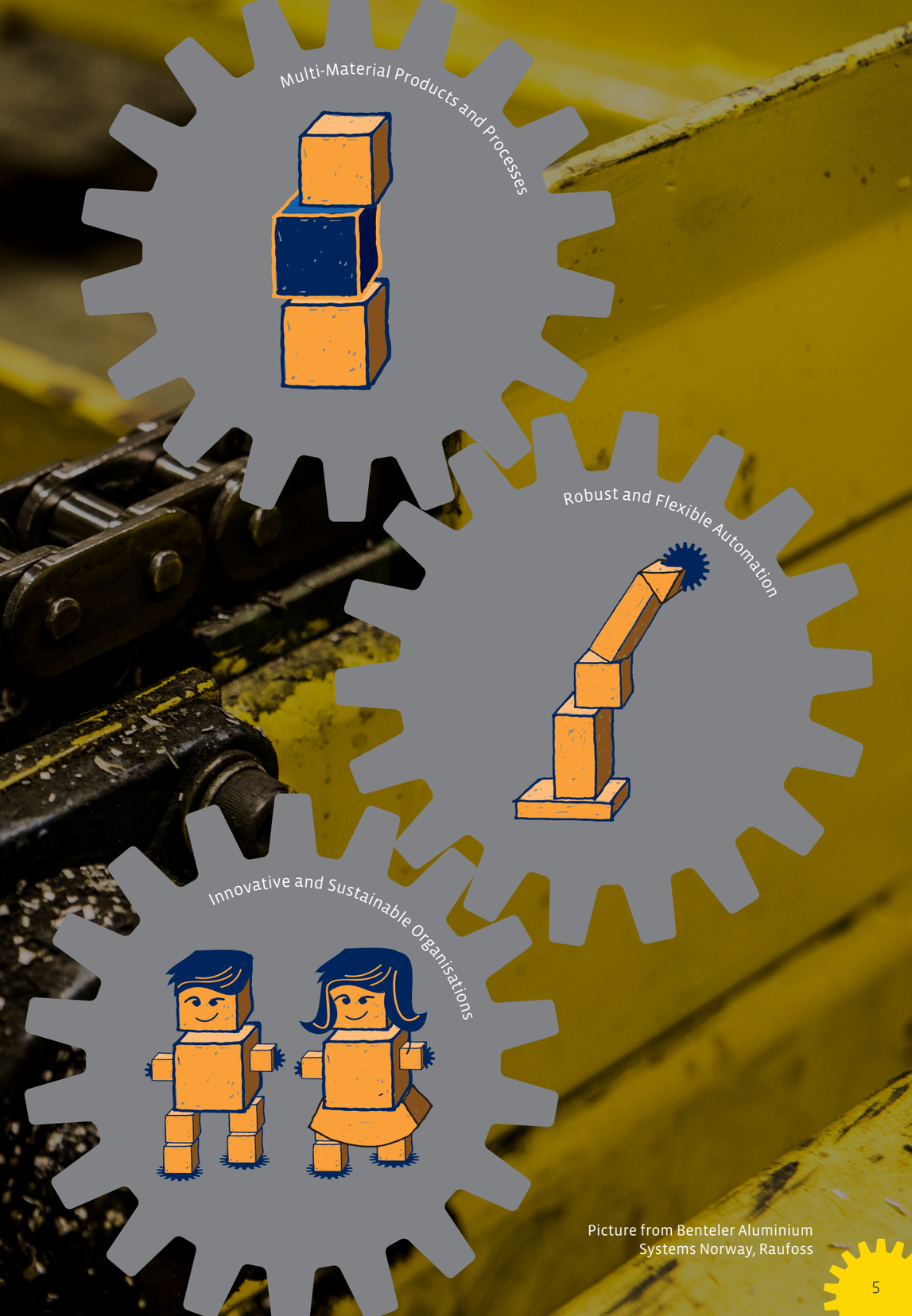
SFI Manufacturing builds on existing national capabilities and aims to strengthen the Norwegian manufacturing companies' ability to innovate. The centre seeks to mirror the inherent cross-disciplinary innovation systems in the industry and combine research on multi-material product solutions, flexible 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

SFI Manufacturing has now been in operation for 3,5 years, and we are close to the mid-term of the centre period. During these initial years, the centre has addressed specific research topics within each of its three research areas: Multi-Material Products and Processes, Robust and Flexible Automation, and Innovative and Sustainable Organisations. In 2018 we have identified the specific results of this research so far and we have started a process of evaluation of their innovation potential. We will have a first overall evaluation ready in 2019, but I would like to give you an introduction here.

In the period of 2015 to 2017, a total of 28 scientific results with a potential for innovation has been identified. The work of SFI Manufacturing is focusing on the Technology Readiness Levels (TRL) 1-3, but several of the identified results have been developed into, or contributed to, innovation projects on TRL 4-7. SFI Manufacturing has a joint ambition of developing a considerable volume of such innovation projects (budget goal over the centre period is 800 MNOK). The status in 2018 is:

21 innovation projects have been granted and started in 2016-2018

The total budget of these projects is 592 MNOK

All partners of SFI Manufacturing are joining at least one of the projects

17 extra industrial partners outside the SFI consortium are participating in the projects

This clearly illustrates the importance of the innovation projects as a value chain for innovation based on knowledge developed in SFI Manufacturing, and their potential as an arena for dissemination.

In the ongoing process of evaluating the innovation potential of SFI Manufacturing, we are now analysing the plan for value creation within each of these innovation projects. We have developed a scheme for collecting all relevant information connected to each of the identified SFI results: Goal of the SFI research, Problem description, Solution, Status of the research activity, TRL development of the SFI activity, connected spin-off projects and their TRL plan, and innovation elements.

I hope you will find the results in this annual report interesting and I am confident that we will develop this value chain of research towards innovations even more in the next coming years.

Sverre Gulbrandsen-Dahl
Centre Director
Raufoss, 21st of March 2019

Research and industrial partners

NTNU

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

SINTEF

Host institution Research:
Product- and process development, Production technology, Materials Technology

