Open Universiteit

NEW HORIZONS FOR SCIENCE

Updated Research Strategy 2023-2027
Faculty of Science, Open Universiteit

Open Universiteit

NEW HORIZONS FOR SCIENCE

March 25, 2024

Updated Research Strategy 2023-2027
Faculty of Science, Open Universiteit

1 Towards an updated strategy

In this report we present the updated research strategy of the Faculty of Science of the Open Universiteit under the title 'New Horizons for Science'. The Faculty of Science is one of the six Faculties at the Open Universiteit. The Faculty is relatively small by national and international standards, but it has a long-standing disciplinary research tradition, going back to the foundation of the OU in 1985. The faculty in its current form came into being early 2020 joining forces of three departments:

- Computer Science
- Information Science
- Environmental Sciences

These three departments constitute the perfect mix of computer scientists, information scientists and environmental scientists, aiming to have an impact on the digital society and research landscape of the Netherlands in the following three core research themes:

- Software engineering, AI, and cyber security
- Digital transformation, and
- Environmental sustainability

Building on the synergistic strengths of Computer Science, Information Science, and Environmental Sciences, the Faculty is exceptionally positioned to address the innovation agenda and policies set forth by the Dutch government (Nationale Technologie Strategie[1]). The Faculty's strategic alignment with national priorities is evident through its core research themes, which resonate with the crucial technologies identified for fostering economic growth, societal advancement, and security.

Software engineering, AI, and cyber security are at the heart of digital resilience and innovation, aligning with the government's focus on enhancing cyber-infrastructure and developing resilient services. This is critical for safeguarding the nation's digital assets and maintaining a competitive edge in AI-driven solutions.

The topic of digital transformation encapsulates the Faculty's commitment to the integration of digital capabilities in various domains, mirroring the government's emphasis on digitalisation across industries. By advancing research in this area, the Faculty contributes to the nationwide goal of optimising processes and services through technological advancements.

[1] open.overheid.nl/documenten/67b0a9e1-135b-483f-9ed9-3aade270dbce/file

Environmental sustainability is at the core of many society's grand challenges, such as climate change, biodiversity loss, pollution, and the need for green transitions. These transitions require inter- and transdisciplinary approaches in which new and existing knowledge are integrated to deepen our social-ecological understanding of these challenges and to co-create strategies for sustainability transitions that are effective, inclusive and just. The research on environmental sustainability echoes the Netherlands' dedication to the realization of sustainable development goals (SDGs) and the European Green Deal roadmap for universities, outlining their contribution to a sustainable future[2].

By addressing these pivotal areas, the Faculty not only contributes to the national innovation landscape but also demonstrates a profound understanding of the strategic importance of multidisciplinary research in propelling the Netherlands towards its ambitious 2035 goals. In the OU-broad multidisciplinary research program Innovating for Resilience[3], focusing on tackling some of the global modern challenges in order to build resilient social systems, the contributions of the disciplines from the Faculty of Science also play a crucial role, among others for the Digital Transformation and Broad Sustainability themes.

The first Research Strategy of the Faculty of Science was created for the period of 2020-2025, and in 2021 the Faculty participated in two research assessments - LIRS (with the department of environmental sciences) and I&I cluster (including he departments of computer science and information science). The general recommendations that were given are summarised below.

1. Scientific Output: Emphasise publishing in high-quality platforms to increase international visibility, foster a culture of goal-driven research, and more focus on open science.
2. Funding: Be more proactive in acquiring research funding, both second stream as international.
3. PhD Candidates: Enhance focus on internal PhD candidates, reduce reliance on external candidates, encourage master students to publish and pursue PhDs, tighten the Training and Supervision Plan (TSP) for all PhD candidates, monitor success rates and investigate delays of PhD candidates, increase the connectivity of PhD candidates, e.g. through social events, and providing a source of information for newcomers, and allocate more resources for visiting conferences, workshops or similar.
4. Staff Recruitment and Development: Align research goals with recruitment strategically, focusing on diversity and clear promotion criteria.
5. Staff Support: Expand faculty staff to reduce teaching loads and provide more resources for conferences and collaborations.

