KLIMA 2050

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FINAL REPORT

Berit Time (editor)

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Final Report

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Preface

Measures based on scientific knowledge are needed to preserve the values invested in the built environment as climate changes accelerates.

The Centre for Research-based Innovation, SFI Klima 2050, set out with a clear vision to be synonymous with excellence within risk reduction through climate adaptation of buildings and infrastructure exposed to enhanced precipitation and flood water. Through the eight years from 2015 to 2023 the Centre has worked to obtain the necessary knowledge, methods and tools to implement solutions of great importance for a safe, sustainable and cost-effective climate adaptation for Norwegian society. It has been an effective instrument for the development and implementation of adaptive innovations for the Centre partners and society.

The production of more knowledge about climate adaptation, as well as risk reduction strategies linked to climate change and increasing levels of precipitation in the built environment, is the social responsibility of Klima 2050. As well as generating innovations and increased wealth creation for the partners, the Centre recognizes that the work of Klima 2050 is part of a much bigger exercise in social responsibility.

With a backdrop where climate changes are happening faster, and the consequences are more extensive and dramatic than previously thought the imminent action on the climate adaption has been lifted to the top of the agenda both nationally and international. Through outstanding leadership of the Centre, the management and team of researchers has developed knowledge representing excellence and established the foundation for further research in the field.

The Centre has been successful in developing best practice with the close cooperation and teamwork between the partners represented by researchers, public bodies and private businesses. Through pilots the Centre has produced results and innovations in the public and private sector, as well as for its research partners.

It is the technologists and natural scientists who are crucial to securing what has already been built, and as climate changes accelerate, the acceptance of investments on prevention rather than repair is imminent, in this the research from Klima 2050 gives the knowledge base for what Norway and the world needs.

Oslo, June 2023

Grethe Bergly,
Chair of the board
Multiconsult

Summary

When Klima 2050 started out in 2015 it was the largest initiative launched in Norway to look into climate adaptation of buildings and infrastructure in order to reduce societal risk related to enhanced precipitation and flood water.

Klima 2050 has proved to be synonymous with excellence within risk reduction through climate adaptation of buildings and infrastructure and it has been an effective instrument for the development and implementation of adaptive innovations for the Centre partners and society.

The main goal has been to reduce the societal risks associated with climate changes and enhanced precipitation and flood water exposure within the built environment. Emphasis has been placed on development of moisture-resilient buildings, stormwater management, blue-green solutions, measures for reducing the risk posed by water-triggered landslides, socio-economic incentives and decision-making processes. Both extreme weather and gradual changes in the climate has been addressed.

The consortium has comprised research partners, private companies, and public partners. The companies and public partners represent key parts of Norwegian building industry; consulting engineers, construction companies, estate developers, producers of construction materials and authorities, i.e the main value chain of Klima 2050's fields of research.

The Centre has produced a range of significant results within a broad set of topics relevant for risk reduction of building and infrastructure in respect of climate change. Predicting the impact a changing climate will have on buildings and infrastructure, is the first step in the process of finding suitable adaptation measures. Somewhat surprising research by the Centre reveals that climate-model-induced uncertainties are often under-communicated, due to either insufficient analysis or neglect.

On the building side, facades have been analysed. Harsh climatic conditions in the Nordic countries are being worsened by climate change, which increases the moisture load on building façades. New types of defects are being observed in air cavities in well-designed and well-built wooden façades and roofs, and more concern is necessary in planning, design, and construction. A building climate adaptation framework for Norway has been developed and the award “Statens pris for byggkvalitet” (The National Award for Building Quality) was given the Centre pilot project building ZEB Laboratory.

As climate change in the Nordic region brings an increase in extreme precipitation events, blue-green roofs have emerged as a solution for stormwater management. The addition of blue-green layers on a conventional compact roof represents several multi-disciplinary technical challenges and quality risks that must be managed. A framework intended to be used to reduce the building technical risks of blue-green roofs, by addressing the most important quality risk elements have been developed.

Green infrastructures have emerged as sustainable technologies for urban stormwater management. The Centre has advanced the national and international research in hydrological modelling, and through documentation of nature-based solutions (NBS) as mitigation measures through the many pilot projects. Just as important, a framework has been developed owing to the need for a systematic documentation of the applied NBS in accordance with the principles of infrastructure asset management and a newly adopted Norwegian Standard.

Landslide risk is increasing in wetter climate and mitigation is limited by data scarcity. The Centre has strongly contributed to the rapid development of investigation of how machine learning models and satellite images are most useful for landslide detection. Further information on how flexible barriers may be installed upstream in debris flow channels to reduce entrainment of bed material in landslide situations has been provided. And in more general terms, an innovative webtool for landslide risk mitigation has been improved to include many nature-based solutions (NBS) for mitigating landslide risk.

Increased knowledge is necessary for the responsible stakeholders to enable them to take the right decisions, in both public and private organizations. A national web portal (*Kunnskapsbanken*) with access to all available data relevant to climate change adaptation has been launched in Norway. Through digitalization and close cooperation with insurance companies, the data in the web portal will improve. Klima 2050 has contributed to accelerating the development continuously by encouraging data sharing among insurance companies, the value of insurance data, and the potential to use these data to predict

events. We have also addressed the municipalities' initial perceptions and experiences. Finally, an important contribution has been initiated in making a climate adaptation monitoring framework for municipalities in Norway.

The building and construction sector consists of more than 50,000 companies and employs about 250,000 people, all of whom must contribute to the best of their ability towards reducing societal risk and adapting buildings and infrastructure to the threats posed by climate change. Much of our research is made available to the sector and those who work there.

We have taken part in several projects and co-creational initiatives with players in the private and public sectors and other research centres, focusing on issues of interest also to many stakeholders outside the Centre's partnership group. We have developed guidelines that are of benefit to the municipalities and have participated in the work to revise BREEAM-NOR, which is the most frequently applied building certification system i Norway. We link our research to other Norwegian initiatives and projects such as the Natural Hazards Forum, the Norwegian water sector organisation Norsk Vann, and SINTEF Building Research Design Guides. These are important fora for the dissemination of our research results.

In total, the Centre established 16 pilot projects. Pilots have been the Centre's main arena for product and process development and the testing of research results. They have been an effective means of disseminating know-how generated at the Centre. Such projects have also been excellent opportunities to showcase the Consortium. Klima 2050 has resulted in close to 1500 scientific articles, reports, popular science articles, chronicles, and presentations, where some articles have received international awards. Klima 2050 researchers have given a number of keynote/invited lectures. 18 PhD and 135 MSc candidates will complete their theses in connection to Klima 2050 and 7 pos.docs have been engaged in the Centre, securing national and international dissemination of knowledge about risk reduction and climate adaptation into planning and construction processes and in society. The Klima 2050 researchers and partners have engaged several national and international (EU) activities, and the Centre has exchanged incoming and outgoing researchers.

Throughout the lifetime of the Centre, the Board and management have placed a major emphasis on innovation and the benefits of research to the Centre's user partners and society in general. Teamwork and effective interaction between partners have been key factors. The choice of research topics, our extensive use of thematic meetings, and investment in pilot projects have been just some of the actions we have taken to raise awareness that research at the Centre shall result in innovations in the public and private sectors, as well as for the research partners.

Norwegian society is becoming increasingly aware of the need to adapt to climate change. The awareness has changed considerably during the 8 years of the Centre period. Large and small municipalities, companies, international actors, and the public have observed many of the activities taking place within the research centre and are getting in touch asking for advice and support in their work. We can clearly see that Klima 2050 Centre activities will continue, and become even more important into the foreseeable future. This was also stated in a new white paper this month (*Meld. St. 26 (2022–2023)*). The Centre is initiating a network focusing on climate adaptation in the built environment to maintain momentum and to be able to proceed working together. The range of activities needed to research and develop topics for reduction of societal risk through climate adaptation of buildings and infrastructure, the knowledge and solutions needed, and the initiation and evaluation of the 16 pilot projects realized within the program period would not have been possible without the eight-year support from the Research Council of Norway and Klima 2050 partners under the Centres for Research-based Innovation scheme.

Sammendrag

Da Klima 2050 startet opp i 2015 var det det største initiativet i Norge med fokus på klimatilpasning og reduksjon av samfunnsrisiko knyttet til økt nedbør og flomvann i det bygde miljø.

Senterets visjon er at Klima 2050 skal være anerkjent innen klimatilpasning av bygg og infrastruktur og et effektivt virkemiddel for utvikling og implementering av innovasjoner for partnerne i senteret og i samfunnet forøvrig.

Hovedmålet til senteret er gjennom langsiktig forskning å redusere samfunnsmessig risiko forårsaket av klimaendringer med økt nedbør. Senteret legger vekt på utvikling av fuktsikre bygninger, overvannshåndtering og blågrønne løsninger, samt tiltak for forebygging av vannutløste jordskred og forbedrede beslutningsprosesser som sikrer klimatilpasning av bygg og infrastruktur. Både ekstremvær og gradvise endringer i klimaet er adressert.

Konsortiet har bestått av næringslivsbedrifter, offentlige partnere og forskere. Næringslivspartnerne og de offentlige partnere representerer sentrale deler av norsk byggenæring; rådgivere, entreprenører, eiendomsutviklere, produsenter av byggevarer, finansnæringen og offentlige myndigheter, det vil si hele verdikjeden til Klima 2050 sine forskningsområder.

Senteret har oppnådd en rekke resultater innenfor et bredt fagfelt som er betydelige for å nå målet om risikoreduksjon. Å forutsi påvirkningen et endret klima vil ha på bygninger og infrastruktur er første steg i prosessen med å finne egnede tilpasningstiltak. Noe overraskende viser forskning i senteret at usikkerheter i klimamodellene ofte er underkommunisert av effektforskere, enten på grunn av utilstrekkelig analyse eller utelatelse.

For bygninger er fasaders klimarobusthet analysert. Tøffe klimatiske forhold i de nordiske landene forverres av klimaendringer ved at fuktbelastningen på fasadene øker. Det observeres nå skader i tilknytning til kledninger i ellers godt planlagte og utførte trefasader. Tilsvarende er andelen fuktskader i tak økende. Dette bekymrer, og det betyr at det i større grad enn tidligere er nødvendig med skarpere fokus på prosjektering, utførelse og vedlikehold. Senteret har utviklet et rammeverk for klimatilpasning av bygninger, og vi ble tildelt «Statens pris for byggkvalitet» for senterets pilotprosjekt ZEB-laboratoriet i 2022. Tema det året var klimatilpasning.

Ettersom klimaendringene i Norden medfører en økning i hyppighet og intensitet av styrtregn-hendelser, har blågrønne tak blitt mer aktuelt som en løsning for overvannshåndtering. Introduksjon av «blågrønne lag» (fordrøyende lag) på et konvensjonelt tak representerer flere tverrfaglige tekniske utfordringer og kvalitetsrisikoer som må håndteres. Senteret har utviklet et rammeverk til bruk i planlegging og prosjektering for å redusere den bygningstekniske risikoen ved å adressere de viktigste elementene for kvalitetsrisiko ved blågrønne tak.

Mer bærekraftige teknologier for urban overvannshåndtering omtales i dag som grønn infrastruktur. Dette har vært et sentralt forskningstema i Klima 2050. Senteret har fått fram resultater med relevans for både nasjonal og internasjonal forskning innen hydrologisk modellering. Gjennom de mange pilotprosjektene med naturbaserte løsninger (NBS) som overvannshåndteringstiltak, er løsningene testet ut og dokumentert til stor nytte for norsk industri. I tillegg er det utviklet en veileder for systematisk dokumentasjon av anvendt NBS med mål om effektiv forvaltning av infrastrukturen og for oppfyllelse av en nylig vedtatt norsk standard.

Skredrisikoen øker i et våtere klima og avbøtende tiltak begrenses av mangel på data om skred-hendelser. Senteret har bidratt sterkt i den raske utviklingen av forskning om hvordan maskin-læringsmodeller og satellittbilder kan være nyttige for skreddeteksjon. Videre har vi sett på hvordan fleksible barrierer kan være et avbøtende tiltak i strømningsveien ovenfor utsatt bebyggelse eller infrastruktur. Dette er lette konstruksjoner som enkelt kan monteres i bratte og utilgjengelige raviner. Et innovativt webverktøy er utviklet og forbedret til å inkludere mange naturbaserte løsninger (NBS) for å redusere skredrisiko.

Innhenting av kunnskap er nødvendig for at ansvarlige interessenter skal ta de riktige beslutningene, både i offentlige og private virksomheter. I Norge har Direktoratet for samfunnssikkerhet og beredskap (DSB) lansert en nasjonal nettportal – *Kunnskapsbanken* - med tilgjengelige data som er relevante for klimatilpasning. Gjennom digitalisering og tett samarbeid med forsikringsselskapene vil dataene i nettportalen bli bedre. Klima 2050 har bidratt til utviklingen gjennom forskning på forsikrings-

selskapenes holdninger til datadeling, verdien av forsikringsdata og potensialet for å bruke dataene for å forutsi hendelser. Vi har også undersøkt kommunenes første erfaringer ved bruk av portalen. Sist, men ikke minst, har vi etablert og testet ut et rammeverk for å måle status på klimatilpasningsarbeidet i kommunene gjennom måleindikatorer for klimatilpasning av arealer, bygninger og infrastruktur.

Bygg- og anleggssektoren består av mer enn 50 000 bedrifter og sysselsetter 250 000 mennesker, som alle må bidra etter beste evne for å redusere samfunnsrisiko gjennom å tilpasse bygninger og infrastruktur til truslene fra klimaendringene. Forskningen vår gjøres tilgjengelig for sektoren og de som jobber der.

Vi har deltatt i en rekke prosjekter og samskapingsinitiativer med aktører i privat og offentlig sektor og andre forskningsgrupper innenfor tema som har bred interesse også utenfor senteret. Vi har utviklet veiledere som er til nytte for kommunene og vi har bidratt i arbeidet med å revidere BREEAM-NOR, som er det mest brukte byggsertifiseringssystemet i Norge og bidratt til utviklingen av BREEAM Infrastruktur, det nye sertifiseringssystemet for infrastruktur prosjekter. Vi har knyttet forskningen vår til andre norske initiativ og prosjekter som f.eks Naturfareforum, Norsk Vann og SINTEF Bygg-forskserien. Alle disse er viktige kanaler for formidling av våre forskningsresultater.

Klima 2050 har etablert 16 pilotprosjekter. Pilotene har vært senterets hovedarena for produkt- og prosessutvikling og testing av forskningsresultater. De har vært et effektivt middel for å spre kunnskap frembrakt av senteret. Prosjektene har også gitt gode muligheter for å vise frem konsortiet.

Klima 2050 har resultert i nærmere 1500 vitenskapelige artikler, rapporter, populærviten-skapelige artikler, kronikker og presentasjoner, hvor enkelte artikler har mottatt internasjonale priser. Klima 2050-forskere har holdt en rekke inviterte foredrag. 18 PhD og 135 M.Sc kandidater knyttet til senteret vil fullføre sine avhandlinger og 7 post.doc'er har vært engasjerte i senteret Gjennom sine arbeider har de tilegnet seg ekspertise som samlet dekker sentrale fagområder innen klimatilpasning av bygninger og infrastruktur. Disse ekspertene er av stor viktighet for næringslivet og offentlig sektor og de vil gjennom sitt virke hos de forskjellige aktørene i næringen og hos forskningsaktørene bidra til både nasjonal og internasjonal formidling av kunnskap om risikoreduksjon og klimatilpasning i plan- og byggeprosesser og i samfunnet forøvrig. Klima 2050-forskerne og brukerpartnerne har engasjert seg i en rekke nasjonale og internasjonale (EU) aktiviteter, og senteret har bidratt til internasjonal utveksling av forskere.

Gjennom senterets levetid har styret og ledelsen lagt stor vekt på innovasjon og den praktiske nytten av forskningen for senterets nærings- og offentlige partnere og samfunnet forøvrig. Lagarbeid og effektiv samhandling mellom partnere har vært nøkkelfaktorer. Valg av forskningstema, vår utstrakte bruk av temasamlinger og satsing på pilotprosjekter har vært noen av tiltakene vi har gjort for å tilgjengeliggjøre forskningen ved senteret slik at den skal resultere i innovasjoner i offentlig og privat sektor.

I det norske samfunnet blir vi stadig mer oppmerksomme på behovet for å tilpasse oss klimaendringene. Bevisstheten har endret seg betydelig i løpet av den åtte år lange senterperioden. Store og små kommuner, bedrifter, internasjonale aktører og allmennheten har lagt merke til de mange aktivitetene som har foregått innenfor senteret, og tar kontakt med oss og ber om råd og støtte i sitt arbeid. Vi tror at Klima 2050 blir viktig i overskuelig fremtid, det viser også stortingsmeldingen fra i år *Meld. St. 26 (2022–2023) Klima i endring – sammen for et klimarobust samfunn*. Senteret setter nå i gang et nettverk med fokus på klimatilpasning i det bygde miljø for å opprettholde momentum og for å jobbe sammen videre.

Våre omfattende forsknings- og utviklingsaktiviteter for å redusere samfunnsrisiko gjennom klimatilpasning av bygninger og infrastrukturville ikke vært mulig uten den åtteårige støtten fra Norges forskningsråd og Klima 2050 partnerne under Sentre for forskningsbasert innovasjon.

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Vision and objectives

The vision of the Centre

The Centre for Research-based Innovation SFI Klima 2050 shall be synonymous with excellence within risk reduction through climate adaptation of buildings and infrastructure exposed to enhanced precipitation and flood water. Klima 2050 shall be an effective instrument for the development and implementation of adaptive innovations for the Centre partners and society.

The main goal

Klima 2050 will reduce the societal risks associated with climate changes and enhanced precipitation and flood water exposure within the built environment. Emphasis will be placed on development of moisture-resilient buildings, stormwater management, blue-green solutions, measures for reducing the risk posed by water-triggered landslides, socio-economic incentives, and decision-making processes. Both extreme weather and gradual changes in the climate will be addressed.

Further, the Centre will be recognised for its research training within the field of climate adaptation of the built environment. Through education of graduate students, training of highly qualified research personnel through PhDs and training of professionals in the sector, the Centre will stimulate new solutions and further research and development in the building, construction, and transportation (BCT) sector long after the term of the Centre's existence.

Figure 1: The launch of Klima 2050 at the NTNU premises in 2015. From left Hanne Rønneberg, Berit Time, Tore Kvande, Grethe Bergly. Carl Thodesen, Ragnhild Wahl og Marit Brandtsegg. Photo: Thor Nielsen/ NTNU

Introduction

Consortium

Research Partners, Companies and Public Partners

The user partners represent important parts of Norwegian building industry: consultants, entrepreneurs, property developers, producers of construction materials and authorities. The value chain within Klima 2050's fields of research is complete.

Private partners in the consortium from 2015 – 2023: Finans Norge, Isola AS, Multiconsult ASA, Mesterhus, Norgeshus AS, Leca Norge AS, Skanska Norge, and Skjæveland Gruppen AS (from 1. February 2016). Powel joined the consortium in the period 2016 to 2020.

Public partners from 2015 - 2023: Avinor AS, Jernbanedirektoratet, NVE (the Norwegian Water Resources and Energy Directorate), Statens vegvesen, and Statsbygg. The municiplity Trondheim kommune joined the Centre from 1. January 2016.

The host institution for SFI Klima 2050 has been SINTEF, and the Centre was directed in close cooperation with NTNU. BI Norwegian Business School, Norwegian Geotechnical Institute (NGI) and Norwegian Meteorological Institute (MET Norway) have been research partners.

Figure 2: The consortium of Klima 2050

Organisation

The main organisation of the Centre is shown in Figure 3, and the representatives for the different positions during the last period are given below.

