sfi Centre for Research-based Innovation

Certus

Certus 2011–2019

Contents

Arnaud Gotlieb
Leader of Certus SFI
Chief Research Scientist
Simula Research Laboratory

Strong ties: the secret to success for Certus

Certus Centre leader for seven of its eight years, Arnaud Gotlieb took the step to Certus to be part of the unique collaborative environment between public and industrial partners being cultivated at Simula.

"My predecessor was in fact responsible for establishing the Certus SFI, and he suggested that I join the project. At that time we were exploring the use of constrained optimization for software testing. I had always had a hand in Artificial Intelligence through Constraint Programming research and Software Engineering, and how to use AI for solving complex software testing problems."

Starting as a researcher, Gotlieb found the working environment at Simula extraordinarily stimulating. *"I liked the open interaction between research and industry, and the autonomy we were given to put our research results to work, so I took the opportunity to apply for the Certus leadership position."*

He recalls that software testing research was at that time more accessible in Norway than in France, where research on formal verification methods was more privileged. *"There were more avenues open here. Though the application domains were sensitive, like testing maritime software systems and quality assurance of communication and data-intensive systems, they were not as highly critical as the issues being dealt with in France, like quality assurance of nuclear power plants, railway and civil aviation software-systems. This allowed for more freedom, with less pre-determined direction in the research."*

Gotlieb earned his PhD while working for the French defence giant Dassault, giving him insight into the wealth of research material that industry has to offer: *"Some of my colleagues believe that industrial problems are not suited for public research, but I do not agree. Deeper problems to be addressed by public research can emerge from industry. Working with industry is a great opportunity to find like-minded partners, and together we seek to find applications relevant for society."*

Understanding industry

To succeed with public-private industry research initiatives, Gotlieb maintains that identifying industrial champions is essential, those with a willingness to adopt public research in their own businesses. *"In Certus we nurtured good collaboration with industrial and public partners. This is the key to success. Good professional relationships of course, but good social relationships as well."*

Certus workshops were a key instrument in achieving this goal: *"The workshops served to build confidence and trust between partners from different fields. The research environment is challenging, and the competition is tough for publishing and positions. Companies also live in a highly competitive world. Certus was a construction in between the two worlds that created a space where competitive pressures could more easily be dealt with."*

Success in industrial research is measured first by creating something in the lab, Gotlieb says, then getting it adopted in business. *"In order to do that, researchers need to understand industrial constraints of budgets, equipment, and recruiting, and this requires establishing a fruitful dialogue with industry. The same goes in reverse. Industry needs to invest in understanding the realities of research."*

Certus has demonstrated the value of this formula, he maintains: *"The proof is in the high number of co-authored papers we have published, and the number of individual exploitation tasks. Those are indicators of success in the transfer of knowledge and technologies."*

Lessons learned

Gotlieb acknowledges that the learning curve in Certus has taken several turns. *"We started out believing that identifying fundamental problems to be solved was the most important. But deploying industry-strength solutions can also drive good research results, because we are forced to refine a problem down to its essence and convert the proposed solution into an exploitable technology, something that also lead to resolving difficult issues."*

By the same token, he is impressed by the progress made by Certus' partners: *"We have seen them learning by working closely with researchers. The collaboration has steepened their learning curve, both from the workshops and in the projects. As their competence in software validation and verification (V&V) grew, we also observed a greater focus on that topic in Norway, partly due to the dissemination activities of the Centre."*

The first stages of Certus were typified by focus on industrial exploitation, Gotlieb reports. *"We were learning by experience, but we extracted key principles and applied them to new tasks. Transferring tools developed in research to industrial and public partners was a priority task. We created models and important KPIs to address that challenge, but still it was largely leaning by doing."*

Making a good exit

From industrial exploitation, the focus in the second half of the project shifted to shaping a viable exit strategy. *"Identifying an exit strategy was in fact on our minds from the beginning,"* Gotlieb relates. *"We wanted an idea or a vision for future, but we had to make sure that we were not alone in our vision. Our focus was to make sure that partners were involved, with a critical focus on what worked and what did not, including research, technology transfer, and a timeline. It was important to shape not only a vision, but also a viable path forward."*

The project determined to use workshops as an arena to achieve this goal. *"We used electronic devices to facilitate collaboration and understanding between the researchers and user partners. The concept is called 'Design Thinking' and it involves ongoing experiments where teams sketch, construct and test physical solutions to solve problems,"* he says. *"We felt it was important to gather the industrial and public partners to build something together. I think using a physical platform to share ideas is a good way to collaborate. It led to more fruitful dialogue by breaking down barriers, but also by building enthusiasm."*

In beginning, Gotlieb recalls that the partners were chiefly occupied with presenting their own perspectives. *"But using the open source concept, it was easier to forget individual problems and try to collaborate on solving collective challenges. The key is to acknowledge that diverse backgrounds offer a great opportunity to design more ambitious and innovative solutions. This opened the way to use ideas from other areas, including the use of machine learning technologies in software V&V."*

The process allowed Certus partners to become more interested in how to tune models to industry needs, he says. *"Researchers have lofty ideas, and they must be imaginative to succeed. But putting these ideas to work is difficult, and the researchers cannot do it alone. Working to solve problems as part of a team created an open mind-set and brought ideals into the realm of reality."*

More time together

"Even as we were writing the midway report, I remember reflecting on what we might have done differently," Gotlieb relates. "When I first came to Simula I saw a poster with the motto, 'Industry is our lab'. I believe we could have implemented this more thoroughly. In fact we tended to think that our lab was Certus. Looking back, we could have used more energy on the partner's terms. We should have spent even more effort understanding the partner's problems and constraints. Our partners evolve in highly competitive markets, which have spread worldwide. This shapes how public research and industrial partners can tackle difficult software V&V problems."

Gotlieb is convinced that human relationships are essential in research and innovation. *"They create good understanding and ease problem-sharing, but they also open new avenues, opportunities to foster innovation and find new solutions by co-creation."*

Conditions and parameters change, he points out, and what failed in the past may lead to future success. *"That's why it is important to just go forward and always revisit proposed solutions in light of new adopting conditions. This is true especially with partners in industry, where conditions change so rapidly. We need to make things happen together, and to be agile in response to each other's needs."*

The takeaways - professional and personal

"I would say that we have achieved success in the area of fundamental software V&V research dedicated to tackle industrial problems. Certus has helped Simula get recognised as a research group that has helped deploy AI for software V&V in concrete settings. This kind of achievement is also the key to attracting good projects for the future," Gotlieb says.

Accordingly, he has been chosen to head up industrial pilots in the 'AI4EU' project funded by the European Commission. *"We are leading the pilot experiments in the project with eight industrial partners including Telenor and ABB, and we have the ambition to create the AI-on-demand platform for Europe, together with the project coordinator Thales,"* Gotlieb relates. *"I believe that I was offered this position because of my work in Certus. Norway is also an important partner country in the project. This to me is proof that Certus has been a vector for international recognition for Simula and Norway."*

Reflecting on the educational component of Certus, Arnaud Gotlieb confirms that serving as a supervisor to Certus PhD candidates stands out as his most rewarding personal takeaway. *"PhD students are in constant doubt, of their knowledge, their career, their focus. To help them grow beyond this is an amazing experience, to see them become engineers or researchers. Supervising a PhD student is much more of a parenting or nurturing experience than a managerial task,"* he concludes.

"My parting thought would have to be that relationships are everything, and these relationships must be based on equality. Whether it a supervisor and a PhD candidate or researchers and industry partners, we all need to meet each other on equal footing."

Foreword (by host institution Simula)

Simula's vision is to be an excellent research lab, solving important and fundamental problems of science and engineering, training highly-qualified experts and leaders, and developing commercial enterprises.

This ambitious statement, which sets the tone for Simula's strategy towards 2028[1], resonates extremely well with the *Centre for Research-based Innovation (SFI)* scheme offered by the Research Council of Norway. By its very design, an SFI must involve competent partners studying important, real-world problems for which the solutions rely on research of the highest international quality. On the way to these research results it is natural and necessary to educate young researchers at PhD and postdoctoral levels, and thereby prepare them for leading roles in academia or industry. Also, for some SFIs, but not all, the research and interaction with the problem owners creates tangible and relevant outcomes that become the basis for commercialisation, either in terms of spin-outs or licensing of technology to already established businesses. With this backdrop, Simula has been an active partner in two SFIs[2], and was the proud host of a third, the *Certus Centre for Software Validation and Verification*. In fact, our positive experience with the SFI scheme has paved the way for suggesting a new centre of this kind, the *Centre for the Development of Sustainable Digital Twins (DiGem)*, for which the proposal is currently under review.

The mid-term evaluations of past and current SFIs, as well as the evaluation of the SFI scheme at large, illustrate a broad diversity of centres both in terms of problem areas, partnerships, and centre dynamics. Compared to other centres, Certus involved relatively few partners but several of considerable size, such as Cisco and ABB Robotics. Naturally, a relatively small consortium permits deep interaction with most partners. Another characteristic is that Certus, which targeted how to optimally test the functionality and behaviour of highly complex software systems, delivered results of great *internal value*. By this, we mean that the largest impact of the research, beyond academic merits, has been to improve the partners' internal processes and tools for effective and accurate software testing. This is different from centres that are closer to design and implementation of products and services intended for an open market, where visibility and impact in terms of commercial indicators are more evident.

It is very satisfying and rewarding to see that the work done in Certus has spawned an impressive collection of new R&D projects at the exit of the SFI period. Most of these projects, which are at both national and European levels, can be directly traced back to results and experiences built in the SFI. It is also particularly encouraging to see that several projects involve key partners from the Certus consortium, which we interpret as a strong and positive response to the values delivered through the SFI period.

[1] Simula Strategy 2018–2028, see https://www.simula.no/sites/default/files/simula_strategy_web.pdf

[2] Information Access Disruption (2007–2015) and Center for Cardiological Innovation (2011–2019).

Examining the current portfolio of scientific initiatives in software engineering at Simula, we clearly see reinforced and new strands of research that emerged from Certus. In particular, there are several data-driven paradigms under development: machine learning and artificial intelligence techniques are now being used to test and secure complex software systems; new methods are being developed to test the software of autonomous systems like industrial robots; digital vulnerabilities are being reduced by data-driven security assessments; and methods are under development for making software systems autonomously self-healing. In addition, existing work on how to assess risk in, and improve management of, cyber-physical systems is accelerated through new projects. Through the portfolio of new projects realising these methods and tools, Simula's involvement in software engineering will triple within the next 18 months. This is a very concrete and impressive legacy of Certus.

On behalf of Simula, as the host institution, we would like to thank the Research Council of Norway for trusting us to build an excellent centre for research in software engineering. The funding allowed Simula to build much closer relations with industrial partners, and has given Simula the international visibility necessary to recruit excellent researchers from all over the world. We are also grateful for the enthusiastic participation of the later Certus partners ABB Robotics, Cisco, the Cancer Registry of Norway, Esito, and of the former partners FMC Technologies, Kongsberg Maritime, and the Norwegian Customs. Finally, and most importantly, we would like to thank all researchers, postdocs and PhD students who filled Certus with life, hard work, frustrations, victories, and joy. A special *"thank you"* goes to Arnaud Gotlieb, the director of Certus, who for eight years put in long hours leading the SFI to success.

Fornebu, November 14, 2019

Professor Aslak Tveito
CEO, Simula Research Laboratory

Professor Are Magnus Bruaset
Research Director for Software Engineering and HPC &
Member of the Certus board

Sammendrag

Certus har fra 2011 til 2019 vært et Senter for forskningsdrevet innovasjon dedikert til validering og verifisering (V&V) av store og komplekse programvaresystemer, finansiert av Forskningsrådet. Senteret har hatt fem industripartnere: Cisco Systems Norway AS (2011-2019), Kongsberg Maritime AS (2011-2018), FMC Technologies (2011-2014), ESITO AS (2011-2019), ABB Robotics (2014-2019); og to partnere fra offentlig sektor: Tolldirektoratet (2011-2015) og Kreftregisteret (2016-2019). Simula Research Laboratory har vært vertskap for forskingspartner i senteret. Konsortiets sammensetning har variert noe over tid, men har vært stabil i form av minst tre industrielle brukerpartnere og en offentlig partner gjennom hele perioden.

I løpet av sin levetid har Certus-senteret utviklet samarbeidende forsknings- og innovasjonsprosjekter innen utvalgte områder av programvareteknikk. Dette inkluderer modellering og testing av svært konfigurerbare programvaresystemer, sertifisering av virksomhetskritiske systemer, kvalitetsvurderinger av testkampanjer for dataintensive programvaresystemer, validering og verifisering av innebygde sanntidsystemer, intelligent testing av programvaresystemer under kontinuerlig utvikling, og datadrevet prediktivt vedlikehold av programvaresystemer. Gjennom et sterkt engasjement i det internasjonale forskningsmiljøet har senteret nådd en ledende posisjon innen V&V, og bidratt sterkt med veiledning av unge forskere på master-, doktorgrads- og postdoktornivå.

Gjennom prosjektperiode har både forskere og brukerpartnere publisert og presentert vitenskapelige artikler på konferanser og i tidsskrifter som regelmessige blir sitert av andre forskere. Ved å fokusere på partnerdrevne forskningsspørsmål har Certus fremmet innovasjon gjennom utvikling av verktøy, teknologi og metoder. Disse resultatene har blitt distribuert og utnyttet av senterets brukerpartnere og andre internasjonale aktører.

Gjennom standardiseringsaktiviteter og godt utviklede forskningsnettverk har senteret etablert sterke vitenskapelige samarbeid med ledende europeiske institusjoner som Inria (Frankrike), Universitetet i Luxembourg, Universitetet i Parma (Italia), Uppsala Universitet og RI.SE SICS (begge i Sverige), i tillegg til andre partnere i og utenfor Europa.

Senteret har tiltrukket seg prominente forskere fra Europa og resten av verden, og har hatt betydelig suksess i europeiske konkurranser om finansiering av forskning. Spesielt mot slutten av prosjektperioden har forskerne i senteret lykkes svært godt med å hente inn betydelige, konkurranseutsatte tilskudd til innovative forskningsprosjekter sammen med sine partnere innen programvareutvikling og kunstig intelligens.

Nøkkelfakta om senteret

- Syv vitenskapelige og industrielle prosjekter som samlet alle senterets partnere, med en samlet produksjon av mer enn 250 leveranser (deliverables)
- 91 artikler publisert i vitenskapelige tidsskrifter, 185 artikler i artikkelsamlinger, 9 ed. bøker og 8 bokkapitler.
- 3 «Best Application Paper»-priser
- 6 doktorgrader direkte finansiert av SFI-bevilgningen til Certus: Shuai Wang, Dipesh Pradhan, Carlo Ieva, Helge Spieker, Carl-Martin Rosenberg, Matheiu Collet, i tillegg til 10 PhD-studenter finansiert av andre kilder
- Fjorten User Partner Workshops (UPW), flere tekniske workshops, samt åpne kurs
- 7 industri-styrkende teknologier (JDART, TITAN, DEPICT, Zen-RUCM, ABBs beregningsmodell, CRYSTAL.FEAT, SWMOD) som er utviklet i samarbeid med Certus-partnere
- Utviklingen av en sterk metodikk for utnytting av resultatene fra programvareutvikling

Summary

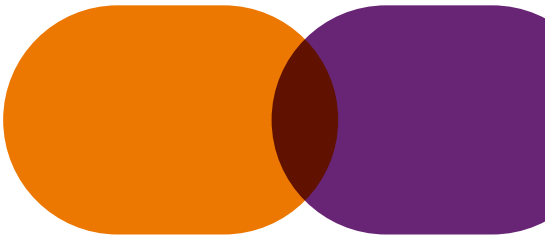
Certus was a centre dedicated to the validation and verification (V&V) of software-intensive systems, in operation from October 2011 to September 2019. The centre was awarded its status of a research-based innovation centre in 2011 and got the support of the Research Council of Norway along its eight years lifetime. The centre comprised five industrial partners, namely, Cisco Systems Norway AS (CISCO, 2011-2019), Kongsberg Maritime (KM, 2011-2018), FMC Technologies (FMC, 2011-2014), ESITO AS (ESITO, 2011-2019), and ABB Robotics (ABB, 2014-2019); two public administration partners, the Norwegian Directorate of Customs and Excise (TAD, 2011-2017) and the Cancer Registry of Norway (CRN, 2016-2019). Simula Research Laboratory (2011-2019), its only research partner, was the host for the centre. The consortium's composition varied over the years, but it remained stable with at least three industrial user partners and one public partner during the centre period.

The Certus centre developed collaborative research and innovation projects in selected areas of software engineering, including modelling and testing of highly variable software systems, the certification of safety-critical systems, quality assessments of test campaigns for data-intensive software systems, validation and verification of real-time embedded, smart testing of evolving software systems, data-driven predictive maintenance of software-systems. Through active involvement with the international scientific community, through conferences and workshops participation and organization, journal editorial board participation, keynote speeches, the centre reached a leading position in software validation and verification. During its eight years of operations, many PhD, Postdoc, and Master students were educated and contributed to the success of the centre. Certus researchers and user partners published articles in Software Engineering and Artificial Intelligence conferences and scientific journals, which are regularly cited by other researchers of these fields. By focusing on partner-driven research questions and organizing intensive collaboration between partners, Certus fostered innovation through the realization of tools and methodologies that were deployed and exploited by the centre's user partners. Through standardization activities and well-developed research networks, the centre established strong scientific collaborations with leading European institutions such as Inria in France, the University of Luxembourg, the University of Parma in Italy, Uppsala University, and RI.SE SICS in Sweden, in addition to other collaborations in Europe and the world.

Moreover, the centre attracted prominent visiting researchers from Europe and abroad and made substantial strides in the European competition for research funding. In particular, the last period of the Centre lifetime was punctuated by successes in attracting ambitious grants for developing innovative research projects among its partners in the field of Software Engineering and Artificial Intelligence.

Key facts about the centre:

- Seven scientific and industrial exploitation projects gathering all the centre's partners, resulting in the direct production of more than 250 deliverables;
- 91 articles published in scientific journals, 185 referred proceedings, 9 edited books, and 8 book chapters.
- Three 'Best Application Paper' awards;
- 6 PhDs directly funded by CertusSFI grant (Shuai Wang, Dipesh Pradhan, Carlo Ieva, Helge Spieker, Carl-Martin Rosenberg, Mathieu Collet) and 10 PhD students funded by other sources;
- Four-teen UP workshops (UPWs), several technical workshops and open courses classes;
- 7 industry-strength technologies (jDART, TITAN, DEPICT, Zen-RUCM, ABB's constraint model, CRYSTAL.FEAT, SWMOD) collaboratively developed by Certus partners;
- The development of a strong exploitation methodology and policy for Software Engineering results.