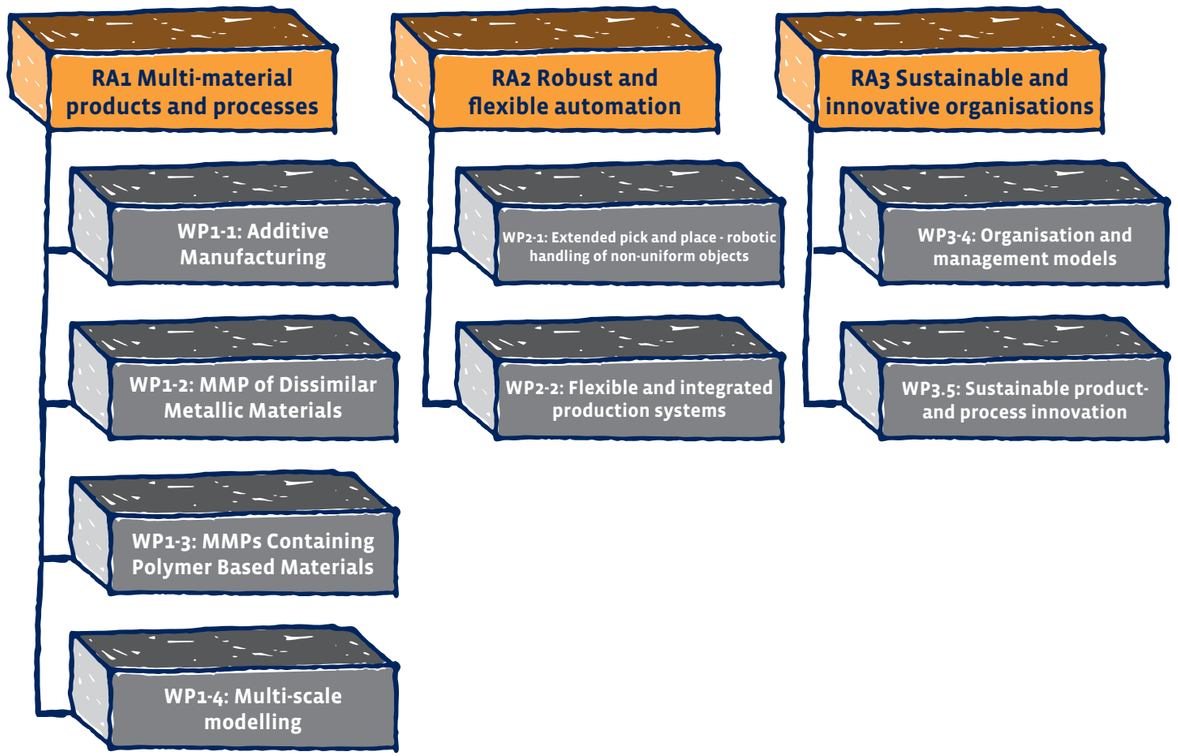
SINTEF

Research:
SINTEF Industry, SINTEF Digital

BENTELER
PLASTO
SANDVIK Coromant
KONGSBERG AUTOMOTIVE
EKORNES
Nammo
NEUMAN ALUMINIUM
Hydro
GKN AEROSPACE
Rolls-Royce
MJØS METALLVAREFABRIKK AS
HEXAGON RAGASCO
HyBond a bonding revolution
BRØDRENE AA
KONGSBERG
The Research Council of Norway

Organisation
Centre structure

Organisation
Centre structure



Meet the next generation scientists

PhD candidates and postdoctoral researchers are essential resources within SFI Manufacturing. Siri Marthe, Tina, Muhammad, Anna-Maria, Linn, Mathias, Henrik, Marit, Vetle and Eirik are doing a PhD, and Signe a Postdoc. Beneath they will tell you a bit more about their research.

RESEARCH AREA 1

Siri Marthe Arbo – New ways of joining steel and aluminium together
During my PhD I will look at primarily two dissimilar metals, steel and aluminium, and I will try to find a new way of joining the two metals together. By combining two dissimilar metals, we can attain new lightweight and high performance products having the best properties from each of the metals.

Tina Bergh – The interface between joined aluminium and steel
In my PhD I will characterize the interface in joined materials, first and foremost joined aluminium and steel. My goal is to get a thorough understanding of the interface, and to link its characteristics at the microscopic scale back to the properties of the joint on the macroscopic scale.

Muhammad Zeeshan Khalid – Atomistic modelling of multi-material interfaces
During my PhD I will focus on atomistic modelling of multi-material interfaces. My project will provide information about the nanostructure changing mechanisms during the welding of dissimilar materials.

Anna-Maria Persson – Mechanical properties of thermoplastic elastomers
My study is related to the field of mechanical properties of thermoplastic elastomers in injection moulded components. During my PhD, I will have a close dialogue with Kongsberg Automotive's Couplings division to get valuable industrial feedback.

RESEARCH AREA 2

Linn Danielsen Evjemo – Large-scale, robotized additive manufacturing
In my PhD I will focus on large-scale, robotized additive manufacturing using industrial robots and cold metal transfer welding. I will try to see if it is possible to combine the large workspace of an industrial robot arm with the flexibility and relative affordability of traditional additive manufacturing methods.

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.

Signe Moe – Set-based control of robotic systems and machine learning
I finished my PhD on the topic of guidance and control of marine vehicles and set-based control of robotic systems. During my Postdoc I am extending set-based theory to industrial needs such as spray painting and additive manufacturing, the latter in cooperation with PhD Linn Danielsen Evjemo. In addition, I am working on machine learning for manufacturing for bin-picking and other relevant applications.