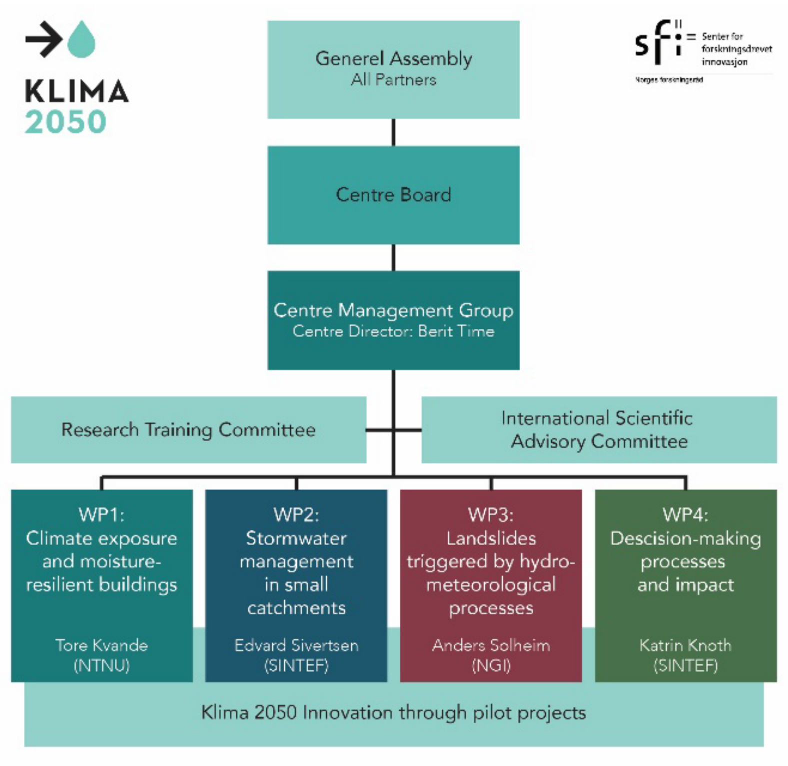

Figure 3: The main organisation of the Centre

Centre Management

Berit Time, chief scientist at SINTEF, Centre Director
Tore Kvande, professor at NTNU, Principal Investigator (WP1)
Edvard Sivertsen, senior research scientist SINTEF (WP2)
Anders Solheim senior geologist at NGI (WP3)
Katrin Knoth, senior research scientist SINTEF (WP4)
Lena Bygballe, associate professor at BI Norwegian Business School (WP4)
Jorunn Auth, administrative coordinator at SINTEF

Centre Board

Grethe Bergly, Multiconsult (Chair)
Grethe Vikane, Statens vegvesen
Anders Fylling, Statsbygg
Einar Aassved Hansen, Trondheim kommune
Rune Egeland, Skjæveland Gruppen
Kristin Holte, Skanska Norge
Dominik Lang, NGI
Vikas Thakur, NTNU
Hanne Rønneberg, SINTEF
Svein Erik Moen, The Research Council of Norway (observer)
Pål Midtlien Danielsen, Jernbanedirektoratet, 1. Deputy
Dag Runar Båtvik, Norgeshus, 2. Deputy

Chair of General Assembly:
Jørgen Young, Isola

Researcher Training Committee:
Tore Kvande and Jardar Lohne, NTNU
Ragnhild Kvålshaugen, BI
Berit Time, SINTEF

International Scientific Advisory Committee
Hallie Eakin, Julie Ann Wrigley Global Institute of Sustainability, USA
Kristina Mjörnell, RISE Research Institutes of Sweden and Lund University, Sweden
Rafaela Matos, LNEC - Laboratório Nacional de Engenharia Civil, Portugal
Thomas Glade, Department of Geography and Regional Research, University of Vienna, Austria

Cooperation within the Centre

We have had a strong focus on real cooperation between partners and have initiated different activities to promote that.

Partner meetings were held with the aim of promoting input and dialogue in connection with activities taking place at the Centre. Such meetings were held primarily in connection with the preparation of work plans and/or at the request of the consortium partners. Partner meetings was held with individual partners, or among groups of partners.

Thematic meetings (59 in total) were organised activities that encompassed all or parts of the consortium with the aim of contributing towards knowledge dissemination, experience and research exchange, and innovation. Such gatherings have been very much appreciated by the partners and important with a view to knowledge exchange, and are arenas in which researchers can obtain direct input to their work, and we found areas where the partners could work more closely. Among other things, the thematic meetings included:

- Work meetings
- Seminars
- Excursions
- Pilot projects
- Ph.D. tutorials
- Klima 2050-dagen

"*Klima 2050-dagen*" was an annual meeting place for the entire partnership. The purpose of the day was to gather the entire partnership and show selected results from the research and its usefulness and innovation opportunities at the partners and in society as a whole.

Pilot projects as a measure; The Centre had 16 pilot projects. Pilots are projects that are designed and administered by one or more of the (user) parties at the Centre. Our experience demonstrates that pilots promote productive interaction between the partners involved. Pilots are the Centre's main arena for product development and the testing of research results. They are also regarded as an effective means of disseminating know-how generated at the Centre. Such projects also represent excellent opportunities to showcase the Consortium. It is often easier to demonstrate the innovation potential linked to a given system, process, etc. by employing a pilot rather than by other forms of research. In general terms, user partners find pilots more focused and thus more attractive. Klima 2050 utilised pilots as key Consortium development arenas.

Researcher Training Arena

Se chapter "Training of researchers" for detailed description.

The Klima 2050 website

The net portal www.klima2050.no has been the Centre's main channel for the general dissemination of information to the Norwegian and overseas building and construction sector, and others who are interested in climate adaptation of buildings and infrastructure. The website was edited by the director of the Klima 2050 Centre, the administrative coordinator and the Principal Investigator. There have been six main banners on the website under which it has been relevant to post or update material on a frequent basis. These have been "News", "Events", "About", "Publications", "Pilots" and "Results". The website will be reorganized and kept another 5 years, and after that it will be moved to the formal SINTEF webpage.

Newsletter: Each quarter, management at the Centre will issue a newsletter in the form of an e-mail. The newsletter was sent to all those that have attended an event organised by the Klima 2050 Centre, or who have requested that a newsletter was sent to them. The newsletter provided a list of highlights from the activity. The information was linked to the eRoom (project hotel), website or other sources are provided so that readers could obtain further information and approach relevant partners/people.

Klima 2050 HUB

The Centre established a Centre HUB on the premises of NTNU to host part of the Centre staff, researchers, PhD-students, some of the master students and visitors. NTNU upgraded the premises and graphical elements from the Klima 2050 Profile programme was applied.

Graphical profile program

Klima 2050 Profile programme was developed right from the start for clear identity, communication, community building and to ease the branding of the Centre. Profile program with logo, colour usage, templates and web pages has been developed by RIM Design.

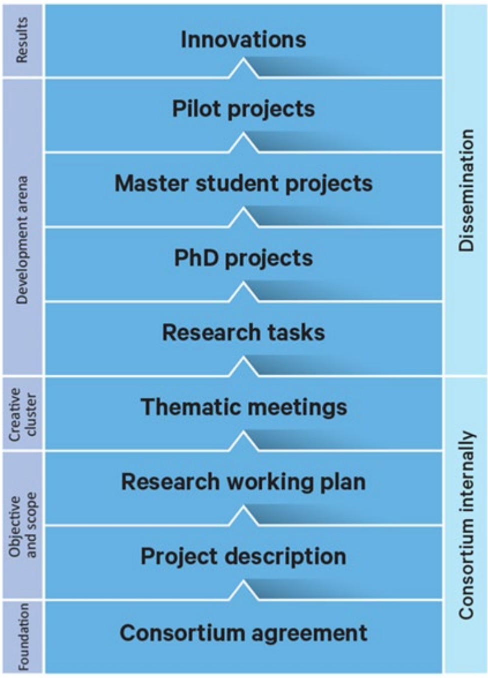

Figure 4: The Klima 2050 Innovation ladder

Financing through the life of the Centre

Summary sheet for the main categories of partner (KNOK)

Contributor	Cash	In-kind	Total
Host		19	19
Research partners		20	20
Companies	11	54	65
Public partners	40	2	42
RCN	96	-	96
Sum	147	95	242

Distribution of resources

Type of activity	NOK million
Research projects	195
Common centre activities	23
Administration	20
Center Dissemination activities	4
Total	242

Results - Key figures

	2015	2016	2017	2018	2019	2020	2021	2022	2023	Total
Scientific publications (peer reviewed)		4	6	19	9	19	15	22	8	102
Dissemination measures for users	39	73	83	96	82	86	86	93	35	673
Dissemination measures for the general public	9	11	7	6	4	9	5	11	6	68
PhD degrees completed				1	2	2	2	4	2	13
Master degrees	1	14	13	28	18	24	18	16	3	135
Number of new/improved methods/models/prototypes finalised		4	3	4	2	4	13	9	5	39
Number of new/improved products/processes/services finalised				2	2			2		6
Patents registered							1			1
New business activity			1			3	2		1	7

Research - development of research plan

All the way through the Centre period the research plan has been organized in four main areas:

WP1 Climate exposure and moisture-resilient buildings
WP2 Stormwater management in small catchments
WP3 Landslides triggered by hydro-meteorological processes
WP4 Decision-making processes and impact

Goals, knowledge gaps to be filled and research tasks were stated in the Klima 2050 Project description. Biannual working plans were developed throughout the Centre period. The Research Working Plans were supplement to the Klima 2050 Project description. Every two years a process was initiated during summer with partner meetings, the first years common meetings, the last years separate meetings with all the partners to get input to research tasks. The Center Management Group has tried their best to balance and take into account the input from the partners. The plans always reflected interests from the partners and to a certain extent direct input and proposals was incorporated in the plans.

The plans developed throughout the years, but all plans had to be read in conjunction with the project description and the previous period's work plans, the summing up and finale dissemination of activities. The Centre Board approved the biannual working plans.

How to focus innovation shifted after two years time. The original idea with an "Innovation Forum" did not work out as intended, it turned out to be too vague and not concrete enough. It was also difficult to engage user partners. Hence, the focus was changed, and more concrete activities was suggested. "Innovation through pilot projects" was established instead. Our experience demonstrates that pilots promote productive interaction between the partners involved and they showed to be a successful arena for innovation, product development and the testing of research results. The pilots have also regarded as an effective means of disseminating know-how generated at the Centre.

In total, the Centre established 16 pilot projects. The working plans the last periods also reflected need to follow up and research the many pilot projects which has been established in a good way. A complete description for the established pilot projects and the results was published on www.klima2050.no consecutively.

Midway Evaluation

The Midway Evaluation report stated that the Centre leadership was excellent, and the Centre was conducting internationally competitive research in response to user needs and had unique opportunities to be world leading by improving the scientific collaboration across research in the work packages. The mid-term evaluation had however highlighted areas which could be improved further and five recommendations to improve the Centre was given, see Figure 5. The Centre Management discussed the recommendations and made some concrete measures how to improve. These measures were discussed, approved and followed up by the Centre Board. The Centre Board challenged the administration of the Centre to establish a system for reporting to the board how the measures are followed up[1]. It is our opinion that working with the evaluation was useful and improved the Centre.

[1] Time, B (Ed.): *SFI Klima 2050 | Forventninger og tiltak til senteret i 2020.* Klima 2050 Note 97. Trondheim 2020

Recommendation 1: That the Centre ensures that WP4 collaborates with the other WPs and user partners to inform planned work on future socio-economic methodologies and analyses of climate change innovations. Deliverables should include co-authored journal papers with industry and researchers from other WPs, and input to associated projects.

Recommendation 2: That the Centre incentivises both outgoing and incoming international exchanges for researchers at all levels.

Recommendation 3: That the Centre improves collaboration between the PhD students and user partners and, in so doing, creates mutual benefits.

Recommendation 4: That the Centre is more ambitious, setting clear targets for science and innovation, in communicating its full scientific capability and innovations to wider audiences including the international research community. This will be critical to delivering sufficient associated projects to sustain the critical mass of the Centre beyond its funding period.

Recommendation 5: That the Centre systematizes its innovation process, including linkages to research and prioritisation of cross-WP collaborations, for the final three years.

Figure 5 The mid-term evaluation five recommendations to improve the Centre

Research achievements

Scenarios for climate change in Norway indicate an increased occurrence of extreme weather. Together with a warmer climate, intense precipitation over parts of Norway will also increase. We must prepare for increased precipitation with subsequent increased strain on drainage systems, more water damage to buildings, several landslides, and more flooding. Unfortunately, the built environment is particularly vulnerable to climate change. Changes in climate will increase the need for maintenance and the renewal of robust key societal infrastructure.

New knowledge, methods, and tools for implementing solutions is of outmost importance for a safe, sustainable and cost-effective development of the Norwegian society. This has been the focus of the research. In the following 8 examples of research achievements is presented in short.

Indicators for measuring climate change adaptation in municipalities[2]

In Norway, the municipalities are responsible for safeguarding buildings, infrastructure and other areas against climate stressors such as flooding, landslides and torrential rain. The Klima 2050 Centre has developed a set of indicators designed to measure the levels of performance achieved by the municipalities. A holistic approach is key to the prevention of damage resulting from climate change. At the same time, there is a need to introduce specific metrics so that those responsible for adaptive measures can succeed in incorporating both quantitative measurement and evaluation of the measures they implement into their everyday work. The performance indicators developed by the Centre include process indicators to monitor the work with climate adaptation, measure indicators to monitor which measures that are taken, and result indicators to monitor the effect of the implemented measures.

Figure 6: The framework for the set of indicators is made in an easily accessible and understandable way for a broad group of users

[2] Sivertsen E, Sandberg E, Fjellheim K, Solli J, Strømø E.B, Lilledal S, Andreassen S.A & Time B: ***Indikatorer for måling av klimatilpasning av arealer, bygninger og infrastruktur i kommuner. Anvisning og rammeverk.*** Klima 2050 Report 26. Trondheim 2021. ISBN 978-82-536-1708-4

Network for climate adaptation[3]

The Centre has investigated how practical, political and personal challenges function as drivers or barriers for the climate change adaptation of buildings and infrastructure. Interviews with government and private sector experts show that there is still a long way to go. Climate adaptation is cross-sectoral and places great demands on inter-departmental collaboration. During interviews that took place for this survey, cooperation between municipal departments for water and wastewater management and plan and building agencies was highlighted as essential. In addition, cooperation between municipalities who share the same waterways is also a driver for climate adaptation.

Municipal plans and risk and vulnerability analyses (ROS) should offer clear guidelines for climate adaptation. Municipal plans and ROS analyses should be used much more actively than is currently the case in many municipalities. Social psychology shows that what other people do – particularly those we want to be like - may be the strongest influence on attitudes. Previous research has shown that municipalities also imitate each other's solutions and climate focus. Well-functioning networks across municipalities, organisations and government actors who work with climate adaptation will therefore play important roles in developing and implementing new technical solutions for the improved climate adaptation of buildings and infrastructure. Trondheim Municipality and the Trøndelag County Municipality have established and developed along with several partners, including Klima 2050, a Trøndelag network for climate adaptation.

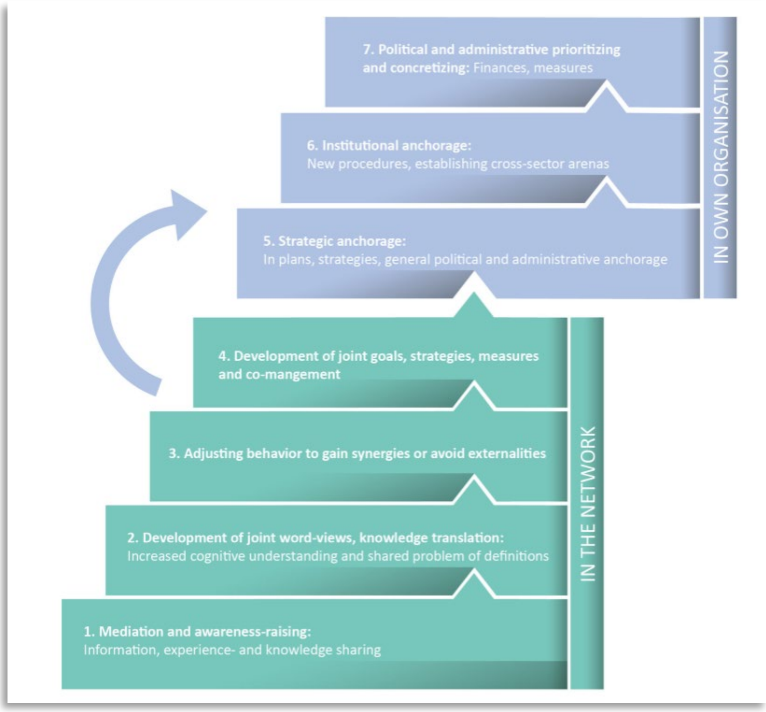

Figure 7: The network ladder as presented in Hanssen, G. S., Mydske, P. K., & Dahle, E. (2013). Multi-level coordination of climate change adaptation: By national hierarchical steering or by regional network governence? Local Environment, 18(8), 869-887.

[3] Hauge Å.L, Hanssen G.S, Flyen C & Strømø E.B: *Nettverk for å lære klimatilpasning. Hvorfor og hvordan?* Klima 2050 Report 9. Trondheim, 2018. ISBN 978-82-536-1582-0

Climate-adapted buildings[4]

The Centre has had a continuation in a work on a framework for climate-adapted buildings. The framework will impact broadly and increase the focus on climate adaptation in many construction projects. In cooperation with the municipality of Trondheim, the Centre has also provided instructions for acquiring players in the construction process when the goal is a climate-adapted building. This work has received a lot of positive attention both among private and public actors.

Klima 2050 pilot-project The ZEB Laboratory was awarded the State's award for building quality:
"*For the fifth time, the Ministry of Local Government and District Affairs has awarded the Government's award for building quality. The award aims to highlight new role models that have outstanding built quality and are the result of good and innovative construction processes.*
- The ZEB Laboratory is a unique knowledge center for sustainable construction that shows how we can adapt to climate change, says Minister for Municipalities and Districts Sigbjørn Gjelsvik (Sp).
Today he presented the award to the laboratory, which is both a workplace for researchers and a building that experiments with climate-friendly solutions.
- The new normal is that the weather is more extreme. This means that buildings and outdoor areas have to endure greater stress than before. Climate adaptation is about who and how we design buildings and outdoor areas. Then we need precisely those good examples, which we must share with each other, says Gjelsvik."

Figure 8: Price winning award event; actors from the team and the Minister for Municipalities and Districts, the pilot project ZEB Laboratory and the report "Framework for climate adaptation of buildings"
Photos top left:Trond Isaksen, bottom left: Nicola Lolli, bottom right: m.c.herzog / visualis-images

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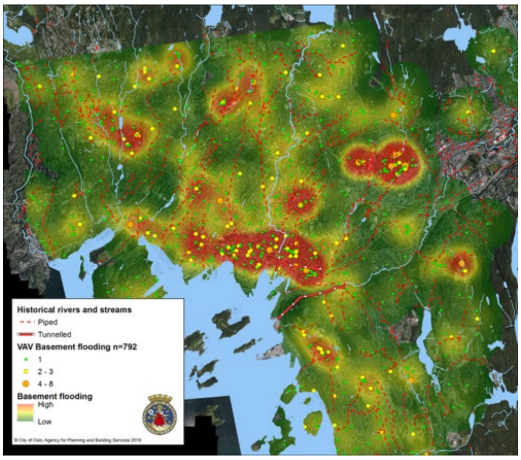
[4] Kvande T, Time B, Gullbrekken L, Sivertsen E, Gaarder J.E & Elvebakk K: ***Rammeverk for klimatilpassing av bygningar***. Klima 2050 Report 40. Oslo 2023. ISBN 987-82-536-1789-3
Sivertsen E, Elvebakk K, Kvande T & Time B: ***Klimatilpasset bygning. Anvisning for anskaffelse i plan- og byggeprosessen***. Klima 2050 Report 12. Trondheim 2019 . ISBN 978-82-536-1610-0

Insurance data[5]

In 2018, Klima 2050 conducted a study on sharing of loss data (skadedata) for better climate adaptation decisions. Previous research has shown high utility value of data on address level from the insurance companies for the municipalities struggling with prevention of nature events. The data helped the municipalities to better understand the picture of risk, and to make informed decisions about measures and which areas to prioritize.

DSB (The Norwegian Directorate for Civil Protection) and Finance Norway collaborate to prevent unwanted natural events and contribute to prevention of events. DSB is developing the Knowledge Bank (Kunnskapsbanken), which will compile and make available data on nature incidents and stormwater/flooding damages in order to strengthen the municipalities and counties work for climate adaptation. Data from the insurance companies is highly relevant for the "Knowledge Bank". Based on this, the Centre examined the attitudes to sharing of loss data among the leaders of the largest insurance companies in Norway.

The study showed that the largest insurance companies in Norway, representing more than 90% of the market, are willing to share their loss data with municipalities and government agencies that work on prevention of damages and climate adaptation. They can share data on address level. Nevertheless, there is a clear assumption that ‘the output data’, must be aggregated higher than address level. This is related to the insurance companies' responsibility for the privacy of the customers, and it is up to the authorities how these legal issues can be resolved. It is very important with login and restricted access to protect commercial sensitivity. The interviewees prefer that the companies shall be ordered to share data. The process of registering data in the companies appears to be sufficiently digitized so that transferring the data will go smoothly. This now appears to lay the foundation for Norway to become a global pioneer through the provision of data from insurance companies for use in municipalities and county municipalities for preventive work on climate adaptation and stormwater management.