[2] eua.eu/resources/publications/1078:agreen-deal-roadmap-for-universities.html

[3] www.ou.nl/innovating-for-resilience

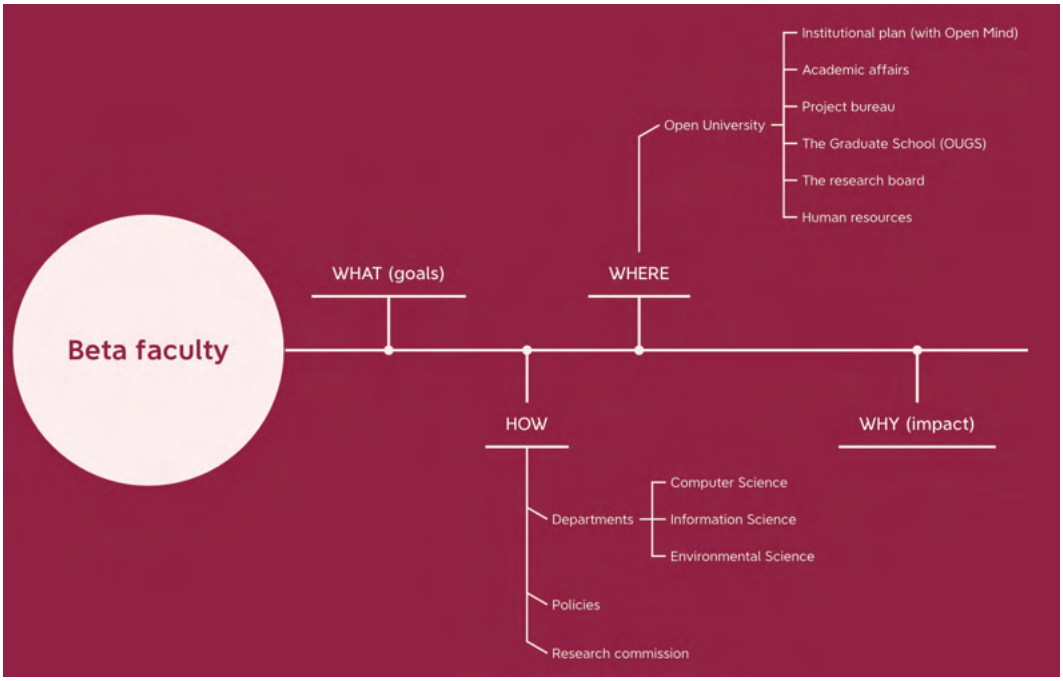


Figure 1.1: Research strategy of the Faculty of Science

Although the SEP[4] (Strategy Evaluation Protocol) does not require faculties to undergo midterm reviews of their research, they do encourage to critically and continuously rethink how to ensure the quality of research and take up the recommendations of research assessments. As a consequence, in 2023, we decided to do an update up the strategy. Firstly, because a new institutional plan (*instellingsplan*) was introduced in 2023 that will extending until 2027. As this plan outlines the strategic direction of our institution for the coming years, it necessitated an alignment of our research strategy to ensure our objectives remain in sync. Secondly, significant personnel changes have taken place, with a dynamic shift in the composition of our research teams. These changes created an opportune moment to reassess our research strategy to incorporate fresh perspectives and expertise. Third, the emergence of new sector-specific plans in the field of computer science and information science has introduced novel challenges and opportunities for research, making it imperative to adapt our approach to stay current and competitive in these rapidly evolving domains.

Together, these factors underscored the need for an update to our research strategy, one that is described in this document.

In structuring this document, we have adhered to a systematic approach, focusing on four essential aspects: what, where, how and why as depicted in Figure 1. This structure

[4] www.universiteitenvannederland.nl/files/documenten/Domeinen/Onderzoek/SEP_2021-2027.pdf

allows us to present a comprehensive picture of our research strategy, from our core objectives to our concrete operational methods and, ultimately, the profound influence we aim to have on our academic and social environment.