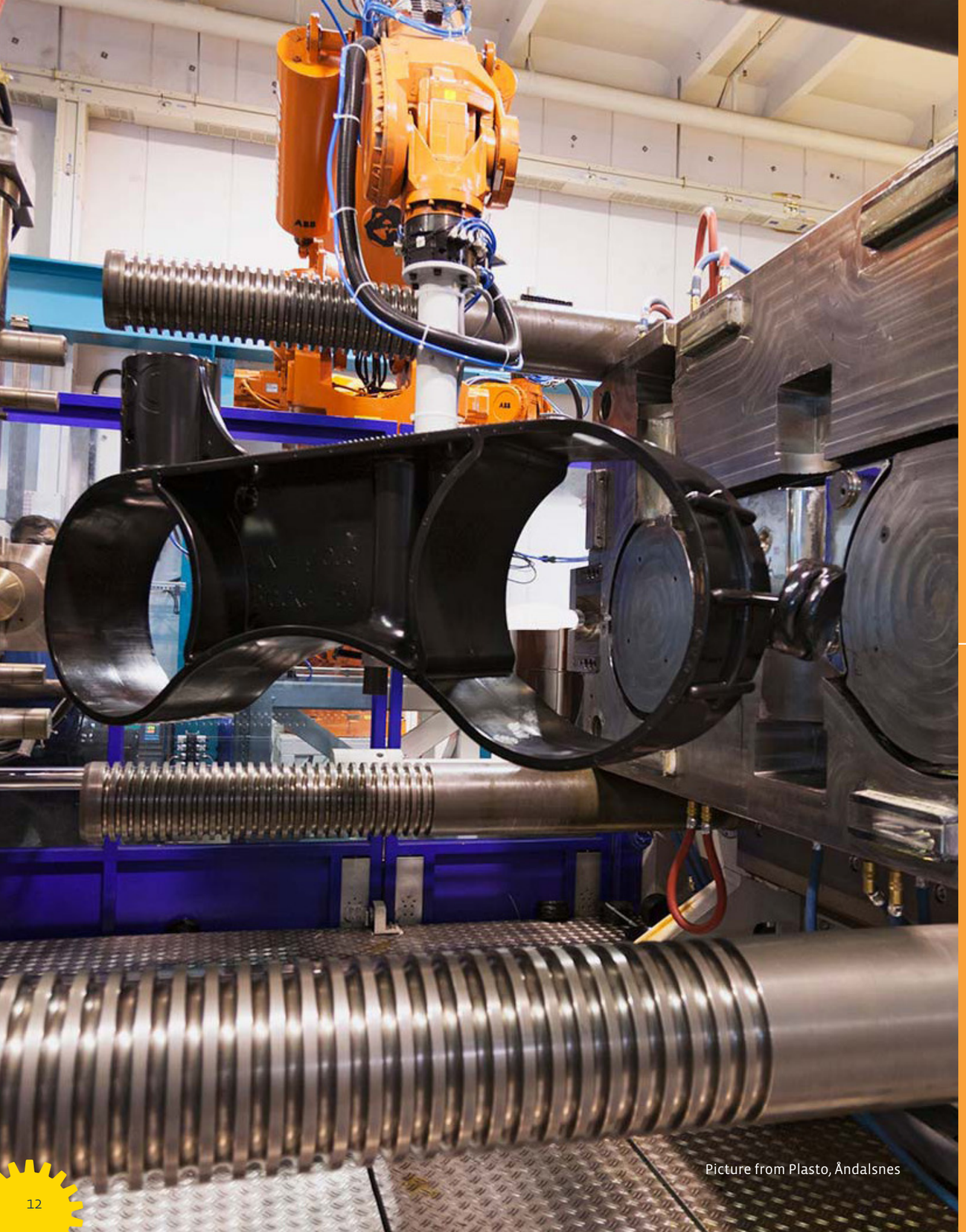
RESEARCH AREA 3

Henrik Brynthe Lund – Industrial networks, learning systems and cluster development
During my PhD I will focus on industrial networks, learning systems and cluster development. I will look at how the industrial clusters at Raufoss and Kongsberg plan to cope with the challenges posed by technological change, and how they work with actors on all levels.

Marit Moe Bjørnbet – LCA as a tool to facilitate the transition towards a green economy
In my PhD I will focus on life cycle assessments (LCA) as a management tool to facilitate the transition towards a green economy. My idea is that life cycle assessments can be utilized to develop tools, preparing the Norwegian manufacturing industry for the green shift, integrating environmental management into core business activities.

Vetle Engesbak – Step-changes in mature production systems
During my PhD I will focus on how organisations with mature production systems may better organize to capture the value from step-change improvements.

Eirik Hamre Korsen – Aligning performance management across organisations
In my research I will do a qualitative case study among a number of manufacturing organisations participating in SFI Manufacturing. In 2018 I have explored how the management tools "balance scorecard" and "hoshin kanri" can be combined successfully in a manufacturing setting.



Picture from Plasto, Åndalsnes

Report from the research areas 2018

SFI Manufacturing aims to strengthen the Norwegian manufacturing companies' ability to innovate, by doing research on multi-material product solutions, flexible automated manufacturing and organisational processes. In this part of the annual report, we will give an insight into the research that has been done in 2018. In the newsletters, which are available on the website www.sfimanufacturing.no, more information can be found.

Multi-Material Products and Processes

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.

Joining dissimilar materials

In 2018 we have continued our research on joining dissimilar materials, and in special joining aluminium to steel. We have continued our work on new joining methods, in order to establish the relationship between process, property and performance, which is needed for high-performance aluminium-steel products. In this work, we have taken a multi-scale approach, combining experimental process studies and advanced characterisation with numerical modelling, involving three PhD-students. As a spin-off in understanding the interface properties between aluminium and steel, we have experimentally in combination with multi-scale modelling studied "galling", the unwanted process where aluminium sticks to a tool surface in a forming process.

Adhesive bonding is often the best method to join very dissimilar materials, but this can be problematic when it comes to the end of the product life cycle of the part, because of the difficult separation. This complicates disassembly, which is a usual requirement for the recycling of multi-material parts. Therefore, we have investigated a novel chemistry of so called "vitrimers" as a potential reversible adhesive, designed to release chemical bonding when heated to a trigger temperature.

Fundamental understanding of adhesion of interfaces between different materials is important in many bonding processes, such as gluing, as well as coating processes. In order to develop a fundamental understanding of the mechanisms behind adhesion, we have performed an initial study using atomistic modelling, in order to study adhesion of a polymer resin to an Al surface.

Additive manufacturing

We have continued our research on additive manufacturing (AM) of metals and polymers. Wire and arc additive manufacturing (WAAM) has been used to produce components in e.g. titanium, aluminium and steel. In SFI Manufacturing, the WAAM technology has been demonstrated by combining cold metal transfer welding equipment and industrial robot arms. This process can be used as a method for repair and refurbishment of large-scale components.

In addition, we have continued our work on studying temperature development and grain structure in Laser Based Directed Energy Deposition and Laser Based Powder Bed Fusion AM processes. A prototype AM system using technical rubber grades has been studied as well, and, as a result, a cm scale demonstrator part has been made.

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.

Bin-picking

One challenge posted by several industrial partners, is related to flexible and cost-efficient solutions for picking up objects with random poses from a bin. This challenge, often referred to as "the bin-picking problem", is considered one of the core problems in computer vision and robotics. In 2018 we have continued our work on this challenge. We have proposed a solution that 1) uses a deep neural network to suggest feasible grasps from point clouds, and 2) calculates safe and efficient paths for the manipulator arm to reach and grasp the object.

Furthermore, we have established a vision-based robotic grasping system which can handle several types of highly reflective objects. This solution is based on training a deep neural network on virtual 3D sensor data of virtual parts, in order to learn where on the surface the object should be grasped by the robot. This work was presented at the IEEE International Conference on Robotics and Biomimetics 2018, where it received T. J. Tarn best paper in robotics award.

For the path planning, we have based our solution on algorithms developed in the SINTEF strategic project SEAMLESS, and further extended the functionality. Whereas previously things would be considered an obstacle, the system can now deal with objects which the manipulator arm is meant to grasp. The planning algorithm has been tested on a physical setup of a six degrees of freedom manipulator arm.

"Batch size one" robotic assembly

Another generic challenge is the assembly of "batch size one" - flexible, robust and cost-efficient approaches for assembly of products in low volumes and many product variants. In SFI Manufacturing, we have suggested a generic architecture, which is based on the digital description of the product, where the CAD models are fed with extended data that can be used to generate the assembly process.

This process is automatically generated from the extended CAD data and stored in different file structures that in sum will be able to feed the process with the necessary information. A process generator then collects the necessary data and publishes this to the different users, which in our architecture is a simulation model, the physical robot, or a mixed reality consisting of both the physical robot and virtual objects, visualised through an augmented reality application.

Software systems

In 2018 we have also continued our work on software that can plan the assembly sequence, choose skills based on CAD information and the robot environment, and handle arbitrary sensors and tight-clearance assembly tasks. A prototype of such software has been developed and tested in collaboration with researchers from Katholieke Universiteit Leuven. This work was published in IEEE International Conference on Automation Science and Engineering (CASE, August 2018), where it received the best student paper award.