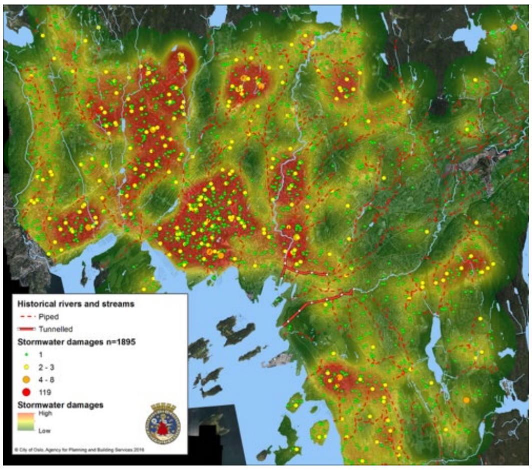


Figure 9: Basement flooding (left) and stormwater damages (right). Illustration: City of Oslo

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[5] Hauge Å, Flyen C, Venås C, Aall C, Kokkonen A, Ebeltoft M: ***Attitudes in Norwegian insurance companies towards sharing loss data.*** Klima 2050 Report 11. Trondheim 2018 . ISBN 978-82-536-1590-5

An early warning system – Near real-time slope stability monitoring

Climate induced hazards impact the safety and availability of roads and railroads. These problems are expected to increase with more frequent and intense extreme precipitation events. Klima 2050 has several activities with the aim of reducing the climate risk to linear infrastructure.

In the pilot project "Railway Corridors" a prototype of an early warning system is developed. At a steep slope facing the new railway at Eidsvoll, several sensors have recently been installed to measure the water content and suction in the slope. These sensors together with the already installed piezometers provide real-time monitoring data remotely accessible. Furthermore, a weather station is to be installed to monitor rainfall and other meteorological variables. All these data are being used to calibrate and validate a hydrogeological model for real-time stability analyses. The slope stability is now constantly monitored, and the calibration of the model is on-going. The final aim is to develop a fully operational local early warning system for the slope facing the high-speed railway north from Oslo. The near-real time estimates of the slope stability, will enable the train operator to act on time.

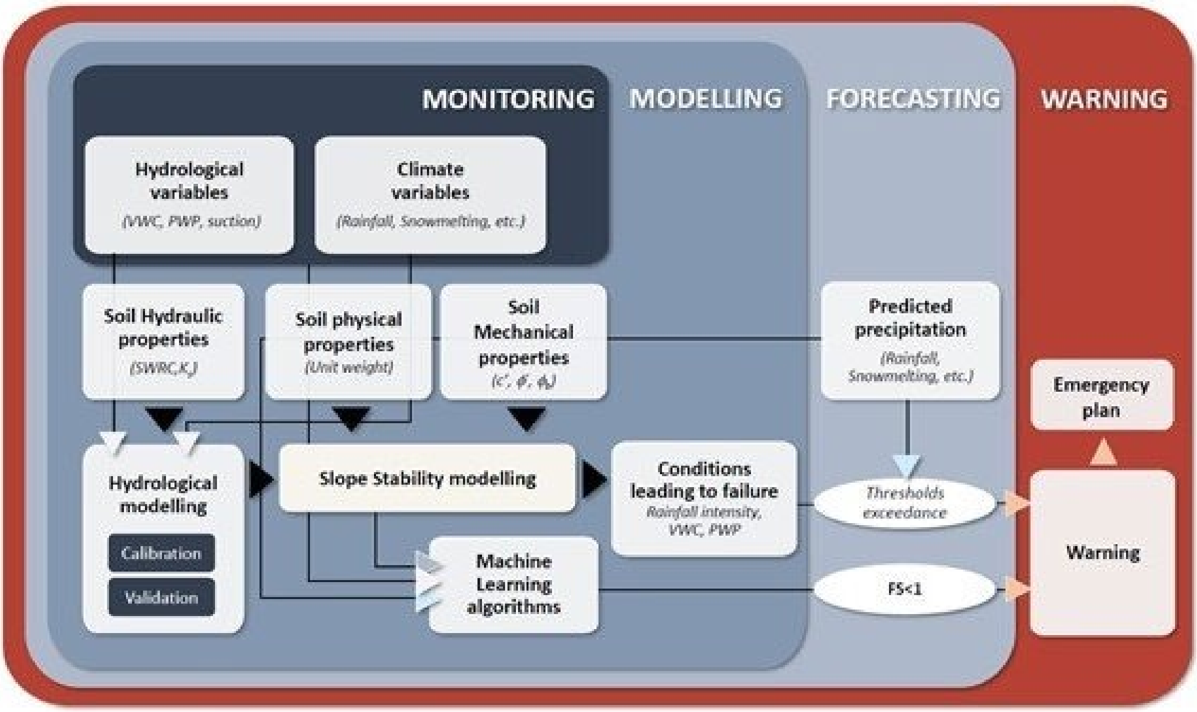

Figure 10: Conceptualization of the phases for a near real-time slope stability monitoring

Stream reopening as a climate change adaptation initiative[6]

The reopening of streams currently running in buried pipelines may reduce flooding risk. However, such reopening processes can be complex and fraught with many pitfalls. Stream reopening usually impacts on large areas and may come into conflict with buildings and infrastructure in densely populated areas. Guidelines from the Centre contain a checklist for the entire reopening process, from the concept stage through planning and construction to operation and maintenance. They also provide an overview of factors that require assessment prior to start-up, as well as a list of available tools. Many Norwegian municipalities have shown great interest in the guide, and it has already been used as part of Rogaland County Council's framework for the implementation of nature-based solutions and it is to be found as a guide at the national government's webpage for climate adaptation.

Figure 11: Ilavassdraget in Trondheim is an example of the opening of a stream that was previously in a pipe. Foto: Tore Kvande

Planning and maintenance of nature-based stormwater solutions[7]

Urban growth, densification and climate change are placing major demands on existing wastewater systems and cause modifications to natural run-off and drainage patterns. One way of reducing the detrimental impacts of these phenomena is to base stormwater management on natural principles by employing nature-based solutions (NBS) such as rain beds and green roofs, which have now become

[6] Sivertsen, E, Bruaset, S, Bø, L.A, Johannessen, B.G, Klausen, R, Nøst, T, Solli, J & Time, B: ***Bekkeåpning som klimatilpasningstiltak. En overordnet og flerfaglig anvisning***. Klima 2050 Report 25. Trondheim 2021. ISBN 978-82-536-1076-0

[7] Raspati G, Bruaset S, Sivertsen E, Møller-Pedersen P & Røstum J: ***Documentation tool of nature-based-solutions - a guideline.*** Klima 2050 Report 18. Trondheim 2019. ISBN: 978-82-536-1642-1

popular stormwater management solutions in urban areas. The Klima 2050 Centre has developed a tool that makes the planning, documentation and maintenance of such solutions much easier. NBS installations must be managed correctly from their inception, and this places major demands on their planning, design and construction, and during their operational and maintenance phases. One particular challenge is that such NBSs are currently produced by a variety of suppliers that employ inconsistent terminologies to explain how they work. A shared set of guidelines for relevant documentation will thus facilitate smoother information flow between suppliers and users, and reduce the risk of incorrect use. The tool can be integrated into digital systems, meets MOMD documentation requirements, and has attracted much attention both in Norway and around the world.

A risk framework for blue-green roofs[8]

The use of blue-green roofs is a stormwater management initiative that is expected to become significantly more common in the future, and the research-driven innovation centre Klima 2050 has prepared a framework for the prevention of building damage using such roofs. Many technical requirements must be met in order to deliver a robust roof construction. A blue-green roof must be planned to ensure that all such requirements are satisfied without making excessive compromises that may result in building damage because certain technical factors have not been taken into account. The successful coordination of the technical requirements needed, to deliver the best possible construction project, represents a major challenge. The framework described is the result of the PhD project of Erlend Andenæs conducted at the Klima 2050 Centre, and is now being used by centre user partners and other commercial organisations that are planning to build blue-green roofs.

Categories / Project phase	Concept	Pre-design	Design	Construction	Use
Blue-green functionality	• Evaluate ... • Etc. • ...	• Determine ... • Etc. • ...	• Select ...	• Schedule ...	• Establish ...
Organization	• Assess ...	• Involve ...	• Verify ...	• Inspect ...	• Review ...
Material integrity	• Estimate ...	• Determine ...	• Choose ...	• Perform ...	• Assess ...
Moisture-proof design	• Assess ...	• Identify ...	• Review ...	• Control ...	• Inspect ...
Drainage and drains	• Estimate ...	• Identify ...	• Develop ...	• Control ...	• Control ...
Structural loads and wind	• Estimate ...	• Identify ...	• Determine ...	• Avoid ...	• Evaluate ...
Fire protection	• Assess ...	• Define ...	• Define ...	• Perform ...	• Remove ...
Maintenance	• Estimate ...	• Establish ...	• Detail ...	• Document ...	• Follow ...
Environmental issues	• Define ...	• Assess ...	• Demand ...	• Ensure ...	• Avoid ...

Figure 12: Principal outline of the presented quality risk reduction framework

[8] Andenæs E, Time B, Muthanna T & Kvande T: ***Risikorammeverk for blågrønne tak.*** Klima 2050 Rapport 30, Trondheim 2022. ISBN 978-82-536-1736-7

Cost-benefit analyses[9]

The Centre has put the socio-economic aspects of climate adaptation on the agenda. One of the topics that has been addressed concerns cost-benefit analyses as a basis for decision making in relation to public investments in the built environment. Central in this research has been to scrutinize to what extent current methods and tools for such analyses capture climate change and the costs and benefits of climate adaptation. In a study of a set of existing cost-benefit methods and tools used by key partners in the Centre, the researchers found that current cost-benefit methods and tools are suitable to analyze cost-benefits in relation to measures against natural hazards, which are characterized by large consequences and that they occur at specific locations. However, the methods and tools are neither well suited to capture the long-term costs of climate change, which is not concerned with extreme weather-related incidents, nor the long-term benefits of climate adaptation measures. The researchers argue that cost-benefit analyses in general are not well-suited to capture the whole of climate adaptation and identify several reasons why. Among these are lack of data and pricing of types of benefits not exchanged on the market. The study finds that new methods and tools are needed, and that they should contribute to choosing the overall best solutions by comparing costs and benefits over time, taking into consideration the prevailing uncertainty, and the changing climate risk. The research has spurred further initiatives by partners in the Centre, aiming at refining the cost-benefit analyses to better reflect and capture the climate change and subsequent needs for climate adaptation.

Web tool for selecting landslide mitigation measures.

The web-based tool LaRiMiT (Landslide Risk Mitigation Toolbox) was launched in November 2018 but has been further developed and gradually improved thereafter. LaRiMiT has also been updated with a number of landslide measures categorized as NBS (Nature-Based Solutions), partly in collaboration with the EU-H2020 project PHUSICOS. LaRiMiT provides an overview and descriptions of almost 100 different measures for different landslide categories. The web solution is intended to help users, e.g., in public agencies and in the municipal sector, in choosing the right mitigation measures for landslides. The tool takes into account a number of input factors from the user, and then uses expert assessments contained in the tool's algorithms to give the user a prioritized list of possible actions. Suggested measures are scored based on how well they solve the landslide problem itself, but the scoring is also based on local physical conditions as well as the local economy.

[9] Seljom, LL: *Kost-nytteanalyse av klimatilpasningstiltak*. Klima 2050 Report 22. Oslo 2021. ISBN: 978-82-536-1688-9

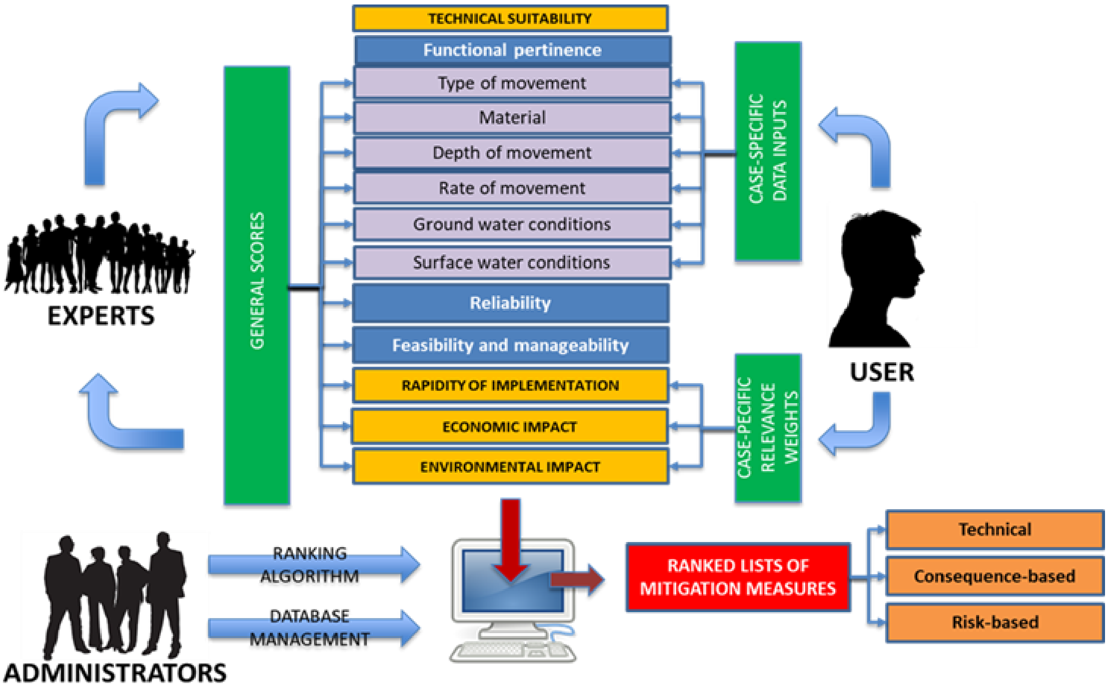

Figure 13: A schematic overview of the LaRiMiT web tool

Highlights of scientific results

Paradigms of urban water management are crucial for climate adaptation

Today it is generally accepted among engineers and planners that urban water management is carried out based on rational principles and that our infrastructure, practices and rules are gradually improved. It is generally assumed that this development will end in sustainable solutions that cover all water-related needs. However, reality shows that innovative solutions for climate adaptation are often rejected and not adopted. Previous research has identified a series of barriers of a social nature that prevent innovations from being adopted.

PhD Manuel Franco Torres has researched how the water and wastewater sector (like other sectors) uses shared mental models, also called paradigms, to understand how the world works, to provide recipes to develop new knowledge, or to identify what is important and what problems need to be solved. The dominant paradigm of an epoque is thus decisive in determining which infrastructures, practices and rules are created and adopted. The PhD work shows that the current paradigm for urban water management is in conflict with new solutions for climate adaptation and undermines efforts to adopt these. The conclusion is that awareness is required of how the paradigms shape practice in order to be able to remove the barriers that prevent the implementation of innovative solutions for climate adaptation. Unfortunately, this awareness is not present in the curricula of Norwegian educational institutions.

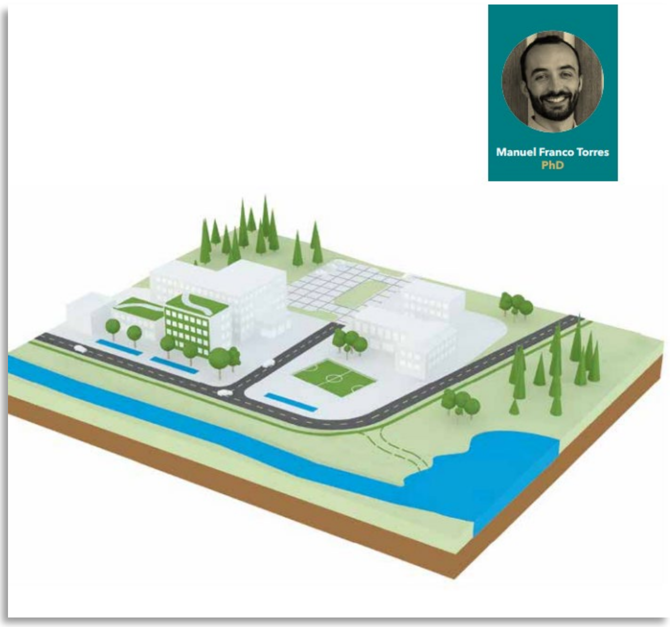

Figure 14: The PhD of Manuel Franco Torres shows that the current paradigm for urban water management is in conflict with new solutions for climate adaptation and undermines efforts to adopt these

Robust and climate-adapted blue-green solutions for stormwater management

In order to cope with climate change and increasing urbanization, green infrastructures for stormwater management are becoming key solutions. In Norway, the 3-step strategy is used. It consists in 1) managing day-to-day rains at the source-based evapotranspiration and infiltration depending on local conditions, 2) dampen and delay the larger rain events through local drainage, and 3) ensure safe diversion through defined floodways. The is a need to link different disciplines such as climatology, urban hydrology and risk quantification to increase understanding of how the steps in the 3-step strategy can be aligned with the operational implementations to provide robust and climate-adapted stormwater management in cities.

PhD candidate Vincent Pons has developed a new framework for designing blue-green solutions in alignment with the 3-step strategy. The framework proposes to move away from an event-based design to look at both long term continuous simulation and large datasets of extreme rain events. The goal is to quantify the retention performance for step 1, and evaluate the design limits in terms of detention through step 2. At the same time, you will receive information about when the solution(s) fails, which will provide useful information and guidance for designing of the floodways (step 3). Vincent also developed a new method based on statistical-temporal downscaling to be able to assess the future performance of the solution(s) using the same framework. Finally, Vincent has also studied the effect by scaling up from a single solution to many solutions within a neighbourhood/district.

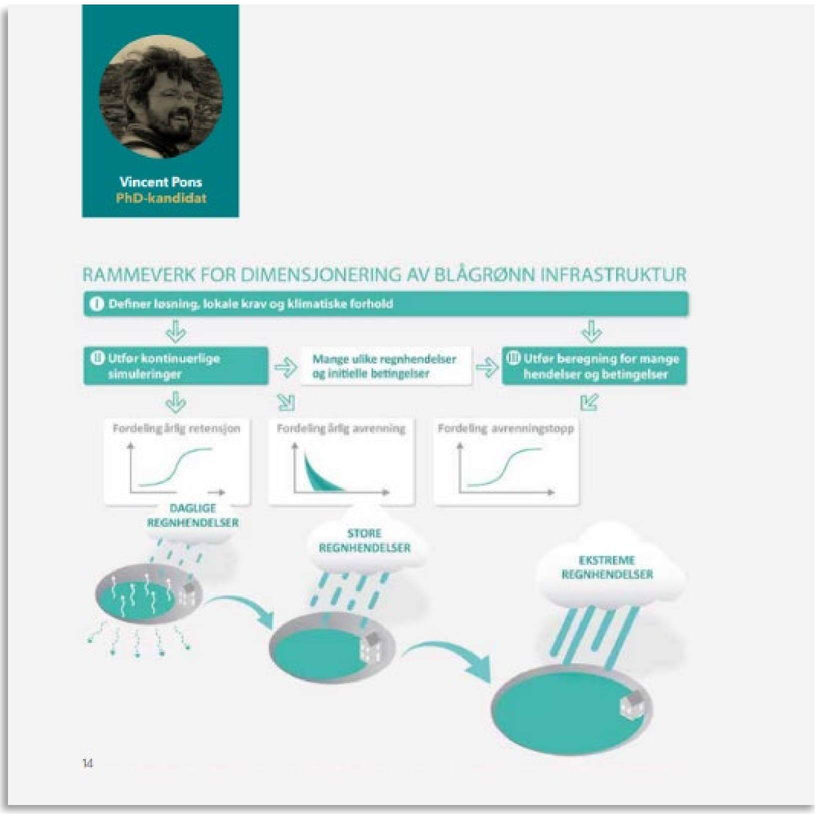

Figure 15: PhD candidate Vincent Pons has developed a new framework for designing blue-green solutions in alignment with the 3-step strategy

Detecting landslides with satellites

In a climate with more rain, the extent of rain-triggered landslides is expected to increase. NVE's landslide database RegObs provides an overview of registered landslides in Norway as a basis for assessment, notification, and mapping of landslide hazard. The Norwegian Public Roads Administration and Bane Nor contribute to updating the database after landslide events affecting their infrastructure. Unfortunately, the database is incomplete since few landslides are registered where there are no roads, railway lines or other infrastructure. To improve prediction models, there is a need for new methods to detect and record landslides.

Landslides can be detected by comparing images of an area taken before and after a heavy rain event. Mapping landslides in this way requires good images for comparison, which is not always easy. Parts of the terrain will always be in shadow, and there may be clouds in the way. Radar images can contain abundant "noise" that varies from image to image. PhD candidate Erin Lindsay's new method involves removing the "noise" by combining several images taken in the time before and after the landslide into two composite "before" and "after" images which are then compared. The image processing is done quickly with the web platform Google Earth Engine. The technique enables the use of satellite data to discover many new landslide events, also in areas without infrastructure, and thus improve the prediction models for landslides.