The **what** delineates the goals we aim to achieve through our research. The goals of the updated research strategy have only changed slightly and are presented in Chapter 2. The reason for making minimal changes to the previous research goals is their enduring relevance in guiding the Faculty toward its intended direction and addressing its current context. These goals remain consistent with the trajectory the Faculty aims to follow and are well-aligned with the present state of affairs.

In section 3 we emphasise the **why** related to the impact we aspire to make, both within our academic community and in the broader industrial and societal context.

The **where** describes the context to which the faculty is affiliated. In Chapter 4 we will briefly describe the context in which the faculty does the research, that is the institutional plan (*instellingsplan*), academic affair (*Academische Zaken (AZ)*), the graduate school (OUGS), the research board and the project bureau.

The **how** consists of the main vehicles for realising these goals at the faculty level:

- A specific set of policies (described in Chapter 5)
- The support of the Research Committee (described in Chapter 6).
- The **departments** and their respective research programmes are described in Chapters 7, 8 and 9.

2 Strategic goals of the faculty's research

At the Faculty level, our objective is to not only facilitate but also enhance research across the three departments, empowering them to achieve their maximum potential. In this pursuit, the Faculty is guided by three strategic goals, each aimed at supporting research excellence, innovation, and impact.

1. **Substance and Significance** - Elevate the faculty's profile to become a prominently visible and recognised presence within the three core themes of the faculty and their combined strengths:

   - software engineering, AI, and cyber-security
   - digital transformation
   - environmental sustainability

   We aim to achieve recognition both nationally and internationally, positioning ourselves as leaders in these important areas and their combination. In pursuing these aims, we focus not just on the *Substance* — the contents, rigour, and innovations of our research and education within these domains — but also on their *Significance*. Our research, which has both theoretical and real-world impact, has the potential to shape the future. Our mission goes beyond advancing knowledge and education; it's about making a positive impact on society and improving the world.

2. **Talent and Teams** - Support the growth of our research staff, by aiding them in acquiring the necessary skills for conducting top-tier research, including proposal writing and obtaining funding, publishing findings in pertinent journals, books, and conference proceedings. Investing in the well-being of our research staff and equipping them with the right skills aims, to create an innovative research environment. Moreover, by focusing on team dynamics and collaborative efforts, we add dynamics to this innovation, advancing the collective capabilities of our faculty and cultivating collaborations with stakeholders to generate meaningful impact.

3. **Culture and Community** - Establish a culture that is characterised by integrity, sound ethics and diversity. This involves the promotion of ethical standards as the foundation of all activities within our faculty. Moreover, we want to create a supportive environment, open for discussions to establish a community that values and upholds these principles. Our goal is to cultivate a faculty where integrity and sound ethics are not just ideals, but the basic norm for conducting research, thereby enhancing the credibility and trustworthiness of our work.

3 A pathway towards impact

Our faculty comprises three distinguished departments, each bringing unique expertise to the table, focusing on diverse research lines, application areas and themes. The ultimate aim of our activities is to bridge the gap between theoretical exploration and practical implementation, ensuring that our research outcomes contribute tangibly to societal needs and advancements.

At the heart of this aim lies a structured approach to research that encompasses both fundamental inquiry and applied problem-solving. The process of translating research outcomes into valuable impact within our faculty is a strategic undertaking. Beginning with fundamental research, our researchers deeply engage in understanding the core principles and mechanisms of their respective fields. This foundational knowledge forms the basis for applied research activities, where the focus shifts towards addressing specific challenges encountered in real-world scenarios.

Through innovation and translation, the findings derived from research projects are transformed into practical innovations, products, or services designed to address a wide range of application areas. Subsequently, the valorisation of research takes shape through active efforts to promote and disseminate these outcomes, thereby amplifying their impact and relevance within academic and professional circles. Ultimately, this process reaches its purpose through practical application, as research outcomes are implemented across diverse contexts, delivering tangible benefits to society, industry stakeholders, and beyond (see Figure 3.1).