Sustainable and Innovative Organisations

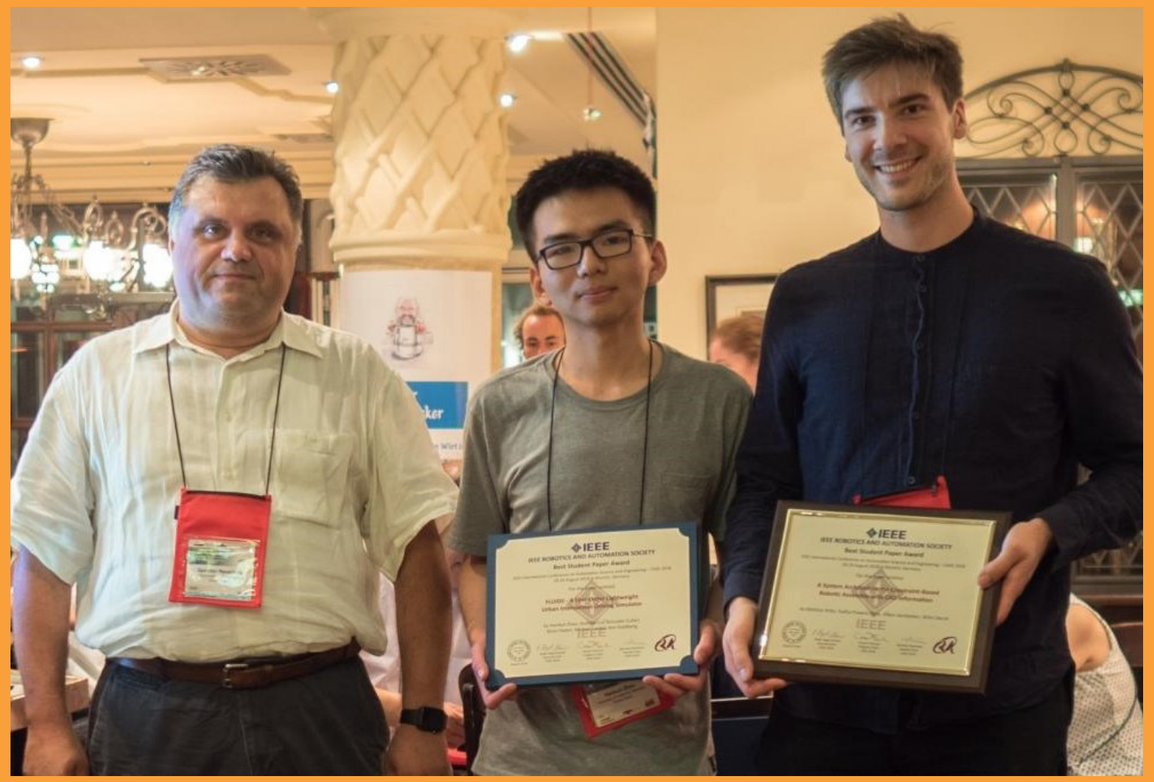
The research area Sustainable and Innovative Organisations concerns organizational and innovative sustainability aspects of advanced manufacturing companies. The overall objective is to develop knowledge and solutions for advanced work systems that are able to utilize new technology and flexible and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

Maturity Mapping

In 2018 we have focused on disseminating results of the SFI Manufacturing Maturity Mapping tool, which is a survey and analytical framework that can be used to map, analyse and reflect on organisations' status and level of maturity when it comes to applying and developing new technology. After analysing the results, presenting and discussing these with the participating organisations, the findings have been send in for review to several international scientific journals.

Industry 4.0

A challenge addressed by the industrial partners is "Industry 4.0 decision support" at shop floor level. Information may exist in various IT systems of the companies, but is not necessarily available or adjusted to the needs for information at shop floor level. This topic has been addressed and resulted in the development of two demonstrators for information provision: one employing an Apple Smart Watch, and the other simply projecting adapted information on screens distributed at shop floor level. Guidelines for information provisions are in development. One master thesis explored companies' rationale for adopting Industry 4.0, and another explored the integration of digital technologies in a multi-plant context, evaluating guidelines for implementation.



PhD candidate Mathias Hauan Arbo receiving the best student paper award during the IEEE International Conference on Automation Science and Engineering (CASE, August 2018).

Organization and management models

As part of the ongoing research on performance management systems, we have explored how the management tools "balance scorecard" and "hoshin kanri" can be combined successfully in a manufacturing setting. We have also investigated how parallel structures can be used to facilitate interplant knowledge transfer and learning. Results of these activities are accepted for international publication in 2019.

Industrial clusters

Additionally, we have conducted research on balancing strategies in industrial clusters and the absorptive capacity of clusters. In one of the papers, we investigate how educational institutions in collaboration with industry, customize their vocational training programs in line with future demands, in order to prepare skilled workers for the implementation of new technologies. In a recently published book chapter, we examine how local industry development alternates between strategies of exploration and strategies of exploitation. We reveal methods for exploitation of unique local knowledge bases in order to absorb knowledge from outside the cluster and share it within the cluster. This work will result in a couple of international publications which will provide a good description of the industrial networks our industrial partners are connected to. Recently, we turned the attention to the trend of reshoring manufacturing industry, and will explain the phenomenon in context with new technologies and the Norwegian way of organizing manufacturing.

SFI Manufacturing's model for innovation

Innovation? At SFI Manufacturing we create this through our research, spin-off projects and new initiatives. On the next pages we will elucidate this.

Our research
As mentioned before, our research is organised into three research areas. Within each of these areas, a set of research tasks has been identified, including activities focused on technology readiness level (TRL) 1-4. In addition, each PhD and Postdoc position is thematically linked to one of the research areas. The main achievements of 2018 have been described on the previous pages.

Incubator for spin-off projects
SFI Manufacturing has an important role as incubator for spin-off projects, such as user driven innovation projects (supported by the Research Council of Norway) and collaborative projects (supported by the European Commission). As mentioned before, the centre's ambition is to generate a portfolio of spin-off projects with a total budget of 800 million NOK, over the 8-year centre period.

In the past few years, we have created a process model for the development and implementation of new project ideas, to ensure the complementarity and relevance of the research throughout the centre's period. Already after 3,5 years of operation, we have succeeded to establish a total activity exceeding 80% of the ambition of the 8-year period. In addition, all SFI partners are also partner in one or more of the spin-off projects.

Birthplace for new initiatives
In addition to this, SFI Manufacturing has been the birthplace for:

MANULAB, the Norwegian research laboratory for manufacturing

Manufacturing Technology Norwegian Catapult at Raufoss, a centre where industrial companies have the possibility to test new technologies and solutions

"Omstillingsmotoren", a national and open arena for learning and innovation across different industries in Norway, and in particular SME's, with a focus on lean through the project "Produktivitetsspranget"