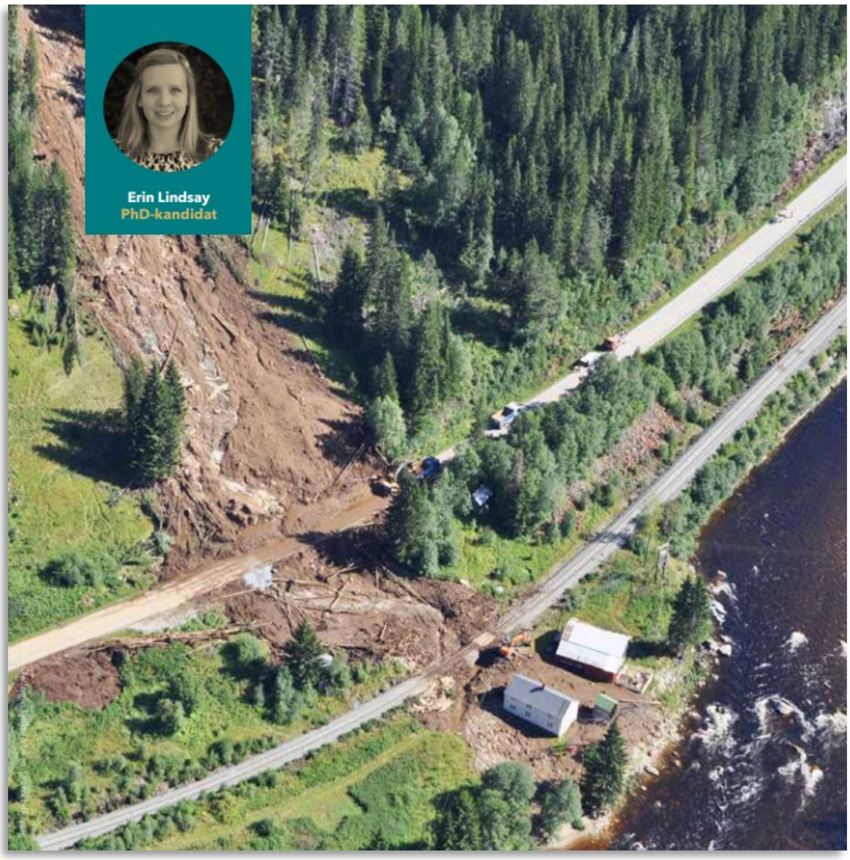

Figure 16: In a climate with more rain, the extent of rain-triggered landslides is expected to increase

A new method for analysing local flood

Flooding in small precipitation fields is a growing problem for infrastructure such as culverts and culverts by roads and railways. Planning such fields can be extremely difficult, as there are relatively few small fields with measurements. Such fields also respond quickly to precipitation, and therefore require good time resolution data to accurately model flood situations. In a new PhD Thesis by Aynalem Tassachew Tsegaw, one has compensated for missing data and developed a method for setting up a hydrological model in precipitation fields where no measurements are available. The method is important for the planning and operation of particularly roads and railways.

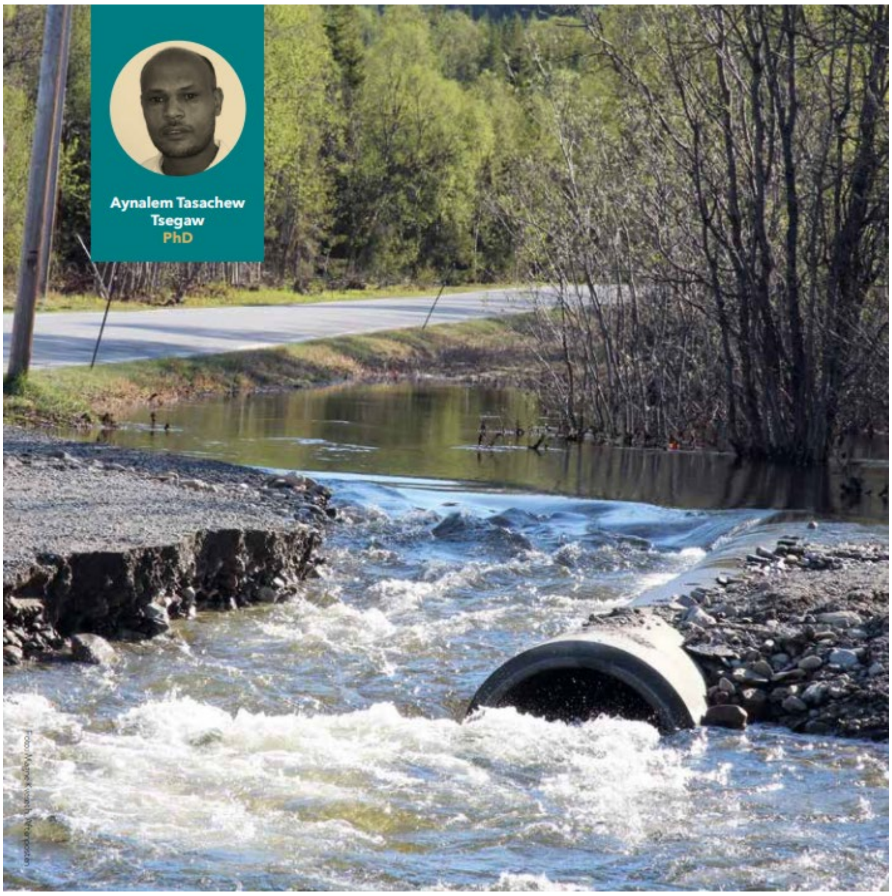

Figure 17: Road damage caused by a flooding situation, Photo: Magne Kveseth, Altaposten

Increased climate resilience for large wooden roofs

Large buildings in wood can be a good climate measure (reduction of greenhouse gas emissions) and the use of wood as a structural material in buildings is increasing. But increased use of wood in buildings can be a risk in a future more humid and warmer climate. Sloped wooden ceilings are built with an air gap between the roof covering and the ceiling. There are two main reasons why the wood ceilings need to be ventilated: One is to prevent temperature rise on the roof covering that can cause snow melting and icing in gutters and downlets, while the other is that excess moisture must be ventilated out of the structure. In the building industry's knowledge system Byggforskserien (Building Research Design Guides) there are currently only recommendations for air cavities for wooden ceilings up to 15 meters in length with slopes higher than 10-15°. When the recommendations were made, the experience was that there was trouble ventilating excess of heat if the roof was longer. Based on new measurements and calculations, the PhD thesis of Lars Gullbrekken concludes that it is possible to build both longer and more low sloped roofs than previously recommended. New recommendations are implemented in the partners' building systems. The findings were presented at several seminars about roofs under the auspices of the Byggforskserien (SINTEF) in the four largest cities in the country with an audience of nearly 500 people from the industry.

Figure 18: Lars Gullbrekken performed experiments at the roof of The ZEB Test Cell Laboratory

Green roofs as stormwater measures

Urban growth, densification and climate change put increased pressure on existing drainage systems. The natural drainage patterns change with consequences for, among other things, groundwater level and water flow in urban waterways. One way to reduce these unfortunate consequences is to base stormwater management on nature's water management principles. Green roofs are an example of such measures where water is temporarily stored in the roof structure and later removed by evapotranspiration (evaporation and plant water consumption). In addition, the water flowing from the roof will be delayed in time compared to runoff from a regular roof. A new PhD Thesis by Birgitte Gisvold Johannessen shows that extensive green roofs can remove a significant proportion of the rainwater from a roof. This will result in reduced volumes of water to be transported and purified, which is particularly useful in areas with a common drainage system (where stormwater and sewage are fed into the same pipe).

Figure 19: Green roofs are becoming extremely popular as a storm water measure with co-benefits

Roofs can contribute towards flood prevention

Intense rain events are becoming an increasingly prominent challenge for urban areas. As roofs may cover up to 40 % of the total area of urban environments, roofs may be the largest surface available for stormwater management measures. Retentive roofs may contribute to reduce the effects of climate change and urbanization by storing rainwater and delaying runoff, and thus reduce the total runoff volume and peak runoff flow. To fully utilise the roofs in this way, the retention potential of the relevant solutions must be found.

Trondheim municipality and Klima 2050 has established a pilot project at the roof of Høvringen sewage treatment plant, where Vladimír Hamouz, in his PhD-thesis, has conducted research on different types of retention-based roof assemblies to increase the retention capacity of roofs without adding too much weight like heavy soils. Green roofs exhibited a larger variation in the measured moisture content than the grey roofs, due to transpiration processes. These processes caused increased stormwater retention (precipitated water that does not become runoff) from the green roofs. The grey roof solutions exhibited much larger detention capacity and peak flow reduction than the green roof that had no additional water storage. The solution that combined green roofs with a sub-layer for water storage, achieved good detention and retention. This solution turned out to be the best in terms of peak flow reduction and water retention.

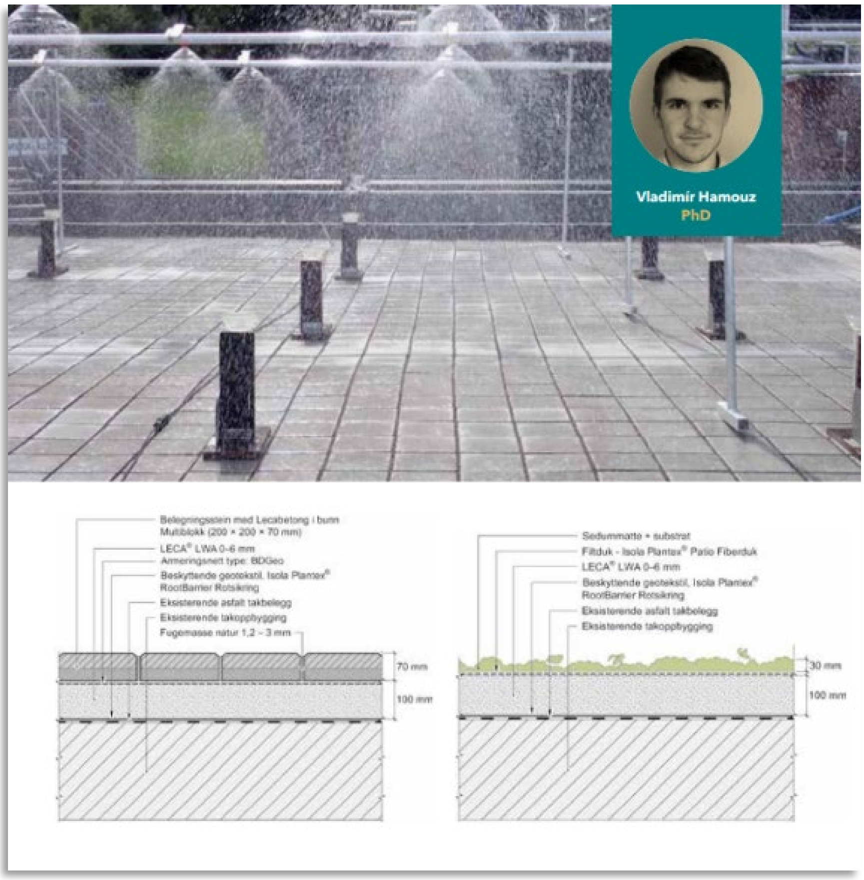

Figure 20: Examples of a blue-grey and a blue-green roof at Høvringen

Achieving moisture safety in basement walls

The way basements are built and used have changed drastically since the 1950's. Traditionally, basements were primarily used for storing food. Today, completely different requirements are imposed in terms of indoor climate, energy efficiency, and moisture safety. Additionally, climate change causes more intense and more frequent rainfall, so that stormwater presents increased strain on the basement wall. In her doctoral work, Silje Asphaug has investigated how the water vapour permeability of different types of EPS, interior and exterior insulation thickness, and the positioning of dimpled membranes affects the drying effect of basement walls.

Laboratory experiments and simulations both show that the exterior drying achieved using vapour permeable insulation, instead of standard quality EPS, has little impact to the moisture conditions on the interior side of concrete walls in new builds. The thickness of exterior and interior insulation, however, affect the moisture conditions to a greater degree. The results also indicate that the exterior drying is greatly dependent on the type of concrete, and that more knowledge is required regarding the moisture properties of concrete to perform more accurate simulations of moisture conditions in concrete basement walls. Silje's studies summarize ten moisture challenges that must be addressed to achieve moisture safety in basements. The ten challenges are differently weighted in different countries with different climates. This prioritization shapes the national moisture safety strategy. Optimal moisture safety is achieved by solving all ten challenges.

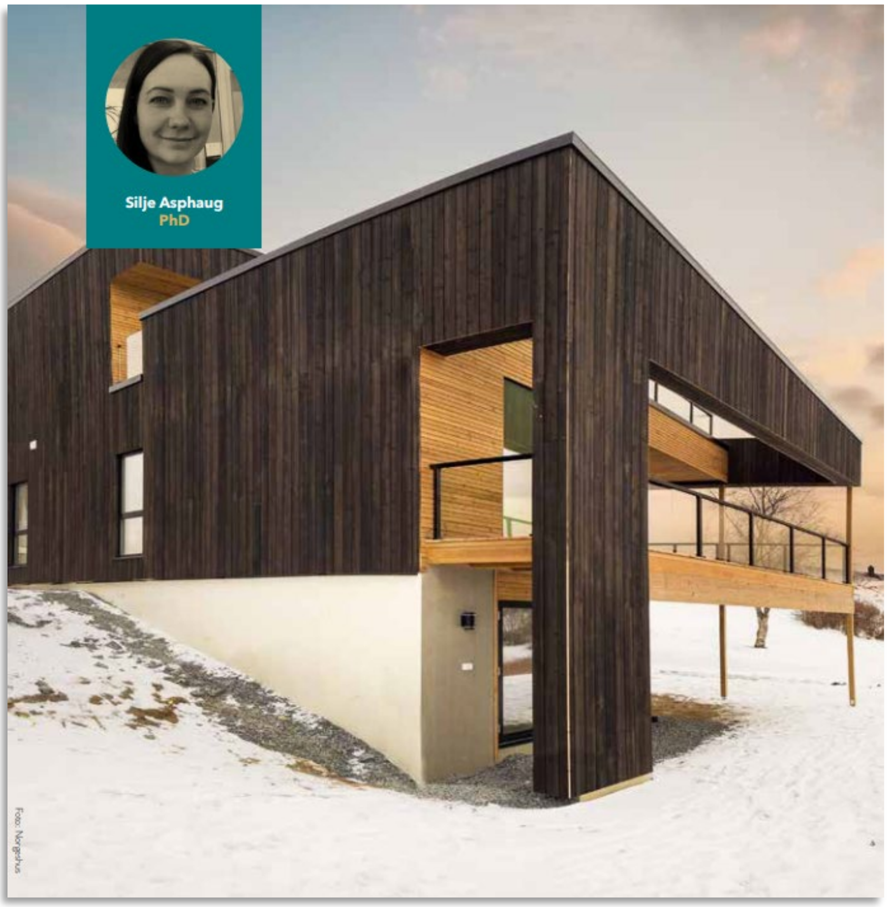

Figure 21: The way basements are built and used have changed drastically since the 1950's, that also means the focus on the moisture situation

Flexible barriers to reduce debris flows

Increased rainfall induced by climate change makes landslides a major and worsening challenge in Norway. Rainfall-induced debris flows typically increase in volume by entraining soil, fluid, and boulders along the flow channel. Debris may include soil, fluids, rocks, and trees.

In his Ph.D. project, Hervé Vicari has investigated ways to inhibit the increase of debris flow volume due to base erosion and entrainment, through compensating measures placed in the flow channel uphill from exposed buildings or infrastructure. One such measure is flexible barriers. These are light structures that may easily be mounted in steep or inaccessible ravines and are found in many locations across Norway. To improve the understanding of how a flexible barrier affects the debris flow, a series of experiments are performed in test channels, both on a small scale (in Trondheim) and a large scale (in Hong Kong). Numerical modelling of debris flow and erosion is also conducted. The results indicate that flexible barriers installed upstream in a flow channel may potentially inhibit the increase of debris flow volume.

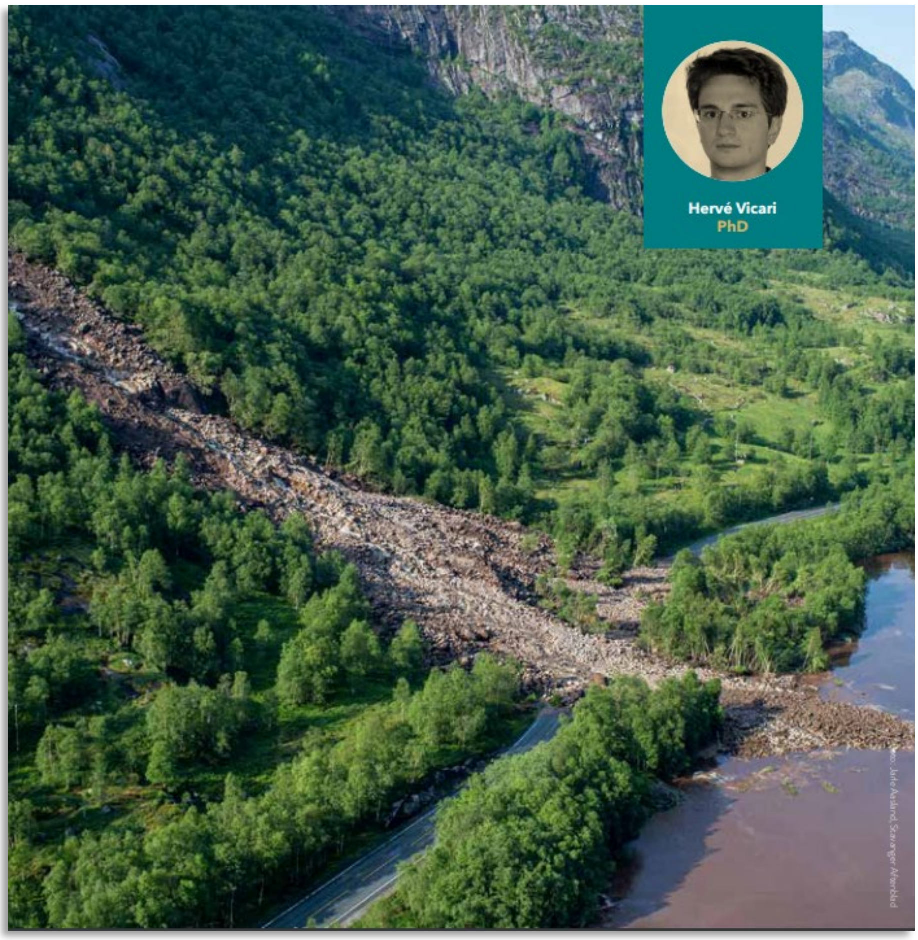

Figure 22: In his Ph.D. project, Hervé Vicari has investigated ways to inhibit the increase of debris flow volume due to base erosion and entrainment, through compensating measures placed in the flow channel uphill from exposed buildings or infrastructure

Modelling of blue-green solutions for stormwater management

Climate change and rapid urbanization are expected to increase the amount of stormwater in cities and will increase the load on the drainage network. This will increase the risk of urban floods and increased pollution around overflow outlets from combined sewage and drainage systems. Blue-green solutions, like green roofs, permeable pavements, and rain gardens, are effective solutions to reduce and delay stormwater runoff through natural processes (evapotranspiration, infiltration, detention). Additionally, blue-green solutions will improve the water quality of stormwater, improve the biodiversity of the city, and are visually pleasing. However, such solutions are little used in Norway, partially due to the lack of clear design guidelines and modelling tools to improve the hydrological performance.

In his doctoral project, Elhadi Mohsen Hassan Abdalla has improved and validated several hydrological models for different blue-green solutions by comparing simulated and measured runoff values. Abdalla has also developed correlations to estimate the parameters of the hydrological models of the solutions where measured data are not available for model calibration. Additionally, laboratory measurements of blue-green roofs are conducted to determine how roof slope angles and roof length may affect the hydrological function of the roof.