In their respective research program descriptions (found in Chapters 7, 8 and 9), each department outlines how they translate their findings into practical solutions with relevance for broader society, visualising their approach through matrices displaying research lines, application areas and themes.

Within the Environmental Sciences department, for example, research focuses on integrated environmental modelling and human health and environment, intersecting with application areas like plastic pollution and climate change transitions. This interdisciplinary method ensures that theoretical insights directly inform actionable solutions, addressing critical environmental challenges faced by society.

Similarly, the Information Sciences department explores research lines such as governance and digital ethics, applied to areas including healthcare, artificial intelligence, and digital transitions. Through this exploration, they not only deepen our understanding of governance frameworks in the digital age but also provide practical guidance for navigating ethical dilemmas posed by emerging technologies.

Figure 3.1: Turning research into impact

Meanwhile, the Computer Science department concentrates on the research lines software engineering, artificial intelligence, security and education, translating their discoveries into practical solutions to ensure the quality, trustworthiness and safety of modern AI-powered digital systems.

The transition from research to practical application, or the valorisation of research, encompasses a myriad of strategies aimed at maximising societal impact. In addition to fostering collaborative projects with practitioners and engaging with the media through interviews on relevant themes, our research groups utilise various avenues to translate research findings into tangible societal benefits. These include forging partnerships with industry leaders to develop and implement innovative solutions, actively participating in policy-making processes to influence decision-making at the highest levels, and engaging in community outreach programs to directly address the needs of local populations.

Furthermore, we are steadfast in our commitment to exploring alternative channels for sharing insights from our research results, thereby reaching a broader audience. Illustrative of this commitment are endeavours such as researchers' participation in "TEDx" sessions, providing insightful commentary on pertinent topics through traditional meetings, hosting or contributing to discipline-specific blogs, and actively contributing to events at the Brightland Smart Services Campus, such as Hackathons and AI Introductory sessions.

Through active engagement with stakeholders beyond academia, encompassing government agencies, non-profit organisations, and community groups, our research groups ensure that their discoveries are not only accessible but also actionable, thereby driving positive change on a larger scale.

Moreover, we commence initiatives aimed at fostering collaboration with society on applied research themes. For instance, our faculty spearheaded the establishment of the "trustworthy AI Lab" community, closely aligned with the Faculty of Humanities. The primary objective is to facilitate the implementation and adoption of AI in a manner that fosters trust, ensuring the development of legal, ethical, and safe AI applications. This initiative fosters collaboration within a university-wide community, where researchers convene to delve into the topics of trustworthy AI and digital ethics. Our contributions span across various domains, including explainable and responsible AI, digital ethics, software validation and verification, IT governance, and environmental applications of AI. Furthermore, this initiative is linked with an extensive international network of sim-

ilar labs, bolstering the prospects for international projects and funding opportunities.

To facilitate multilateral collaboration between researchers and practitioners, we aim at employing a design-oriented research philosophy that balances academic rigour with practical relevance. In this collaborative approach, a consortium comprising companies and/or public organisations collaborates with one or more universities to explore themes of strategic significance for the organisations and scientific relevance for the researchers. Membership fees from the consortium fund one or more full-time doctoral students, alongside the organisation of regular workshops where representatives from companies/organisations actively participate in research activities, informed by the expertise of researchers on the latest developments in the field. This multi-organisational setup ensures that the research remains relevant to a group or class of organisations and is distinct from consultancy services. Moreover, active involvement from organisations provides researchers with empirical data for their studies.

In essence, our faculty embodies a holistic approach to research valorisation, seamlessly integrating theoretical inquiry with practical applications, and actively contributing to societal progress. Through our collaborative activities and unwavering commitment to excellence, our research groups aim to make meaningful contributions to society, addressing contemporary challenges and shaping the future of their respective fields in profound and impact-full ways.