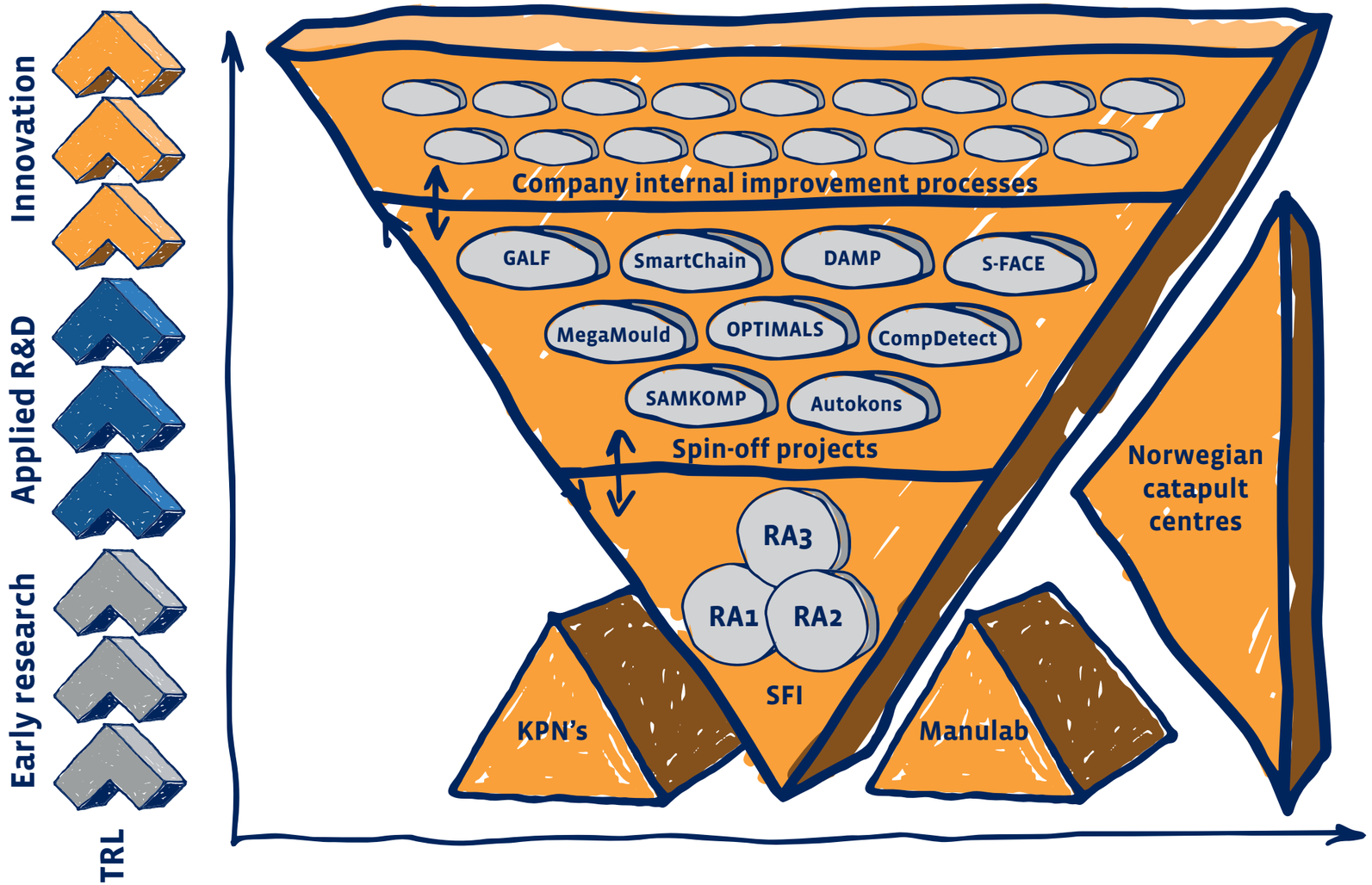
The last two initiatives are important dissemination arenas for SFI Manufacturing, and will have an important role to stimulate commercialisation outside the SFI Manufacturing consortium.

Model for innovation
Innovation associated with SFI Manufacturing, comes from the value chain of 1) our research, 2) spin-off projects and 3) new initiatives and activities. This value chain is illustrated on the next page. Our spin-off projects are an important arena for the transfer of knowledge from the centre to the partners, and feedback from the partners to the centre, for example regarding potential revised research themes. This knowledge transfer is achieved through the direct link between the centre's activities and spin-off projects, for example via researchers and PhD candidates.

The centre also provides state-of-the-art reports and presentations on several different research topics. These SOTAs are intended to be useful for the partners directly, and provide a basis for existing or new spin-off projects as well.

The latest action regarding the stimulation of knowledge transfer within the centre, is a schematic overview of all results from 2015 to 2018. This overview includes a description of the problem, research methodology, presented results and further plans. The development on TRL-scale and link to spin-off projects is included as well.

Based on this overview, all partners may now have an insight into all activities, status and where to find more information. Our ambition is to use this overview as an interactive overview providing close to real-time insights.



IMPROVEMENT PROCESSES

- Omstillingsmotor and Produktivitetsspranget, 2 of the improvement programs for SME's
- 130 companies included
- TRL 7-9

SPIN-OFF PROJECTS

- 21 spin-off projects in the range of TRL 4-7
- Total budget of 592 MNOK
- All partners of SFI Manufacturing are joining at least one of the projects
- 17 extra industrial partners outside of the SFI consortium

SFI MANUFACTURING

- 3 research areas in the range of TRL 1-4
- 16 PhD students
- 3 Postdocs
- NTNU (5 faculties) and SINTEF (3 institutes)
- 15 user partners

Budget/projects/partners

Hydro Aluminium Høyanger awarded Norwegian Lean Organisation 2018

In 2018, Hydro Aluminium Høyanger has been awarded Norwegian Lean Organisation of the year. The SFI Manufacturing partner received the award during last year's Lean Conference in Fornebu.

The purpose of the prize is to create a stage for organisations leading in structural improvement work in Norway, both to recognize them and to learn from them. The five finalists Equinor Mongstad, GKN Aerospace Norway, Glencore Nikkelverk, Hydro Aluminium Sunndal and Hydro Aluminium Høyanger were all praised for their structural work on improvements, good results and high involvement among employees.

Hydro Aluminium Høyanger has been chosen as winner because they have distinguished themselves with their lean-work and its link to its corporate strategy. The company clearly sees the importance of continuous improvement work, and the work is very well rooted at both management and shop floor level. There is a high involvement in the entire organisation when it comes to improvement work, and the company is able to create both competitiveness and good operating results.

Hydro Aluminium Høyanger
Hydro's plant in Høyanger started up in 1917 and was one of the first production sites for primary aluminium, or liquid aluminium, in Norway. The factory counts 156 employees and has both a primary aluminium production line and a roller block foundry.

Photo from Norsk Hydro

SFI Manufacturing on NRK P2

The last couple of years, several large manufacturing companies moved back to Norway, after many years of producing abroad. How do they manage to produce in our high-cost country, and how important is production in Norway actually? On the 27th of November 2018, the theme of NRK P2's program Ekko was: "Made in Norway". PhD candidate Henrik Brynthe Lund participated in this program, and introduced us to the world of producing in Norway. The other participants of the debate were Stein Lier Hansen from Norsk Industri and Trygve Hegnar from Finansavisen.

Stein Lier Hansen starts with explaining the "moving trend" of the past couple of years. – We have seen several manufacturing companies moving their production back to Norway, such as Hunton at Gjøvik, manufacturer of building materials, and Dale of Norway, manufacturer of sweaters. These manufacturing companies are now using technologies that enable them to produce more efficient and at a lower cost level, and therefore they are able to produce outside Asia or East-Europe as well.

Profitability

SFI researcher Henrik Brynthe Lund has interviewed many companies that have "taken home" their production. "Why do they do that?" asks the host of the radio program. – First and foremost because it is profitable, explains Henrik. – The Norwegian industry is still interested in making money. By using new technology and combining it with knowledge and expertise, one can be more competitive on parts of the production process, and these parts could be moved to Norway.