Vision and goals

From October 2011 to September 2019, the Certus Centre developed collaborative research and innovation projects in selected areas of software engineering, including modelling and testing of highly configurable software systems, the certification of safety-critical systems, quality assessments of test campaigns for data-intensive software systems, the validation of real-time embedded and evolving software systems, and data-driven predictive maintenance of software systems. Through strong involvement with the international scientific community, the centre reached a leading and recognised position in software validation and verification. During the eight years, the centre published 91 articles in scientific journals in the field, and 182 referred proceedings. As stated by its Scientific Advisory Board, this was a remarkable feat for such a small group of researchers and software engineers. By focusing on partner-driven research questions and organizing intensive collaboration between partners, the centre fostered innovation through the realization of new tools and methodologies, some of which were deployed and exploited by the centre's user partners, such as DEPICT, TITAN, SWMOD and other tools.

Through scientific community service activities and well-developed research networks, the centre developed a strong international profile and established fruitful scientific collaborations with leading European institutions such as Inria and the University of Montpellier in France, Uppsala University and the SICS Research Institute in Sweden, the University of Parma in Italy in addition to other collaborations in Europe and further afield. Moreover, the centre attracted prominent visiting researchers from Europe and elsewhere and made substantial strides within European competition for research funding.

Even more importantly, throughout the eight years of its existence, Certus supported the development of solid relationships between Master's and PhD students, Simula's researchers and external scientists and user partners' engineers by enhancing trust and confidence. More than just a scientific adventure, the centre was also a strong human adventure for all its participants.

Basic facts about the Centre

Board 2019

Jan Christian Kerlefsen, Chair, ABB Robotics

Are Magnus Bruaset, Simula

Marius Christian Liaaen, Cisco

Mette Wam, ESITO AS

Jan F. Nygård, Cancer Registry of Norway

Scientific Advisory Board

Prof. Antonia Bertolino from Italian National Research Council, CNR-ISTI, Italy

Prof. Laurence Duchien from University of Lille, France

Prof. Franz Wotawa from Graz University of Technology, Austria

Certus Administration

Arnaud Gotlieb, Certus Centre Leader

Tom D. Atkinson, Certus Administrative Manager

Emmy Terese Lind, Certus Advisor

Projects

1

Project 1:
Management

Simula Research Laboratory
Cisco
Directorate of Norwegian Customs
Esito
FMC Technologies
Kongsberg Maritime
ABB Robotics
Cancer Registry of Norway

2

Project 2:
Industrial Exploitation

Simula Research Laboratory
ABB Robotics
Cisco
Esito
Directorate of Norwegian Customs
Kongsberg Maritime
FMC

3

Project 3:
Training and Knowledge Transfer

Simula Research Laboratory
Cisco
Directorate of Norwegian Customs
Esito
FMC Technologies
Kongsberg Maritime
ABB Robotics
Cancer Registry of Norway

4

Project 4:
Dissemination and Communication

Simula Research Laboratory
Cisco
FMC Technologies
Kongsberg Maritime
ABB Robotics
ESITO

5

Project 5:
Model-based Engineering for Highly Configurable Systems

Simula Research Laboratory
The Cancer Registry of Norway
FMC Technologies

6

Project 6:
Safety Analysis and Certification of Embedded Systems

Simula Research Laboratory
Kongsberg Maritime

7

Project 7:
Testing of Data-Intensive Systems

Simula Research Laboratory
Directorate of Norwegian Customs
CISCO
ESITO
The Cancer Registry of Norway

8

Project 8:
Testing of Real-Time Embedded Systems (RTES)

Simula Research Laboratory
ABB Robotics
Cisco
FMC Technologies

9

Project 9:
Smarter Testing of Evolving Software Systems

Simula Research Laboratory
Cisco
Kongsberg Maritime

10

Project 10:
Data-Driven Predictive Maintenance for Software Systems

Simula Research Laboratory
ABB Robotics

The Certus board comprised of

Jan Christian Kerlefsen (chair), ABB Robotics

Are Magnus Bruaset. Simula Research Laboratory

Marius Christian Liaaen, Cisco Systems Norway

Mette Wam, ESITO

Jan F. Nygård, Cancer Registry of Norway

Previous board members

Katrine Langset	Tolldirektoratet (Norwegian Customs)	2011-2017
Henrik Auster	FMC Kongsberg Subsea	2011-2012
Merethe Gotaas	Kongsberg Maritime	2011-2015
Geir Magne Merkesvik	FMC Technologies	2012-2014
Bjørn Ove Olafsen	Kongsberg Maritime	2015-2018

Previous partners

FMC Kongsberg Subsea AS	2011-2014
Kongsberg Maritime AS	2011-2018
Tolldirektoratet (Norwegian Customs)	2011-2017

Scientific Advisory Board

The Scientific Advisory Board of Certus comprised of three highly reputed researchers in the area of software testing, variability modelling, and testing of autonomous systems – Prof. Antonia Bertolino from the Italian National Research Council, Prof. Laurence Duchien from the University of Lille, France, and Prof. Franz Wotawa from Graz University of Technology, Austria.

The board confirmed the excellent competence of the research team in a report of their last visit: *"The centre carried out excellent research with a very productive record of publications, when compared to the relatively small size of the group. Some of these have achieved appreciation with best paper awards in their conference. The researchers of the centre have also a very good visibility in the international community, as they actively participate in organization and Program committees of mainstream conferences, such as ICST (Intl. Conf. on Software Testing) and ICSE (Intl. Conf. on Soft. Engineering)."*

Certus researchers

Many people have been involved in Certus, both through the industrial and public partners and through the research at the host institution. During the eight years, the Centre Directors *Lionel Briand (2011-2012)*, and *Arnaud Gotlieb (2012-2019)* have headed a multinational research organisation involving people from at least 17 different countries.

- Researchers: 16
- Research engineers: 1
- Postdocs: 9
- PhD students: 22
- Research trainees: 6
- Master's degrees: 17

Achieving excellent research requires harnessing the full potential of everyone involved. It seems unfair to focus on certain people, when all the cogs in the wheel are necessary to function efficiently and perform first-class research by international standards. We do however owe a special thanks to the researchers who took on the additional task of heading and coordinating work packages at the centre:

Arnaud Gotlieb (Centre Director and Chief Research Scientist): Project 3 (2011-2012; 2016-2019); Project 7 (2011-2012); Project 8 (2018-2019)

Carlo Ieva (Senior Research Engineer): Project 2 (2016-2018)

Dusica Marijan (Senior Research Scientist): Project 2 (2012-2015; 2019); Project 8 (2011-2012); Project 10 (2018-2019)

Erlend Arge (Dr.): Project 2 (2011-2012)

Leon Moonen (Chief Research Scientist): Project 9 (2014-2019)

Mehrdad Sabetzadeh (Research Scientist): Project 6: (2011-2012)

Sagar Sen (Senior Research Scientist): Project 3 (2013-2015); Project 7 (2013-2019)

Shaukat Ali (Research Scientist): Project 8 (2013-2015)

Shuai Wang (Postdoc): Project 8 (2016-2017)

Tao Yue (Chief Research Scientist): Project 5 (2011-2017)

Please consult Appendix 2 for the full list of researchers involved in the Certus Centre.

Project 2:	Industrial Exploitation
Project 3:	Training and Knowledge Transfer
Project 5:	Model-Based Engineering for Highly Configurable Systems
Project 6:	Safety Analysis and Certification of Embedded Systems
Project 7:	Testing of Data-Intensive Systems
Project 8:	Testing of Real-Time Embedded Systems
Project 9:	Smarter Testing of Evolving Software Systems
Project 10:	Data-Driven Predictive Maintenance for Software Systems

Cooperation within the Centre

Certus created an innovative working environment with 14 biannual User Partner Workshops, collaboration techniques inspired by Design Thinking, open courses, and technical workshops gathering several user partners on dedicated topics (model-based testing, search-based testing, test execution scheduling, etc.). Getting the support of OKONI[3], a French consultancy company which helped us to create a vibrant collaborative environment, three User Partner Workshops used the electronic platform Arduino to foster co-creation and technologies adoption. Certus also increased the level of interaction between user partners by deploying the same research results in different companies (e.g. in test suite optimization, test recommendations and test execution scheduling). Embedding PhD students within our industrial partners and reciprocal visits to each others' premises were also very helpful in facilitating collaboration between the researchers and the partners.

Additionally, every partner in the Centre was represented on the Certus board to facilitate engagement and ownership of the decisions and direction of the centre's activity. An added benefit of this tight-knit organization was facilitating the mutual sharing of ideas, with each partner gaining a deeper understanding of their individual and mutual needs. This, combined with newsletters, a dedicated Certus website, and regular meetings at the User Partner Workshops ensured a good flow of information and ideas at all levels.

[3] https://okoni.fr/

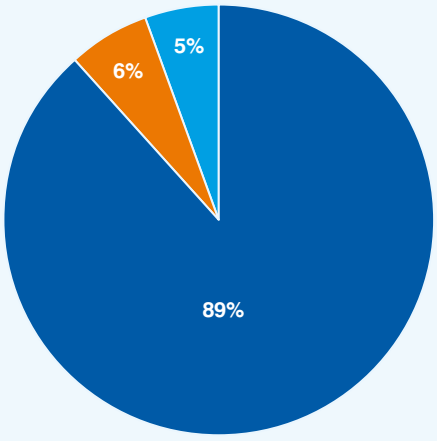
Financing through the life of the Centre

A lot of things can and will happen during the lifetime of a long project like an SFI.

Plans made in 2010-2011 when applying for the Certus funding included stable consortiums and no contingencies for unforeseen outside events that might threaten these plans. However, life (and research) is never entirely predictable. Within a few years FMC Kongsberg Subsea had to withdraw from the consortium due to shifting priorities during a market downturn, while Tolldirektoratet (Norwegian Customs) was reorganised and the tasks relevant for Certus were moved to a different entity. The market downturn followed by downsizing and internal reorganisation also hit Kongsberg Maritime (KM), which chose to withdraw from the consortium at a later stage. Finding and recruiting new and relevant partners to the consortium took some time and careful considerations. Luckily, through ongoing collaborations, we found a good match in both ABB Robotics and the Cancer Registry of Norway (CRN). These new partners provided very valuable additions to the consortium, and, as mentioned elsewhere, collaboration between some of the partners have continued even after the end of the Centre period.

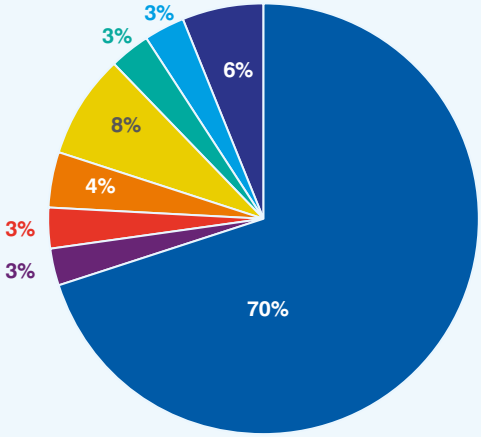
The withdrawal of three of the five original industrial and public partners could have had a marked effect on the Certus budgets. However, decisive action by the Centre leadership and board to address this issue, and successful reorganisation and addition of the two new partners, only led to a 10% drop in funding from the originally planned budget.

Budget vs. Accounts	Original budget (kNOK)	Accounts 2011-2019 (kNOK)		
CONTRIBUTOR	2011-2019	Cash	In-kind	TOTAL
HOST	22,300	31,325	3,670	34,995
Research Partners	-	-	-	-
Companies	63,640	-	37,686	37,686
Public partners	15,910	-	11,034	11,034
RCN	78,400	78,400	-	78,400
TOTAL (kNOK)	180,250	109,725	52,390	162,115



Estimated distribution of cost between activities	
Research and development	143,227
Common Centre activities and internal knowledge transfer	10,276
Administration	8,611
Total	162,114

The table below shows each partners contribution to the Certus centre, the host contribution includes the RCN SFI funding.



Certus 2011-2019 distribution of cost between partners	Type	2011	2012	2013	2014	2015	2016	2017	2018	2019	TOTAL
Simula Research Laboratory (2011-2019)	Research org.	4,602	10,823	14,781	14,410	15,764	13,153	15,824	14,828	9,210	113,395
Kongsberg Maritime AS (2011-2018)	Large enterprise	507	197	180	1,058	1,102	786	599	-	-	4,428
FMC Kongsberg Subsea AS (2011-2014)	Large enterprise	508	1,038	1,480	996	-	-	-	-	-	4,022
ESITO AS (2011-2019)	SME	63	525	1,130	761	313	965	1,672	927	6	6,363
CISCO Systems Norway AS (2011-2019)	Large enterprise	238	1,770	1,836	1,874	1,767	1,530	1,581	1,432	1,284	13,312
Tolldirektoratet (2011-2017)	Public sector	152	826	1,715	1,801	895	119	-	-	-	5,508
CRN - Cancer Registry of Norway (2016-2019)	Public sector	-	-	-	-	-	963	1,656	1,628	1,280	5,526
ABB AS (2014-2019)	Large enterprise	-	-	-	767	1,436	1,517	2,246	2,104	1,490	**9,560**
Total		6,070	15,180	21,121	21,667	21,277	19,032	23,579	20,919	13,270	162,115

Results – Key figures

The two tables summarise some of the scientific output and key figures from the Certus Centre during the Centre period. In the following pages we will expand further on these figures with perspectives from both our user partners, and our host institution on the tangible and intangible results during the eight-year period.

The development of Certus Publications	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
Articles in int. Journals	3	12	14	10	10	16	13	6	7	91
Edited books	0	0	1	3	0	2	1	1	1	9
Proceedings (refereed)	16	29	36	25	12	28	23	11	5	185
Book chapters	1	1	1	1	2	0	2	0	0	8
PhD degrees completed*	0	2	1	1	4	1	1	3	0	13
Posters	0	1	0	0	1	1	5	2	1	11
Technical reports	13	20	7	6	3	12	5	2	0	68
Keynote talks	0	0	0	3	0	2	4	2	0	11
Invited talks	0	0	1	1	7	3	15	2	4	33
Selected contributed talks	0	31	30	35	27	6	24	5	20	178
	33	96	91	85	66	71	93	34	38	607

Results Key figures	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
Scientific publications (Peer reviewed)**	20	42	52	39	24	46	39	18	13	293
Dissemination measures for users	12	19	8	9	3	12	5	2	0	70
Dissemination measures for the general public	0	1	0	3	0	1	2	2	4	13
PhD degrees completed*	0	2	1	1	4	1	1	3	0	13
Master degrees	0	0	1	4	2	3	6	0	1	17
Number of new/improved methods/ models/prototypes finalised	0	1	0	4	2	3	3	13	4	30
Number of new/improved products/ processes/services finalised	0	0	0	0	0	0	3	2	0	5
Introduction of new/improved methods/processes/ models/technology to enhance value creation	0	1	0	3	1	0	1	4	1	11
Companies external to the project that have introduced new/improved methods/models/technology	0	0	0	1	1	0	0	2	1	5
Patents registered	0	0	0	0	0	0	0	0	0	0
New business activity	0	0	0	0	0	0	0	0	0	0

*7 Certus related PhD degrees are to be completed during 2020-2022

**Includes articles in international journals, edited books, chapters in books, and refereed proceedings

Research

8.1 The original research plan and further development

Certus is a centre dedicated to Software Validation and Verification, in operation from October 2011 to September 2019, and run according to eight annual work plans negotiated with its partners. The original Certus proposal[4] contained the following goal: *"The centre will develop novel, industry-strength solutions to a broad range of software V&V problems faced by the user partners."* The eight annual work plans show that Certus has delivered innovative tools and methodologies, some of which have been adopted, re-implemented or even deployed by the user partners.

Research activities in the area of Software Validation and Verification have focused on six high-level projects:

- Model-Based Engineering for Highly Configurable Systems (Project 5)
- Safety Analysis and Certification of Embedded Systems (project 6)
- Testing of Data-Intensive Systems (Project 7)
- Testing of Real-Time Embedded Systems (Project 8)
- Smarter Testing of Evolving Software Systems (Project 9)
- Data-Driven Predictive Maintenance for Software Systems (Project 10)

All of the projects delivered strong results in innovation, adoption, and scientific publications. The activities of each project have been described in depth in the work plans, including tasks and deliverables (presentations, software, technical reports, publications). The main research achievements and the work undertaken in each project task are detailed in the remainder of this section, along with result highlights and awards received.

[4] Certus Centre, Attachment 1: Project description SFI proposal 2011-09-04

8.2 Research achievements

Model-Based Engineering for Highly Configurable Systems (Project 5)

In this project, completed in 2015, Certus created industry-strength methodologies and software tools to improve the quality and efficiency in development of highly configurable software systems such as CISCO's video conference systems and FMC's oil and gas subsea production systems. Testing these systems was also challenging, particularly when selecting test configurations, but also when selecting test cases and reducing test suites. One goal was to preserve or improve the fault-revealing capabilities of test cases. New multi-objective test suite optimization methods using constraint reasoning and search-based techniques were also proposed and evaluated in this project. Through the project, Certus developed strong competence in system modelling and model-based engineering for highly configurable systems, with innovative ways to represent variability choices in structural and behavioural models. Moreover, Certus developed model-based testing techniques and revised the management of user requirements from the perspective of model-engineering techniques.

Safety Analysis and Certification of Embedded Systems (project 6)

This project applied model-driven engineering techniques to the certification of embedded software applications within the maritime domain. In 2012, Certus addressed the certification process for safety-critical systems and the challenge related to the interpretation of distinct certification standards. Automation of the verification of performance requirements required by these standards was also proposed. Participating in standardization activities also gave Certus the opportunity to disseminate the results of the research.

Testing of Data-Intensive Systems (Project 7)

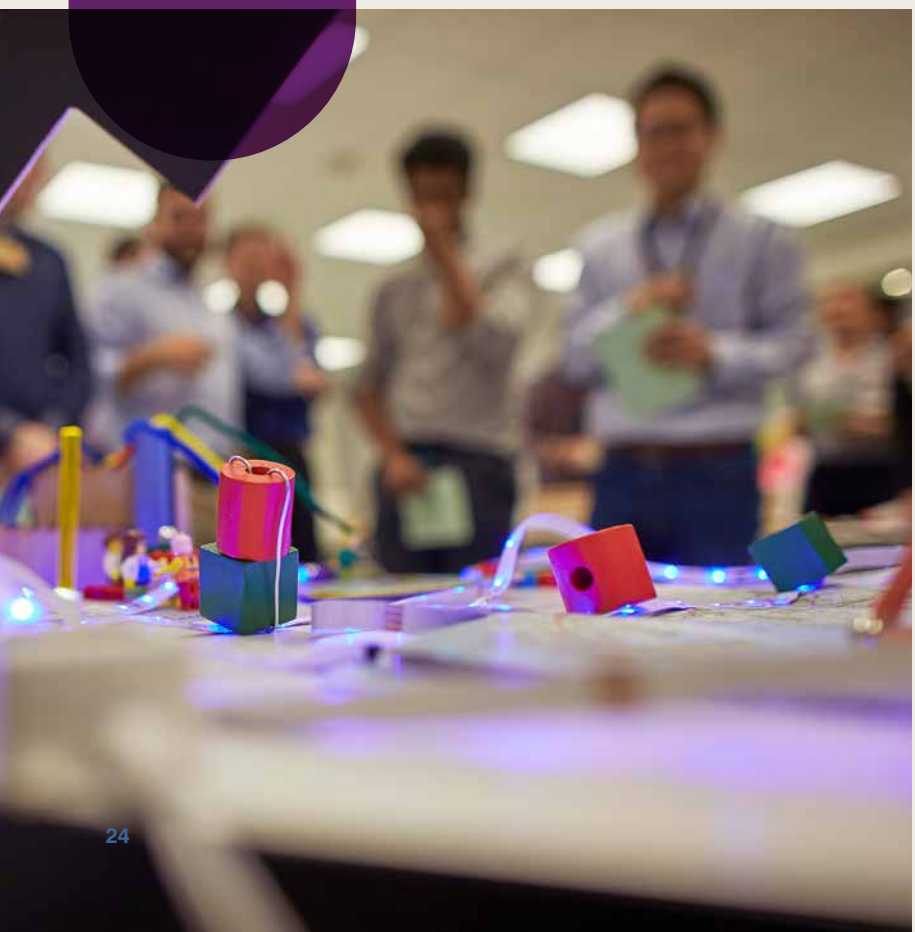
Customs declarations in Norway must go through multiple checks before they are archived. The software checks are encoded in legacy code that is complex to read and hard to test. One of the principal research achievements was to help verify whether checks were correctly executed on thousands of live customs declarations. Using the principles of combinatorial interaction testing, Project 7 developed algorithms to generate all 2- and 3-way combinations of data attribute values that should not appear after an internal check has been executed. An industry strength tool called Depict was also developed to automatically connect to any RDBMS database and verify it against a model of valid/invalid data interactions. The project also explored the usage of formal verification to provide evidence of the correctness of tax computations.