4 **Research context at the Open University**

4 Research context at the Open University

4.1 Institutional plan (Instellingsplan) 2023-2027

The institutional plan of the Open University[1] outlines the course for 2023-2027 of the whole Open University. To align the faculty's research strategy with the institutional plan, the following key focus areas need to be addressed or taken into account:

High societal impact of research: The institutional plan emphasises the importance of high societal impact of its research endeavours. This involves conducting research that not only contributes significantly to academic knowledge but also addresses pressing societal challenges. Such research is expected to have a tangible and positive effect on the community at large, fostering advancements that benefit society in various aspects, from social welfare to technological innovations.

Connection and impact on with Education: Another cornerstone of the research strategy is the strong link between research activities and educational programs. This connection ensures that the research undertaken at the Open Universiteit directly influences and enhances the quality of education provided. It also facilitates the incorporation of cutting-edge research findings into the curriculum, thereby keeping the educational offerings up-to-date and relevant to current and future societal needs.

Focus on Interdisciplinarity within SSH and Beta Disciplines: The plan places a special focus on fostering interdisciplinary research, to break down silos between disciplines, encouraging a more holistic and inclusive view of research topics, leading to more comprehensive solutions and innovations.

University-Wide Graduate School: An important feature of the Open Universiteit's approach is the establishment of a single, university-wide Graduate School (OUGS). This school encompasses all doctoral candidates, regardless of their discipline. This structure promotes a multidisciplinary research environment and encourages collaboration and knowledge exchange among doctoral students from diverse fields, enriching their research experience and fostering a sense of unity and shared purpose within the university's research community. The OUGS is described in more detail Section 4.4.

[1] Open Universiteit. Met open mind - Instellingsplan 2023-2027, December 2022.

4.2 Responsibilities and support

The responsibility for executing the Faculty's program rests with the individual researchers/research teams, the chairs of the departments, the research committee, and the dean. At the university level, the Rector Magnificus is responsible for research, and is supported by Academic Affairs (Academische Zaken (AZ)), the project bureau, and the Research Board.

4.2.1 The research board

The Research Board advises the rector on overarching, university-wide research issues. As such, all six departments of the Faculty are represented in the Research Board. The chair of the research committee participates in the Research Board at the university level, together with the chairs of other faculties' research committees. The rector magnificus chairs the Research Board.

Topics on the agenda include obtaining extra funding, collaborating with strategic partners such as Zuyderland, IT support or open science policy. The Research Board is also acting jury for a number of OU prizes such as the annual Dissertation Prize, awarded at the PhD Day, or the annual Science Prize (Wetenschapsprijs), awarded at the Dies Natalis.

4.2.2 Academic Affairs (Academische Zaken (AZ))

The department Academic Affairs (AZ) makes policy for and supports teaching, research, educational innovation and impact. The three main tasks of AZ are:

1. Policy and Strategy
2. Quality Assurance
3. Research support (Research Support Office)

Policy and Strategy is the main domain of the policy officers, who advise the Executive Board and are taking part or secretaries to a number of committees within the university, such as the College voor Promoties, Research Board or IT for Research. The beadle of the university is also embedded within Academic Affairs and coordinates the process of PhD defence and graduation.

Quality assurance is closely related to policy advise.

The Research Support Office is part of the department and includes:

Research Ethics Review Committee (cETO) The cETO supervises the provision of information about and compliance with the (legal) rules concerning human-related research. Ethical clearance is obligatory for all studies involving human partici-

pants, and Research Ethics Committee has the authority to give binding recommendations on study design.

Grant officers advise on and supporting grant applications Academic staff can contact the grant officers for help in acquiring second- and third-funding, from individual to consortium applications, from national to European applications. The officers aim to increase the chances of applications being awarded. NB: at the Open University, every grant application passes through the Rector's Office. This process goes through the Project Office (Project Bureau, please see below).

Data steward The data steward advises before, during and after conducting research on the responsible use of data. She can, among other things, help with the drafting of a data management plan (DMP), questions about open science protocols, and safe and secure access to data.

The OU provides support to researchers for their DMPs through the tool DMPonline, so that the plans are in line with funders' requests.

PURE Support Research output is recorded in PURE. For support or questions about PURE, the PURE team can be contacted.