Henrik comes with an example on Neuman Aluminium at Raufoss, manufacturer of wheel suspension for cars sold at the European market. – Previously, these wheel suspension systems were produced in China, but this was not that beneficial as hoped: there were quite some unforeseen costs, and there was uncertainty in the shipping process. Instead of producing in China, sending it to Raufoss for repacking, and sending it to the European car manufacturers, Neuman now produces at Raufoss. New technology enabled the company to produce with less employees, which has lowered the costs, and made production in Norway actually more profitable than in China.

Manufacturing expertise

"Should all manufactures move back to Norway?" asks the host. Henrik explains that one must be able to prove that moving back is a competitive choice. – At Raufoss for example, there is special expertise on manufacturing, on production systems, robotics and automation, especially around aluminium. This is something that is typical for other clusters in Norway as well: they have a long history, and they have been able to build up specific knowledge over a long time.

Exploitation of robots

Trygve Hegnar from Finansavisen comes with another example on Ekornes, manufacturer of furniture. – Ekornes started with investigating the advantages of automated production lines already in the 90s. What we can see with other companies nowadays, who did not jump on this "robot train" so early, is that they are producing at much higher costs, and that they are struggling with competing against low cost countries. "Is it smart to invest in robots now?" asks the host. Trygve: – Yes, I think so, but it is important to remember that everyone can buy a robot, that is not the problem. The problem often lies in the exploitation, how do you use the robot, how can you optimize it?

Level of bureaucracy

During the debate, the level of bureaucracy at the Norwegian labour market is discussed as well. Henrik explains that Norway has a high level of autonomous skilled workers. – Floor level workers are both skilled, willing and able to make decisions themselves, without asking permission of their managers. This streamlines the production process, because we do not need a signature or three when replacing parts, or adjusting the settings of a machine.

Stein adds to this that this "flat structure" is an enormous competitive factor. It enables companies to be adaptive and to quickly make changes and implement improvements, without asking permission to several layers of managers. – With moving back to Norway, companies are saving their competitive position, but they are also creating the possibility to scale up, and increase their production. "Increasing their production as a consequence of improved competitiveness" concludes the host.

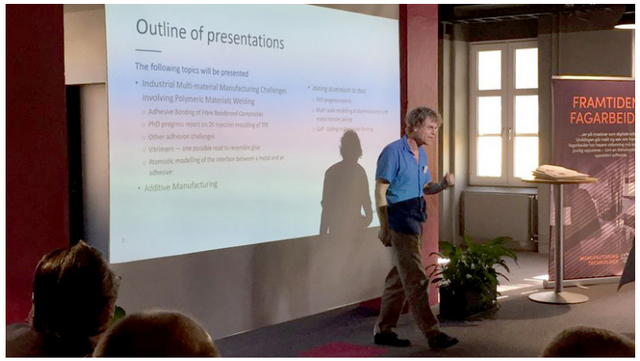
The 2018 workshops

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 2018, the workshops took place at Karmøy with Hydro as host, in Oppland with Hexagon Ragasco as host, and in Horten with Kongsberg Maritime Subsea as host.

From evening to evening
The, typically between 40 and 70, participants gather in the evening at the carefully chosen site, to become up to date with trends and ongoing activities in the different environments directly connected to or around the SFI, and to have time to chat and rebond during the following dinner and social activities. Some go to bed early after a long day with work and travelling 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, including a visit to the hosting company, group discussions and research area presentations.

Visits to Norwegian world class industries
In 2018, 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 Hydro in Haugesund, where the three members of the centre's new Scientific Advisory Board were presented, followed by an exiting tour around the aluminium production site at Karmøy. At Raufoss in June, the participants were welcomed into the industrial park and the high-tech production facilities of Hexagon Ragasco, leading manufacturer of composite LPG cylinders with 15 million cylinders in use worldwide and over 15 years of experience. In Horten in October, Kongsberg Maritime Subsea invited us to their production site, situated on the shore of the Oslo fjord, where the participants got introduced to the world of systems for positioning, monitoring and navigation to merchant fleet and offshore installations, such as satellite navigation, ship and process simulators and hydroacoustics.

Inspirational research briefings
During the workshops of 2018, 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 material joining, advanced modelling, additive manufacturing, deep learning, organisation 4.0, innovation and product development, industrial cluster and learning systems, and 3D-vision and simulation. In addition to these research topics, we also discussed the research plan for 2019, as well as the work on the mid-term evaluation, which the Norwegian Research Council uses when deciding on the centre's financial support the next coming years.



Vivid group discussions
With the production site visits and research briefings in mind, the participants take active part in the cross-functional group discussions towards the end of the workshop days. In 2018, these group discussions were focused on solving problems and discussing topics related to the business of the host, combined with the research area in focus: Hydro and RA3, Hexagon and RA1 and Horten and RA2. After vivid discussions, the results were 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. We are already looking forward to the workshops of 2019, starting with Raufoss in April.

International collaboration 2018

In 2018, SFI Manufacturing has been involved in Manufuture work, as well as the international project INMAN: Intelligent circular manufacturing research and educational collaboration with Japan and India.

Manufuture
A document describing a vision for future research needs for European manufacturing, called Manufuture-Vision 2030, has been developed in the European Technology Platform mission: Manufuture. The document can be downloaded from www.manufutre.org and describes a vision for manufacturing in Europe in 2030, including megatrends, challenges and scenarios for future manufacturing, as well as future innovation strategy and systems, sustainable manufacturing, new business models, new technology, education paradigms and employment. The European Technology Platform is currently working in a Strategic Research Agenda.

CIRP – International academy for production research
SFI Manufacturing has been represented at the CIRP general assembly in 2018, as well as 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 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:

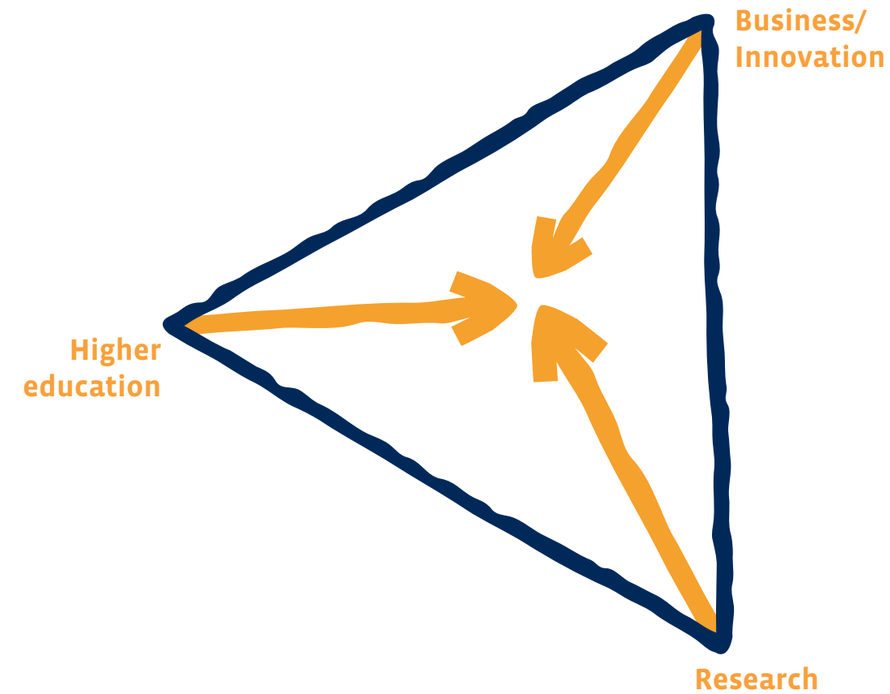
Common research agendas and funding applications for all INMAN-institutions

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



Our model for international collaboration. Close cooperation creates innovation and work of high quality.