The Cancer registry of Norway manages a socio-technical system with the main objective of increasing attendance to their cancer screening programs and hence reducing incidents of cancer in Norway. The main research achievement was to develop a software intervention to educate and encourage women between the ages of 25-69 years to attend to cervical cancer screening. FightHPV is a game-based learning tool that also recruited women in Norway to a study to evaluate its own effectiveness as a software intervention to prevent cervical cancer. The game was formally verified and downloaded by more than 10,000 participants and helped increase general awareness of HPV infection and cervical cancer in Norwegian society. The game was also pilot-tested in Zambia.

The Cancer Registry of Norway collects data from the population that is often anonymiszd and provided to external researchers. The main contribution was to develop a standard fuzzification algorithm, based on k-anonymization, to ensure preservation of data quality for scientific research purposes while minimizing risk of re-identification. The project also established re-identification risk analysis as part of the process. Datasets were verified for the prosecutor risk both before and after fuzzification.

Testing of Real-Time Embedded Systems (Project 8)

Project 8 dealt with the testing issue of real-time embedded software systems in the presence of strong industrial constraints. The project addressed several research questions related to the validation of highly-configurable software-systems. The testing of cyber-physical systems and robotics systems applied techniques from Artificial Intelligence such as Constraint Programming and Machine Learning. The main research questions raised in the project were tackled in the domain of test case generation and prioritization, test suite reduction, and test execution scheduling. These are the most relevant aspects when considering industrial software development processes in continuous integration or DevOps. The project was run with the cooperation of ABB, CISCO, and KM on various systems such as video-conferencing, industrial robots and alarm systems.



Project 8 was divided into seven tasks: automated test generation using feature models; testing extra-functional properties of real-time systems; testing of complex industrial robotics systems; automated test execution scheduling; automated generation of robustness test cases; intelligent testing of robotic control systems; and time-optimization for DevOps. Significant research results were achieved with new methods for generating testing for highly-configurable systems by using variability models and new constraint-based models for generating test cases for alarm systems on ships. For painting robots using constraint optimization, new technologies for dynamically scheduling the execution of test cases for multiple robots were devised. The project also studied how to deploy machine learning methods in DevOps contexts, and proposed the use of reinforcement learning to schedule test case execution. In these tasks, we worked closely with user partners CISCO, ABB and KM to deliver new results in the form of software prototype tools, guidelines and testing methodologies. Applying these results on concrete use cases provided by our partners has enabled evaluation of the benefits of these assets, and helped to convince stakeholders to adopt them or appropriate the results in their own processes.

Smarter Testing of Evolving Software Systems (Project 9)

The goal of the project was to investigate the use of historical development data to improve detail in regression testing. Regression testing generally executes test suites on the software system under the assumption that the tests should have similar outcomes before and after the changes were made. These test suites tend to grow in size as the software evolves. Moreover, parts of the test suite may become outdated, or start to overlap with other parts. The overall result is that it becomes too costly to execute all test suites available for a system. The project pursued techniques to help maximize the value of available test suites while reducing testing costs and maintaining high coverage and fault detection properties. The principal idea investigated is if these techniques on the analysis of trends and patterns in historical data about changes made to successive releases of the system. To this end, the project developed novel extensions to targeted association rule mining, a machine learning technique that helps identify evolutionary coupling between parts of a system. These couplings can be used to identify which parts of a system need to be retested after a change.

Continuous engineering (CE) practices such as continuous integration and continuous deployment have become key to modern software development. They are characterised by short automated build and test cycles that give developers early feedback on potential issues. CE practices help companies to release software more frequently, and reduce risk by increasing incrementality. However, effective use of CE practices in industrial projects requires making sense of the vast amounts of data resulting from repeated build and test cycles. The goal of this project was to investigate novel techniques to address this issue. The main focus has been on two aspects, the first of which was Clustering-Based Anomaly Detection on Continuous Engineering Logs. The goal here was to develop data-driven techniques to reduce the effort needed to understand CE run failures by grouping the logs for all runs that failed for similar reasons and highlighting the anomalies, i.e., the logs for runs that failed for reasons not observed before. The second aspect was Spectrum-Based Diagnosis of Continuous Engineering Logs. Here the goal was to develop data-driven techniques that can automatically identify in the log of a failed CE run the events most likely to explain the causes of the failure. This is a form of automated diagnosis that highlights and reduces the number of events that need to be inspected to understand a failure.

Scientific contributions in the clustering work concerned the adoption of log clustering to the continuous engineering domain, exploring the solution space of choices regarding vectorization, weighting and hyper parameters, and the introduction of dimensionality reduction to make the approach less sensitive to variations in the parameters and input. Scientific contributions in the diagnosis work concerned adoption of spectrum-based approaches previously used for fault localization to log diagnosis, and the use of event clustering to prioritise their presentation. These algorithms were implemented in prototype tools and their performance evaluated empirically.

Data-Driven Predictive Maintenance for Software Systems (Project 10)

This project dealt with the development of novel techniques for predictive maintenance for software-intensive systems, aimed at enabling more cost-effective operation of complex industrial systems. In this project, the use of machine learning techniques for leveraging heterogeneous information sources was investigated, combining historical and live data obtained from system development, testing, and operation to enable identification of system/component failures as early as possible, and to provide warnings to system operators that enable timely prevention of failures.

The project focused on the predictive maintenance of robotic systems, in collaboration with ABB. The team studied software maintenance aspects by performing risk-based analysis with historical and real-time system operational data, in order to predict future trend of software failures and perform corrective actions before software failures occur.

The task, also conducted in collaboration with ABB, examined techniques for the comprehensive visualization of test results and smart analytics. The goal was to propose a solution for automatic classification of alarms using Machine Learning techniques.

8.3 Highlights of scientific results

1. **Development of test optimization technology, TITAN, in collaboration with CISCO.** TITAN implements practical test prioritization and minimization techniques, and provides test traceability and visualization for improving the quality of testing. The technology is suited for testing highly configurable software developed in continuous integration. For this type of software, exhaustive testing is rarely feasible in practice due to the configuration space of exponential size on the one hand, and strict time constraints on the other. TITAN addresses these challenges by providing selective testing techniques to determine the most failure-inducing test cases, conforming to highly constrained time budgets. The result is increased cost-efficiency of testing.

2. **Development and deployment of SWMOD at ABB Robotics.** Within a given time-contract, SWMOD schedules automatically test-case execution for various robots, based on their availability, in a continuous integration process. Using historical data on success/failure of test cases in previous runs, together with other meta-data of test cases such as priority and expected execution time, SWMOD is in daily use at ABB. The technology is currently dedicated to robot testing and deployment, but can be used in other contexts. Notably, Netflix created and deployed a tool that schedules the execution of test cases on a variety of devices by taking inspiration from a Certus research paper "Reinforcement Learning for Automatic Test Case Prioritization and Selection in Continuous Integration", related to the scheduling of test-case execution at ABB.

3. **Development and deployment of DEPICT for test quality assessment of database applications.** Test campaigns performed on large-scale data-intensive systems must be thoroughly evaluated. To assess their quality, specific interactions between individual data that lead to ad-hoc treatment must be considered during testing. In tight collaboration with software analysts at Tolldirektoratet (Norwegian Customs), the Toll and Custom department of Norway, Certus researchers designed DEPICT, a new technology enabling test quality assessment based on classification trees and database management system queries. This innovative technology has been evaluated and deployed in TAD.

4. **A constraint-based testing model has been deployed at ABB Robotics for test-case generation of industrial robotics systems.** Industrial robots embed complex distributed real-time systems that must be thoroughly tested before being shipped and put into operation. Considering that the timing aspects are the most business-critical element of these robots, a new approach was proposed based on constraint reasoning to generate timed-event sequences of the integrated painting systems in industrial robots. This resulted in new methods based on a parametrised constraint model that is versatile enough to accommodate continuous integration processes. This technology was put into operation at ABB, and a thorough experimental evaluation revealed that the new testing strategy can not only find re-injected faults (found in previous test campaigns), but discover new faults as well.

5. **HART, a recommender system for History-based Regression Testing.** Deployed as Software-as-a-Service for partners Kongsberg Maritime and CISCO. The TARMAQ algorithm improves on the state-of-the-art in targeted association rule mining by making the approach applicable (i.e. able to give correct recommendations) in a wider range of situations than previously. In addition, the ATARI algorithms add an adaptive component that considers a dynamic selection of the complete history, enabling them to provide correct recommendations while using only a fraction of the time and space required by state-of-the-art complete-history algorithms.

6. **Log clustering and log diagnosis.** Approaches originally developed for different domains can be successfully adapted to the analysis of continuous engineering logs. In addition, it was shown that dimensionality reduction can be used to reduce sensitivity of the algorithms. CISCO has implemented their own variant of the log clustering approach and integrated it in their Continuous Engineering environment.

7. **FlightHPV learning game and Portinari tool.** Together with the Cancer Registry of Norway, Certus developed and verified FightHPV, a learning game designed to improve attendance at cervical cancer screening, and Portinari, a data exploration tool to personalise cervical cancer screening. Such software tools have been termed **socio-technical systems** due to their constant interaction with medical experts and society.

Awards and distinguished talks

Awards

The Kreftregisteret Grand Prix is held annually at the Cancer Registry of Norway, where every working group has four minutes to present their research to the general audience. FightHPV was presented by Sagar Sen and won the second prize in the year 2017.

Best Paper Award for ***"A New Approach to Feature-based Test Suite Reduction in Software Product Line Testing"*** (A. Gotlieb, M. Carlsson, D. Marijan and A. Petillon), in the 11th International Joint Conference on Software Technologies, ICSOFT-EA 2016, Lisbon, Portugal, July 2016

Best Application Paper Award for ***"Using CP in automatic test generation for ABB robotics' paint control systems"*** (M. Mossige, A. Gotlieb and H. Meling), in Principles and Practice of Constraint Programming, The 20th International Conference on Principles and Practice of Constraint Programming, Lyon, France, September 2014

Best Application Paper Award for ***"Automated test case selection using feature model: An industrial case study"*** (S. Wang, A. Gotlieb, S. Ali and M. Liaaen), in the 16th ACM/ IEFE International Conference on Model Driven Engineering Languages, Miami, Florida. July 2013

Most Influential Paper award for ***"Assuring Software Quality by Code Smell Detection"*** (E. van Emden, L. Moonen), at the International Working Conference on Reverse Engineering (WCRE), 2012

Leon Moonen – Distinguished Reviewer Awards

- IEEE International Conference on Source Code Analysis and Manipulation (SCAM), September 23-24 2018, Madrid, Spain
- IEEE International Conference on Program Comprehension (ICPC), May 27-28 2018, Gothenburg, Sweden

Best Poster Award for ***"FightHPV: A game to raise HPV awareness and nudge people to take action against cervical cancer in Norway"*** by Sagar Sen from Certus and Simula, and Tomas Ruiz-Lopez, Mari Nygård, and Elisabeth Jackobsen from the Cancer Registry of Norway. In the International Papillomavirus Conference, February 28-March 4, 2017, Cape Town

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Best Paper Award for ***"Data Center Clustering for Geographically Distributed Cloud Deployments"*** by Dipesh Pradhan, in the workshops of the 33rd International Conference on Advanced Networking and Applications (AINA 2019), Matsue, Japan

Distinguished talks

Invited and keynote speeches are among the most prestigious distinctions we can get in the Software Engineering Research community.

The Appendix ***"Community Services"*** contains our long list of participation in Program Committees and editorial board journals.

A. Gotlieb – Invited Talk
Testing Robotic Systems: A New Battlefield!
At RoboSoft: Software Engineering for Robotics – Royal Academy of Engineering, London, UK, 13-14 November, 2019.

A. Gotlieb – Invited Keynote
Intelligence Testing of Autonomous Software Systems
In 31st IFIP WG6.1 International Conference, ICTSS 2019, October, Paris, France, Springer LNCS 11812, 2019.

S. Sen – Invited Talk
AI for Internet of Things (AI4IoT)
At AI Night, Palais de Tokyo, Paris, France, April 2019

L. Moonen – Invited Talk
Supporting Continuous Engineering with Automated Log Clustering and Diagnosis
At KTH Royal Institute of Technology, Stockholm, Sweden, 2019.

S. Sen – Invited Talk
Should artificial intelligence be part of your strategy?
At Klosser Innovation, Hamar, Norway, 2019.

A. Gotlieb – Invited Keynote (~900 attendees)
Artificial Intelligence in Software Testing: An Overview
At French Days on Software Testing (JFTL'18), Paris, France, 2018.

D. Marijan – Contributed Talk
Practical selective regression testing with effective redundancy in interleaved tests
At International Conference on Software Engineering (ICSE), Gothenburg, Sweden. Software Engineering in Practice, 2018.

A. Gotlieb and H. Spieker – Invited Talk
Boundary Estimation: Learning Boundaries for Constraint Optimization Problems
At International Symposium on Mathematical Optimization (ISMP'18), Bordeaux, France, 2018.

C. M. Rosenberg and M. Liaaen - Invited Talk
SW Testing: Can ML save us?
At NDC TechTown 2018, Kongsberg, Norway, 2018.

A. Gotlieb – Invited Keynote
Testing Robotic Systems: A New Battlefield!
At French National Days of GDR-GPL 2017, Montpellier, France, 2017.

L. Moonen – Invited Talk
History-Based Recommendations to Guide Software Evolution
At National Institute of Advanced Industrial Science and Technology (AIST), Japan, 2017.

L. Moonen – Invited Talk
Leveraging Machine Learning to Guide Software Evolution
At 8th IEEE International Workshop on Empirical Software Engineering in Practice (IWESEP), Tokyo, Japan, 2017.

C. M. Rosenberg, M. Liaaen and T. H. Nordnes – Talk
Effective test scrubbing with machine learning and Python
At NDC TechTown, Kongsberg, Norway, 2017.

A. Gotlieb – Invited Keynote
Constraint-Based Test Suite Optimization
At 28th International Conference on Testing Software and Systems (ICTSS'16), Graz, Austria, October 17-19, 2016.

A. Gotlieb – Invited Keynote
Constraint-Based Testing: An Emerging Trend in Software Testing
In XVI Jornadas sobre Programación y Lenguajes (PROLE 2016), Salamanca, Spain, 14-16 Sep. 2016, 2016.

D. Marijan – Invited Talk
Variability Testing of Highly-Configurable Software
In The Norwegian Computer Society, 2014.

L. Moonen – Invited Talk
Supporting Certification and Evolution of Cyber-Physical Product Families
In BENEVOL 2014 – Software Evolution in Belgium and the Netherlands, Amsterdam, the Netherlands, 2014.

D. Marijan – Invited Talk
Managing Test Configurations in High-Variability Testing Environments With TITAN and Pure::variants
In pure::variants Solutions Forum, Software Product Line Conference, 2013.

L. Moonen – Invited Talk
Assuring Software Quality by Code Smell Detection
In Most Influential Paper Award, 19th Working Conference on Reverse Engineering (WCRE), 2012.

International cooperation

Certus engaged in a number of carefully selected academic collaborations at both European and international level.

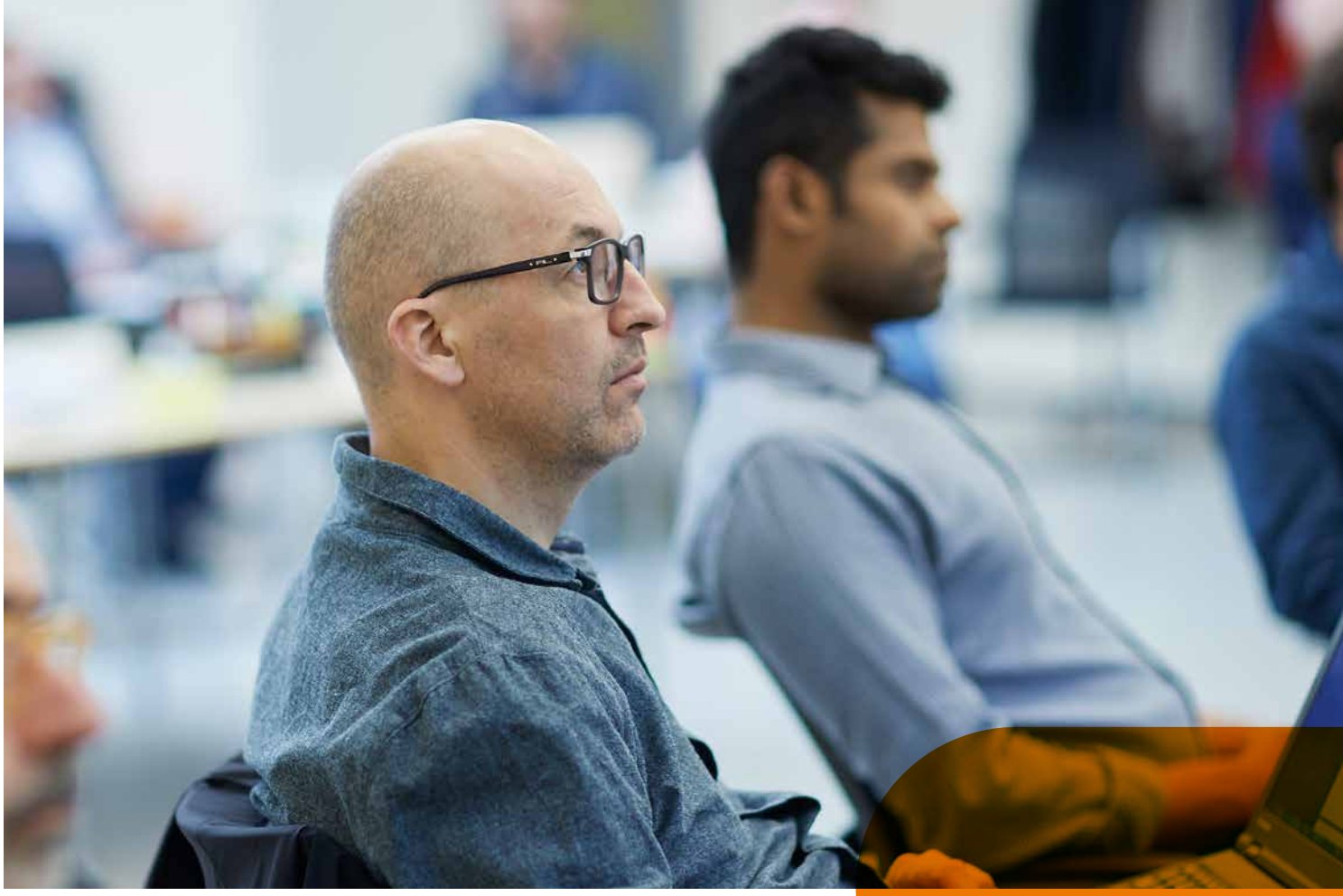
These collaborations have taken place through different means, including H2020 co-authored project proposals, joint PhD supervision, scientific collaborations, researcher exchanges, and regular visits. Industrial cooperation in Europe has also been significantly extended since the creation of the Centre. The efforts put into the H2020 project proposals also led the centre to enter into dialogue with companies such as Thales in France, Siemens in Germany, and other major industrial partners. From the end of 2018, it participated in the AI4EU[5], one the largest European consortia created to develop Europe's AI-on-demand platform. Its role was mainly to coordinate the Industrial Committee of the project and lead the eight industrial pilot experiments with the platform.