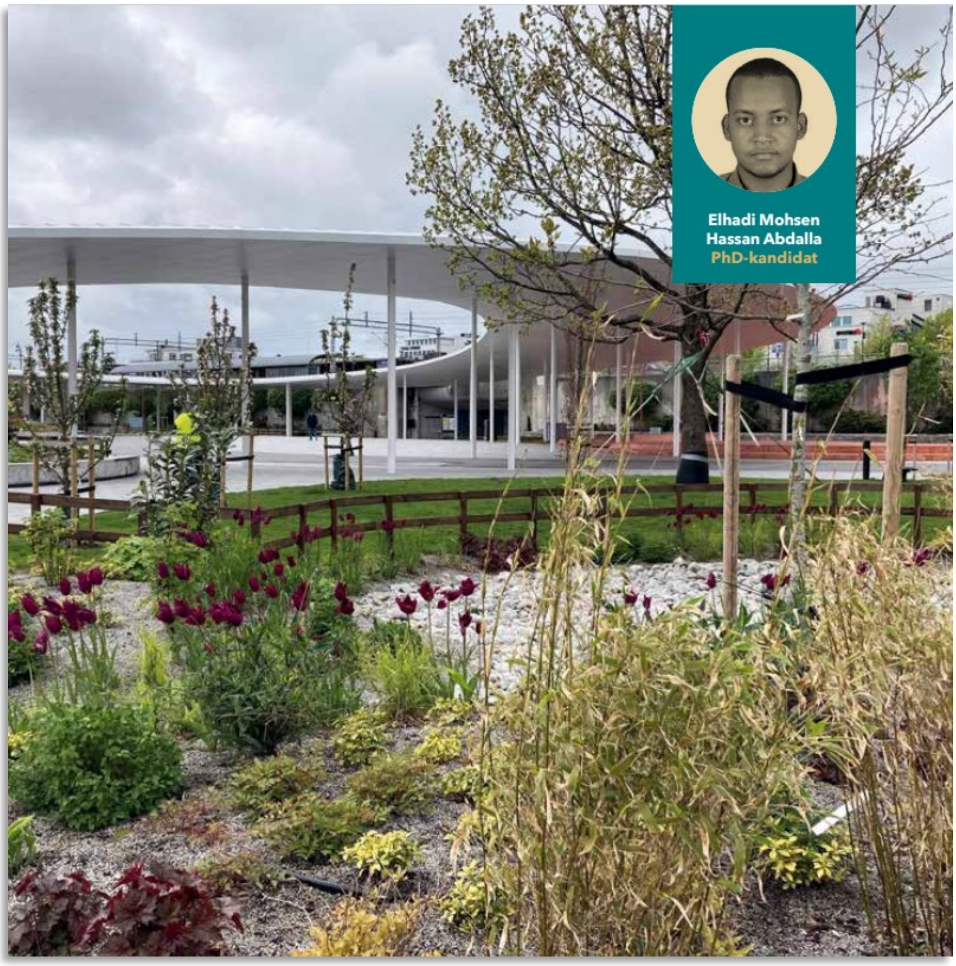

Figure 23: In his doctoral project, Elhadi Mohsen Hassan Abdalla has improved and validated several hydrological models for different blue-green solutions by comparing simulated and measured runoff values

Cooperation-based building process

Historically, the building sector has been a tough, project-based market featuring low margins and high degrees of competition. As technology, the climate, and society have evolved, the projects have also become increasingly complex. Meanwhile, new project delivery methods have emerged as a response to ever more difficult projects. The new methods are often labelled “collaborative” due to the focus on aligning the interests of the clients with the rest of the value chain at an early stage of the project cycle.

The Ph.D. project of Atle Engebø has contributed to develop the empirical understanding of the use of collaborative elements in project delivery methods. In the work, the ZEB Laboratory, a Klima 2050 pilot project, has been closely followed as a primary case. Many positive effects from collaborative delivery methods have been observed and documented. Contractual, organizational, and cultural elements affect the project and the team behind it. By being deliberate in selecting and using various elements, the collaborative effort of every participant can be maximized throughout the project.

Experience suggests that the chosen project delivery method was effective for the ZEB Laboratory, and a main reason behind the successful result. It should, however, be pointed out that collaboration should not be sought at any cost for its own sake. Not all projects are suitable for collaborative delivery methods. The crucial element is to find an appropriate balance between collaboration and competition.

Figure 24: The Ph.D. project of Atle Engebø has contributed to develop the empirical understanding of the use of collaborative elements in project delivery methods

Risk assessment in moisture design of buildings

The Norwegian climate exhibits large variations. Due to the topography and coastal landscape, variations can be substantial even over short distances. The seasonal variations are also significant, with relatively cold winters and mild summers. Climate change projections indicate that one should be prepared for more precipitation, more intense rainfall events, and higher temperatures. Unfortunately, the building stock is vulnerable to defects even in the current climate. Hence, more attention is required concerning topics like building physics, moisture durability, risk reduction measures against moisture defects, and extreme weather events.

The goal of Jørn Emil Gaarder's Ph.D. project is to incorporate the consideration of risk into moisture design, while also allowing for future climate loads and local variations. Jørn Emil is primarily investigating how uncertainty is being handled. Tools and methods for climate adaptation of buildings are developed using predictions of future climate loads, mapping current practices, and investigating risk management methods.

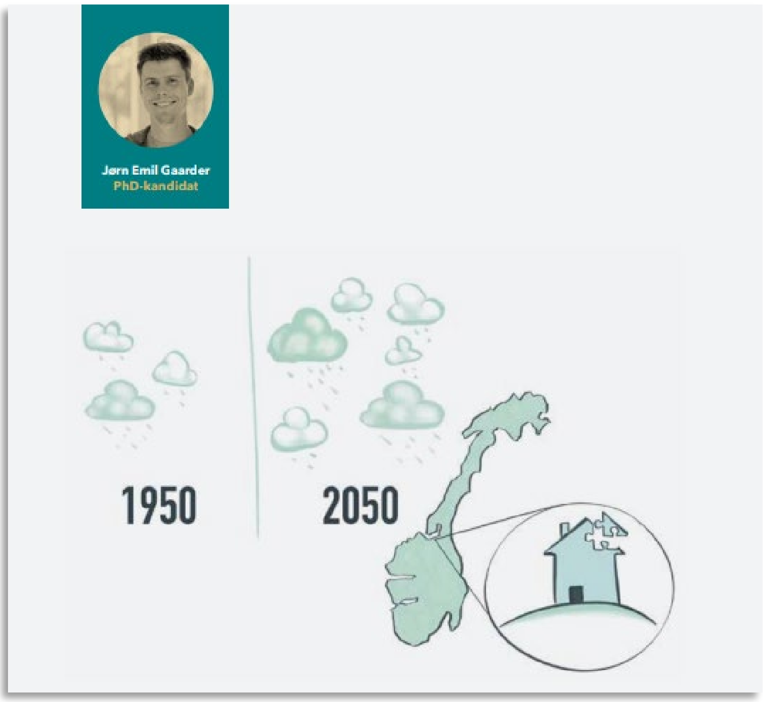

Figure 25: The goal of Jørn Emil Gaarder's Ph.D. project is to incorporate the consideration of risk into moisture design, while also allowing for future climate loads and local variations

Organizational change[10]

Climate change requires organizations to change. These changes are transformational, penetrating an organization's structures and processes. To effectuate these changes, often reflected in new strategies, requires the efforts and contribution of many individuals in the organization, beyond top management.

In her post-doctoral project, Anne Kokkonen, has investigated what it takes for organizations to adapt to climate change. In one of the studies, she has focused on the implementation of environmental sustainability strategies, including climate adaptation, and more specifically addressed the role of change agents in driving these processes. The study shows how these agents, which might be top managers but not necessarily so, are able to drive change through three key processes. First, by seeking to learn and develop knowledge about the topic, the change agents can identify and communicate the relevance and benefits of implementing the goals and strategies in the organization. Second, this communication needs to be differentiated in relation to the audience. Those change agents that do so, are also better at driving the change forward. Third, the change agents must motivate others to engage in the work by being good examples and providing knowledge. These key processes, in turn, depend on organization-wide attention being given to the goals, resources being allocated to the agents and the work, and that the climate and sustainability work is integrated in people's daily activities, not as a time-consuming add on.

[10] Kokkonen, A. H. (2022). Endringsagenters betydning for å realisere bærekraftsmål. Praktisk økonomi & finans, 38(1), 89-103. https://doi.org/10.18261/pof.38.1.7

Awards

Tore Kvande, NTNU and Berit Time, SINTEF et.al	Klima 2050 pilot project The ZEB Laboratory was awarded the Norwegian State's award for building quality in 2022.
Tore Kvande, NTNU and Berit Time, SINTEF et.al	Klima 2050 pilot project The ZEB Laboratory was awarded Bygg21's price for best practise "Betonghammeren" in 2022
Erin Lindsay, NTNU	PhD Candidate Erin was invited speaker to "Geo for Good Summit 2022", Google Earth Event 2022 about the method she has developed using Google Earth Engine to improve the visibility of landslides in satellite images, in order to detect more landslides in Norway.
Berit Time, SINTEF	Keynote speaker. 12th Nordic Symposium on Building Physics. Tallinn, Estonia, 07.09.2020.
Lars Gullbrekken, SINTEF	Keynote speaker. 1st Forum Wood Building Baltic 2019. Tallinn, Estonia, 27.02.2019
Vincent Pons, NTNU	PhD Candidate Vincent was among top 3 finalists invited to present their papers at the International Conference on Urban Drainage (ICUD2021) in Melbourne 2021 hosted by the joint committee on Urban Drainage (IWA/IAHR).
Thea I. Skrede, NTNU	RIF Best master thesis within water and environmental technology 2018
Fredrik Slapø, NTNU	Best master thesis at the Master's degree programme in civil and environmental engineering 2017
Nathalie Labonnote, SINTEF	Best presentation at NTNU Sustainability Science Conference 2017
Mareike A.Becker, NTNU	Best master thesis at the Master's degree programme in civil and environmental engineering 2016
NGI	World Centre of Excellence on Landslide Disaster Reduction 2017-2020 given, based on NGI's landslide activities within SFI Klima 2050. Awarded by the International Consortium on Landslides
Skjæveland Gruppen	Alma Regnbed has been selected by the EU program BRIGAID in 2018 as one of six innovations to receive funding and expertise support for further development

Figure 26: Fredrik Slapø is receiving the best master award in 2017

International cooperation

The awarded SFI status expanded our international network with other universities and research institutes and has promoted the formation of new collaborations in benefit for our partners from private and public sector.

The Centre has had an international scientific advisory committee from the start. The idea was to make sure that the research and development was at an international level and have input from experts from abroad.

Figure 27: Edvard Sivertsen presenting the Centre and its results at the Nordic Conference on Climate Change Adaptation (NOCCA) in Reykjavik in April 2023

Internationalisation was focused on the Centre Communication plan. The Centre wanted to make a contribution to a global focus on, and dissemination by means of i) international spin-off projects, ii) co-authoring of articles in scientific journals with overseas researchers the following iii) researcher exchange and iv) organisation of scientific conferences.

International spin-off projects

The Centre has been successful in international spin-off projects (Horizon 2020, Horizon Europe, JPI, Nordforsk). Some relevant examples:

NGI was successful in the Horizon 2020 Innovation Action SC5-08-2017, as a coordinator of the project "*Phusicos" (Solutions to reduce risk in mountain landscapes*)

NGI was successful as a participant in "*Safeway*" (*GIS-based infrastructure management system for optimized response to extreme events on terrestrial transport networks*) in a H2020 in 2017.

SINTEF was successful in the Horizon 2020 JPI Water program with the application; *Evidence based assessment of Natural Water Retention Measures for sustainable water management (EviBaN).*

SINTEF and NTNU were granted the international project *The Minnesota - Norway Collaboration for excellence in education and research on adaptation to climate change* through the Research Council of Norways INTPART-program in 2017.

NTNU were granted the international project *Landslide mitigation of Urbanized Slopes for Sustainable Growth* through the Research Council of Norways INTPART-program in 2020

NGI has lead NordicLink - *Securing Nordic linear infrastructure networks against climate induced natural hazards* from 2020-2023 (Nordforsk).

SINTEF was successful in the Horizon-Miss-2022-Clima-01 call as a partner in *Solutions Testing for Regions through Insurance for climate adaptation* (Soteria) in 2022.

The partners have also contributed to applications which have failed, but nevertheless lessons have been learnt and networks have increased.

Co-authoring of articles in scientific journals with overseas researchers

The Centre has attracted foreign post.docs and exchange students. This has among other effects, resulted in co-authoring and achievement of scientific journal articles with overseas researchers. The 5 most recent examples are:

Pons V, Abdalla E.M.H, Tscheikner-Gratl F, Alfredsen K, Sivertsen E, Bertrand-Krajewski J-L & Muthanna T.M: *Practice makes the model: A critical review of stormwater green infrastructure modelling practice*. Water Research 2023, Vol 236, 119958; doi.org/10.1016/j.watres.2023.119958, ISSN 0043-1354

Gaarder J.E, Friis N.K, Larsen I.S, Time B, Møller E.B & Kvande T: *Optimization of thermal insulation thickness pertaining to embodied and operational GHG emissions in cold climates – Future and present cases*. Building and Environment 2023, Vol 234, 110187;

Friis N.K, Gaarder J.E & Møller E.B: *A Tool for Calculating the Building Insulation Thickness for Lowest CO2 Emissions—A Greenlandic Example*. Buildings 2022, Vol 12(8), 1178;

Pons V, Benestad R, Sivertsen E, Muthanna T.M & Bertrand-Krajewski J-L: *Forecasting green roof detention performance by temporal downscaling of precipitation time-series projections.* Hydrology and Earth System Sciences 2022, Vol 26, 2855–2874;

Capobianco V, Uzielli M, Kalsnes B, Choi J.C, Strout J, Tann L, Steinholt I, Solheim A, Nadim F & Lacasse S: *Recent innovations in the LaRiMiT risk mitigation tool; implementing a novel methodology for expert scoring and extending the database to include nature-based solutions,* Landslides 2022

Researcher exchange

Additional focus has been directed at the development of, and participation in, Nordic R&D projects and collaboration. Firstly, this has been desirable because of the somewhat comparable climate change challenges in the region, and, secondly, because the Centre's business partners are prioritising the Nordic market.

Because of the Covid- situation there has been restrictions on travelling and not as many PhD students as intended has been visiting foreign institutions. However, all of the PhD Candidates or researchers related to the Centre has been visiting a foreign institution. And vice a versa, we have had several researchers visiting the Centre premises.

Organisation of scientific conferences

The Centre had a prominent role in the arrangement of the 11th Nordic Symposium on Building Physics in 2017. Climate adaptation of buildings were awarded a session, and moisture resilience was a core topic at the conference. An International Scientific Committee ensured high quality papers. 220 researchers and practitioners from 26 countries were participating.

Key researchers have also been part of scientific committees for international conferences.

Figure 28: Key researcher Lars Gullbrekken from SINTEF and Targo Kalames at Talltech has common interests in climate adaptation of wooden constructions, here at Forum Wood Building Baltic 2019

Water Europe contributes to the development and implementation of key policy on the water sector in the EU. Klima 2050 researcher Kamal Azrague, SINTEF is the leader of the Nature-based solution working group.

All in all, international collaboration has strengthen the research, given new insight to the topics and we have increased our network of collaborators through new international projects and activities.

Training of researchers

To keep a strong focus on the progress, interaction and well-being of the Ph.D. candidates, a Klima 2050 Research Training Committee was established. The Training Committee should encourage the candidates interact and coordinate with relevant researchers and consortium partners ensuring good interaction and an extensive scope of work, and internships.

The activity concerning researcher training focus three main areas: publication activity, Ph.D.-gatherings, and the ambition to include the industry and public partners of the Centre into the research activity through the work of the Ph.D.'s.

On a practical level, the ambition of the Centre has been to enable the involved PhD Candidates/-researchers in assembling productive creative clusters with industry and public partners for research and publication purposes. Two-days PhD-gatherings for candidates of the Centre was arranged annually. In addition to being a social come-together event at a particular location fairly close to Trondheim, the gatherings included sessions with scientific content provided by the candidates and partners of the Centre as well as training in practical research strategies. A main focus was put on practical skills involved in research design and publication. Introductions to and discussions concerning research ethics formed a key part of the gatherings.

Figure 29: Researcher training events and social gatherings were appreciated among the PhD-students

Master students are particularly important for the society as they bring new knowledge to the companies as they start their working life. The Centre has been particularly successful in engaging master students. The ambition at the start was to engage 50 students during the 8 years. The final number is 135. Figure 30 shows an overview to which part of the professional society the students have gone.

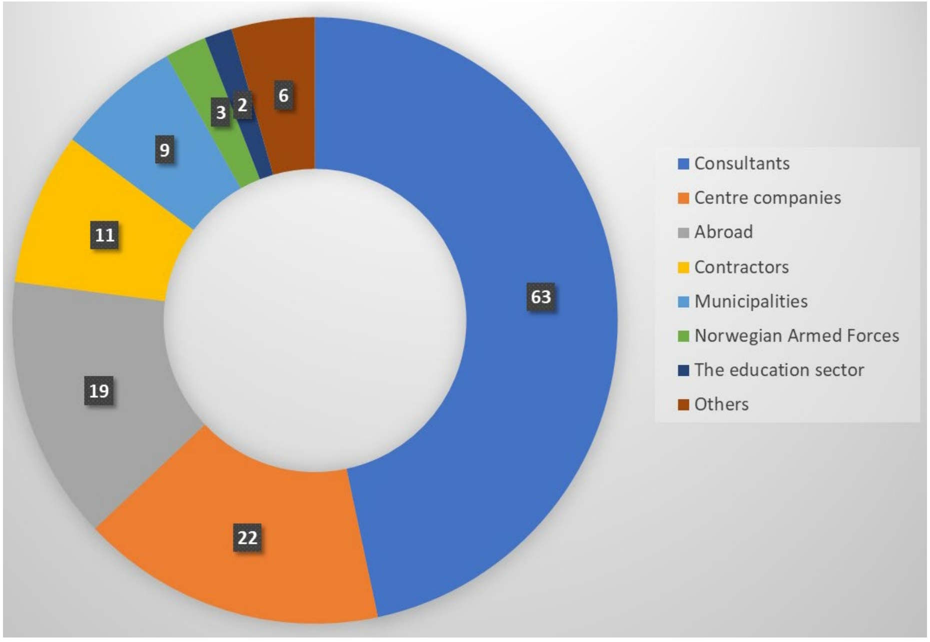

Figure 30: An overview of the selected employers for the 135 master students

Table 1 Employment of PhD candidates, i.e where the doctoral candidates are employed after completing their degree

Employment of PhD candidates (number)							
By centre company	By other companies	By public organisations	By university	By research institute	Outside Norway	Other	**Total**
3	**2**	**2**	**1**	**5**	**3**	**2**	**18**

Communication and popular dissemination of knowledge

Already from the start of the Centre back in 2015 we were very conscious that research conducted demanded dissemination of knowledge beyond the limits of the consortium partners. Moreover, any work to stimulate a more innovative industry faces a major communication challenge simply because the Norwegian building sector is so fragmented – consisting of many small and medium sized players.

As well as effective internal communication between its partners, the Centre has also succeeded to disseminate its results more widely by means of the following:

Research-oriented dissemination

A greater part of the primary dissemination of research results is directed at other researchers in the form of scientific articles published in highly reputed peer reviewed journals. Such dissemination has been important as a means of underpinning research quality and the preparation of authors' CVs. The Klima 2050 Centre aimed to place itself in the global forefront of research into its areas of focus, and scientific publication promoted the production of high-quality research results.

User-oriented dissemination

This form of dissemination was directed at those who use the know-how and technology that results from work carried out at the Centre, in particular the Centre's partners. Here, the Klima 2050 Centre worked with all professional communities within the building, property, construction and transport sectors because effective climate adaptation solutions have to be implemented by all players.

Public-oriented dissemination

This form of dissemination was directed at the wider public and was also known as popular science dissemination. It was important to the Klima 2050 Centre as a means of increasing public awareness of, and demonstrating the needs and opportunities linked to, climate adaptation of buildings and infrastructure.

The *Klima 2050 Communication Plan*[11] set out the Centre's communication ambitions, and explained the "why, who, what and how" about the work we carried out to achieve our ambitions in promoting the dissemination of research results generated by the Centre.

The Centre stated the following ambitions already from the start:

- To be a robust brand in the field of know-how, innovative solutions, and researcher education and development linked to climate adaptation in built-up areas.
- To be an active player in the research-, user- and public-oriented dissemination of the Centre's project activities.
- To operate with an effective platform for information flow between our research and industry partners, and with an information exchange process that all partners will perceive as positive.
- To assist in bringing to the fore the contributions made to innovation by the consortium partners.

The Klima 2050 Centre's profile programme was developed to underpin the Centre's identity (its brand). The aim of the programme was to create a distinct identity that was used actively in references to, and promotion of, the Centre and its results.