Research communication The AZ Research Communication team is responsible for positioning and creating visibility of scientific research and advises Open University staff on impact activities. As soon as staff members start a new project, have published an article, organise or participate in an external activity, they are invited to contact the communication advisers.

4.2.3 The Project Office (Project Bureau)

The Project Office (*Project Bureau*) supports academic staff with the administrative handling of their grant proposals, and if grant, projects. As part of the Finance and Control department, it prepares the project budget and ensures all financial obligations are met. Beyond that, it guarantees other administrative questions are being dealt with and obtains the mandatory agreement by the Rector Magnificus.

4.2.4 Innovating for Resilience

In 2020 the Open University started the multidisciplinary research programme Innovating for Resilience[2]. This programme focuses on tackling some of the global modern challenges in order to build resilient social systems:

- Inequalities in Vulnerable Areas
- Digital Transformation
- Open Societies

[2] www.ou.nl/innovating-for-resilience

- Broad Sustainability

The central theme for all research on these challenges is 'turning points'. All disciplines that are represented within the Open Universiteit contribute to this programme. Focus: Turning points.

The faculty of Science, participates in this programme. Since 2021, it has hosted four internal PhDs at the Faculty of Science, and seven PhD students at other faculties with a co-promotor from the Faculty of Science.

4.3 Open science

The position paper "Room for everyone's talent"[3] by the Dutch public knowledge institutions and funders of research refers to Open Science as "a new approach to science and academia", that "gives others, in addition to the academics themselves, the opportunity to cooperate on, contribute to and make use of the academic process. This means, for example, that academics share the results of their research more broadly with society, that they make research results more accessible and that they can involve society in the research (such as through citizen science). Open science is bound up inextricably with the modernisation of the system of recognition and rewards. It requires time and attention from academics that cannot be automatically translated as traditional academic output such as publications, but which can have a significant impact on society, science and academia (such as sharing research data)".

The Open Universiteit signed the "Agreement on Reforming Research Assessment" in December 2022, which is agreement between the European Commission, the European University Association and Science Europe. It contains agreements on how, within the transition to Open Science, results should be assessed with the aim of improving the quality and impact of research and it is in line with the national programme "Recognition and Rewards" and the San Francisco Declaration on Research Assessment (DORA). More particularly, it recognises the diversity of contributions to research and emphasises the societal impact, open science, diversity and talent management.

4.4 Open University Graduate School (OUGS)

The OUGS stresses that it is the PhD students that are the future for a university, both in terms of research and teaching (see memorandum, OUGS January 2020). Therefore, the mission of the Graduate School of the Open University (OUGS) is to facilitate optimal development, training and supervision of its PhD students. To achieve this, the OUGS informs, educates and inspires PhD students as well as their supervisors and launches a platform where they can meet (digitally) and learn from each other.

[3] www.nwo.nl/en/position-paper-room-for-everyones-talent

The OUGS is preparing for an institution-wide monitoring system around PhD students. To this end, a project team is looking into the procurement and implementation of Hora Finita.

The OUGS provides several courses for PhD students, offers consultancy and organises events.

Courses – The following courses are offered:

- Introduction to critical writing
- Advanced critical writing skills
- PhD presentation skills
- Doing your PhD@OU

The course *Doing your PhD@OU* deals with scientific integrity, ethics and data management, and is mandatory for all PhD students who started their PhD after 1-1-21 and next to new PhD students (internal and external) more 'seniors' are recommended to register for this course as well. The other courses are optional.

Consultancy – The OUGS offers consultancy on methodology & statistics in response to individual questions which cannot be addressed sufficiently within the supervision teams and is developing a basic statistics course.

Events – The OUGS also organises a series of online meetings called the PhD hang-out, which in 2022 and 2023 included the topics: acquisition of grants, publishing scientific articles, preparing for the defence, sampling your data and open science.

Each year, at a OU PhD day PhD students have the opportunity to get to know each other and tell each other about their research. In 2023, the day was attended by 70 PhD students and rated with a 8 out of 10. Finally, a course on guiding and supervising PhD students is offered yearly to a selected number of supervisors from all OU faculties.