Certus also developed a number of scientific collaborations with prominent academic institutions. The following list is not exhaustive, but presents major collaborations especially leading to co-authored H2020 project proposals:

University of Luxembourg, SnT centre (UoL): After the departure in 2012 of Prof. Lionel Briand and two other research scientists to UoL, Certus and UoL engaged in strong collaborative activities to follow up on ongoing research projects. A number of co-authored publications were delivered, in addition to co-supervised PhD projects and partnering in the organization of conferences. Together with UoL, Simula coordinated CertMe, an H2020 proposal on the open certification of safety-critical systems (the proposal was evaluated on grade 14.0/15.0 but was unfortunately not funded). Certus leader Arnaud Gotlieb and Prof. Briand were involved in the co-supervision of two PhD students working at Simula who defended their PhD in 2015. In connection with software certification, another PhD student, who was initially supervised by UoL's researchers while working on the OPENCOSS FP7-Integrated Project, was co-supervised by Prof. Tim Kelly from the University of York.

Beihang University (BU), China: Certus had a fruitful collaboration with Certus enjoyed a fruitful collaboration with BU from 2011. BU was ranked fourth in the 2013 national evaluation of Chinese universities. The relationship included exchanges and regular visits, research collaborations with co-authored papers, and common educational activities. Led by senior researcher Tao Yue from Simula and Prof. Ji Wu of BU, this produced results in terms of scientific publications, methodologies, and software development. One innovation of the Centre, Zen-RUCM, was realised with partial support from visiting BU students

[5] https://www.ai4eu.eu/



Inria, France: Productive collaboration took place between Certus and Inria from 2011. Research scientist Dusica Marijan established scientific cooperation with Benoit Baudry, and Certus leader Arnaud Gotlieb with Prof. Catherine Dubois (ENSIEE and Inria Paris) in testing highly configurable software systems and formal verification (through the adjacent AURORA bilateral mobility project CertiSkatt). In 2013, a Certus delegation (administration and researchers) visited Inria Rennes to define priorities for a long-term collaboration and to identify synergies between scientific topics. This resulted in combined efforts for H2020 proposals that were strongly linked to Certus' research and innovation agenda. Following this lead, Inria and Simula entered into an institutional collaboration which resulted in the visit to Certus of a large delegation, led by Bruno Sportisse, Inria's CEO, in September 2019.

University of Parma, (UoP) Italy: From September 2013 to 2015, Certus collaborated with Prof. Roberto Bagnara from UoP regarding the testing of floating point computations. This resulted in scientific publications and student co-supervision.

Uppsala University (UU) and RI.SE SICS Institute[6], Sweden: Certus was engaged in scientific collaboration with Prof. Pierre Flener of UU and Mats Carlsson from RI.SE SICS from 2011 in the usage of constraint-solving techniques for software verification. This resulted in co-organised workshops (CPmeetsVerif and CSTVA in 2015), co-authored H2020 project proposals, and several co-authored papers.

[6] https://www.ri.se/en

Training of researchers

Training of researchers

By offering interesting thesis topics combining research and innovation on concrete use-cases, Certus managed to attract an impressive number of Master's students to its activities, of whom 17 successfully finished their thesis. Some even continued at the Centre afterwards.

Undertaking a PhD is an extraordinary experience for the students and a scientific adventure for their supervisors. Certus greatly valued the human relationships behind the scientific project, meaning that nurturing high-quality dialogue and excellent personal relationships between PhD students, academic supervisors and researchers, and engineers was a top-priority. This created strong supportive environments for doing excellent research and innovation.

Certus throughout the Centre period maintained its tight links with the Simula School of Research and Innovation (SSRI). All PhD students and postdoctoral fellows at Certus were affiliated with SSRI, which provided enhanced support in supervision and mentoring, as well as special courses on topics such as entrepreneurship and communication of scientific research.

Certus' recruitment philosophy was to look for the best possible candidates and strive to have a gender balanced work environment. That focus was particularly important, considering that only 15 percent of MSc-level software engineering graduates (prerequisite for PhD study) are women. This created a stimulating, multi-ethnic work environment, with students and researchers with diverse but complementary backgrounds enriching each other and bringing new perspectives to the research and industrial collaborations.

Completing a PhD is demanding. During its eight years of operation, the Centre employed 22 PhD students. Of those, 13 completed their PhD while seven more are in various stages of completing their PhD. Two students resigned their position without finishing. This was unfortunate, but is not uncommon in the Software Engineering research. The industry is in dire need of the competence we gave our students, and companies are willing to give generous offers when they find people with the right background. It is assumed that all Certus' candidates found relevant job opportunities quickly.

The Centre organised three open-courses sessions during its lifetime:

- 1st Open courses in *Software Validation and Verification* on November 20-21, 2013, at Simula
- 2nd Open courses in *Software Validation and Verification* on November 10-11, 2014, at Simula
- Crash Course on Machine Learning on August 22-24, 2016, at Simula

In addition, we conducted a number of technical workshops gathering researchers from the Centre and abroad, and engineers from our partners. Workshop and open courses topics ranged from Software Engineering with software validation and verification, software testing to Artificial Intelligence featuring courses on Machine Learning and Constraint Programming. Most noteworthy of these were:

- 14 User Partners Workshops from 2012 to 2019 hosted at either Simula, our partners, or in locations close to Oslo
- Seminar on Model-Based Testing, November 27, 2013, at Simula
- NordConsNet Workshop, May 27, 2019, at Simula

"I started at Certus because I liked the master's thesis topic from the Centre, where I could work closely with one of the industrial partners from the Centre. So, I chose the Centre and continued my doctorate. Working at the Centre was great. I loved being a part of Certus. The industrial partners helped me understand the problem they faced, which I could address in my research and verify the results using their datasets. Currently, I work as a tech lead at EVRY. I plan to continue working in the industry and contribute to open source software."

- Dipesh Pradhan

Employment of PhD candidates (as of 2019)

Of the 13 completed PhD students, only 3 were of Norwegian nationality. This is slightly less than the national average for ICT PhD students. Through the collaboration with the Simula School of Research and Education we have offered PhD students (and their spouses) free courses in Norwegian (beginners and intermediate levels) at our premises, to ease their way into the Norwegian society. The experience of studying, and working in collaboration with Certus researchers and industrial partners have qualified them for a fulfilling work life in Norwegian companies. Presently only 4 of the candidates have decided to leave Norway after completing their degree. Two of those four have further pursued an academic career, which normally requires that you seek out international expertise to broaden and strengthen your research network and scope.

Employment of PhD candidates	
By Centre company	1
By other companies	7
By public organisations	-
By university or college	1
By research institute	-
Outside Norway	4
Other	-
TOTAL	13

"Working at Certus allowed me have a quite unique experience where, while investigating applications of machine learning to software engineering, I could have a tight collaboration with industries and public institutions providing me an invaluable feedback.

The combination of working in a research environment with a strong focus on industrial exploitation was among the things who attracted me the most toward Certus.

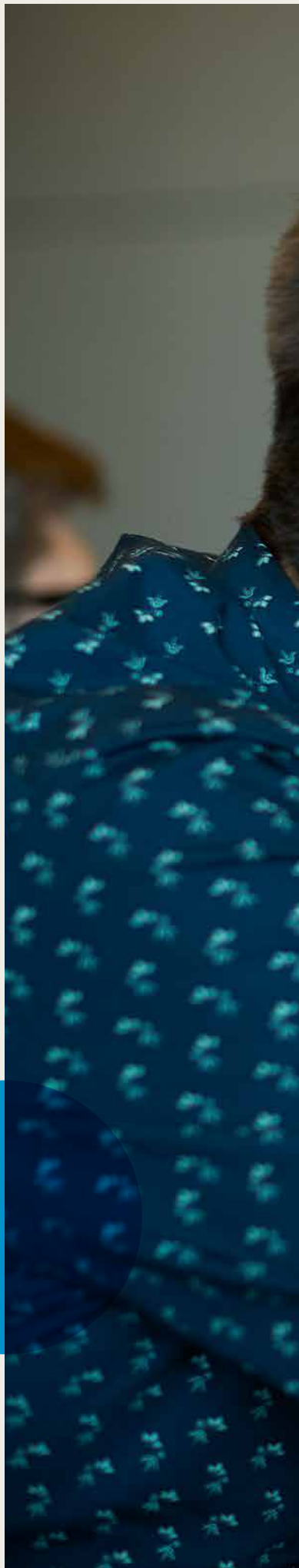
I am currently leading the creation of a new unit within the APP (Product and Price Analysis) department at Gjesidige Forsikring ASA. This unit will take care of workflow automation, software architecture design and development, data engineering, etc."

- Carlo Ieva

Communication / Popular dissemination of knowledge

Scientific communication became an important goal for Certus. The centre published 91 journal articles and 185 referred conference papers. In addition, by organizing open courses and technical workshops, Certus also disseminated its results to practitioners and early technology adopters.

Several public outreaches were organised during the lifetime of the Centre in Norway and Europe. By participating at developer and tester professionals events such as Maritime Innovation Days, Odin Software Testing Conference, NDC Techdown, French Days of Software Testing, and many others, Certus researchers and engineers widely disseminated results and knowledge on software validation and verification.



Effects of the Centre for the host institution and research partners

Long-term funding instruments, such as the SFI scheme provide unique possibilities for developing important lines of research that can impact the institution's scientific agenda for years to come.

Important results do not come for free, but Certus through hard and systematic work proved itself instrumental in forming Simula's research strategy in the software engineering area. The strategy now addresses several data-driven paradigms:

- use of machine learning and AI techniques to test and secure complex software systems;
- new approaches to testing the software of autonomous systems such as industrial robots;
- reduction of digital vulnerabilities through data-driven security assessments;
- methods designed to make software systems autonomously self-healing;
- improved methods for risk assessment and management of cyber-physical systems.

Through a comprehensive portfolio of new projects that emerged at the exit of the SFI, Simula will triple the number of staff members in software engineering within the next 18 months. The portfolio consists of both Norwegian- and European-funded projects, including those that involve Certus user partners. This development is indeed a very concrete and impressive legacy of Certus.

Since Certus had only one research partner, Simula, its direct influence on the Norwegian research system has been limited. However, its achieved results have been thoroughly noticed by other national research institutions, and several of new projects that grew out of Certus involve different national collaborations. It should also be noted that international collaboration in Certus, in particular with Europe's leading software research institution Inria, has big potential in generating positive effects for the years to come also at a national level.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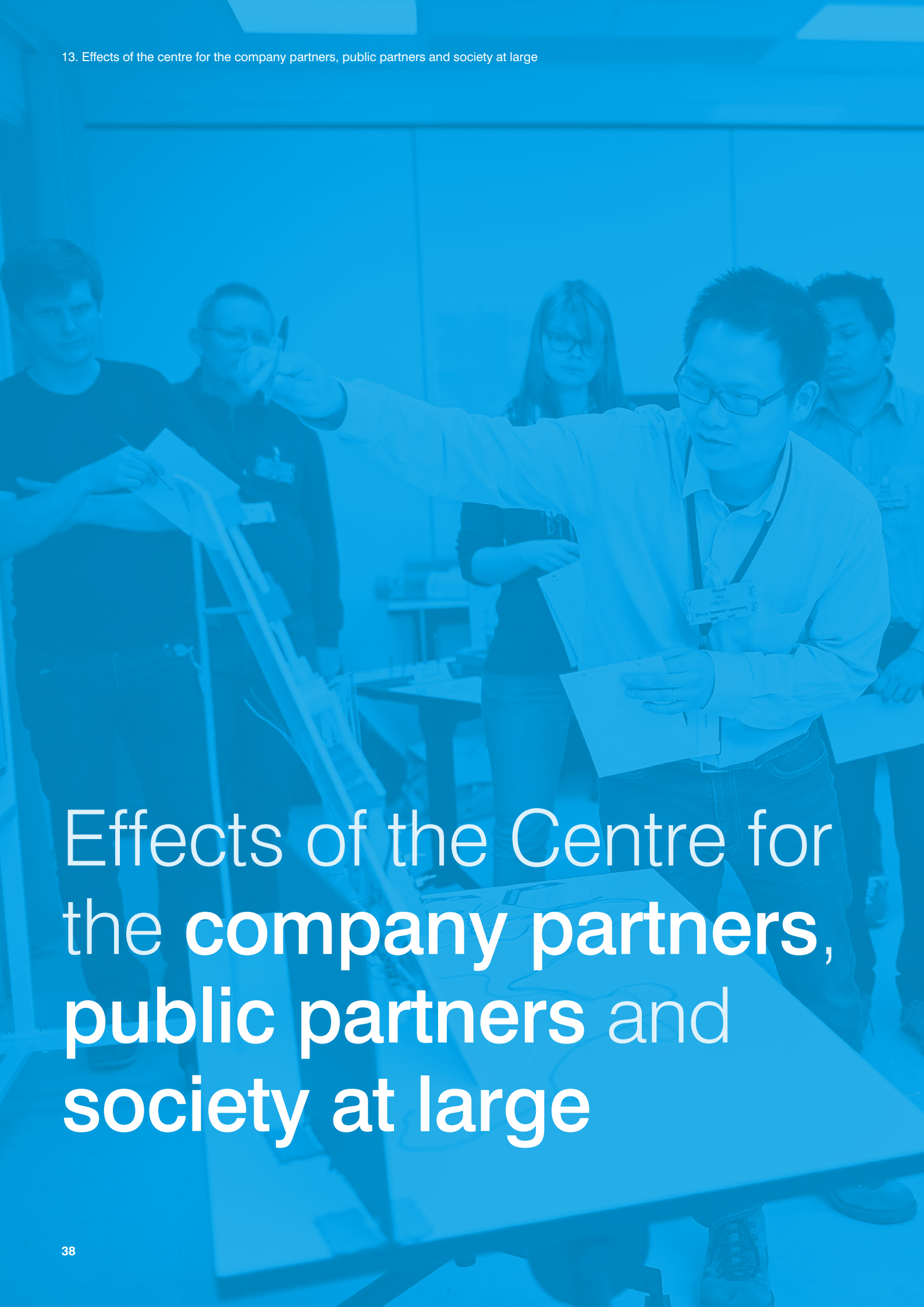

Effects of the Centre for the **company partners**, **public partners** and **society at large**

Certus from the start: A software entrepreneur at the helm

An entrepreneur in a world of engineers, inaugural Certus chairman Are Magnus Bruaset has a long history of building, marketing, and selling software to technically demanding industrial customers.

"*I have always had an interest in software and the challenge of getting it to behave,*" says Bruaset. "*My background has also provided me with fairly broad exposure to industry.*" The overlap between the two led him to Certus, with its focus on testing software in industrial environments.

Bruaset joined Simula in 2003, where he soon faced the challenge of establishing industrial collaboration with energy major Statoil, now Equinor. In 2011, he was asked by Simula CEO Aslak Tveito to take the Certus chair, which he occupied until 2015.

"*After our mid-term evaluation in 2015, Simula decided to offer the chair to an industry partner. We felt it was important to set the research agenda in the first period, while the second half should be dedicated to realizing the value of the research for the industrial partners,*" Bruaset tells. A long-time member of the Simula corporate management group, Bruaset continued to serve as Simula's representative on the Certus board until project closeout in 2019.

When worlds collaborate

"*There is a duality between long-term research and the shorter-term delivery cycle that drives industry,*" Bruaset points out. "*Managing this dichotomy is dependent on identifying the right industry partners. They have to see value of longer-term investments in resolving issues, and understand that this can provide them with a foundation for building better products and services.*"

The research community must also be ready to adapt to industry norms, he says. "*Eight years is an eternity in business. Partners join collaboration projects with best of intentions, but things change over time. Some leave, some join.*" In the case of Certus, FMC withdrew in response to a market downturn, and Toll's direction shifted with an internal restructuring of responsibilities. In both cases withdrawal was determined by decisions made beyond the participants' control, Bruaset says. "*On the other hand, the Cancer Register of Norway and ABB Robotics joined later, and they have been very active.*"

Bruaset underscores that successful project engagement runs deeper than idealistic goals. "*Many companies would like to be involved in research, but they lack the necessary financial and resource base.*" Involving the right individuals is equally as important, he says, preferably those with research experience. "*Management support is of course critical, but the buy-in must also penetrate down to the layers in the organization actually performing the work.*"

Achieving a good balance of industrial interests is another key to project success, Bruaset notes: "*This tends to fuel productive discussions, but it is also easier to get partners to work together when they have a mutual interest in research topics, without being in direct competition. They operate in different fields, but they share common goals in the project.*"

Zeroing in

"*One of our challenges in a multifaceted project like Certus has been to keep the focus trained on a set of achievable goals,*" Bruaset says. "*This is natural in a project where there are strong personalities and high ambitions.*" Noting that the early scope of Certus was perhaps too broad, he relates that focus was narrowed down over the course of the project: "*We basically went from scattershot to target practice.*"

Learning from that experience, Bruaset believes that future project applications will target more narrowly defined goals: "*We will also put a lot of effort into getting stakeholders to commit to those goals from beginning,*" he notes, adding that success hinges on mutual understanding.

"*Unrealistic expectations can lead to disappointment. We need to be very frank in our discussions of goals and expectations. This applies to all of Simula's research collaboration with external problem owners, really.*"

Playing to partner strengths

The importance of engagement and enthusiasm from the problem owner cannot be overestimated, Bruaset maintains. He points to the ABB Robotics case as a good example of what can be achieved when the industrial partner is fully engaged.