Different publication categories were established already from the start of the Centre period. See Figure 31, 32 and also www.klima2050.no

[11] Kvande, T & Time, B: *SFI Klima 2050 | Kommunikasjonplan, versjon 3.* Klima 2050 Note 65. Trondheim 2018

No.	Title	Explanation
	Research-oriented	**Scientific-/research-related dissemination**
1	Ph.D. theses	Doctoral theses from BI and NTNU
2	Peer-reviewed scientific journals	Peer-reviewed scientific articles published in international journals
3	Conference proceedings	Publications of papers given at scientific conferences
4	Handbooks	Technical handbooks published by SINTEF, the Norwegian Public Roads Agency (NPRA) and Norwegian Water (*Norsk vann*).
5	Klima 2050 Reports series	See item 5.2
6	M.Sc. theses	Student dissertations
7	The SINTEF Building Research Design Guides	SINTEF Building Research Design Guides (Byggforskserien)
	User-oriented	**User-oriented dissemination**
8	Klima 2050 Notes series	See item 5.3
9	Technical journals	Technical articles published in Norwegian or international technical journals See item 5.4
10	Presentations, lectures, courses and seminars	Presentations, courses and seminars
	Public-oriented	**Popular science dissemination**
11	Popular scientific articles, debates and feature articles	Popular scientific articles, debates and feature articles
12	Press releases and news stories	Press releases and news stories
13	Other publications	Other publications

Figure 31: Klima 2050 publication categories. Taken from the Centre Kommunikasjonplan, versjon 3

Figure 32: Examples of publications from the Centre. All publications within all categories are listed at www.klima2050.no

As a result of being faithful to the Centre Communication Plan it is our opinion that the Centre has been successful in dissemination and generating attention both nationally and internationally.

Effects of centre for the host institution and research partners

Klima 2050 has been strategically and operationally very important for SINTEF Community (previously SINTEF Building and Infrastructure). The Centre has given a lot of nourishment to the collaboration between the disciplines and the building research department and the infrastructure research department, water and environment group in particular at the host, but also within these disciplines at research partner NTNU and all the partners of the Centre and beyond.

Climate adaptation of the built environment is a field of major importance for many of the strategic research areas of SINTEF. The thematic approach has also fitted other institutes in SINTEF and promoted and facilitated interdisciplinary collaboration in national research projects (Applications to the Research Council of Norway) and international projects (Horizon 2020 and Horizon Europe). It underlines the SINTEF vision Technology for a Better Society. The Head of SINTEF Community (until 2020 and from that on Special Advisor) has been the Deputy Chair of the Board in Klima 2050.

One of NGI's strategic focus areas is 'Research and consulting for societal security and the green transition'. Nature-based solutions and climate adaptation are particularly mentioned, and as such the themes of Klima 2050 fits very well with NGI's vision and strategy. The Centre has enlarged NGI's network and has been instrumental in obtaining new research projects within the frameworks of RCN and the EU.

Education at master's level

135 M.Sc students have been involved in the work of Klima 2050. This includes mainly students at NTNU, but also at BI, as well as students from collaborative institutions nationally and abroad. The students have been supervised by researchers, PhD Candidates, and also user partners of the Centre. Three of the M.Sc has been awarded Best master thesis of the year.

The establishing of UROP (Undergraduate Research Opportunity Program) for civil and environmental engineering at NTNU was strongly motivated by Klima 2050. The purpose of UROP was to introduce students to research early in the study and to stimulate the students to learn by themselves by practising research. The involvement of students in UROP and as research assistants strengthen the Centres recruitment of excellent master students, highly qualified employees amongst the project partners and future PhD Candidates for the research community.

It is our opinion that the Centre’s activities have contributed to renewal, increased quality, and reduced fragmentation among all the research partners SINTEF, NTNU, NGI, Met.no and BI.

Effects of centre for the partners and society at large

Strategic composed consortium

Value chain of actors

The Centre partners represent the whole value chain of the Norwegian construction industry, relevant public stakeholders and governmental actors. In addition to the research organisations, the Consortium consists of 15 merited partners, all of whom have key roles in activities to reduce societal risk in the built environment. The Centre's public sector partners are dealing, on a day-to-day basis, with key challenges. Klima 2050 is, along with the private sector partners, developing risk-reducing measures. Our partner group is diverse, to ensure a breadth of knowledge and expertise, and to maximize the opportunities for innovation.

The value chain of the Consortium private partners represents a "pulling force", the partners asking for each other's solutions and measures. Processes, products, and solutions developed by one private partner may be carried further by some of the others. The new knowledge through processes, products and solutions can be tested in laboratories, in field tests and in pilot projects. The public partners, responsible for overall regulatory plans, regulations, and norms, represents a "pushing force" for implementation of climate adaptation measures. In this way the value chain becomes an "innovation chain".

Innovation promotion and pilot projects

The Centre defined innovation as new and improved solutions, methods, products, processes, systems, and business models that utilize knowledge developed in Klima 2050, bringing added value to the partners and to society. To promote and facilitate the innovation processes, the Centre initially established a Klima 2050 Innovation Arena across work packages. However, as work developed, we experienced that pilot projects were the real innovation arena, and the focus of the innovation arena changed to establishing and follow up on the pilot projects, 16 in total.

It is often easier to demonstrate innovation and innovation potential within a given system, process, etc. by employing a pilot rather than by other forms of research. In general, user partners found pilots focused and thus attractive. Our pilots have been linked to the development of new systems or processes. The objective was that a pilot should act as a model and example of how we can mitigate risk to society by measures designed to adapt to the impact of climate change, and we experienced that they demonstrated innovation and productive interaction between the partners involved. They were also regarded as an effective means of disseminating know-how generated at the Centre. Some of the partners also came together in spin-off project applications to extend the activity related to topics in focus at the pilot projects.

Many of the pilot projects have been presented in the booklet "Pilotprojects"[12]

Our social responsibility

During the Centre period we were again and again witness to dramatic climate-related events, and the latest IPCC report has re-emphasising in the strongest possible terms the seriousness of the current situation.

The production of more knowledge about climate adaptation, as well as risk reduction strategies linked to climate change and increasing levels of precipitation in the built environment, is the social responsibility of the Klima 2050 Centre. As well as generating innovations and increased wealth creation for our partners, we all recognise that our work at the Klima 2050 Centre is part of a much bigger exercise in social responsibility.

[12] Time B & Kvande T: ***Pilotprosjekter***. Klima 2050 Report 44. Trondheim 2023. ISBN 978-82-536-1796-1

The Centre has made clear how many Norwegian government ministries and public sector agencies have a role in the field of climate adaptation, but it is the local municipalities that have the primary responsibility for applying adaptation strategies in Norway. They have responsibility for holistic planning and risk management, as well as for community safety. The Norwegian Municipal Planning Act is key to all land management and building activities in Norway, and the municipalities have a duty to adapt their infrastructure to anticipated changes in climate, and to put measures in place to prevent damage and injury. Climate change thus puts ever-increasing pressure on the Norwegian municipalities.

Klima 2050 has contributed with research and innovations as part of our greater social responsibility. The building and construction sector is made up of more than 50,000 companies and employs 250,000 people, all of whom must contribute to the best of their ability towards reducing societal risk and adapting buildings and infrastructure to the threats posed by climate change. Much of our research is made available to the sector and those who work there.

We have taken part in a number of projects and co-creational initiatives with players in the private and public sectors and other research centres, focusing on issues of interest also to many stakeholders outside the Centre's partnership group. We have participated at Arendalsuka, the largest political gathering in Norway. We have developed guidelines that are of benefit to the municipalities and have participated in the work to revise BREEAM-NOR, which is the most frequently applied building certification system in Norway. We link our research to other Norwegian initiatives and projects such as the Natural Hazards Forum, the Norwegian water sector organisation Norsk Vann, and the Building Research Design Guide series. These are important fora for the dissemination of our research results.

Key Performance Indicators

Effective innovation system

Throughout the lifetime of the Centre, the Board and management have placed a major emphasis on innovation and the benefits of research to the Centre's user-partners and society in general. Teamwork and effective interaction between partners have been key factors. The choice of research topics, our extensive use of thematic meetings, and investment in pilot projects have been just some of the actions we have taken to raise awareness that research at the Centre shall result in innovations in the public and private sectors, as well as for the research partners.

The Centre Board saw the need for a set of KPIs (Key Performance Indicators) for Klima 2050 in addition to the performance indicators reported to the Research Council of Norway. These KPIs was tools that promoted the Centre vision in setting the right direction and in order to answer the success criterion for Innovation and Value Creation for the SFI. The KPIs acted as a performance management for the Centre Board and measured relevant partner benefits and partner involvement. Examples of KPIs the late years of the Centre period were no. of pilot projects, thematic meetings, PhD visits to user partners, and external publicity (visit at the website).

Future prospects

The vision of SINTEF is Technology for a better society. SFI Klima 2050 is in line with the strategic plans of SINTEF. Contributions to the development of a sustainable future, e.g. by improved adaptation performance of the built environment related to climate change and increased precipitation make SINTEF reach towards its vision.

SINTEF, in close cooperation with NTNU, have been working within the research field of moisture robust and climate adapted buildings for the last sixty years. SINTEF had already from the year 2000 put a strong focus on consequences of climate change exposure through the former Klima 2000 programme. Increased precipitation both as rain and snow has been a focus area, so has wind exposure and increase in temperature. SINTEF has been working with these aspects both from a technological point of view, but also from a societal and organisational point of view (societal research). SINTEF has through the Centre period strengthen the multidisciplinary research and collaboration within the fields of climate exposure, building technology, stormwater management, slide risks and decision-making processes in society and organisations. Together with NTNU, we probably boost the largest number of research scientists, students, industry, and public partners in Scandinavia who work in a multi-disciplinary collaborative effort to reduce societal risk associated with climate change and enhanced precipitation.

Through the Centre, we have had better possibilities to give input to hearings and contribute with knowledge to the development of building regulations and policy documents. The relevance of the field of the Centre is increasing as years go by. Klima 2050 is envisioned as a start of a permanent research and innovation centre on technology for climate adaptation of buildings and infrastructure. This will be in focus in the coming years.

There have been made a summary report for the partners for each of the 16 pilot projects explaining what has been achieved and disseminated, where and how data are stored and if and how the different pilot projects, which also involve research infrastructure, will be continued in new initiative.

The research partners, in particular, have a strong focus on gaining new R&D projects within the field. The competition for business-oriented national research projects is particularly strong for the time being. Horizon Europe has large programs highly relevant for the Centre researchers and user partners and initiatives have been taken, projects won and lost.

Conclusions

Path to innovation

The centre for research-driven innovation (SFI) have a goal of developing competence that is important for innovation and value creation with the user partners. The overall goal for SFI Klima 2050 has been to reduce associated societal risks with climate change, increased rain- and floodwaters exposure in the built environment. The objective has been determining the broad composition of the consortium with both industry partners and public partners, all with key roles when it comes to climate adaptation.

The industry partners in the Center represent important parts of the Norwegian construction industry; advisors, contractors and manufacturers of building materials and technology: Skanska Norge, Multiconsult ASA, Mesterhus, Norgeshus AS, Leca Norge AS, Isola AS and Skjæveland Gruppen AS. The Center also includes important public developers and property developers: Statsbygg, the Norwegian Public Roads Administration, the Norwegian Railway Directorate and Avinor AS. Key policy makers and actors are also Trondheim municipality, Norway's waterways and Directorate of Energy (NVE) and Finance Norway.

The composition of partners has given a wide scope in type of innovations. At the end of the SFI period it is registered more than 50 innovations and user-oriented results from the Centre. In "Partnerskapets Innovasjoner"[13] (Partner Innovations) we show examples of innovations from each of the Centre's user partners. The wish is to show the breadth in type of innovations more than presenting the most important innovation for each partner.

New experts in climate adaptation

An important part of the SFI has been to train specialists in climate adaptation within Klima 2050's focus areas; moisture-resistant buildings, stormwater management, water-triggered landslides and decision-making processes and instruments. The goal at the start of the Center was to contribute to the education of 50 M.Sc and 15 PhD/post.docs. By at the end of the SFI period, we have reached 135 M.Sc and 18 PhD Candidates will complete. In addition 7 post.docs has been engaged by the Centre.

The students have contributed a large and important effort to achieve Klima 2050s academic results, but most importantly, the result is nevertheless the professional competence they bring into the construction industry. Furthermore, our experience is that the activity linked to the master's students and PhD Candidates has been central to bring together subjects and partners in the Centre. In the booklet "Spesialister i klimatilpasning"[14] (Experts in climate adaptation), we provide an overview of key results from the PhD works and our contribution to the education of M.Sc specialization in climate adaptation.

Pilot projects as a measure for innovation and collaboration

In SFI Klima 2050, we have defined a pilot project to be a building or structure, a delimited part of, or connected to, a building or facility a process or framework. In total we have had 16 pilots. The pilots have included the development of new solution(s) or new process(es), all with goals to show reduction of social risk through measures for climate adaptation. A central motivation for the pilots has been to document the solutions or the processes so that they provide security for use in other projects. The pilot projects have been central development arenas for the partnership. We have through the pilots achieved a good interaction between the partners and a closer link between the user partners and the Centre's PhD candidates and master's students. The pilot projects have been the Centre's main arena for product development and testing results at the same time as they have been positive for the dissemination of knowledge from the Centre. The innovation potential associated with a solution, process or similar has

[13] Time B & Kvande T: ***Partnerskapets innovasjoner***. Klima 2050 Report 41. Trondheim 2023. ISBN 978-82-536-1790-9
[14] Time B & Kvande T: ***Spesialister i klimatilpasning***. Klima 2050 Report 42. Trondheim 2023. ISBN 978-82-536-1792-3

proved easier to obtain demonstrated through research in a pilot than through other research methods. The projects have also been a great opportunity to show off the partnership. In a booklet “Pilotprosjekter”[15] (Pilot projects), we present the pilot projects and the most central innovations they have resulted in.

Tools and guidelines for climate adaptation

SFI Klima 2050 aims to reduce societal risks associated with climate change, increased rain- and floodwater exposure in the built environment. That objective cannot be achieved by the partnership alone. The partnership therefore wants central tools and guides to be available for use by the whole Norwegian construction industry. An industry that is characterized by a large number of small and medium-sized companies, and which can therefore be difficult to change quickly. Klima 2050 has contributed to the development of a number of tools to contribute to climate adaptation of buildings and infrastructure in view of a changing climate. The tools include guides, instructions and models within climate exposure and moisture-resistant buildings, stormwater management, measures for prevention of water-triggered landslides and improved decision-making processes. The target group for the overall package of tools from Klima 2050 embraces most of the key players in construction, real estate, the construction and transport sector including municipalities and other public actors. A booklet “Verktøy og veiledere for klimatilpasning»[16] (Tools and guidelines for climate adaptation) presents examples of tools and guidelines. Several of the tools can be used in certification and management systems and the buildings regulations can point to some of the tools as aid for planning and construction. We have had focus on ease of use in the development of the tools. There is a great societal benefit in that climate adaptation and consequences of climate change is thought of in the development and transformation of development areas, measures, management and operation.

What is next?

Through 8 years of research, development and innovation activities in a collaborative atmosphere between research, private and public sector we think we can state that our goals to a large degree have been fulfilled.

There is a strong will in the partnership to proceed collaboration, the Klima 2050 Centre Board has therefor decided to establish a “Klima 2050 network”. Why? Society is only at the start of the work on better climate adaptation of the built environment. For 8 years, SFI Klima 2050 has identified challenges, developed new knowledge and contributed to many new innovations, but the "challenge" is by no means completed and the collaboration about knowledge and solutions should continue. It is a wish that the network shall i) share best practices ii) be an accelerator for best practice iii) collaborate in communicating with/to the society iv) have a common dialogue towards the authorities and v) create and establish new projects

[15] Time B & Kvande T: ***Pilotprosjekter***. Klima 2050 Report 44. Trondheim 2023. ISBN 978-82-536-1796-1
[16] Time B & Kvande T: ***Verktøy og veiledere for klimatilpasning***. Klima 2050 Report 43. Trondheim 2023. ISBN 978-82-536-1794-7

Appendix

Appendix 1

Statement of accounts for the complete period of centre financing

Note: Funding and cost summarised for the entire centre period.

SFI Annual Work Plan 2015-2023 - Project Characteristics and **Costs** (All figures in 1000 NOK)

Item	Collaboration project *	Type of Research**	Incentive effect***		SINTEF	NTNU	Meterologisk Institutt	NGI	BI	Skanska	Multiconsult	Weber	Isola	Finans Norge	Mesterhus	Norgeshus	Powel	Skjæveland gruppen	Statens Vegvesen	Statsbygg	Avinor	Jernbaneverket	NVE	Total cost
WP1	YES	F	1111		9 449	9 070	852	-	-	1 044	861	570	909	-	426	1 089	-	1 250	-	186	-	-	-	25 706
WP1	YES	I	0110		9 449	9 070	852	-	-	1 044	861	570	909	-	426	1 089	-	1 250	-	186	-	-	-	25 706
WP2	YES	F	1111		11 867	10 199	750	-	-	774	1 305	949	895	643	107	178	1 074	2 961	-	288	-	-	-	31 989
WP2	YES	I	1110		11 867	10 199	750	-	-	774	1 305	949	895	643	107	178	1 074	2 961	-	288	-	-	-	31 989
WP3	YES	F	0111		3 358	4 956	410	13 181	-	641	1 135	611	-	-	-	-	898	1 097	-	-	-	-	-	26 285
WP3	YES	I	0111		3 358	4 956	410	13 181	-	641	1 135	611	-	-	-	-	898	1 097	-	-	-	-	-	26 285
WP4	YES	F	1111		18 593	360	18	40	9 416	738	1 279	-	-	995	211	347	-	3 094	-	600	-	-	-	35 690
Innovation Arena	YES	I	1111		2 028	-	-	-	560	744	859	765	633	401	159	345	450	2 165	-	226	-	-	-	9 335
SFI Equipment					755	2 745	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3 500
SFI Administration					19 644	3 984	-	-	-	-	-	-	-	-	-	-	50	1 806	-	-	-	-	-	25 484
Total budget					**90 367**	**55 537**	**4 042**	**26 403**	**9 977**	**6 399**	**8 739**	**5 024**	**4 242**	**2 683**	**1 436**	**3 225**	**4 443**	**17 680**	**-**	**1 774**	**-**	**-**	**-**	**241 971**

* **Collaboration project:** YES / NO. *If NO, explain the reasons in a separate annex (see the guidelines).*

** **Type of Research**: F= Fundamental research, I=Industrial Research

*** **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

SFI Annual Work Plan 2015-2023 - **Funding** (All figures in 1000 NOK)

Item	Aid Intensity Limit*****		SINTEF	NTNU	Meterologisk Institutt	NGI	BI	Skanska	Multiconsult	Weber	Isola	Finans Norge	Mesterhus	Norgeshus	Statens Vegvesen	Powel	Skjæveland gruppen	Statsbygg	Avinor	Jernbaneverket	Trondheim Kommune	NVE	Other Private funding	RCN Grant	Other Public funding	Total funding	Indirect state aid ******
Type of partner****			R	R	R	R	L	L	L	L	L	SME	SME	SME	P	P	P	P	P	P	P	P					
WP1	100		3 758	2 168	452	0	0	1 242	1 014	824	1 269	0	533	1 089	0	0	1 250	460	322	0	25	0	0	13 121	0	27 527	c
WP1	65		3 758	2 168	452	0	0	1 242	1 014	824	1 269	0	533	1 089	0	0	1 250	460	322	0	25	0	0	13 121	0	27 527	c
WP2	100		3 624	2 169	400	20	0	973	1 458	1 178	1 255	1 000	213	178	1 582	1 156	3 241	562	322	1 814	280	1 720	0	10 582	0	33 725	c
WP2	65		3 624	2 169	400	20	0	973	1 458	1 178	1 255	1 000	213	178	1 582	1 156	3 241	562	322	1 814	280	1 720	0	10 582	0	33 725	c
WP3	100		883	1 350	235	1 181	0	839	1 288	840	0	0	0	0	1 573	978	1 379	0	0	1 769	249	1 620	0	11 584	0	25 768	c
WP3	65		883	1 350	235	1 181	0	839	1 288	840	0	0	0	0	1 573	978	1 379	0	0	1 769	249	1 620	0	11 584	0	25 768	c
WP4	100		2 467	360	18	0	3 326	1 135	1 586	0	0	1 708	423	347	3 146	0	3 094	1 147	644	3 598	50	3 241	0	10 091	0	36 379	c
Innovation Arena	65		0	0	0	0	448	944	1 034	940	808	576	234	345	362	475	2 290	374	168	267	43	253	0	295	0	9 856	c
SFI Equipment			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	272	0	0	728	0	1 000	c
SFI Adm.			78	0	0	0	0	27	200		2		87	0	1 383	700	1 956	256	300	170	200	1 025	0	14 311	0	20 694	c
Transfer																									0	0	
Total budget			**19 074**	**11 735**	**2 192**	**2 403**	**3 774**	**8 214**	**10 339**	**6 624**	**5 857**	**4 283**	**2 236**	**3 225**	**11 200**	**5 443**	**19 080**	**3 819**	**2 400**	**11 200**	**1 672**	**11 200**	**0**	**96 000**	**0**	**241 971**	

**** **Type of partner**: R=Research organisation, P=Other public, L=Large Enterprise, SME=Small and medium sized enterprise

***** **Aid Intensity Limit:** Indicate percentage as follows: Fundamental research 100 %. Industrial research 65 % for collaboration projects, 75 % if only SMEs included in the collaboration project .