Besides the more general training activities of the OUGS, the Open Universiteit acknowledges that there will be a need for more disciplinary training opportunities for PhD students within their own field of science.

5 Culture and policies

Within the context described in the previous chapter, the Beta Faculty of the OU aims to underpin the following cornerstone policies of the faculty as one strategic means of implementing the goals mentioned in Section 2.

5.1 Regular Research Assessment

Research activities within the departments undergo periodic assessment, typically occurring every five years. This assessment process take place at the National level together with other universities. The assessment adheres to the nationally established protocol known as the Dutch abbreviation SEP[1] (Standard Evaluation Protocol) that is applicable at the time of assessment.

5.2 Research time

The Faculty aims to maintain an equilibrium among various responsibilities of its staff members, including research, teaching, societal engagement, and management. It is the Faculty's general aspiration that tenured staff allocate approximately 30% of their time to research, although individual variations do occur. Research performance is a pivotal component of annual performance evaluations, and plays a significant role in Faculty personnel policies. Performance criteria are tailored to different personnel categories and conform to nationally agreed-upon guidelines, known as UFO[2] guidelines. Staff may choose to save holiday hours for sabbaticals and are encouraged to do so. If the sabbatical is spend to enrich and strenghten research performance, extra resources are available.

5.3 Travel and conference budget

Every research-active staff member is entitled to a travel and conference of 1500 euro per year (2023 and 2024, subject to change). Staff are encouraged to engage in 2nd or

[1] www.universiteitenvannederland.nl/onderwerpen/onderzoek/evaluatie-protocol-onderzoek-sep

[2] www.universiteitenvannederland.nl/en/job-classification-system-ufo

3rd money stream projects which include allowance for travel and stays abroad. There are also other possibilities to increase the budget (e.g. contract teaching or research).

5.4 Membership in National Research Schools

The Faculty encourages that its Departments become members of national research schools in their respective fields. Active participation in the activities of these schools is also encouraged, especially by PhD students.

5.5 Faculty research meetings

Research meetings are held within the departments, and in some cases also in subgroups (e.g. the AI group) on a regular basis ranging from once per week to monthly. Typically, these meetings are hybrid. On the Faculty level, two days are organised every year, one in Spring and the other in the Fall, focusing on education/teaching and research, respectively. These faculty days may include site- or ecosystem visits. Next to that, a seminar series called 'New Horizons' is organised under the auspices of the research committee to further research collaboration among the departments and research lines, also focusing on valorisation, funding and impactful activities.

Every year in November, PROMISES is held, a bottom up research conference for the Faculty's internal and external PhD students where they present their papers/progress in a safe environment.

Fostering the research climate and processes in general, strengthening the research strategy execution and specifically improve the supervision of PhD students are on the agenda for the two meetings with the full professors of the faculty - one in Summer, one in Winter, joined by associate professors and co-promotors depending on the topical agenda.

5.6 PhD Student Education and Training

The faculty has defined complementary policies and provides additional support for PhD students. These policies are embedded in the three strategic goals of the faculty (Substance and Significance, Talent and Teams, and Culture and Community), in accordance with the doctoral regulations of the OU (as adopted by the Doctorate Board of the Open University on 11 October 2023) and aligned with the policies of OUGS.

The primary goals of these policies are:

1. enabling PhD students to finalise their PhD trajectories in accordance with the (scientific) requirements and in a timely manner and
2. strengthen the bonding between PhD's within the Science Faculty.

To achieve these objectives, the faculty focuses on the following aspects.

Quality assurance and support: On average seventy PhD students are connected to the faculty (roughly a third are employed by the faculty and the remainder are external PhD students). Since January 2023 extra support has been allocated to optimise the quality assurance regarding PhD trajectories and 0.5 Fte is dedicated to enhance policies, streamline administration and monitoring of the progress of PhD students (research assistant and secretarial assistant). To that end, a single point of contact is made available to (co)promotors as well as PhD students that can be contacted at promoveren.bw@ou.nl. The quality assurance is executed under direction of the dean of the faculty.