"We chose ABB Robotics to chair the board after the mid-term evaluation because we felt certain that they would be a committed and influential partner for the duration of the project," he relates. "They are an OEM with short deadlines and development windows, but they have still been able to create a dedicated pocket of time and resources to address research-based work that will come to fruition later."

Having a PhD candidate with a Certus supervisor in the ABB Robotics organization proved to be a critical element, Bruaset says. *"Qualified PhD candidates are often important resources in a company, and they are typically in demand for many key tasks. With management support, the industrial PhD role can help shield them from operative responsibilities and protect their time to work on research."*

Bruaset maintains that an additional benefit for companies emerges when a key employee who has invested in a research field returns to full time work. *"I believe all companies need a local champion, someone who is personally invested, to connect the dots from research to operations."* The same is true in research, he says: *"It is a great advantage for Simula to have PhD researchers working with dedicated industry partners."*

The Certus legacy

"The legacy of Certus outside the standard KPIs must be that more people in research have been exposed to industrial problems. I believe this has influenced their thinking and increased the potential for future collaboration with industry," Bruaset says.

Technologies have also been developed, he notes, both as objects of new research and for potential commercialization. One example is the emergence of ML and AI in software engineering during the Certus project period: *"We are using these technologies to improve software engineering through testing of complex systems. AI is complex in itself, and also needs testing. One of the Certus contributions that will be continued has been figuring out how to do that,"* he says

"I am happy and impressed with the important contributions that Certus has made to software engineering," Bruaset states. *"Ironically, for a while it was difficult to attract funding for new software engineering projects for Simula, but toward the end of the Certus period this has really picked up. I would almost call it a comeback victory, fuelled by important developments in Certus over the last couple of years."*

A final takeaway, Bruaset concludes, points to the future: *"If you start devising an exit strategy halfway through a project, it may be too late. All stakeholders must work to ensure that the end of a project does not mean the end of valuable contributions to the research and industrial communities. This has been a challenge for most centres in the SFI program, and it is great to see that Certus has tackled this by attracting a new generation of prestigious research grants."*

"We chose ABB Robotics to chair the board after the mid-term evaluation because we felt certain that they would be a committed and influential partner for the duration of the project"

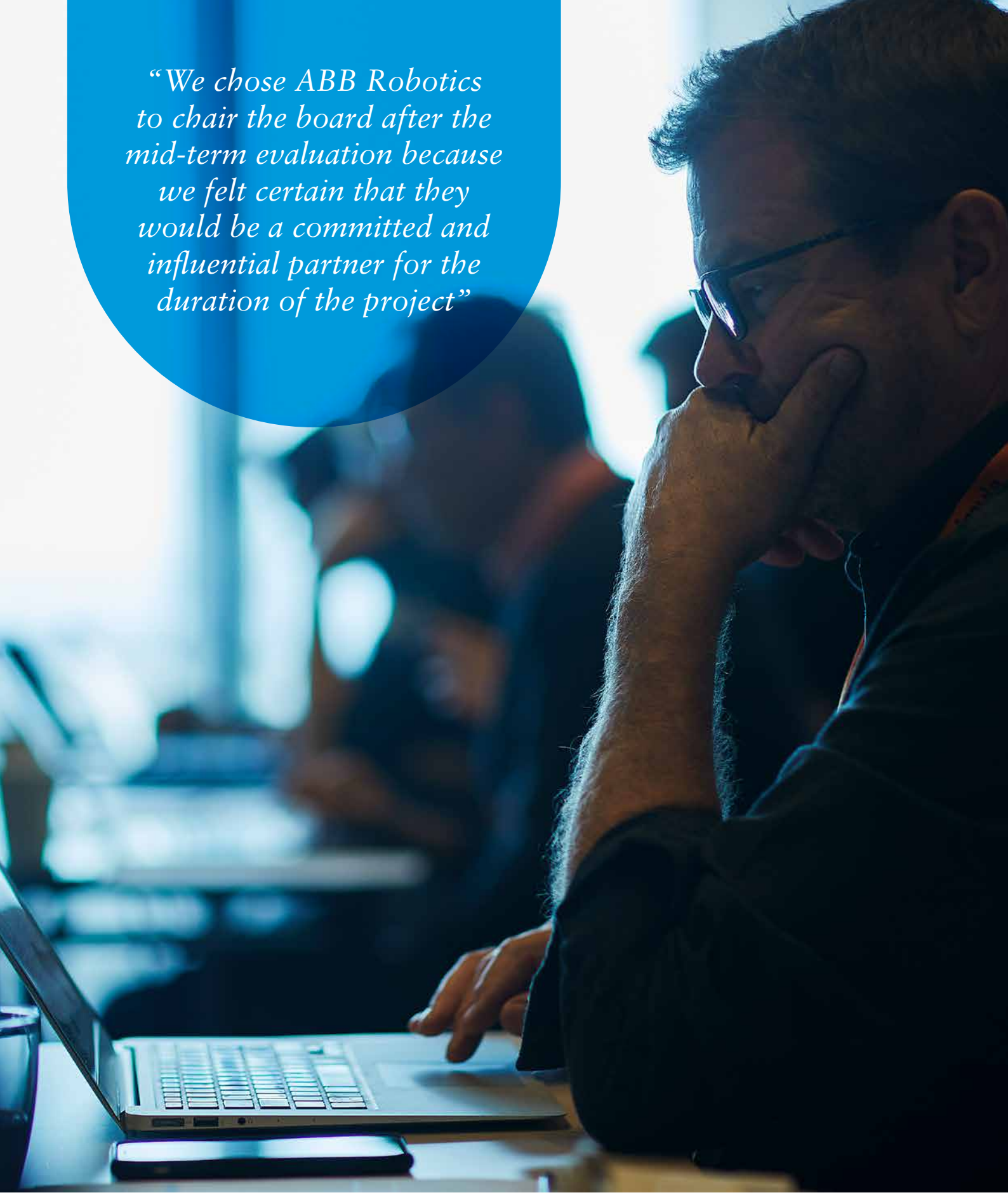

ABB Robotics and Certus – a good fit

Like many Certus partners, ABB Robotics found their way into the project through mutual acquaintances. A doctoral candidate in their office had Certus Centre leader Arnaud Gotlieb as his supervisor, and Arnaud invited ABB Robotics to join Certus as an industry partner.

"We joined later in the project, in 2015. The Norwegian Research Council at that time wanted an industrial partner as chair, so we took on that responsibility, and we have played an active role since then," says Jan Christian Kerlefsen, Head of ABB Robotics Norway and Certus chairman.

"The scope of the project was a good fit with the ABB Robotics focus, where we are intensely occupied with software testing," says Kerlefsen. *"Also we wanted to work closer with academia to increase our access to specialised competencies, as we tend to have more general competence."*

There were some differences to overcome in the interface between the two cultures, Kerlefsen acknowledges. *"Industry generally has an annual budget cycle, while Certus has a multiyear budget. The advantage is that this gives them a longer-term perspective, rather than having to focus on meeting shorter-term goals. This is just one of the reasons we have found Simula and the Certus researchers to be good sparring partners."*

On the value of working with Certus, Kerlefsen emphasises the power of collaboration with other environments: *"Working alone we can achieve state-of-the-art. Certus helps us go beyond that. In industry we work with applied research, while Certus delivers fundamental research. They explore their subjects more deeply and can help give us a deeper understanding of the foundation that our work is built on."*

He relates that ABB Robotics does continuous testing, but can only do so much with their available resources. *"We need intelligent ways to select the best test cases in order to achieve the best quality in as many products as possible."* Certus has worked together with ABB Robotics to further develop the algorithms used for choosing test cases, with AI used to optimise selection and running of cases.

The human factor

Kerlefsen cites the bi-annual user partner workshops as the project tool that has given ABB Robotics the best opportunities to interact with the other partners.

"Aside from these very inspiring gatherings, we have had relatively little direct interaction with other partners, but this varies between partners. We have shared the results of our work, but not through specific projects. Some researchers have moved between projects, and this has given them a unique competence that could very well be of value going forward."

He notes that working together with the academic researchers at Certus was highly motivating for ABB Robotics employees. *"They gained inspiration from the expertise of these new colleagues, and were eager to come back to work on new ideas."* Sharing knowledge has proved to be a major added value from the project, he says, noting that employees also contribute to academic publications through the Certus cooperation.

"The scope of the project was a good fit with the ABB Robotics focus, where we are intensely occupied with software testing"

Life after Certus

"The Certus Centre will be closed out, but we have a new project with Simula, as part of an EU research and development project, 'AI4EU'." ABB Robotics is an industrial partner in the project, which aims to leverage AI in robotics products by gathering and analysing performance data from robots. *"This is well aligned with ABB strategies, using AI to augment programming and conditional and predictive maintenance,"* Kerlefsen says.

"We also supervise two PhD students in collaboration with Simula. They will continue to build on project results. In addition we have participation in one additional NRC project." He notes that though they have shared development costs with the Research Council, Certus participation has required resources and commitment from ABB Robotics: *"But through this commitment, we have achieved things we would not have achieved otherwise."*

In closing, Kerlefsen notes the challenges and rewards that result when industry and academia meet. *"It has demanded that we be sensitive to the cultural differences between industry and research,"* he says. *"It's not like giving a concrete assignment to a consultant. The desired result is not always clear when you start. We have tried many variations on collaboration, some successful, some not so much, but always intriguing, mostly very useful, and always very pleasant,"* he concludes.

"I believe we have delivered more than just results for either industry or academia. We have produced publications of value for the entire research community. Our experience of Certus has been a place where world class industry meets world class research."

Quality cancer data: your life may depend on it

In most businesses, faulty data may cost money. In cancer research, it could cost lives.

In most businesses, faulty data may cost money. In cancer research, it could cost lives.

"Errors in our database can lead to errors in research. Clinical studies are very regimented, and we need to deliver data of highest quality," says Jan F. Nygård of the Cancer Register of Norway (CRN).

CRN joined the Certus project in 2105: *"I met some of the partners through mutual activities, and Certus Centre leader Arnaud Gotlieb invited me to present at a Certus conference. We could see it was an exciting project, and the focus of Certus research was a good fit for CRN,"* Nygård says. *"We collect, curate and analyse a lot of data, and all the data has to be accurate. What we do is not passive data transfer. We have multiple data sources, including laboratories, surgeons, oncologists, other registers and more, and everything must be compatible and consistent."*

In addition, Nygård notes, cancer has become a chronic illness, posing challenges in data longevity for CRN. *"Some patients might live 20 to 30 years after their diagnosis. In order for doctors to be able to follow the entire case history, we have to make old and new data match."*

CRN follows a strict set of rules in their data clean-up work. *"Our rules engine is driven by algorithms. In fact, our collaboration with Simula and started with our work on the rules engine. The aim is to validate and secure data,"* says Nygård.

When data first comes in from a case, CRN is on data cleanup duty from the start: *"What we do can be compared to an insurance company in the event of a car accident,"* Nygård tells. *"There is a collision, and the insurance companies get input from driver A and driver B, but they may not necessarily match. Then there might be a police report which gives a third version of what has happened, and new witnesses might be introduced. Then the companies have to make all the data line up."*

CRN's job, Nygård says, is to try and derive the most likely scenario for use in research from the total data input. *"We comb out the tangles to provide a clean result, but all the original data still has to be available."*

Better with Certus

"We have seen many benefits from participation in the Certus project. In general we now have stronger focus on control of data quality. We have also broadened our contact with experts in other fields, and this has led to projects with new partners and researchers," says Nygård. *"There are natural synergies with some partners, but Certus has made it possible to make connections between seemingly unrelated fields that could lead to new and unexpected solutions."*

For example, Nygård relates, Toll Customs in Norway, a former Certus partner, faces many of the same challenges as CRN, with large amounts of data coming in from multiple sources. *"They have to harmonise their data in much the same way as we do."*

International cross-disciplinary research opportunities have also arisen through Certus activities. *"We are not just a data factory. We need to cooperate and communicate with other specialists in order to make what we do possible, and we have used Certus to achieve this,"* Nygård confirms.

"We collect, curate and analyse a lot of data, and all the data has to be accurate. What we do is not passive data transfer."

Moving forward, looking back

"Though I do not see any linear continuation of project work, we have delivered an application for continued collaboration with Simula. We also have cooperation with another project partner, Esito. I feel certain that we will take the learning from Certus with us," Nygård says.

"As far as activities in the project go, I think the partner workshops have been great, both in networking and professional value, and as a good source of new ideas," he concludes. *"A common project where the partners are not competitors is conducive to openness. We have no secrets from each other. It's a unique combination of dissimilar partners with similar goals."*

Looking back, Jan F. Nygård has a good feeling about CRN's participation in Certus. *"We have moved forward from where we started, and I feel we have achieved what we wanted to accomplish. Of course we would like to have been in from the beginning to ensure better access to Certus research resources, but overall it has been a worthwhile journey,"* he says.

"I also believe there are good possibilities for the future, building on our experiences from Certus. Personally I didn't feel that the project should have lasted longer, or ended earlier. I think this is a good ending to a good project."

Cisco: eight years with Certus

In 2011, the same year as they joined the Certus project, the Norwegian teleconferencing pioneer Tandberg was acquired by Cisco Systems of the US. *"It's been a long journey and a time of big changes,"* says Marius Liaaen of Cisco.

"The differences are huge between the way a home-grown outsider and a global powerhouse operate," says Liaaen. *"Software release cycles went from monthly to daily. Lab systems tests have gone from 100 in 2011 to 1500 in 2019. Tests per day have gone from 800 in 2011, to 28,000 in 2019."*

Despite the vast differences in operating philosophies, Cisco remained in the Certus project on the same basic terms as defined by Tandberg. *"The Certus mission was to look for areas for improvement in Software Verification & Validation (SVV), and to develop tools we could use for test optimization and improvement,"* Liaaen tells. *"This was perhaps a better fit for Tandberg, where we were very careful with money, and the simpler structure allowed more space for advanced SVV projects with a focus on improving resource utilization."*

In Cisco, time to market is the key driver, he says, and there is no problem that can't be solved by adding more resources. *"When we needed to improve resource usage, the fastest solution was to buy more equipment. When our goal was to optimise test suites and reduce overtesting, the solution was again, to get more equipment to minimise the problems."*

This flip on resource management presented challenges integrating with the Certus goals. *"Creating useful quality tools is a big and continuous job,"* says Liaaen. *"Problems must be fixed ASAP, and it is difficult to find room for outside experiments in a fast-moving environment. In order of importance, nothing beats time to market, and 'scale up' wins out over clever tool optimizations."*

Nonetheless, Liaaen is clear on the benefits for Cisco of their Certus partnership. *"We gained good insight into the academic world, where they work very differently toward very different goals, but still with value for us. It also gave us a third-party perspective on our tools and methods. All this helps us understand better what we are really doing, to understand the underlying problems we encounter."*

A critical view on how Cisco solve problems is another valuable takeaway from the Certus experience. *"We learned to seek out and address core problems, instead of just fixing the symptoms."*

Not least, Liaaen reports they have had many good discussions with students and researchers: *"Smart people who very quickly ask the right questions. The outside perspective has helped make me aware that we are not special. Everyone has to solve basically the same type of problems."*

Certus participation also generated visibility both inside and outside Cisco, through papers and conferences, Liaaen reports. And as with the other Certus partners, the User Partner Workshops have been highly valued in Cisco: *"There were many rewarding workshops, and more than 15 different people from Cisco attended. It has been a great way to get to know other organizations and people."*

Following PhD students from start to end was another benefit. *"They are so driven, and their dedication teaches us to never rest, that there is always a better way."* Liaaen relates that the students' fields of study also kindled new interest for Cisco in areas like machine learning and artificial intelligence to improve on testing problems.

Takeaways for next time

Liaaen notes that they would have appreciated tighter cooperation with the researchers and students. *"An Industrial PhD is probably a better model for achieving this,"* he offers. *"And we would have liked to have spent more time figuring out what to do in the project and why. There was perhaps too little discussion around what´s behind the data."*

Stronger focus on the big problems would also have been more in keeping with the Cisco's priorities, he says. *"Forget the 5% improvement increments. The big changes are the ones that pay off."*

Lastly: Never underestimate the importance, or the difficulty, of the internal 'sell-in'. *"Changing habits can be difficult,"* Marius Liaaen concludes, *"but often worth the effort."*

"The Certus mission was to look for areas for improvement in software verification & validation, and to develop tools we could use for test optimization and improvement"

"Our motivation in joining the project was to get fresh input on how to make both existing and new tools even better."

Esito: in for a penny, in for a pound

***"We were part of the original Certus application to the Norwegian Research Council,"* says Mette Wam of Esito. *"This was partly due to our work with Toll,"* another of the original Certus industrial partners.**

"Esito has been a product development company since we started up in 2004, and the earlier versions of our tools date back to the late 1980s," Wam tells. "Our tools are designed for building models based on domain knowledge, and the models are used to generate code. Our motivation in joining the project was to get fresh input on how to make both existing and new tools even better."

Wam recalls that Esito saw two possible directions in the Certus project: either working with real-time data and configuration, like ABB Robotics and Cisco, or focusing on data intensive systems, like Toll, and later the Cancer Register of Norway.

"Test case optimisation is typically a major need for Certus partners working on configurable systems, while our focus is more on test data," Wam says. *"Most of the partners use live data in their research, and this is not always well suited to our needs. But we are still very occupied with software validation and verification, which is the main focus of Certus, so this was another argument for committing to the project."*

Lessons learned

Looking back, Wam believes that Esito could have been more involved in shaping tasks with more relevance for the company. *"Our target group is businesses developing applications, and we measure success in new products. With a stronger focus from our side, I think the project work could have had even more added value for us."*

For example, Esito proposed an initiative to explore the benefits of using synthetic test data in product development, but it never got off the ground. *"This is one initiative I wish we had followed up more closely,"* Wam relates.

"Ideally we would have given our participation more of an industrial or commercial angle, with a higher priority on commercialisation of Certus results," she confirms.

Better together

That being said, Wam is clear on the overall benefits of Certus for Esito. Though no major new products were developed during Esito's participation in the project, they did develop Anonymizer, an app designed to help companies meet GDPR requirements. *"We have created some spinoff products as a result of our participation, and this is something we would not have done without Certus,"* she says.

"We have also expanded our network and established new contacts in the project. It has been an opportunity to learn from others, both the researchers and our industry partners." Among the partners, Wam anticipates maintaining contact with the Cancer Register of Norway. *"They also deal with administrative systems and databases rather than real-time data, so our needs and goals are similar."*

Summing up, Mette Wam emphasises the big-picture benefits of Certus participation: *"One of the strengths of the Certus model has been the focus on cooperation between the public and private sectors. The project has encouraged a broader, more open cooperation between all stakeholders, and I believe we will continue to reap the benefits of this approach going forward."*

Future Prospects

From 2016 to 2019, The Certus Testing Lab. was established to serve as testing facility for the Certus User Partners. With this concept, we developed our understanding of industrial robot testing and we were granted with the RCN Frinatek/ Iktpluss T-Largo project, which aims at developing a platform for testing learning robots. This also allowed us to enter into the H2020 AI4EU project as leader of the industrial experiments of the European AI-on-demand platform. However, at the end of 2019, a necessary internal reorganization took place at Simula at the end of the Certus centre lifetime which terminated the Certus Testing Lab. experience.