****** **State aid:** If no indirect state aid, cf. paragraph 28 and the consortium agreement: specify which condition a) - d) is fulfilled.
If none of the conditions are fullfilled, leave the column blank and include a separate calculation of indirect aid as annex (see the guidelines).

Appendix 2
List of Post-docs, Candidates for PhD and MSc degrees during the full period of the centre

Postdoctoral researchers with financial support from the centre budget

Name	M/F	Nationality	Scientific area	Years/period in the centre	Scientific topic	Main contact
Anne Kokkonen	F	Finnish	Decision-making processes and impact	2018-2021	Decision making processes and impact/organizational change processes.	L.Bygballe
Åshild L. Hauge	F	Norwegian	Decision-making processes and impact	2016-2018	Decision processes for climate adaption	B. Time
Jardar Lohne	M	Norwegian	Climate exposure and moisture resilient buildings	2016-2021	Climate adaptation by maintenance and upgrading of existing buildings	T. Kvande
Erlend Andenæs	M	Norwegian	Climate exposure and moisture resilient buildings	2021-2023	Risk assessment of blue-green/grey roofing solutions	T. Kvande
Luca Piciullo	M	Italian	Landslides trigged by hydro-meteorological processes	2016-2018	Performance analysis of landslide early warning systems at regional and local scales	A. Solheim
Luca Schiliro	M	Italian	Landslides trigged by hydro-meteorological processes	2018-2019	Physical modelling of landslide initiation at regional	A. Solheim
Victoria Capobianco	F	Italian	Landslides trigged by hydro-meteorological processes	2019	Landslides safety measures	A. Solheim

PhD candidates who have completed with financial support from the centre budget

Name	M/F	Nationality	Scientific area	Years/period in the centre	Thesis title	Main thesis Advisor
Lars Gullbrekken	M	Norwegian	Moisture resilient buildings	2015-2017	Climate adaptation of pitched wooden roofs	T. Kvande
Vladimir Hamouz	M	Czech	Stormwater management	2016-2018	Retention and detention-based roofs for stormwater management in urban environments in cold climates	T. Muthanna
Aynalem Tassachew Tsegaw	M	Ethioian	Stormwater management	2016-2019	Predicting flows in ungauged small rural catchments using hydrological modelling	K. Alfredsen
Erlend Andenæs	M	Norwegian	Moisture resilient buildings	2017-2021	Risk assessment of blue-green roofs	T. Kvande
Herve Vicari	M	Italian	Landslides trigged by hydro-meteorological processes	2018-2021	Investigation of debris flow entrainment and mitigation using flexible barriers. Physical and numerical modelling	V. Thakur
Silje Asphaug	F	Norwegian	Moisture resilient buildings	2017-2022	Moisture performance of thermally insulated basement walls in cold climates	T. Kvande
Erin Lindsay	F	New Zealand	Landslides trigged by hydro-meteorological processes	2017-2023	Landslide early warning system	S. Nordal
Vincent Pons	M	French	Stormwater management	2019-2023	Climate change and future of green infrastructure from roof to city scale.	T. Muthanna

PhD candidates who have completed with other financial support, but associated with the centre

Name	M/F	Nationality	Source of funding	Scientific area	Years in the centre	Thesis title	Main thesis Advisor
Birgitte G. Johannesen	F	Norwegian	Trondheim commune	Stormwater management	2017-2019	Investigating the use of extensive green roofs for reduction of stormwater runoff in cold and wet climates	T. Muthanna
Kaj Petterson	M	Swedish	Chalmers University	Moisture resilient buildings	2016-2020	Mitigation of urban storm water runoff through application of computational fluid dynamics	Angela Sasic Kalagasidis
Yifru, Ashenafi Lulseged	M	Ethiopian	NTNU	Landslides and slope stability	2017-2020	Investigation of a screen structure for mitigation debries-flows along coastal roads	V. Thakur
Atle Engebø	M	Norwegian	NTNU	Moisture resilient buildings	2017-2022	Collaborative project delivery methods	Ole Jonny Klakegg
Manuel Franco Torres	M	Spanish	Multiconsult	Stormwater management	2016-2022	Framing Urban Water	R. Ugarelli
Naja Kastrup Friis	F	Danish	DTU	Moisture resilient buildings	2021-2022	Building technology in artic climate	Eva Birgit Møller

PhD students with financial support from the centre budget who still are in the process of finishing studies

Name	M/F	Nationality	Scientific area	Years in the centre	Thesis topic	Main thesis Advisor
Bridget O'Brian Thodesen	F	American	Moisture resilient buildings	2015-2023	Blue-green roof solutions in cold climates	T. Kvande
Elhadi Mohsen Hassan Abdalla	M	Sudan	Stormwater management	2019-2023	Developing design tools for green stormwater infrastructures in cold climates.	T. Muthanna
Jørn Emil Gaarder	M	Norwegian	Moisture resilient buildings	2020-2024	Climate implication and adaption measures for buildings	T. Kvande
Jon Ivar Belghaug Knarud	M	Norwegian	Moisture resilient buildings	2017-2023	Hygrothermal Modeling of Masonry with Interior Insulation Retrofit	T. Kvande
Petter Fornes	*M*	*Norwegian*	*Landslides trigged by hydro-meteorological processes*	*2016-2019*	*Landslides, development of analytical and numerical code*	*S. Nordal*
Ola Eggen Thorseth	*M*	*Norwegian*	*Decision-making processes and impact*	*2016-2017*	*Understanding (un)learning as a catalyst for change in institutional logics*	*R. Kvålshaugen*
Anna Eknes Stagerum	*F*	*Norwegian*	*Moisture resilient buildings*	*2019*	*Moisture resilient buildings*	*T.Kvande*

MSc candidates with thesis related to the centre research agenda and an advisor from the centre staff

Name	M/F	Nationality	Scientific area	Year(s) in the centre	Thesis title	Main thesis Advisor
Jessica Ka Yi Chiu	F	Hong Kong	Landslides trigged by hydro-meterological processes	2015	Landslide risk management perceptions in territories -- comparative case studies of Hong Kong and Norway	A. Solheim
Sandvik, Hanna Vebjørnsen	F	Norwegian	Climate exposure and moisture resilient buildings	2016	Heftsonekarakterisering i teglmurverk	T. Kvande
Lindseth, Hanna Kristine Haug	F	Norwegian	Stormwater management	2016	Investigation of filter media towards road pollution and airport de-icing chemicals	T. Muthanna
Andersen, Ole Kristian Mørch:	M	Norwegian	Decision-making processes and impact	2016	Flomrisiko og konsekvenser for arealplanleggingsprosessen og hvordan det oppleves av beboere i flomutsatte områder	K. O'Brien
Andersen, Julie Elisabeth Hilland:	F	Norwegian	Stormwater management	2016	Hydraulic Performance of Advanced Treatment Media to Improve Quality of Stormwater from Airports Exposed to De-icing Chemicals	T. Muthanna
Wood, Iselin Helene	F	Norwegian	Decision-making processes and impact	2016	Hvorfor trepartssamarbeid? En casestudie av konsortiet Klima 2050: perspektiver fra det offentlige, næringslivet og forsknings- og utdanningssektoren.	B. Aarset
Trandem, Jens Hissingby	M	Norwegian	Stormwater management	2016	Testing of Infiltration System for Stormwater - Permeable Pavement	T. Muthanna
Hansen, Espen	M	Norwegian	Climate exposure and moisture resilient buildings	2016	Luftstrømning i skrå tretak - Eksperimentelle undersøkelser og numeriske beregninger.	T. Kvande
Skjeldrum, Petter Martin	M	Norwegian	Climate exposure and moisture resilient buildings	2016	Ombygging til Blågrønne Tak - En undersøkelse av bygningstekniske utfordringer ved å bygge om eksisterende tak til blågrønne tak.	T. Kvande
Vikan, Torun Krangsås	F	Norwegian	Climate exposure and moisture resilient buildings	2016	Klimatilpasning av bygninger - Kartlegging av markedspotensiale til klimatilpasning blant partnere i SFI Klima 2050.	T. Kvande
Stefferud, Sindre	M	Norwegian	Stormwater management	2016	Soil Moisture Measurements and Evapotranspiration in Extensive Green Roofs.	T. Muthanna
Becker, Mareike Anika	F	Norwegian	Stormwater management	2016	Assessment of Downspout Disconnection by Modelling Infiltration Potential in Urban Areas.	T. Muthanna
Mjønes, Tore Bjørge	M	Norwegian	Stormwater management	2016	Detektering av snø- og vindfordelingen over grønne tak.	T. Muthanna
Wolebo, Amanuel Petros	M	Ethiopia	Landslides trigged by hydro-meterological processes	2016	Advanced Probabilistic Slope Stability Analysis on Rissa Slope	G.R. Eiksund

Name	M/F	Nationality	Scientific area	Year(s) in the centre	Thesis title	Main thesis Advisor
Hidalgo , Carlos Martinez	M	Spanish	Stormwater management	2016	Infrastructure asset management for nature-based solutions (NBS): a guidance for collecting asset information and data for NBS maintenance management Application at Trondheim district	R. Ugarelli
Søndenaa, Mathilde Hansen	F	Norwegian	Stormwater management	2017	Hydrologiske dimensjoneringsmetoder i små nedbørfelt.	K. Alfredsen
Nyhus, Even	M	Norwegian	Stormwater management	2017	Implementation of GARTO as an infiltration routine in a full hydrological model.	K. Alfredsen
Ravindra, Ganesh	M	India	Stormwater management	2017	Impacts of climate change on flow regimes in middle Norway	K. Alfredsen
Aas, Marte Irtun	F	Norwegian	Stormwater management	2017	Infiltrasjonskummer – kapasitet og design	T. Muthanna
Balstad, Sondre	M	Norwegian	Stormwater management	2017	Regnbed – dimensjonering og måling av infiltrasjon på vinteren.	T. Muthanna
Rognstad, Audhild Bakken	F	Norwegian	Stormwater management	2017	Treatment of Stormwater Using Large Particle Size Fraction of Incineration Bottom Ash.	T. Muthanna
Kleiven, Guro Heimstad:	F	Norwegian	Stormwater management	2017	Assessing the robustness of raingardens under climate change using SDSM and temporal downscaling	T. Muthanna
Mittet, Jonas	M	Norwegian	Stormwater management	2017	A regionalisation technique for urban ungauged catchments	T. Muthanna
Slapø, Fredrik	M	Norwegian	Climate exposure and moisture resilient buildings	2017	Kvalitetsvariasjon i murverk som følge av vannmengde i mørtelen	T. Kvande
Lund, Sondre Dahlen	M	Norwegian	Climate exposure and moisture resilient buildings	2017	Fuktsikre bygningsdeler mot terreng	T. Kvande
Olsen, Tom-André	M	Norwegian	Climate exposure and moisture resilient buildings	2017	Uttørking av kompakte tretak med smarte dampsperrer – Bjelkelagets betydning for fuktforholdene	S. Geving
Østgren, Liv Malin Ellen Mo	F	Norwegian	Landslides trigged by hydro-meterological processes	2017	Mitigation of Uncertainties in Rainfall-Induced Landslide Prediction Models in a Changing Climate - Kvam Case Study	G.R. Eiksund
Arnfinnsen, Simon	M	Norwegian	Landslides trigged by hydro-meterological processes	2017	Characterization of shallow landslides, based on field observations and remote sensing	J.M. Cepeda
Stagrum , Anna Eknes	F	Norwegian	Climate exposure and moisture resilient buildings	2018	Fuktopptak i plastisolasjon	T. Kvande
Eggen, Martin	M	Norwegian	Climate exposure and moisture resilient buildings	2018	Lufting av skrå tretak	T. Kvande
Røer, Olaf	M	Norwegian	Climate exposure and moisture resilient buildings	2018	Lufting av skrå tretak	T. Kvande

Name	M/F	Nationality	Scientific area	Year(s) in the centre	Thesis title	Main thesis Advisor
Hauge, Emilie Olsen	F	Norwegian	Landslides trigged by hydro-meterological processes	2018	The Influence of Water Content and Mineralogy on the Shear Strength of two Petrographically Contrasting Norwegian Tills	B. Frengstad
Falck, Mattis	M	Norwegian	Landslides trigged by hydro-meterological processes	2018	Hydrometeorologiske terskler for jordskred på lokal skala - Undersøkelser i Hornindal og Gudbrandsdalen	A. Solheim
Carey, Graeme Robert	M	Canadian	Landslides trigged by hydro-meterological processes	2018	Back-analysis study of selected Norwegian debris flow and debris Avalanche events	J.M. Cepeda
Skrede, Thea Ingeborg	F	Norwegian	Stormwater management	2018	The Applicability of Urban Streets as Temporary Open Floodways - A case study from Bergen, Norway.	T. Muthanna
Schärer, Lotte Askeland	F	Norwegian	Stormwater management	2018	Comparing experimentally measured runoff coefficients with field observations for detention-based roofs.	T. Muthanna
Kalnes, Hege Merete	F	Norwegian	Stormwater management	2018	Prediction of Culvert Failure - A desktop study of water-driven culvert failure in Soknedal using a developed method	K. Alfredsen
Drageset, Anine	F	Norwegian	Stormwater management	2018	Co-Creating Nature-Based Solutions and Green Spaces in a Nordic Municipality	T. Muthanna
Russwurm, Ingrid Lindberg	F	Norwegian	Stormwater management	2018	Modelling detention performance of green roofs in cold climates	T. Muthanna
Danbolt, Julie	F	Norwegian	Climate exposure and moisture resilient buildings	2018	Klimatilpasning av bygninger - Aktuelle hjelpemidler for prosjektering	T. Kvande
Kliewer, Dennis	M	German	Stormwater management	2018	Runoff Modelling and thereon based Dimensioning of Stormwater Management Solutions: Raingarden and Detention Roof by Considering Norwegian Stormwater Management Practices	E. Sivertsen
Pedersen, Vendel Marie	F	Norwegian	Stormwater management	2018	Kombinert hydrologisk - hydraulisk modell for urbane nedbørsfelt	K. Alfredsen
Lange, Frieda	F	Norwegian	Landslides trigged by hydro-meterological processes	2018	Modelling Seasonal Stability of Shallow Glacial Till on Steep Rock Slopes in Southeast Norway via Finite Element Analysis	S. Nordal
Solymar, A	F	Hungarian	Decision-making processes and impact	2018	Green public procurement in the construction industry: Current practices, drivers, barriers, and opportunities in Oslo municipality.	L. Bygballe
Klingbeil, Artur	M	German	Stormwater management	2018	Development of methods to combine social network analysis and institutional logics applied to research projects in the urban water sector	R. Ugarelli
Hernes, Ragni Rønneberg	F	Norwegian	Stormwater management	2018	Evaluating Hydrological Performance of LID-Modules in Mike Urban - A Case Study of CSO Reduction in Grefsen, Oslo	T. Muthanna

Name	M/F	Nationality	Scientific area	Year(s) in the centre	Thesis title	Main thesis Advisor
Huynh, Bao-Thy	F	Norwegian	Stormwater management	2018	Virkninger av arealbruk og klimaendringpå avrenning fra små nedbørsfelt	K. Alfredsen
Baloloy, Christian	M	South-Sudan	Decision-making processes and impact	2018	Benefit cost analysis as a tool for sustainability and resiliency of transport infrastructure system to future climate uncertainty	R.A. Bohne
Vicari, Hervé	M	Italian	Landslides trigged by hydro-meterological processes	2018	Physical and numerical modelling of debris flows	C. Scavia
Clark, Bradley	M	Canadian	Landslides trigged by hydro-meterological processes	2018	Numerical Modelling of Debris Flow Hazards using Computational Fluid Dynamics	V. Thakur
Fjeld, Mads Brandt	M	Norwegian	Landslides trigged by hydro-meterological processes	2018	Detection of Landslides - Using Optical Satellite Remote Sensing	S. Nordal
Hognestad, Åmund	M	Norwegian	Landslides trigged by hydro-meterological processes	2018	Model Testing and Rheology of a Fine Grain Rich Debris Flow	S. Nordal
Parnas, Frida Elisif Ågotnes	F	Norwegian	Stormwater management	2018	Modelling Runoff from Permeable Surfaces in Urban Areas	T. Muthanna
Sondell, Rebecka Snefuglli	F	Norwegian	Stormwater management	2018	Information needs in planning for adaptation to climate-induced floods	T. Skjeggedal
Berg, Julie Eriksen	F	Norwegian	Decision-making processes and impact	2018	Falling Between The Silos: Fragmentation in Roles and Responsibilities Create Barries to Climate Adaption	R. Kvålshaugen
Salvesen, Anniken	F	Norwegian				
Abdalla Elhadi Mohsen Hassan	M	Sudan	Stormwater management	2019	Evaluating approaches to estimate runoff from small ungauged catchments in Norway.	K. Alfredsen
Birkeland, Inger Merete	F	Norwegian	Climate exposure and moisture resilient buildings	2019	Fuktmåling i LVL med trådløse sensorer	T. Kvande
Bunkholt, Nora Schjøth	F	Norwegian	Climate exposure and moisture resilient buildings	2019	Eksperimentell studie av termisk oppdrift i tak med luftet tekning	T. Kvande
Fagerhaug, Anne Kristin Strøm	F	Norwegian	Landslides trigged by hydro-meterological processes	2019	Detaljert geomorfologisk kartlegging og modellering av løsmasseskred	J.M. Cepeda
Gjeset, Grete Eliassen	F	Norwegian	Stormwater management	2019	Modelling of stormwater measures and performance evaluation of underground detention basins	S. Sægrov
Johansen, Katalin Sandor	F	Norwegian	Climate exposure and moisture resilient buildings	2019	Internal Rain Gutter for BIPV Roof	T. Kvande
Kragseth, Birgitte Taugbøl	F	Norwegian	Stormwater management	2019	Modelling of the Interaction Between Storm and Foul Sewers in a Joint Model and Assessment of Infiltration and Inflow (I/I).	S. Sægrov

Name	M/F	Nationality	Scientific area	Year(s) in the centre	Thesis title	Main thesis Advisor
Li, Li	M	Chinese	Stormwater management	2019	Hydrologgical modelling of grey roof during winter: Case study of a pilot project in Trondheim.	S. Sægrov
Marthinussen, Nora	F	Norwegian	Stormwater management	2019	Modelling Airport Runoff Containing De-icing Chemicals	S. Sægrov
Nedza, Nicoline Myhre	F	Norwegian	Stormwater management	2019	Dimensioning detention systems for small urban catchments.	S. Sægrov
Olsen, Eirik Grimsrud	M	Norwegian	Landslides trigged by hydro-meterological processes	2019	Sammenheng mellom regionale hydrometeorologiske forhold og poretrykk mht. utløsning av løsmasseskred.	J.M. Cepeda
Rafdal, Asbjørn	M	Norwegian	Stormwater management	2019	Innvirkning av frost på grunne overvannsssystemer.	S. Sægrov
Rugland, Lise Berit	F	Norwegian	Stormwater management	2019	: A Stochastic Modelling Technique for a Multi-Component Stormwater Management Facility	S. Sægrov
Sletfjerding, Ellinor Bratt	F	Norwegian	Climate exposure and moisture resilient buildings	2019	Smart vapour barriers in compact timber-framed roofs	S. Geving
Sun, Anwei	F	Chinese	Stormwater management	2019	Performance of combined rainbed and storage chamber – Alma.	S. Sægrov
Wahlstrøm, Simen	M	Norwegian	Climate exposure and moisture resilient buildings	2019	Anvisning for massivtrebygging	T. Kvande
Svantesson, Martina	F	Swedish	Climate exposure and moisture resilient buildings	2019	Ventilation by Thermal Buoyancy in the Air Cavity of Pitched Roofs.	K. Hagrydh
Säwén, Toivo	M	Swedish	Climate exposure and moisture resilient buildings	2019	Ventilation by Thermal Buoyancy in the Air Cavity of Pitched Roofs.	K. Hagrydh
Mo, Bendik Haga	M	Norwegian	Climate exposure and moisture resilient buildings	2020	Slagregninntrenging i horisontale fuger på fasader med plane plater	S. Geving
Lid, Henrik Sindre	M	Norwegian	Climate exposure and moisture resilient buildings	2020	Slagregninntrenging i horisontale fuger på fasader med plane plater	S. Geving
Storaas, Knut	M	Norwegian	Climate exposure and moisture resilient buildings	2020	Smart dampsperre i kompakte tretak - vurdering av fuktsikkerhet	S. Geving
Liu, Tianshu	F	Chinese	Climate exposure and moisture resilient buildings	2020	Numerical Study of Air Flow in Air Cavities for Pitched Wooden Roofs	T. Kvande
Johnsen, Ida-Helene	F	Norwegian	Climate exposure and moisture resilient buildings	2020	Vanndampgjennomgang i vindsperretape	T. Kvande
Olsen, Kristina Fjeldstad	F	Norwegian	Climate exposure and moisture resilient buildings	2020	Kjøleeffekten av regn- og smeltevann i omvendte takkonstruksjoner	T. Kvande
Bakken,Eirik Feldberg	M	Norwegian	Climate exposure and moisture resilient buildings	2020	Aktive tak av massivtreelementer og celleglassisolasjon	T. Kvande
Kolsaker, Morten	M	Norwegian	Climate exposure and moisture resilient buildings	2020	Aktive tak av massivtreelementer og celleglassisolasjon	T. Kvande