Recruitment and communication

We are according to our plan with our PhD education. SFI Manufacturing has 10 PhD candidates in total now, and 1 Postdoc. We are pleased to inform that 50% of our candidates is female, and that all candidates are equally distributed over the different research areas.

In 2018, we continued updating our website, **www.sfimanufacturing.no**, which now includes updated information on the centre, partners, research areas, PhD candidates and publications. The website includes a blog as well, with news on mainly the workshops, PhD candidates and partners. We are sharing all blogposts on Twitter, and most of the blogposts on the website and social media of SINTEF Manufacturing as well. We are using Twitter actively during conferences, workshops, meetings and other gatherings where the centre is involved. SFI Manufacturing has tweeted 159 times until now, and has 263 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 2017 in the start of 2018.

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
Ragnhild Aune	SINTEF Industr	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
Prashanth Konda Gokuldoss	NTNU-IV (Gjøvik)	Additive manufacturing
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
Dirk Nolte	SINTEF Industry	Multi material metallic products
Hoang Hieu Nguyen	SINTEF Industry	Multi material metallic products
Jesper Friis	SINTEF Industry	Multi material metallic products, Multiscale modelling
Tèrence Coudert	SINTEF Industry	Multiscale modelling
Xiaobo Ren	SINTEF Industry	Multiscale modelling
Ole Martin Løvvik	SINTEF Industry	Multiscale modelling
Afaf Saai	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	Senor fusion
Esten Ingar Grøtli	SINTEF Digtal	Robotic handling of flexible objects, Flexible and integrated production systems
Øystein H. Holhjem	SINTEF Digtal	Robotic handling of flexible objects
Katrine Seel	SINTEF Digtal	Robotic handling of flexible objects
Marianne Bakken	SINTEF Digtal	Robotic handling of flexible objects
Helene Schulerud	SINTEF Digtal	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
Lars Erik Wetterwald	SINTEF Manufacturing	Flexible and integrated production systems
Per Nyen	SINTEF Manufacturing	Flexible and integrated production systems
Lars Tore Gellein	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 Digital	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
Jonas Ingvaldsen	NTNU-Økonomi-IØT	Work systems and organization, Innovation and product development
Asbjørn Karlsen	NTNU-SU-GEO	Industrial clusters and learning systems
Markus Steen	SINTEF Digital	Industrial clusters and learning systems
Eli Fyhn Ullern	SINTEF Digital	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	Norwegian	2017-2019	F	Flexible 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

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
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

Scientific publications

Reporting year: 2018
Type: Article
Authors: M.H. Arbo, E.I. Grøtli, J.T. Gravdahl
Title of work: *On Model Predictive Path Following and Trajectory Tracking for Industrial Robots*
Book/compendium/journal: IEEE International Conference on Automation
Page no.: 100-105
ISSN/ISBN: 2161-8070

Reporting year: 2018
Type: Article
Authors: O. Ogorodnyk, M.V. Granheim, H. Holtskog
Title of work: *Preconditions for learning factory : a case study*
Book/compendium/journal: Procedia CIRP
Page no.: 35-40
ISSN/ISBN: 2212-8271

Reporting year: 2018
Type: Article
Authors: O. Ogorodnyk, M.V. Granheim, H. Holtskog, I. Ogorodnyk
Title of work: *Roller Skis Assembly Line Learning Factory? Development and Learning Outcomes*
Book/compendium/journal: Procedia Manufacturing
Page no.: 121-126
ISSN/ISBN: 2351-9789

Reporting year: 2018
Type: Article
Authors: S. Gale, H. Rahmati, J.T. Gravdahl, H. Martens
Title of work: *Improvement of a Robotic Manipulator Model Based on Multivariate Residual Modeling*
Book/compendium/journal: Frontiers in Robotics and AI
ISSN/ISBN: 2296-9144

Reporting year: 2018
Type: Book
Authors: O. Semeniuta
Title of work: *Flexible Composition of Robot Logic with Computer Vision Services*
Book/compendium/journal: Gothenburg, Sweden: Chalmers tekniska högskola
ISSN/ISBN: 978-91-7597-777-5

Reporting year: 2018
Type: Book/article in book
Authors: O. Semeniuta
Title of work: *Control of visually guided event-based behaviors in industrial robotic systems*
Book/compendium/journal: Control of visually guided event-based behaviors in industrial robotic systems

Reporting year: 2018
Type: Article
Authors: O. Semeniuta, P. Falkman
Title of work: *Flexible Image Acquisition Service for Distributed Robotic Systems*
Book/compendium/journal: Second IEEE International Conference on Robotic Computing
Page no.: 106-112
ISSN/ISBN: 9781538646519

Reporting year: 2018
Type: Article
Authors: O. Semeniuta, P. Falkman
Title of work: *Discrete event dataflow as a formal approach to specification of industrial vision systems.*
Book/compendium/journal: Automation Science and Engineering (CASE), 2015 IEEE International Conference on

Reporting year: 2018
Type: Article
Authors: M.H. Arbo, E.I. Grøtli, .T. Gravdahl
Title of work: *On the globally exponentially convergent immersion and invariance speed observer for mechanical systems*
Book/compendium/journal: American Control Conference (ACC)

Reporting year: 2018
Type: Article
Authors: O. Semeniuta
Title of work: *Analysis of Camera Calibration with Respect to Measurement Accuracy*
Book/compendium/journal: Procedia CIRP

Reporting year: 2018
Type: Article
Authors: O. Semeniuta, S. Dansfeld, K. Martinsen, P. Falkman
Title of work: *Towards increased intelligence and automatic improvement in industrial vision systems*
Book/compendium/journal: Procedia CIRP
Page no.: 256-261

Reporting year: 2018
Type: Article
Authors: O. Semeniuta, S. Dansfeld, P. Falkman
Title of work: *Vision-based robotic system for picking and inspection of small automotive components*
Book/compendium/journal: IEEE International Conference on Automation Science and Engineering

Reporting year: 2018
Type: Article
Authors: A. Moldavska, K. Martinsen
Title of work: *Monitoring and Control for Thermoplastics Injection Molding A Review*
Book/compendium/journal: Procedia CIRP
Page no.: 380-385

Reporting year: 2018
Type: Article
Authors: O. Fergani, B.L. Batut, V.Brøtan, M. Bambach, M. Mansouri
Title of work: *Analytical and Numerical Temperature Prediction in Direct Metal Deposition of Ti6Al4V*
Book/compendium/journal: Journal of Manufacturing and Materials Processing