The Centre has been a vector for finding new scientific projects and leads. In particular, the involvement of Simula into the H2020 EU frame-programme was significantly boosted by Certus. The participation of ABB Robotics and Simula into the H2020 AI4EU project is one direct example of the successful collaboration created within Certus. Future prospects includes strengthening our collaboration with ABB Robotics and establishing even more new projects through national and international funding.

The SFI funded research and activity has positioned Certus researchers to gain traction and a substantial amount of new externally funded projects during the last couple of years. Our researchers have entered into a new era of scientific collaboration and exploitation activities through newly acquired RCN projects in the IKTPLUSS “Reducing digital Vulnerabilities” programme. These projects will build on and further strengthen and develop the research, competence, products and expertise that we have gained during the SFI.

In fact, the added project funding that we have secured during the last two years of operation (77,2 MNOK) is by it self almost equal to the full RCN SFI grant for the whole 8-year centre period (78,3 MNOK).

Certus related projects that will be continued after 2019:				
Project name	**Funding source**	**Related Certus project**	**Project period**	**Project funding**
AI4EU	H2020 (LEIT)	Project 2	2018-2022	520 154 EUR
cureIT	RCN (IKTPLUSS)	Project 9	2019-2023	15 999 000 NOK
secureIT	RCN (IKTPLUSS)	Project 9	2019-2023	24 018 000 NOK
SmartMed	RCN (IKTPLUSS)	Project 7	2019-2021	4 043 000 NOK
T-Largo	RCN (IKTPLUSS)	Project 8	2018-2023	9 864 000 NOK
T3AS	RCN (FRINATEK)	Project 10	2019-2023	7 999 000 NOK
TSAR	RCN (IKTPLUSS)	Project 10	2019-2022	9 995 000 NOK


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Conclusions

Through the period 2011 – 2019, the Certus Centre has been dedicated to Software Validation and Verification (V&V) in close collaboration with a total of seven user partners from industry and the public sector: Cisco Systems Norway AS, Kongsberg Maritime, FMC Technologies, Esito, ABB Robotics, the Norwegian Directorate of Customs and Excise, and the Cancer Registry of Norway. The work in the centre evolved around seven projects connecting researchers and practitioners from different partner organisations, supported by a total of 14 User Partner Workshops and frequent on-premise consultations with relevant partner personnel. The Certus centre has been led by Dr. Arnaud Gotlieb with active participation of the Certus Board, the PIs of the different projects, and administrative personnel at the host institution Simula Research Laboratory.

The centre has raised awareness of V&V at a national level, contributed significantly to improved testing procedures inside partner organisations, developed novel tools for V&V that have been adopted by the partners, and made the Norwegian research in this area recognised world-wide. In total, Certus has completed more than 250 project deliverables, developed seven industry-strength technologies, and published 185 referred proceedings and 91 papers in scientific journals or series. Certus has also created a vibrant Norwegian community in V&V by educating 13 PhD students and 17 Master students, organising several courses and various public outreach.

Certus has made a successful exit through the recent acquisition of two European and seven nationally funded projects that brings forward important strands of research from the centre. In fact, the project funding secured during the last two years of operation is by itself almost equal to the full 8-year Certus grant from the RCN. It is also noteworthy that industrial partners from Certus are involved in some of the new projects, and in ongoing project proposals.

Appendix 1: Statement of accounts for the complete period of Centre financing

COSTS (All figures in 1000 NOK)											
Item	**Type of Research**	**Incentive effect***	**Host/Simula**	**Cisco**	**ESITO**	**KM**	**ABB**	**TOLL**	**CRN**	**FMC**	**Total cost**
Project 1. Management - SFI administration			8,497	784	266	647	859	326	87	166	**11,631**
Project 2. Industrial exploitation	Industrial research	1110	19,839	1,156	5,816	83	379	171	-	44	**27,488**
Project 3. Training and knowledge transfer	Industrial research	0110	2,049	1,378	234	418	398	282	530	88	**5,377**
Project 4. Dissemination and communication	Industrial research	1001	2,098	101	15	132	73	-	-	-	**2,419**
Project 5. Model-based engineering for highly configurable systems	Fundamental Research	1101	14,586	-	-	150	-	-	369	3,665	**18,769**
Project 6. Safety analysis and certification of embedded systems	Fundamental Research	1101	1,176	-	-	299	-	-	-	-	**1,475**
Project 7. Testing of data-intensive systems	Fundamental Research	1101	14,096	148	33	-	-	4,729	4,540	-	**23,545**
Project 8. Testing of real-time embedded systems	Fundamental Research	1101	24,470	7,587	-	-	7,765	-	-	50	**39,872**
Project 9. Smarter testing of evolving software systems	Fundamental Research	1101	13,382	2,139	-	2,692	-	-	-	-	**18,213**
Project 10. Data-driven predictive maintenance for software systems	Fundamental Research	1101	3,928	-	-	-	-	-	-	-	**3,928**
SFI equipment and direct costs			9,274	20	-	8	87	-	-	9	**9,398**
Total budget			**113,395**	**13,312**	**6,363**	**4,428**	**9,560**	**5,508**	**5,526**	**4,022**	**162,115**

*Incentive effect, 1=Present, 0=Not present. First digit: New R&D activity triggered, Second digit: Increase in size of related R&D activity, Third digit: Enhanced scope of related R&D activity, Fourth digit: Increased speed in execution of related R&D activity

FUNDING (All figures in 1000 NOK)										
Item	**Host/Simula Research Laboratory**	**Cisco**	**ESITO**	**KM**	**ABB**	**TOLL**	**CRN**	**FMC**	**RCN Grant**	**Total funding**
Type of partner	Research organisation	Large enterprise	Small and medium sized enterprise	Large enterprise	Large enterprise	Public partner	Public partner	Large enterprise		
Project 1. Management - SFI administration	2,208	784	266	647	859	326	87	166	6,289	**11,631**
Project 2. Industrial exploitation	6,255	1,156	5,816	83	379	171	-	44	13,584	**27,488**
Project 3. Training and knowledge transfer	637	1,378	234	418	398	282	530	88	1,412	**5,377**
Project 4. Dissemination and communication	609	101	15	132	73	-	-	-	1,489	**2,419**
Project 5. Model-based engineering for highly configurable systems	4,006	-	-	150	-	-	369	3,665	10,579	**18,769**
Project 6. Safety analysis and certification of embedded systems	170	-	-	299	-	-	-	-	1,006	**1,475**
Project 7. Testing of data-intensive systems	4,515	148	33	-	-	4,729	4,540	-	9,581	**23,545**
Project 8. Testing of real-time embedded systems	7,695	7,587	-	-	7,765	-	-	50	16,775	**39,872**
Project 9. Smarter testing of evolving software systems	4,546	2,139	-	2,692	-	-	-	-	8,836	**18,213**
Project 10. Data-driven predictive maintenance for software systems	1,470	-	-	-	-	-	-	-	2,457	**3,928**
SFI equipment and direct costs	2,883	20	-	8	87	-	-	9	6,391	**9,398**
Total budget	**34,995**	**13,312**	**6,363**	**4,428**	**9,560**	**5,508**	**5,526**	**4,022**	**78,400**	**162,115**

Partners financial contributions to the Certus Centre (in kNOK) during 2011-2019											
	Type	2011	2012	2013	2014	2015	2016	2017	2018	2019	TOTAL
Simula Research Laboratory (2011-2019)	Research org.	4,602	10,823	14,781	14,410	15,764	13,153	15,824	14,828	9,210	**113,395**
Kongsberg Maritime AS (2011-2018)	Large enterprise	507	197	180	1,058	1,102	786	599	-	-	**4,428**
FMC Kongsberg Subsea AS (2011-2014)	Large enterprise	508	1,038	1,480	996	-	-	-	-	-	**4,022**
ESITO AS (2011-2019)	SME	63	525	1,130	761	313	965	1,672	927	6	**6,363**
CISCO Systems Norway AS (2011-2019)	Large enterprise	238	1,770	1,836	1,874	1,767	1,530	1,581	1,432	1,284	**13,312**
Tolldirektoratet (2011-2017)	Public sector	152	826	1,715	1,801	895	119	-	-	-	**5,508**
CRN - Cancer Registry of Norway (2016-2019)	Public sector	-	-	-	-	-	963	1,656	1,628	1,280	**5,526**
ABB AS (2014-2019)	Large enterprise	-	-	-	767	1,436	1,517	2,246	2,104	1,490	**9,560**
TOTAL		6,070	15,180	21,121	21,667	21,277	19,032	23,579	20,919	13,270	162,115

COST (in kNOK) per project per year										
	2011	2012	2013	2014	2015	2016	2017	2018	2019	TOTAL
Project 1. Management - SFI administration	1,934	1,617	1,113	1,868	1,853	1,231	843	699	472	**11,631**
Project 2. Industrial exploitation	51	1,407	3,677	4,655	4,234	4,701	5,464	3,203	95	**27,488**
Project 3. Training and knowledge transfer	-	673	398	1,209	1,226	809	258	420	384	**5,377**
Project 4. Dissemination and communication	-	782	240	152	427	351	222	125	121	**2,419**
Project 5. Model-based engineering for highly configurable systems	1,635	4,383	4,297	3,832	2,035	1,254	1,333	-	-	**18,769**
Project 6. Safety analysis and certification of embedded systems	968	507	-	-	-	-	-	-	-	**1,475**
Project 7. Testing of data-intensive systems	257	1,962	4,450	3,729	2,044	2,118	2,766	2,703	3,515	**23,545**
Project 8. Testing of real-time embedded systems	958	3,050	5,221	3,767	4,880	3,999	7,932	6,818	3,247	**39,872**
Project 9. Smarter testing of evolving software systems	-	-	-	2,390	3,143	2,681	3,281	3,548	3,171	**18,213**
Project 10. Data-driven predictive maintenance for software systems	-	-	-	-	-	-	-	2,554	1,374	**3,928**
SFI equipment and direct costs	266	799	1,725	64	1,434	1,888	1,481	849	891	**9,398**
TOTAL	6,070	15,180	21,121	21,667	21,277	19,032	23,579	20,919	13,270	162,115

Appendix 2: List of Researchers, Postdocs, Candidates for PhD and MSc degrees during the full period of the Centre

Postdoctoral researchers with financial support from the CERTUS Centre budget				
Name	**Sex M/F**	**Nationality**	**Period**	**Topic**
Ali, Shaukat	M	Pakistani	21.11.2011-31.12.2014	Software Verification and Validation
Marian, Dusica	F	Croatian	01.11.2011-31.12.2013	Test optimization for highly configurable software systems.
Wang, Shuai	M	Chinese	01.03.2015-31.12.2017	Software Testing

Postdoctoral researchers working on projects in the CERTUS Centre with financial support from other sources					
Name	**Sex M/F**	**Nationality**	**Funding**	**Period**	**Topic**
Alesio, Stefano Di	M	Italian	EvolveIT	17.12.2014 - 16.12.2016	Software Evolution
Behjati, Razieh	F	Iranian	EvolveIT	01.08.2012-30.07.2015	Test Automation, Software Repository Mining, Software Product Line Engineering, Formal Verification
Bhandari, Guru Prasad	M	Nepal	secureIT	16.09.2019 - 15.03.2022	Software security, vulnerability prediction and data-driven software engineering
Lu, Hong	F	China	ZenConfigurator	01.06.2016 - 31.05.2018	Search-based software engineering and constraints evaluation/solving
Nguyen, Phu-Hong	M	Vietnam	U-Test, MBT4CPS, ZenConfigurator	01.07.2015 - 31.12.2017	Model-Based Testing
Vare Gonzales, Jose Luis de la	M	Spanish	OpenCoss	01.10.2011-31.12.2013	Safety-critical embedded systems

PhD students with financial support from the CERTUS Centre budget						
Name	**Sex M/F**	**Nationality**	**Period**	**Thesis title**	**Thesis advisors**	**Present place of work**
Collet, Mathieu	M	French	20.02.2017 - 19.02.2020	In progress (to be submitted)	Arnaud Gotlieb, and Morten Mossige	Certus
Hesari, Shokoofeh	F	Iranian	01.10.2011-23.09.2014	Did not complete	Tao Yue, Razieh Behjati	Schlumberger
Ieva, Carlo	M	Italian	01.01.2014 - 23.11.2018	Unveiling Source Code Latent Knowledge. Discovering Program Topoi	Arnaud Gotlieb, (Nadjib Lazaar, and Souhila Kaci)	Gjensidige
Pétillon, Alexandre	M	French	01.01.2015- 30.09.2015	Did not complete	Arnaud Gotlieb	NA
Pradhan, Dipesh	M	Nepal	01.09.2015 - 31.08.2018	Evolutionary Computation Based Test Optimization of Large-Scale Systems	Tao Yue, Shaukat Ali, and Shuai Wang	EVRY
Rosenberg, Carl-Martin	M	Norwegian	15.09.2016 - 14.09.2019	In progress (to be submitted)	Leon Moonen, and Are Magnus Bruaset	Certus
Spieker, Helge	M	German	01.10.2016 - 01.10.2019	Software Testing in Continuous Integration with Machine Learning and Constraint Optimization (to be submitted)	Arnaud Gotlieb, Morten Mossige, (and Magne Jørgensen)	Certus
Wang, Shuai	M	Chinese	01.10.2011 - 28.02.2015	Systematic Product Line Testing: Methodologies, Automation, and Industrial Application	Arnaud Gotlieb, Shaukat Ali, (and Magne Jørgensen)	Testify AS

PhD students Working on projects in the CERTUS Centre with financial support from other sources							
Name	**Sex M/F**	**Nationality**	**Funding**	**Period**	**Thesis title**	**Thesis advisors**	**Present place of work**
Alesio, Stefano Di	M	Italian	ModelFusion	01.10.2011-17.12.2014	Supporting Stress Testing of Real-Time Systems with Constraint Programming	Lionel Briand, Shiva Nejati, and Arnaud Gotlieb	Nordea
Hervieu, Aymeric	M	French	KEREVAL/ Industrial PhD	10-12-2010 - 09-12-2013	Covering Array generation using constraint programming	Arnaud Gotlieb, (Benoit Baudry, and Alain Ribaut)	Energiency
Iqbal, Muhammad Zohaib	M	Pakistani		01.10.2011-12.06.2012	Environment Model-based System Testing of Real-Time Embedded Systems	Lionel Briand and Andrea Arcuri	National University of Computer & Emerging Sciences (Fast-NU), Islamabad, Pakistan. Chief scientist at Software Quality Engineering and Testing (QUEST) Laboratory and President of Pakistan Software Testing Board.
Li, Yan	F	Chinese	U-Test	01.10.2016 - 01.09.2017	Requirements Support for Enabling Automated Reuse and Configuration for Product Line	(Li Zhang), Tao Yue, and Shaukat Ali	China Academic of Electronics and Information Technology
Ma, Tao	M	Chinese	MBT4CPS, ZenConfigurator	01.08.2015 - 31.07.2018	(PhD not submitted yet)	Tao Yue, and Shaukat Ali	TIDAL, Machine Learning Engineer
Mohan, Sunil Nair Kolaserry	M	Indian	OpenCoss	01.10.2011-31.03.2015	Characterization of Safety Evidence for Assessment and Certification of Critical Systems	(Tim Kelley), Jose Louis de la Vara, (and Magne Jørgensen)	DNB
Mohit Kumar Ahuja	M	Indian	T-Largo	24.09.2018-23.09.2021	In progress (to be submitted)	Arnaud Gotlieb, Dusica Marijan, and Are Magnus Bruaset	Certus
Mossige, Morten	M	Norwegian	ABB Robotics/ Industrial PhD	26.06.2012-26.08.2015	Testing Robotics Software using Constraint Programming in a Continuous Integration Process	Arnaud Gotlieb, Simula; Hein Meling, University of Stavanger	ABB Robotics
Razieh Ardakani Behjati	F	Iranian	EvolveIT, ModelFusion	01.10.2011-31.07.2012	"A Model-Based Approach to the Software Configuration of Integrated Control Systems"	Lionel Briand, Shiva Nejati, and Tao Yue	Testify AS; Revolut, London
Rogstad, Erik	M	Norwegian	ATOS	01.10.2011 - 28.02.2015	Automated regression testing of database applications	Lionel Briand and Arnaud Gotlieb	Testify AS
Rolfsnes, Thomas Gramstad	M	Norwegian	EvolveIT	01.10.2013 - 31.12.2016	Improving History-Based Recommendation Systems for Software Evolution	Leon Moonen, Razieh Behjati, (and Magne Jørgensen)	Egmont publishing
Rubasinghe, Iresha Dilhani	F	Siri Lanka	secureIT	15.09.2019-15.092022	In progress (to be submitted)	Leon Moonen	Certus
Safdar, Safdar Aqeel	M	Pakistani	ZenConfigurator	01.07.2015 - 30.06.2018	In progress (to be submitted)	Tao Yue, Shaukat Ali	DNB
Zhang, Man	F	Chinese	U-Test, ZenConfigurator	01.08.2015 - 31.07.2018	Uncertainty-wise Cyber-Physical Systems Testing	Tao Yue, and Shaukat Ali	Kristiania University College

Master degrees					
Name	**Sex M/F**	**Period**	**Title of thesis**	**Advisor**	**Institution granting degree**
Butt, Waqas Moazzam	M	2014-2016	Scientific Hangman: A Framework to Gamify Scientific Evidence for the General Public	Sagar Sen, Magne Jørgensen and Gisle Hannemyr	University of Oslo
Dipesh Pradhan	M	2013-2015	Test Optimization using Weight Based Search Algorithms in a Maritime Application	Tao Yue, Shaukat Ali, Magne Jørgensen	University of Oslo
Dongjing, Liu	F	2016	Virtual machines for GUI testing of programs	Morten Mossige, Andreas Skaar	University of Stavanger
Dzhakishev, Daviet	M	2013-2014	NoSQL Databases in the Enterprise An Experience with Tomra's Receipt Validation System	Sagar Sen, Magne Jørgensen	University of Oslo
Førsund, Jens	M	2017	Estimating position using QR-codes	Morten Mossige, Karl Skretting, and Ståle Freyer	University of Stavanger
Kucmann, Patryk	M	2018-2019	Selection of Software Tests and Mutants with Contextual Bandits	Helge Spieker, Arnaud Gotlieb, Dag Langmyhr (UiO)	University of Oslo, Department of Informatics
Louarn, Marine	F	2016	Modelling and Exploring Rules of Play in a Board Game for Social Computing	Arnaud Gotlieb, Sagar Sen and Laurent Albera	University of Rennes 1, France
Machnik Marek	M	2013-2015	Crowdpinion: Motivating People to Share their Momentary Experience	Sagar Sen, Magne Jørgensen	University of Oslo
More, Pooja	F	2013-2017	Crowd-driven Systematic Literature Review	Sagar Sen and Magne Jørgensen	University of Oslo
Munir, Imad	M	2015-2017	A Large-Scale OCL Constraint Repository and Comprehensive Analysis for Supporting Automated Cancer Registry System	Shuai Wang, Shaukat Ali, and Tao Yue	University of Oslo
Petillon, Alexandre	M	2013-2014	Test Execution Scheduling	Arnaud Gotlieb	Universitè de Poitiers
Pourabedin Islami, Mozhgan	F	2016-2017	Security Modeling of Cyber-Physical Systems: A Case Study of Smart Grid	Phu H. Nguyen, Tao Yue, Shaukat Ali	University of Oslo
Rolfsnes, Thomas Gramstad	M	2012-2013	Towards Automated Transformation of UML/ OCL to Prolog for Efficient Configuration of Integrated Control Systems	Tao Yue, Razieh Behjati	University of Oslo
Schwitalla, Thomas	M	2015-2017	A rule-Based Framework for Supporting Automated Change Impact Analysis in the Cancer Registry of Norway	Shuai Wang, Shaukat Ali, and Tao Yue	University of Oslo
Sletten, Kristian	M	2017	Automated testing of industrial robots using HTC Vive for motion tracking	Morten Mossige, Karl Skretting, and Ståle Freyer	University of Stavanger
Zhang, Gong	M	2012-2014	Research on Real-Time Software Requirement Modeling Technology Based on RUCM Approach	Tao Yue	Beihang University, China
Zhang, Man	F	2013-2014	Requirements Based Testing	Tao Yue, Shaukat Ali	Beihang University, China