Name	M/F	Nationality	Scientific area	Year(s) in the centre	Thesis title	Main thesis Advisor
Rønningen, Erlend Sune	M	Norwegian	Climate exposure and moisture resilient buildings	2020	Feltstudie av klimatiske forhold i luftespalter bak kledning og taktekning.	T. Kvande
Strømshoved, Kristoffer	M	Norwegian	Climate exposure and moisture resilient buildings	2020	Fuktmåling i lettklinkerfylling	T. Kvande
Østrøm, Kristoffer Sigurdsson	M	Norwegian	Climate exposure and moisture resilient buildings	2020	Oppfukting og uttørking av limte trematerialer	T. Kvande
Strømberg, Merethe A.	F	Norwegian	Stormwater management	2020	Retrofitting combined sewer systems with nature-based solutions using long-term climate scenarios.	T. Muthanna
Tørudstad, Veronica	F	Norwegian	Stormwater management	2020	A methodology for mapping the vulnerability and hazard potential of temporary floodway	T. Muthanna
Hølleland, Marina	F	Norwegian	Stormwater management	2020	Retrofitting combined sewer systems with nature-based solutions using long-term climate scenarios	T. Muthanna
Teetzmann, Anna	F	Norwegian	Landslides trigged by hydro-meterological processes	2020	Influence of earth pressure coefficients on numerical simulations in RAMMS.	R.M. Singh
Geberegergis, Merhawi Berhe	M	Ethiopia	Stormwater management	2020	Modelling inflow to culverts for E6, Helgeland Sør	K. Alfredsen
Shrestha, Sandeep	M	Nepal	Landslides trigged by hydro-meterological processes	2020	Effect of forest on debris flow	R.M. Singh
Rouault, Christy	F	Canadian	Landslides trigged by hydro-meterological processes	2020	Extreme Multiple Landslide Events in Norway	S. Nordal
Holmli, Espen Daaland	M	Norwegian	Decision-making processes and impact	2020	Klimatilpasset overvannshåndtering i kommunal planlegging	T. Skjeggedal
Sagli, Pernille Moe	F	Norwegian	Stormwater management	2020	Infiltration based systems for stormwater management with multipurpose use	T. Muthanna
Nordstrand, Cecilie	F	Norwegian	Decision-making processes and impact	2020	Investigating key drivers of institutional change in natural hazards fields: An empirical study of quick clay management in Norway	L. Bygballe
Langseth, Cecilie	F	Norwegian				
Thon, Lars Henrik Verde	M	Norwegian	Decision-making processes and impact	2020	Trondheim Spektrum under vann – Samfunnsøkonomiske konsekvenser av flom, stormflo og havstigning.	C. Garnache
Andersen, Vegard	M	Norwegian	Climate exposure and moisture resilient buildings	2020	Fuktskader i tilknytning til terrassedører	T. Kvande

Name	M/F	Nationality	Scientific area	Year(s) in the centre	Thesis title	Main thesis Advisor
Hjermann, Ingrid	F	Norwegian	Climate exposure and moisture resilient buildings	2021	Uttørking av isolerte kjellervegger	T. Kvande
Faukald, Tobias	M	Norwegian	Climate exposure and moisture resilient buildings	2021	Beregninger av fuktforholdene i yttervegger mot terreng	T. Kvande
Larsen, Ingrid Sølverud	F	Norwegian	Climate exposure and moisture resilient buildings	2021	Konsekvens av klimaendringer for bygninger. Endring i behov for oppvarming og varmeisolering i et fremtidig klima	T. Kvande
Nilsen, Miriam Syvertsen	F	Norwegian	Climate exposure and moisture resilient buildings	2021	Vanndampmotstanden til tapen i kombinerte undertak og vindsperre	T. Kvande
Rønningen, Sigurd Torfinnson	M	Norwegian	Climate exposure and moisture resilient buildings	2021	Uventilert fundamentering av moduler	T. Kvande
Skagseth, Vegard Andre	M	Norwegian	Climate exposure and moisture resilient buildings	2021	Isdannelse i nedløpssystemer fra kompakte tak.	T. Kvande
Robstad, Tobias	M	Norwegian	Climate exposure and moisture resilient buildings	2021	Fuktsikkerhet i kompakte tretak med solceller og smart dampsperre	S. Geving
Ninon Gisèle Yvonne Le Floch	F	French	Stormwater management	2021	Spatial and cumulative effects of alternative stormwater management methods	K. Alfredsen
Bergaas, Julie Risti	F	Norwegian	Landslides trigged by hydro-meterological processes	2021	Optical remote sensing and change detection for landslide mapping in a humid climate	A.M. Kääb
Harald Birkeland Larsen	M	Norwegian	Landslides trigged by hydro-meterological processes	2021	Physically Based Modelling of Shallow Landslides with "TRIGRS". A Review of Applications and an Implementation in the Case Study of Jølster 2019, Western Norway	L. Piciullo
Fredrikke Lien Jevne	F	Norwegian	Decision-making processes and impact	2021	Brukerevaluering av nasjonal nettportal for bedre klimatilpasning – En kvalitativ casestudie av DSBs Kunnskapsbanken	Å.L. Hauge
Alhasan, Fatmi	F	Norwegian	Decision-making processes and impact	2021	Cross-sector partnerships (CSP) for climate adaptation of the built environment: A multiple case study of pilot projects within SFI Klima 2050	L. Bygballe
Bernts, Cathrine	F	Norwegian				
Fredriksen, Ole-Morten	M	Norwegian	Stormwater management	2021	Asset Management for Nature-based Solutions (NBS): A Data Registry to Support Decision Making in Stormwater Management in Norway	R. Ugarelli
Bergseng, Kristine	F	Norwegian	Stormwater management	2021	Performance of closed particle removal systems for treatment of road runoff	T. Muthanna

Name	M/F	Nationality	Scientific area	Year(s) in the centre	Thesis title	Main thesis Advisor
Vartdal, Annette	F	Norwegian	Stormwater management	2021	Modelling of combined infiltration and detention solution with investigation of system performance	T. Muthanna
Lillegraven, Marit Gilje	F	Norwegian	Stormwater management	2021	Hydrological modelling of swale and local catchment by Rv3 Stabekken.	K. Alfredsen
Kjellsen, Eirik	M	Norwegian	Stormwater management	2021	Performance evaluation of a combined stormwater detention and reuse system	T. Muthanna
Raugstad, Torill	F	Norwegian	Climate exposure and moisture resilient buildings	2022	Regntett innsetting av tunge skyvedører i yttervegger.	T. Kvande
Strid, Jonas	M	Norwegian				
Støver, Eva Armstrong	F	Norwegian	Climate exposure and moisture resilient buildings	2022	Rain Intrusion Through Horizontal Joints in Façade Panel Systems - Experimental Investigation	T. Kvande
Sundsøy, Marte Haugen	F	Norwegian				
Fuglestad, Fride Engesland	F	Norwegian	Climate exposure and moisture resilient buildings	2022	Dampmotstand til klebefelt i kombinerte undertak og vindsperrer	T. Kvande
Ingebretsen, Sara Bredal	F	Norwegian	Climate exposure and moisture resilient buildings	2022	Mikroklima i luftespalter i luftede fasader og skråtak	T. Kvande
Flytør, John Einar Føll	M	Norwegian	Climate exposure and moisture resilient buildings	2022	Klimatilpasning gjennom forvaltning, drift og vedlikehold ved Avinors lufthavner	T. Kvande
Astrup, Ingrid	F	Norwegian	Climate exposure and moisture resilient buildings	2022	Fuktindekser som hjelpemiddel i fuktprosjektering	T. Kvande
Clausen, Runar Høien	M	Norwegian	Climate exposure and moisture resilient buildings	2022	Usikkerhetsvurdering i fuktprosjektering	T. Kvande
Ranasinghe, Dinithi Nilanthika	F	Sri lankans	Climate exposure and moisture resilient buildings	2022	Effectiveness of innovative Green Roofs and its implications in Storm Water Management for Sustainable Development in Norway	R.A. Bohne
Furuseth, John Isak	M	Norwegian	Landslides trigged by hydro-meterological processes	2022	Automation of landslide detection using Deep Learing	O. Fredin
Riise, Elin Meinich	F	Norwegian	Climate exposure and moisture resilient buildings	2022	Klimatilpasning i plan- og byggeprosessen – en casestudie fra Oslo og Trondheim kommune.	T. Skjeggedal
Haveraaen, Ida Hovland	F	Norwegian	Stormwater management	2022	An Evaluation of the Activation Frequency of Detention Solutions in Current and Future Climate	T. Muthanna
Berger, Christina Marie Krajci	F	Norwegian	Stormwater management	2022	A decision support framework for holistic stormwater management planning	T. Muthanna

Name	M/F	Nationality	Scientific area	Year(s) in the centre	Thesis title	Main thesis Advisor
Grasdal, Øystein	M	Norwegian	Landslides trigged by hydro-meterological processes	2022	Infrastructure exposure to shallow landslides in upper Gudbrandsdalen	G. Gilbert
Passanha, Vasco Maria	M	Portoguise	Stormwater management	2022	Rainwater harvesting performance: Comparison between Portugal and Norway	Maria Cristina De Oliveira Matos Silva
Berg, Martin	M	Norwegian	Climate exposure and moisture resilient buildings	2023	Kompakte tak med utvendig nedløp	T.Kvande
Sakya, Maar Aastesønn	M	Norwegian	Climate exposure and moisture resilient buildings	2023	Fuktsikkerhet i kompakte tretak med smart dampsperre	T.Kvande
Tomren, Jørgen Haldorsen	M	Norwegian	Climate exposure and moisture resilient buildings	2023	Vanndampmotstand til takmaling	T.Kvande

Appendix 3

List of Publications

PhD Theses

Pons, V: ***The Future of Green Infrastructure: From climate data to informed hydrological performance***. PhD in cotutelle between NTNU (Norway) and INSA Lyon (France). Doctoral theses at NTNU, 2023:224, Norwegian University of Science and Technology, Faculty of Engineering, Department of Civil and Environmental Engineering. ISBN: 978-82-326-7147-2

Lindsay, E.R.P: *Using Satellite Imagery to Improve Landslide Detection*. Doctoral theses at NTNU, 2023:199, Norwegian University of Science and Technology, Faculty of Engineering, Department of Civil and Environmental Engineering. ISBN: 978-82-326-7099-4

Vicari, H: ***Investigation of debris flow entrainment and mitigation using flexible barriers. Physical and numerical modelling***. Doctoral theses at NTNU, 2022:351, Norwegian University of Science and Technology, Faculty of Engineering, Department of Civil and Environmental Engineering. ISBN: 978-82-326-5538-0

Asphaug, S.K: ***Moisture performance of thermally insulated basement walls in cold climates***. Doctoral theses at NTNU, 2022:298, Norwegian University of Science and Technology, Faculty of Engineering, Department of Civil and Environmental Engineering. ISBN: 978-82-326-5809-1

Engebø, A: ***Collaborative Project Delivery Methods***. Doctoral theses at NTNU, 2022:210, Norwegian University of Science and Technology, Faculty of Engineering, Department of Civil and Environmental Engineering. ISBN: 978-82-326-6128-2

Franco Torres, M: ***Framing Urban Water***. Doctoral theses at NTNU, 2022:119, Norwegian University of Science and Technology, Faculty of Engineering, Department of Civil and Environmental Engineering. ISBN: 978-82-326-5634-9

Andenæs, E: ***Risk assessment of blue-green roofs***. Doctoral theses at NTNU, 2021:333, Norwegian University of Science and Technology, Faculty of Engineering, Department of Civil and Environmental Engineering. ISBN: 978-82-326-6596-9

Petterson, K: ***Mitigation of urban storm water runoff through application of computational fluid dynamics.*** Doctoral thesis at Chalmers, 2021:4967, Chalmers University of Technology. ISBN: 978-91-7905-500-4

Hamouz, V: ***Retention and detention-based roofs for stormwater management in urban environments in cold climates***. Doctoral theses at NTNU, 2020:305, Norwegian University of Science and Technology, Faculty of Engineering, Department of Civil and Environmental Engineering. ISBN: 978-82-326-4958-7

Yifru, A.L: ***Investigation of a screen structure for mitigating debris-flows along coastal roads.*** Doctoral theses at NTNU, 2020:249, Norwegian University of Science and Technology, Faculty of Engineering, Department of Civil and Environmental Engineering. ISBN: 978-82-326-4846-7

Tassachew Tsegaw, A: ***Predicting flows in ungauged small rural catchments using hydrological modelling***. Doctoral theses at NTNU, 2019:322, Norwegian University of Science and Technology, Faculty of Engineering, Department of Civil and Environmental Engineering. ISBN: 978-82-326-4240-3

Johannessen, B.G: ***Investigating the use of extensive green roofs for reduction of stormwater runoff in cold and wet climates***. Doctoral theses at NTNU, 2019:99, Norwegian University of Science and Technology, Faculty of Engineering, Department of Civil and Environmental Engineering. ISBN : 978-82-326-3796-3

Gullbrekken, L: ***Climate adaptation of pitched wooden roofs***. Doctoral theses at NTNU, 2018:124, Norwegian University of Science and Technology, Faculty of Engineering, Department of Civil and Environmental Engineering. ISBN : 978-82-326-3038-7

Scientific journal articles with peer review

Thodesen B, Andenæs E, Bohne RA & Kvande T: **Mapping Public-Planner Conflicts in SUDS Implementation Using Cultural Dimensions—A Case Study**. *Urban Science* 2023, Vol 7(2), 61; doi.org/10.3390/urbansci7020061, ISSN 2413-8851 (Published online 6 June 2023)

Gaarder JE, Hygen HO, Bohne RA & Kvande T: **Building Adaptation Measures Using Future Climate Scenarios—A Scoping Review of Uncertainty Treatment and Communication**. *Buildings* 2023, Vol 13(6), 1460;

doi.org/10.3390/buildings13061460, ISSN 2075-5309 (Published online 3 June 2023)

Ravindra GHR, Killingtveit Å, Hung CR, Sandberg E, Tveit OA Sivertsen E & Bjelle EL: Aktiv flomdemping: Casestudie av Ilavassdraget i Trondheim kommune. *Vann* 1 /2023, p. 33-44, ISSN 0042-2592

Lohne J, Solheim A, Muthanna TM, Time B, Hauge ÅL, Kalsnes BG, Lædre O & Kvande T: **Ethics of Climate Change Adaptation—The Case of Torrential Rains in Norway**. *Buildings* 2023, Vol 13*(5)*, 1111; doi.org/10.3390/buildings13051111, ISSN 2075-5309 (Published online 22 April 2023)

Jevne FL, Hauge ÅL & Thomassen MK: **User evaluation of a national web portal for climate change adaptation – A qualitative case study of the Knowledge Bank**. *Climate Services* 2023, Vol 30, 100367; doi.org/10.1016/j.cliser.2023.100367, ISSN 2405-8807 (Published online 20.April 2023)

Pons V, Abdalla EMH, Tscheikner-Gratl F, Alfredsen K, Sivertsen E, Bertrand-Krajewski J-L & Muthanna TM: **Practice makes the model: A critical review of stormwater green infrastructure modelling practice**. *Water Research* 2023, Vol 236, 119958; doi.org/10.1016/j.watres.2023.119958, ISSN 0043-1354 (Published online 9. April 2023)

Gaarder JE, Friis NK, Larsen IS, Time B, Møller EB & Kvande T: **Optimization of thermal insulation thickness pertaining to embodied and operational GHG emissions in cold climates – Future and present cases**. *Building and Environment* 2023, Vol 234, 110187; doi.org/10.1016/j.buildenv.2023.110187, ISSN 0360-1323 (Published online 9 March 2023)

Ganerød AJ, Lindsay E, Fredin O, Myrvoll T-A, Nordal S & Rød JK: **Globally vs. Locally Trained Machine Learning Models for Landslide Detection: A Case Study of a Glacial Landscape**. *Remote Sensing* 2023, Vol 15(4), 895; doi.org/10.3390/rs15040895, ISSN 2072-4292 (Published online 6 February 2023)

Brozovsky J, Nocente A & Rüther P: **Modelling and validation of hygrothermal conditions in the air gap behind wood cladding and BIPV in the building envelope**. *Building and Environment* 2023, Vol 228, 109917; doi.org/10.1016/j.buildenv.2022.109917, ISSN 0360-1323 (Published online 13 December 2022)

Abdalla EMH, Alfredsen K & Muthanna TM: **On the use of multi-objective optimization for multi-site calibration of extensive green roofs.** *Journal of Environmetnal Management* 2023, Vol 326 Part A, 116716; doi.org/10.1016/j.jenvman.2022.116716, ISSN 0301-4797 (Published online 9 November 2022)

Abdalla EMH, Muthanna TM, Alfredsen K & Sivertsen E: **Towards improving the hydrologic design of permeable pavements.** *Blue-Green Systems* 2022, Vol 4(2), pp 197-212; doi.org/10.2166/bgs.2022.004, ISSN 2617-4782 (Published online 2 November 2022)

Ingebretsen SB, Andenæs E, Gullbrekken L, Kvande T: **Microclimate and Mould Growth Potential of Air Cavities in Ventilated Wooden Façade and Roof Systems—Case Studies from Norway**. *Buildings* 2022, Vol 12(10), 1739; doi.org/10.3390/buildings12101739, ISSN 2075-5309 (Published online 19 October 2022)

Fuglestad FE, Andenæs E, Geving S & Kvande T: **Determining the Vapour Resistance of Breather Membrane Adhesive Joints**. *Materials* 2022, Vol 15(19), 6619; doi.org/10.3390/ma15196619, ISSN 1996-1944 (Published online 23 September 2022)

Støver EA, Sundsøy MH, Andenæs E, Geving S & Kvande T: **Rain Intrusion through Horizontal Joints in Façade Panel Systems—Experimental Investigation**. *Buildings* 2022, Vol 12(10), 1497; doi.org/10.3390/buildings12101497, ISSN 2075-5309 (Published online 21 September 2022)

Solheim A, Kalsnes B, Strout J, Piciullo L, Heyerdahl H, Eidsvig U & Lohne J: **Landslide risk reduction through close partnership between research, industry, and public entities in Norway: Pilots and case studies.** *Frontiers in Earth Science*, September 2022; doi.org/10.3389/feart.2022.855506, ISSN 2296-6463 (Published online 1 September 2022)

Friis NK, Gaarder JE & Møller EB: **A Tool for Calculating the Building Insulation Thickness for Lowest CO2 Emissions—A Greenlandic Example**. *Buildings* 2022, Vol 12(8), 1178; doi.org/10.3390/buildings12081178, ISSN 2075-5309 (Published online 6 August 2022)

Le Floch N, Pons V, Abdalla EMH & Alfredsen K: **Catchment scale effects of low impact development implementation scenarios at different urbanization densities**. *Journal of Hydrology* 2022, Vol 612, Part B, 128178; doi.org/10.1016/j.jhydrol.2022.128178, ISSN 0022-1694 (Published online 29 July 2022)

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Thi Le: **Modelltesting gir bedre sikring mot skred.** *Byggeindustrien* 12/2016 s 32

Kvande T & Jacobsen T: **Vi bygger nullutslippslaboratorium**. *Byggeindustrien* 10/2016 s 41

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Sægrov S: **Ned med vannet!** *Byggeindustrien* 15/2015 s 224

Kvande T: **Nytt klima: Nye laster.** *Byggeindustrien* 11/2015 s 36

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Thorolfsson ST: **Blågrønne overvannsløsninger**. *Byggeindustrien* 9/2015 s 42

For more results see:

https://www.klima2050.no/

Presentation, lectures, courses and seminars

Popular scientific articles, debates and chronicles

Press releases and news stories

Other publications

Appendix 4 Booklets (informal final report)

Partnerskapets innovasjoner*. Klima 2050 Report 41. Trondheim 2023*

Spesialister i klimatilpasning*. Klima 2050 Report 42. Trondheim 2023.*

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