Reporting year: 2018
Type: Article
Authors: O. Fergani, B.L. Batut, V.Brøtan, M. Bambach, M.T. Pérez-Prado
Title of work: *Texture evolution in stainless steel processed by selective laser melting and annealing*
Book/compendium/journal: Materials Science and Technology

Reporting year: 2018
Type: Article
Authors: S. Moe, J.T. Gravdahl, K.Y. Pettersen
Title of work: *Set-Based Control for Autonomous Spray Painting*
Book/compendium/journal: IEEE Transactions on Automation Science and Engineering

Reporting year: 2018
Type: Article
Authors: S.M. Arbo, T. Bergh, I. Westerman, B. Holmedal
Title of work: *Influence of Stacking Sequence and Intermediate Layer Thickness in AA6082-IF Steel Tri-Layered Cold Roll Bonded Composite Sheets*
Book/compendium/journal: Key Engineering Materials
Page no.: 316-322

Reporting year: 2018
Type: Article
Authors: S.M. Arbo, T. Bergh, H. Solhaug, I. Westerman, B. Holmedal
Title of work: *Influence of thermomechanical processing sequence on properties of AA6082-IF steel cold roll bonded composite sheet*
Book/compendium/journal: Procedia Manufacturing
Page no.: 152-160

Reporting year: 2018
Type: Conference paper
Authors: Karlsen, A., Lund, H.B. And Seen M.
Title of work: *Adapting to Industry 4.0 in manufacturing clusters: a question about cluster absorptive capacity*
Book/compendium/journal: Fifth Conference on Economic Geography Cologne

Reporting year: 2018
Type: Conference paper
Authors: Karlsen, A., Lund, H.B. And Seen M
Title of work: *RManufacturing Reshoring due to Industry 4.0?*
Book/compendium/journal: Fifth Conference on Economic Geography Cologne

Reporting year: 2018
Type: Proceeding
Authors: Romero, D., Gaiardelli, P., Powell, D., Wuest, T. & Thürer, M.
Title of work: *Digital Lean Cyber-Physical Production Systems: The Emergence of Digital Lean Manufacturing and The Significance of Digital Waste*
Book/compendium/journal: In: Moon I., Lee G., Park J., Kiritsis D., von Cieminski G. (eds) Advances in Production Management Systems. Production Management for Data-Driven, Intelligent, Collaborative, and Sustainable Manufacturing. APMS 2018. IFIP Advances in Information and Communication Technology, vol 535. Springer, Cham
Page no.: 01.11.2019

Reporting year: 2018
Type: Proceeding
Authors: Powell, D., Romero, D., Gaiardelli, P. Cimini, C. & Cavalieri, S.
Title of work: *Towards Digital Lean Cyber-Physical Production Systems: Industry 4.0 Technologies as Enablers of Leaner Production*
Book/compendium/journal: In: Moon I., Lee G., Park J., Kiritsis D., von Cieminski G. (eds) Advances in Production Management Systems. Smart Manufacturing for Industry 4.0. APMS 2018. IFIP Advances in Information and Communication Technology, Springer, Cham.
Page no.: 353-362

Reporting year: 2018
Type: Article
Authors: E.Lodgaard, L.P. Johannessen
Title of work: *Shop floor teams and motivating factors for continuous improvement*
Book/compendium/journal: IWAMA 2018, Lecture Notes in Electrical Engineering

Reporting year: 2018
Type: Conference proceedin
Authors: E.F. Ullern, L.R Slettbakk
Title of work: *How manufacturing companies can utilize innovation test-centres in facilitating environmental sustainability.*
Book/compendium/journal: ISPIM Innovation Conference; 2018-06-17 - 2018-06-20

Reporting year: 2018
Type: Book
Authors: Å. Mariussen, S.Virkalla, H. Finne, T.M. Asen
Title of work: *The entrepreneurial Discovery process and Regional Development*
Book/compendium/journal: Routledge
Issue/Volume/Year: 978-1-138-57455-7

Reporting year: 2018
Type: Conference
Authors: H.B Lund, M. Steen
Title of work: *Manufacturing Reshoring due to Industry 4.0?*
Book/compendium/journal: Presented at the Fifth Conference on Economic Geography Cologne 24-28 July 2018

Reporting year:	2018
Type:	Conference
Authors:	A. Karlsen, H.B Lund, M. Steen
Title of work:	*Adapting to Industry 4.0 in manufacturing clusters: a question about cluster absorptive capacity.*
Book/compendium/journal:	Presented at the Fifth Conference on Economic Geography Cologne 24-28 July 2018

Reporting year:	2018
Type:	Conference
Authors:	H.B. Lund, M. Steen
Title of work:	*Changing GPNs: Manufacturing Reshoring due to Industry 4.0?*
Book/compendium/journal:	Global Conference on Economic Geography 2018
Page no.:	24-27 July 2018

Reporting year:	2018
Type:	Book
Authors:	Holtskog, H., Kaloudis, A., Carayannis, E., & Ringen, G.
Title of work:	*Learning Factories: The Nordic Model of Manufacturing.*
Book/compendium/journal:	New York: Palgrave Macmillan.

Reporting year:	2018
Type:	Book
Authors:	H. C. G. Johnsen, H. Holtskog, & J. R. Ennals (Eds.)
Title of work:	*Coping with the Future - rethinking assumptions for society, business and work.*
Book/compendium/journal:	London: Routledge.

Reporting year:	2018
Type:	Article
Authors:	Johnsen, H.C.G and Holtskog, H.
Title of work:	*Guest editorial doble special issue,*
Book/compendium/journal:	International Journal of Action Research (in print)
Page no.:	79-89

Reporting year:	2018
Type:	Article
Authors:	Holtskog, H. and Ringen, G.
Title of work:	*Social mechanisms of performance systems*
Book/compendium/journal:	Journal of Workplace Innovation
Page no.:	27-43
Issue/Volume/Year:	4/2018

Key performance indicators from our original description of work

	Plan 2015-2023	Sum 2015-2018	2015	2016	2017	2018
Book about MMP manufacturing	1	0	-	-	-	-
Scientific paper published in international journals and conferences with peer review	112	68	1	7	28	32
Popular science articles	16	3	-	-	1	2
National and international conferences and seminars/workshops	2	1	-	1	-	-
Master students	100	19	-	2	6	11
PhD candidates	17	10	2	7	1	-
Postdocs	3	1	-	-	1	-

Statement of accounts

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

Funding	**2018**
The Research Council	14 370 000
The Host Institution (SINTEF Manufacturing AS)	581 680
Research Partners*	4 453 374
Enterprise Partners*	9 684 385
Total	**29 089 439**

Costs	
The Host Institution (SINTEF Manufacturing AS)	5 220 179
Research Partners	18 309 876
Enterprise Partners	5 559 385
Public Partners	
Equipment	
Total	**29 089 439**

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)
Rolls Royce Marine (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 IME (university)
NTNU SVT (university)
NTNU NT (university)
NTNU GJØVIK (university)

SFI Manufacturing

One of the 24 SFI's in Norway

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

manufacturing

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