Key Researchers funded by Certus						
Name	**Sex M/F**	**Nationality**	**Years**	**Position**	**Main research area**	**Institution**
Acuri, Andrea	M	Italian	2012-2014	Adjunct Research Scientist	Software testing	CERTUS Centre @ Simula Research Laboratory
Ali, Shaukat	M	Norwegian	2015-2017	Senior Research Scientist	Software Testing, Search-based Software Engineering, Model-Based Engineering	CERTUS Centre @ Simula Research Laboratory
Behjati, Razieh	F	Iranian	2015, 2016	Research Scientist	Test Automation, Software Repository Mining, Software Product Line Engineering, Formal Verification	CERTUS Centre @ Simula Research Laboratory
Briand, Lionel	M	French	2011-2012	Centre director (2011-2012)	"Testing, verification, and validation of software systems. Application of ML and evolutionary computing to software engineering. Model driven development and engineering."	CERTUS Centre @ Simula Research Laboratory
Gotlieb, Arnaud	M	French	2012-2019	Centre director (02.2012-09.2019)	Application of constraint solving to software testing	CERTUS Centre @ Simula Research Laboratory
Ieva, Carlo	M	Italian	2013-2018	Senior Research Engineer	Software Testing	CERTUS Centre @ Simula Research Laboratory
Marijan, Dusica	F	Croatian	2014-2019	Research Scientist (2015-2018); Senior Research Scientist (2018-2019)	Test optimization for highly configurable software systems.	CERTUS Centre @ Simula Research Laboratory
Moonen, Leon	M	Dutch	2013-2019	Senior Research Scientist	Smarter Testing of Evolving Systems, Software analytics and software repository mining techniques	CERTUS Centre @ Simula Research Laboratory
Nejati, Shiva	F	Iranian	2011-2012	Research Scientist	Model-driven engineering	CERTUS Centre @ Simula Research Laboratory
Sabetzadeh, Mehrdad	M	Iranian	2011-2012	Research Scientist	Model-based Software Engineering	CERTUS Centre @ Simula Research Laboratory
Selic, Bran	M	Canadian	2015, 2016	Adjunct Research Scientist	Model-based engineering of cyber-physical systems	CERTUS Centre @ Simula Research Laboratory
Sen, Sagar	M	Indian	2012-2019	Research Scientist (2012-2018); Senior Research Scientist (2019)	Testing data-intensive systems	CERTUS Centre @ Simula Research Laboratory
Torkar, Richard	M	Swedish	2011-2012	Senior Research Scientist	Searchbased Software engineering	CERTUS Centre @ Simula Research Laboratory
Vara Gonzales, Jose Louis de la	M	Spanish	2014-2015	Adjunct Research Scientist	Requirements Engineering, Model-Driven Engineering, and Empirical Software Engineering	CERTUS Centre @ Simula Research Laboratory
Yue, Tao	F	Canadian	2011-2017	Chief Research Scientist	Model Based Engineering, Empirical Software Engineering, Model Based Testing, Search-based Software Engineering, Product Line Engineering and Cyber Physical Systems.	CERTUS Centre @ Simula Research Laboratory
Baudry, Benoit	M	French	2013-2014	Adjunct Research Scientist	Model-driven engineering	CERTUS Centre @ Simula Research Laboratory

Visiting Researchers					
Name	**Sex M/F**	**Nationality**	**Period**	**Affiliation**	**Topic**
Aitor Arrieta Marcos	M	Spanish	10.10.2017 - 17.10.2017	University of Mondragon	Search Based Cyber Physical System Testing
Aitor, Arrita Marcos	M	Spanish	11.04.2016 - 11.05.2016	University of Mondragon, Spain	Search-Based Software Testing for Cyber Physical Systems
Alba, Enrique	M	Spanish	19.04.2015- 23.04.2015	University of Malaga	Evolutionary Computation and Optimisation, Search-Based Software Engineering
Andrew Begel	M	American	2013	Microsoft Research in Redmond, WA, USA	Stopping Programming Mistakes Before They're Made
Binkley, David W.	M	American	01.05.2015- 01.08.2016	Professor of Computer Science, Computer Science Department, Loyola University Maryland, Baltimore, USA	Targeted association rule mining
Caballero, Rafael	M	Spanish	01.08.2014- 30.09.2014	Researcher, Complutense University of Madrid (UCM)	Constraint programming
Catherine Dubois	F	French	2013	ENSIEE-CNAM, France, Paris	Formal certification of tax computations
Emilia Mendes	F	Brazilian	2013	Blekinge Institute of Technology Sweden	
Francis, Kathryn	F	Australian	04.05.2015- 15.05.2015	"Department of Computer Science, University of Melbourne, Australia "	Constraint Programming applied to code-based testing
Kostis Sagonas	M	Greek	2013	University of Uppsala, Sweden	Concurrency analysis in distributed systems
Lazaar, Nadjib	M	French	08.10.2018- 12.10.2018	LIRMM; University of Montpellier, France	Constraint Programming, Data Mining, Constraint Acquisition
Li, Yan	F	Chinese	02.09.2016 - 01.09.2017	Beihang University, Beijing, China.	Software engineering (searchbased, and Requirements managemant)
Li, Yan	F	Chinese	02.09.2016 - 01.09.2017	Beihang University, Beijing, China.	Software engineering (searchbased, and Requirements managemant)
Lima, Bruno	M	Portugise	30.10.2017 - 02.11.2017	University of Porto	Model-Based Testing
Maged Elaasar	M	Canadian	2013	IBM Rational Research Canada	Open Services for Lifecycle Collaboration and IBM Rational Tools
Mamaar, Mehdi	M	French	08.10.2018- 12.10.2018	LIRIS, IAE Lyon, France	Data Mining, Global Constraint
Miszczak, Jaroslav	M	Polish	01.10.2017 - 07.10.2017	Institute of Theoretical and Applied Informatics, Polish Academy og Sciences	Quantum Computing
Mottu, Jean Marie	M	French	18.06.2016 - 30.06.2016	INRIA and University of Nantes	Model Transformation Testing
Olga Grinchtein	F	NA	2013	Ericsson and University of Uppsala, Sweden	Test generation using constraint models

Visiting Researchers					
Name	**Sex M/F**	**Nationality**	**Period**	**Affiliation**	**Topic**
Pollock, Lori L.	F	American	23.09.2015-25.09.2015	Professor of Computer Science, Department of Computer and Information Sciences, University of Delaware, Newark, USA	Cross-language analysis of heterogeneous software systems
René Just	M	NA	2013	University of Seattle, WA, USA	Mutation analysis and mutation-based test data generation
Roberto Bagnara	M	Italian	2013	University of Parma, Italy and BUGSENG	Automatic test input generation
Roberto DiCosmo	M	Italian	17.01.2018-18.01.2018	Software Heritage; Inria, Paris	Software Engineering, Source Code Repository
Roberto E. Lopez-Herrejon	M	Mexican	2013	Johannes Kepler University of Linz, Austria	Software Product Lines Analysis
Salinesi, Camille	M	French	03.11.2015-04.11.2015	Professor at Centre de Recherche en Informatique, University of Paris 1 Pantheon - La Sorbonne, France	Variability modelling, requirement engineering
Vinju, Jurgen J.	M	Dutch	23.09.2015-25.09.2015	Software Analysis & Transformation, Centrum Wiskunde & Informatica, the Netherlands	Cross-language analysis of heterogeneous software systems
Wu, Ji	M	Chinese	01.01.2013-31.12.2013	Associate Professor, Beihang University, Beijing, China.	Software testing, requirements analysis
Yongqi Dong	M	Chinese	17.06.2019-18.06.2019	University of Waterloo, Canada	ML and data-driven research
Zohaib, Muhammad	M	Pakistan	29.10.2017 - 02.11.2017	National University of Computer and Emerging Sciences	Product-line Engineering Approach for Generating and Testing Mobile Applications

Research engineers with financial support from other sources				
Name	**Sex M/F**	**Nationality**	**Period**	**Topic**
Hammad, Muhammad	M	Pakistan	01.12.2015 - 30.11.2017	Model based Software engineering

Research Trainees working on projects in the CERTUS Centre				
Name	**Sex M/F**	**Nationality**	**Period**	**Topic**
Bernabé, Pierre	M	French	01.01.2019-30.03.2019	Machine Learning for Maritime Traffic Surveillance
Collet, Mathieu	M	French	01.06.2015-31.08.2015	Constraint Programming for Robotics
Louarn, Marine	F	French	15.03.2016 - 15.09.2016	Software engineering and modelling
Lu, Hong	F	China	01.01.2015 - 31.12.2015	Software engineering and modelling
Ribeiro, Manoel	M	French	26.06.2016 - 28.02.2017	Software engineering and modelling
Sarkar, Arnab	M	Indian	20.10.2013-01.10.2014	Software engineering and modelling

Administrative personnel with financial support from the CERTUS Centre budget			
Name	**Sex M/F**	**Nationality**	**Period**
Arge, Stein Erlend	M	Norwegian	01.10.2011-31.12.2012
Atkinson, Tom David	M	Norwegian	15.11.2015 - 30.09.2019
Bjerke, Christian	M	Norwegian	01.01.2013 - 31.01.2016
Bruaset, Are Magnus	M	Norwegian	01.01.2011 - 30.09.2019
Hagane, Inger Karoline Frøberg	F	Norwegian	01.06.2015 - 31.05.2018
Kylstad, Nina Kristine	F	Norwegian	01.07.2013-01.04.2014
Lind, Emmy Terese	F	Norwegian	01.01.2019 - 30.09.2019

Appendix 3: List of Certus Adjacent projects that have fully or partially supported the Certus research

To create synergies and ensure the proper management of related scientific activities, the Certus Centre use the notion of adjacent projects to describe projects that are separately funded and reported. This can refer to both Certus-initiated projects funded outside the centre's SFI grant and other ongoing projects that was initiated outside Certus but that later gravitated towards it. The following list of projects in the latter category supplements the Certus-initiated projects described at the beginning of this section:

List of Certus Adjacent Projects		
Project name	**Funding source**	**Project period**
AI4EU	H2020 (LEIT)	2018-2021
ATOS	Norwegian Tax Administration	2010-2015
CRN project	Cancer Registry Norway	2014-2017
cureIT	RCN (IKTPLUSS)	2019-2023
EvolveIT	RCN (FRINATEK)	2013-2017
Forny-Titan	RCN (FORNY2020)	2014-2016
MBE4CR	Regional Research Fund Oslo og Akershus	2015-2017
MBT4CPS	RCN (VERDIKT)	2015-2017
ModelFusion	RCN (FRITEK)	2011-2014
OpenCoss	FP7	2011-2015
SARcos	Universite Bourgogn	2019-2019
secureIT	RCN (IKTPLUSS)	2019-2023
SmartMed	RCN (IKTPLUSS)	2019-2021
T-Largo	RCN (IKTPLUSS)	2018-2022
T3AS	RCN (FRINATEK)	2019-2023
TSAR	RCN (IKTPLUSS)	2019-2022
U-Test	H2020 (LEIT ICT)	2015-2017
Zen-Configurator	RCN (FRINATEK)	2015-2017

Appendix 4: Publications

Certus only reports publications where a significant part of the research has been funded by Certus or adjacent projects of Certus. By this we mean that at least one of the authors of the reported publications must have his/her main affiliation with Certus, and has contributed to the publication as laid out in Simula's publication guidelines.

Publications from people with part time positions at Certus are generally not counted, unless the research is particularly relevant for a Certus project. Such exceptions from the main rule are few, and must be approved by the director.

Articles in International Journals

Random Testing: Theoretical Results and Practical Implications.
A. Arcuri, M. Z. Iqbal and L. Briand
IEEE Transactions on Software Engineering, vol. 38, pp. 258—277, 2011

Planning for Safety Evidence Collection: a Tool-Supported Approach Based on Modeling of Standards Compliance Information
D. Falessi, M. Sabetzadeh, L. C. Briand, E. Turella, T. Coq and R. K. Panesar-Walawege
IEEE Software, vol. pp, 2011

Assessing, Comparing, and Combining State Machine-Based Testing and Structural Testing: a Series of Experiments
S. Mouchawrab, L. C. Briand, Y. Labiche and M. Di Penta
IEEE Transactions on Software Engineering, vol. 37, 2011

Does Aspect-Oriented Modeling Help Improve the Readability of UML State Machines?
S. Ali, T. Yue and L. C. Briand
Software and Systems Modeling, 2012

Modeling Robustness Behavior Using Aspect-Oriented Modeling to Support Robustness Testing of Industrial Systems
S. Ali, L. C. Briand and H. Hemmati
Software and Systems Modeling, vol. 11, pp. 633—670, 2012

A Hitchhiker's Guide to Statistical Tests for Assessing Randomized Algorithms in Software Engineering
A. Arcuri and L. C. Briand
Software Testing, Verification and Reliability, vol. 24, pp. 219—250, 2012, [DOI]

Formal Analysis of the Probability of Interaction Fault Detection Using Random Testing
A. Arcuri and L. C. Briand
IEEE Transactions on Software Engineering, vol. 38, pp. 1088—1099, 2012

A Precise Method-Method Interaction-Based Cohesion Metric for Object-Oriented Classes
J. A. Dallal and L. C. Briand
ACM Transactions on Software Engineering and Methodology, vol. 21, 2012

Empirical Principles and an Industrial Case Study in Retrieving Equivalent Requirements Via Natural Language Processing Techniques
D. Falessi, G. Cantone and G. Canfora
IEEE Transactions on Software Engineering, vol. 39, pp. 18—44, 2012, [DOI]

Tcas Software Verification Using Constraint Programming
A. Gotlieb
The Knowledge Engineering Review, vol. 27, 2012
A CP Framework for Testing CP
N. Lazaar, A. Gotlieb and Y. Lebbah
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A SysML-Based Approach to Traceability Management and Design Slicing in Support of Safety Certification: Framework, Tool Support, and Case Studies
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S. Ali
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A. Gotlieb
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S. Di Alesio
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D. Marijan
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L. Moonen
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L. Moonen
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A. Gotlieb
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A. Gotlieb
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S. Ali
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A. Gotlieb
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L. Moonen
Graduate School of Information Science and Technology, Osaka University, Osaka, Japan, 2017

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L. Moonen
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C. M. Rosenberg
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D. Marijan
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M. Collet
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M. Collet
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A. Gotlieb
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M. Monperrus, B. O'Reilly, L. Moonen and G. Grosch
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L. Moonen
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L. Moonen
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S. Sen
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S. Sen
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S. Sen
Klosser Innovation, Hamar, 2019

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S. Sen
OsloMet, Oslo, Norway, 2019

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H. Spieker
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Portinari: Communicating Personalized Risk in Cervical Cancer Screening using Data.
S. Sen, M. Ribeiro and M. Nygård
2016

Using mobile games as an educational platform to promote human papillomavirus vaccination and improve sexual health in Zambian adolescents
A. Adedimeiji, S. Kapambwe, S. Sen and M. Nygård
2017

FightHPV : A Game to Raise Awareness and Nudge People to Take Action Against Cervical Cancer in Norway
T. R. Lopez, S. Sen, E. Jakobsen and M. Nygård
2017

SUnCPS: A Taxonomy of Security-related Uncertainty in Cyber-Physical Systems
P. H. Nguyen, S. Ali and T. Yue
2017

Portinari: An Interactive Visualization Tool To Explore Alternative Patient Paths in Cervical Cancer Screening
M. Ribeiro, S. Sen and M. Nygård
2017

Uncertainty-wise and Model-based Testing of Industrial Cyber-Physical Systems
M. Zhang, S. Ali, T. Yue and P. H. Nguyen
2017

Constraint-Based Generation of Trajectories for single-Arm Robots
M. Collet, A. Gotlieb and M. Mossige
2018

Different Cycle, Different Assignment: Diversity in Assignment Problems with Multiple Cycles
H. Spieker, A. Gotlieb and M. Mossige
2018

Towards Sequence-to-Sequence Reinforcement Learning for Constraint Solving with Constraint-Based Local Search
H. Spieker
2019

Appendix 5: Community Service

Certus researchers have been selected to chair and participate in prestigious scientific committees. Committee membership is not merely volunteer work. Membership is by invitation only, and some of these invitations are among the hardest to come by in the software engineering world.

Arnaud Gotlieb

Journal Editorial Board Member

- Journal of Software Testing, Verification and Reliability, Edited By: Tao Xie and Robert M. Hierons Impact factor:1.171, ISI Journal Citation Reports © Ranking: 2018:69/107 (Computer Science, Software Engineering); Online ISSN:1099-1689, John Wiley & Sons Ltd

Steering Committee, co-Organiser

- CSTVA Workshop on Constraint Solvers in Testing, Verification and Analysis, 2011-2017

Program co-Chair

- 1st IEEE Int. Conf. On Artificial Intelligence Testing, San Francisco, CA, USA, Apr. 2019
- 36th International Conference on Software Engineering, Software Engineering in Practice (SEIP) Track, 2014, Hyderabad, India
- 13th International Conference on Quality Software Nanjing University, China, Jul 2013

Track co-Chair

- CP'19 25th Int. Conf. on Principles and Practice of Constraint Programming, Stamford, CT, USA, Sep. 2019
- CP'18 24th Int. Conf. on Principles and Practice of Constraint Programming, Lille, France, Aug. 2018
- CP'17 23rd Int. Conf. on Principles and Practice of Constraint Programming, Melbourne, Australia Sep. 2017
- CP'16: 22nd Int. Conf. on Principles and Practice of Constraint Programming, Toulouse, France, Sep.

Other Chair Responsibilities

- QRS'17 IEEE Int. Conf. on Software Quality, Reliability and Security, Prague, Czech, Jul. 2017 (workshop chair)
- ICST'15 IEEE Intl Conf. on Soft. Testing, Verif. and Valid., Graz, Austria, 13-17 April 2015 (PhD symposium chair)
- FM'15 20th International Symposium on Formal Methods, Oslo, Norway 22-26 June, 2015 (finance chair)

Program Committees

- IJCAI'19 Int. Joint Conf. on Artificial Intelligence, Macao, China, Aug. 2019
- QRS'19 19th IEEE Int. Conf. on Software Quality, Reliability and Security, Sofia, Bulgaria Jul. 2019
- DSO'19 Data Science Meets Optimization Workshop, an IJCAI 2019 Workshop, Macao, China, Aug. 2019
- IFIP-ICTSS'19 31th IFIP Int. Conf. on Testing Software and Systems, Paris, France Oct. 2019
- LOPSTR'19 25th Int. Symp. on Logic-Based Program Synthesis and Transformation, Porto, Portugal, Oct. 2019
- QRS'18 18th IEEE Int. Conf. on Software Quality, Reliability and Security, Lisbon, Portugal, Jul. 2018
- IJCAI-ECAI'18 Int. Joint Conf. on Artificial Intelligence, Stockholm, Sweden, July 2018
- TAP'18 12th Int. Conf. on Tests and Proofs, Toulouse, France, Jun. 2018
- ICTAI'18 30th Int. Conf. on Tools with Artificial Intelligence, Volos, Greece, Nov. 2018
- FIP-ICTSS'18 30th IFIP Int. Conf. on Testing Software and Systems, Cadiz, Spain, Oct. 2018
- IJCAI'17 Int. Joint Conf. on Artificial Intelligence, Melbourne, Australia, Aug. 2017
- TAP'17 12th Int. Conf. on Tests and Proofs, Marburg, Germany, Jul. 2017
- ICTAI'17 29th Int. Conf. on Tools with Artificial Intelligence, Boston, MA, USA, Nov. 2017
- ICTSS'17 29th IFIP Int. Conf. on Testing Software and Systems, St Petersburg, Oct. 2017
- COMPSAC'16: 40th IEEE Annual Int. Computer Software & Applications Conf., Atlanta, USA, Jun.
- QRS'16: IEEE Int. Conf. on Software Quality, Reliability & Security. Vienna, Austria, Jul. 2016
- TAP'16: 11th Int. Conf. on Tests and Proofs, Vienna, Austria, Jul. 2016
- MET'16: Int. Workshop on Metamorphic Testing, Austin, USA, May 2016
- iFMCloud'16: Int. Workshop on Formal Methods for and on the Cloud, Reykjavik, Iceland, Jun. 2016
- CP meets Verification Workshop at CP'2016, Toulouse, France, Sep. 2016
- MODELS'16: ACM/IEEE 19th Int. Conf. on ModelDriven Engineering Languages and Systems, Saint Malo, France
- MODELSWARD'16: 4th Int. Conf. on Model-Driven Engineering and Software Development, Feb. 19-21, Rome, Italy
- RE'16: 24th Int. Conf. on Requirements Engineering. Beijing, China
- SPLC'16: 21th Int. Systems and Software Product Line Conf. Beijing, China
- COMPSAC'16: IEEE 40th Annual Int. Computers, Software & Applications Conf.. Atlanta, Georgia, USA

- CP'15 - 21st International Conference on Principles and Practice of Constraint Programming. August 31-September 04, 2015, Cork, Ireland
- IJCAI'15 - International Joint Conference on Artificial Intelligence. July 25-31, 2015, Buenos Aires, Argentine
- TAP'15 - 10th Int. Conf. on Tests and Proofs. July 20-24, 2015, L'Aquila, Italy
- LOPSTR'15 - 25th Int. Symp. on Logic-Based Program Synthesis and Transformation. July 13-15, 2015, Siena, Italy
- ICST'15 - IEEE Intl Conf. on Soft. Testing, Verif. and Valid. April 13-17, 2015, Graz, Austria
- ICST'14 - 7th IEEE International Conference on Software Testing, Verification and Validation, Cleveland, Ohio, USA
- COMPSAC '14 38th IEEE Annual International Computer Software & Applications Conference, Västeras, Sweden
- ISSRE'14 25th IEEE International Symposium on Software Reliability Engineering, Naples, Italy
- LOPSTR'14 24th International Symposium on Logic-Based Program Synthesis and Transformation, University of Kent, Canterbury, UK
- TAP'14 9th International Conference on Tests and Proofs, York, UK
- HCVS'14 Workshop on Horn Clauses for Verification and Synthesis, Vienna, Austria
- COMPSAC'13 37th IEEE Annual International Computer Software & Applications Conference, Kyoto, Japan, July 22-26, 2013
- ISSRE'13 24th IEEE International Symposium on Software Reliability Engineering, Pasadena, CA, USA, Nov. 2013
- TAP'13 Int. Conf. on Tests and Proofs, Budapest, Hungary, June 18-19, 2013
- ICST'13 6th IEEE International Conference on Software Testing, Verification and Validation, Luxembourg, Mar. 2013
- ICSE'13 SEIP 35th IEEE International Conference on Software Engineering, SEIP Track, San Francisco, Jun. 2013
- CP'13 Application track 19th Int. Conf. on Principles and Practice of Constraint Programming, Uppsala, Sweden, Sep. 16-20, 2013

Dusica Marjan

Workshop Chair (and Program Committee)

- 14th International Conference on Quality Software, 2014

Program Committees

- Organising committee member, SER&IP workshop at International Conference on Software Engineering, May 2018, Gothenburg Sweden
- Program committee member, International Conference on Software Quality, Reliability, Security, July 2018, Portugal
- Program committee member, SEIP track at International Conference on Software Engineering, May 2018, Gothenburg Sweden
- Program committee member, International Conference on Fundamentals and Advances in Software System Integration, September 2018, Italy
- QRS'17: IEEE International Conference on Software Security and Reliability, July, Czech Republic
- SEIP'17: Software Engineering in Practice Track at International Conference on Software Engineering, May, Argentina
- QRS'15 - IEEE International Conference on Software Quality, Reliability and Security. August 03-05, 2015, Vancouver, Canada
- COMPSAC'15 - IEEE Annual International Computers, Software & Applications Conference. July 01-05, 2015, Taichung, Taiwan
- CAISE'15 - International Conference on Advanced Information System Engineering. June 08-12, 2015, Stockholm, Sweden

Journal Review Boards

- IEEE Software Software: Practice and Experience
- International Journal of Control Theory and Computer Modeling
- International Journal of Systems Assurance Engineering and Management

Jose Luis de la Vara

Program Committee

- Third Workshop on Next Generation of System Assurance Approaches for Safety-Critical Systems
- Second International Workshop on Quality and Measurement of Software Model-Driven Developments
- 26th International Conference on Software Engineering and Knowledge Engineering

Leon Moonen

General Chair

- HISS'15 - 2nd High Integrity Systems Symposium. June 03, 2015, Oslo, Norway

Program Chair

- ESEC/FSE SRC 2019 - 27th ACM Joint European Software Engineering Conf. and Symp. Foundations of Software Engineering - Student Research Competition
- ICPC 2014 - 22nd IEEE International Conference in Program Comprehension
- ICSM 2014 - 30th IEEE International Conference on Software Maintenance and Evolution

Steering Committees

- Int'l Workshop on Pattern Promotion and Anti-pattern Prevention (PPAP) (2013-2018)
- High Integrity Systems Forum (HISF) (2014-…)
- IEEE Int. Working Conf. on Source Code Analysis and Manipulation (SCAM), (2011-2014; 2014-2017, chair)
- IEEE International Conference on Program Comprehension (2011-2012; 2012-2015, chair)

Program Committees

- IEEE Int'l Conf. on Software Maintenance and Evolution (ICSME, 2011-2019)
- IEEE Int'l Working Conf. on Software Analysis, Evolution and Reengineering (SANER 2015, 2016)
- IEEE Working Conf. on Reverse Engineering (WCRE, 2011; 2012)
- IEEE Int'l Conf. on Program Comprehension (ICPC, 2011-2016; 2018-2019)
- IEEE Int'l Working Conf. Source Code Analysis and Manipulation (SCAM, 2011; 2012; 2014; 2016-2019)
- European Conf. on Software Maintenance and Reengineering (CSMR 2011-2013)
- Euromicro Conf. on Software Engineering and Advanced Applications (SEAA), track on Software Engineering and Technical Debt (SEaTeD 2018, 2019)
- 18th Int'l Conf. on Evaluation and Assessment in Softw. Eng. (EASE 2014)
- ICSE Track on Software Engineering Education (ICSE-SEE 2012)
- Testing: Academic & Industrial Conf. - Practice and Research Techniques (TAIC PART 2012)
- 7th Int'l Ws. Realizing Artificial Intelligence Synergies in Software Engineering (RAISE 2019)
- 3rd Int'l Ws. on (Meta)modelling for Healthcare Systems (MMHS'16)
- 14th BElgian-NEtherlands software eVOLution seminar (BENEVOL 2015)
- Int'l Ws. on Comprehension of Complex Systems (CoCoS 2013)
- Int'l Ws. on Controversial Implementation Choices (CIC 2012)

Sagar Sen

Program Chair

- SER&IP'16: 3rd Int. Workshop on Soft. Eng. Research and Industrial Practice
- ISSRE'16: 28th IEEE Int. Symp. on Software Reliability Engineering
- iFMCloud'16: Int. Workshop on Formal Methods for and on the Cloud, Reykjavik, Iceland, Jun. 2016
- SANER'16: 23rd IEEE Int. Conf. on Software Analysis, Evolution, and Reengineering,

Program Committees

- SANER 2018 IEEE Int. Conf. on Software Analysis, Evolution, Reengineering - Industry Track
- SER&IP 2018 Int. Workshop on Software Engineering Research and Industrial Practice
- ISSRE 2018 IEEE International Symposium on Software Reliability Engineering
- SER&IP'17: 4rd Int. Workshop on Soft. Eng. Research and Industrial Practice
- ISSRE'17: 29th IEEE Int. Symp. on Software Reliability Engineering
- SANER'17: 24th IEEE Int. Conf. on Software Analysis, Evolution, and Reengineering
- ISSRE 2015 - 26th International Symposium on Software Reliability Engineering. November 02-05 Ottawa, Canada
- 36th International Conference on Software Engineering 2014 – Software Engineering in Practice
- 1st International Workshop on Software Engineering Research and Industrial Practices
- 14th International Conference on Quality Software

Shaukat Ali

Program Co-Chair (and Program Committee)

- A-MOST'15 (Co-Chair) - Workshop on Advances in Model Based Testing. April 17, 2015, Graz, Austria.

Program Committees

- ECMFA 2017: 13th European Conference on Modelling Foundations and Applications
- MEDI 2017: 7th International Conference on Model and Data Engineering
- SPLC 2017: 21th International Systems and Software Product Line Conference
- MDEbug 2017: 1st International Workshop on Debugging in Model-Driven Engineering
- SSBSE 2017 Challenge Track: Search-based Software Engineering 2017 Challenge Track
- TECPS 2017: 1st International Workshop on Testing Embedded and Cyber-Physical Systems
- MODELS2017: ACM/IEEE 20th International Conference on Model Driven Engineering Languages and Systems
- SDL Forum 2017, SDL Forum 2017
- T&D MODELS 2017: Tools and Demos at 20th MODELS Conference 2017
- A-MOST 2017: 13th Workshop on Advances in Model Based Testing
- ICST 2017: 10th IEEE International Conference on Software Testing, Verification and Validation
- MODELS'16: ACM/IEEE 19th Int. Conf. on Model Driven Engineering Languages and Systems, Saint Malo, France

- ECMFA'16: 12th European Conf. on Modelling Foundations and Applications
- ICST'16: 9th IEEE Int. Conf. on Software Testing, Verification and Validation
- SPLC'16: 20th Int. Systems and Software Product Line Conf.
- SAM'16: 9th System Analysis and Modelling Conf.
- SSBSE'16: 8th Int. Symp. on Search-based Software Engineering
- SPLC'16: Doctoral Symp. at the Systems and Software Product Line Conf.
- MODELS'15 - ACM/IEEE 18th International Conference on Model-Driven Engineering Languages and Systems. September 30-October 02, 2015, Ottawa, Canada
- ECMFA'15 - European Conference on Modelling Foundations and Applications. July 20-24, 2015, L'Aquila, Italy
- ICST'15 - IEEE International Conference on Software Testing, Verification, and Validation. April 13-17, 2015, Graz, Austria
- SPLC'15 - 20th International Systems and Software Product Line Conference. July 20-24, 2015, Nashville, USA
- ACM/IEEE 17th International Conference on ModelDriven Engineering Languages and Systems, 2014
- 14th International Conference on Quality Software, 2014
- Eighth Conference on System Analysis and Modelling, 2014

Shuai Wang

Co-organiser (general chair)

- 13th Workshop on Advanced in Model Based Testing (A-MOST 2017), collocated with ICST 2017

Program Committees

- MODELSWARD'17 International Conference on Model-Driven Engineering and Software Development
- SAC'17 ACM/SIGAPP Symposium on Applied Computing
- SAC'16: 31st ACM/SIGAPP Symp, on Applied Computing
- MODELSWARD'16: 4th Int. Conf. on Model-Driven Engineering and Software Development, Rome, Italy
- A-MOST'16: 12th Workshop on Advances in Model Based Testing, Chicago, USA.

Stefano di Alesio

Program Committees

- CSTVA'16: 7th Int. Workshop on Constraint Solvers in Testing, Verif. and Analysis
- WoSoCer'16: 6th IEEE Int. Workshop on Software Certification
- A-MOST'16: 12th Advances in Model based Testing Workshop

Sunil Nair

Program Committees

- Third Workshop on Next Generation of System Assurance Approaches for Safety-Critical Systems, 2014
- 14th International Conference on Quality Software, 2014

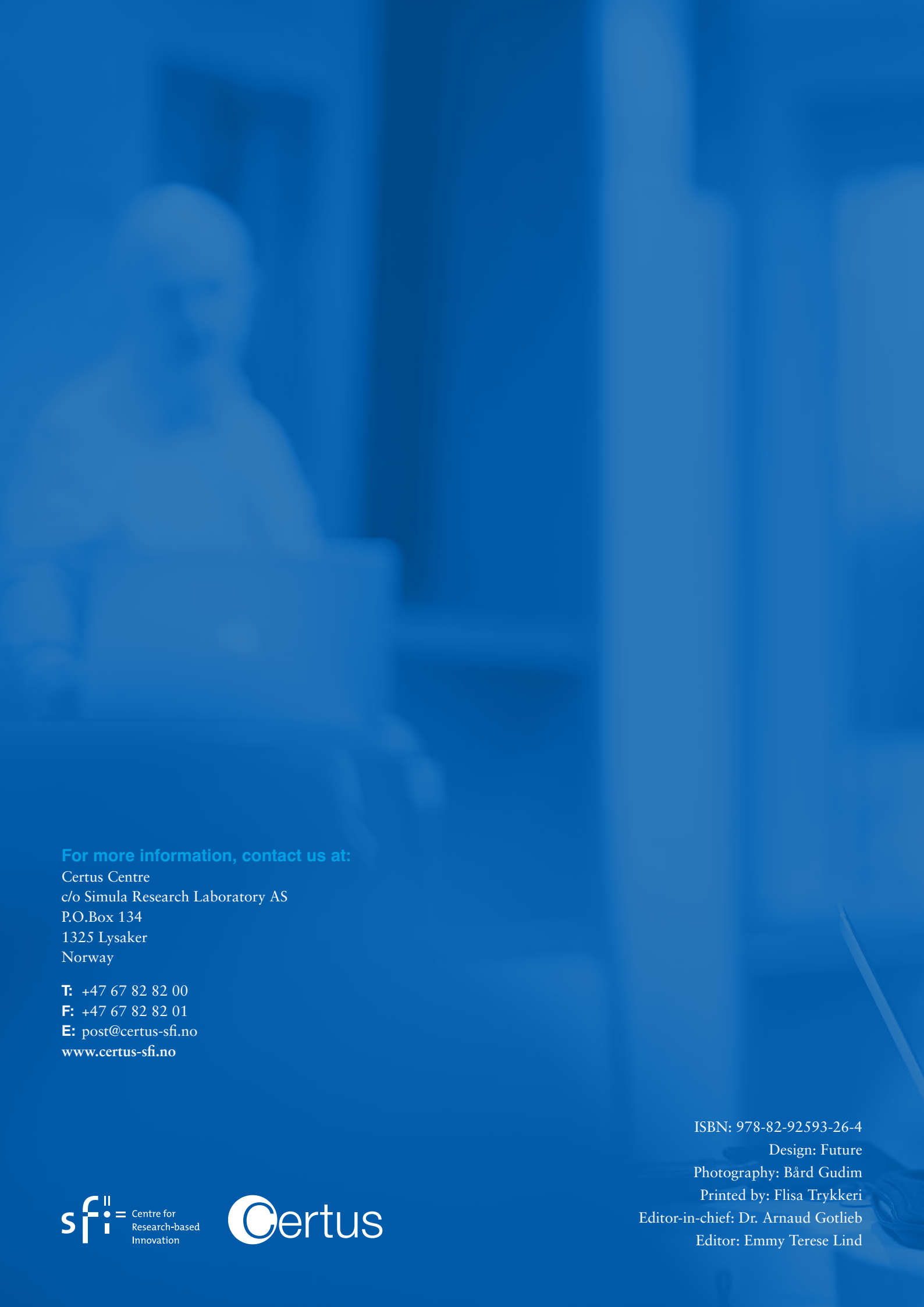
Tao Yue

Track co-chair

- MODELSWARD'17: 4th Int. Conf. on Model-Driven Engineering and Software Development, Feb. 19-21, Rome, Italy

Program Committee

- MODELS'17: ACM/IEEE 19th Int. Conf. on ModelDriven Engineering Languages and Systems, Saint Malo, France
- RE'17: 24th Int. Conf. on Requirements Engineering. Beijing, China
- SPLC'17: 21th Int. Systems and Software Product Line Conf.. Beijing, China
- QRS'16: IEEE Int. Conf. on Software Quality, Reliability & Security. Vienna, Austria
- MODELS'15 - ACM/IEEE 18th International Conference on ModelDriven Engineering Languages and Systems. September 30-October 02, 2015, Ottawa, Canada
- RE'15 - 23rd International Conference on Requirements Engineering. August 24-28, Ottawa, Canada
- QRS'15 - IEEE International Conference on Software Quality, Reliability & Security. August 03-05, 2015, Vancouver, Canada
- COMPSAC'15 - IEEE 39th Annual International Computers, Software & Applications Conference. July 01-05, 2015, Taichung, Taiwan
- ACM/IEEE 17th International Conference on ModelDriven Engineering Languages and Systems
- SPLC'15 - 20th International Systems and Software Product Line Conference. July 20-24, 2015, Nashville, USA
- European Conference on Modelling Foundations and Applications, 2014
- 14th International Conference on Quality Software, 2014



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