Enhance on-boarding: The faculty welcomes a growing number of PhD students every year. To ensure a smooth start of their trajectory, a new on-boarding process for welcoming PhD students in our Faculty is introduced, which includes an introductory mail and (online) meeting to get acquainted with the available support, to explain the connections with the OUGS and national research schools of the departments and other guidance and support that is available in the Open University. In addition, attention is drawn to the Training and Supervision Plan that needs to be completed and approved by the supervision team within three months after the start. Further improvements will be made, such as expanding the PhD buddy system.

Streamline first year evaluation of PhD students: After the first year PhD students are required to present their research proposal, progress report and the (if necessary revised) Training and Supervision plan, which are approved by the supervision team, and present their work to an evaluation committee. The aims of the first year evaluation are:

To provide the student with feedback on progress towards completing their PhD. This evaluation serves as an opportunity for the student to reflect on the research goals, receive constructive criticism and support from their supervisors and committee members, and make any necessary adjustments to the research plan.

To enable the supervisor to provide an advice to the dean as to whether a completed dissertation is feasible within the specified period. This assessment should be sufficiently supported by the advice of the evaluation committee so that the dean can make a balanced go/no-go decision based on the supervisor's advice.

The evaluation committee assesses the scientific quality, feasibility, scientific and/or societal impact of the PhD research and the competencies and skills of the candidate.

Guide supervision teams: After the first year evaluation, yearly progress meetings with the PhD student are held. The Training and Supervision plan contains the initial agreements about the guidance of supervisors and the timing and frequency of meetings, and can be adjusted when necessary each year. New supervisors of the

faculty are provided with the opportunity to take a course on supervision and guidance that is provided by the OUGS. Because there is a limited amount of spots at the course that the OUGS organises, if needed, the faculty will arrange for an extra courses.

Encourage involvement in education: Internal PhD students can take on educational tasks to a maximum of 20% of their time (depending on their source of funding this may be less) in line with their field of study and in agreement with the supervision team. Tasks can involve tutoring or guidance of bachelor or master students. They are given the opportunity to follow relevant courses in the educational program for teachers if necessary. External PhD students can be involved in education when they are interested, for example for co-supervising graduation assignments fitting with the research.

Travel and research costs: Internal PhD students can use the same travel budget that is provided for other researchers in the faculty. Next to that, provisions can be made that are depending on the way the PhD trajectory is funded and what budgets are secured in third party funding. External PhD students do not have access to financial compensation for research costs at the OU. The faculty assists students in finding and acquiring subsidies and funds that are available to PhD students, such as opportunities to conduct fieldwork abroad, spend time at another university or take part in conferences.

Strengthen the PhD community: In addition to the taking part in the courses and meetings of the OUGS, the faculty also encourages PhD students to get to know each other. A committee of PhD students organises a yearly meeting, with a focus on the connection between science and society and outside-the-box workshops that are relevant to the students from all three departments. Another opportunity for PhD students to meet and present their research is the PROMISES conference

Requirements for training: Every PhD student is required to plan their doctoral education and draw up a Training and Supervision plan (TSP) within the first 3 months. The faculty proposes that the TSP covers a minimum of 30 credits1, and is evenly spread to the scientific discipline (50%) and the academic and personal skills (50%). The TSP can include formal courses as well as on the job training, such as teaching and supervision/coaching, peer-reviewing of articles for scientific journals or coordination of research events. The faculty encourages to attend (international) conferences in the research field and/or doctoral workshops at different universities. In addition to the courses the OUGS offers, PhD students can take part in the external research schools in their respective fields. The faculty provides access to the external research schools SIKS, IPA and SENSE, which can have additional requirements or mandatory courses. An inventory of the most relevant courses for PhD students of the faculty will result in updated guidelines for TSPs.

The thesis: In the doctoral regulations of the Open University the thesis can consist of either an academic treatise (i.e., monograph) on a certain subject or a number of

separate academic treatises, some or all of which have been published, provided that there is sufficient connection between these with regard to a certain subject and that they come with an introduction in which this connection is indicated. When the thesis consists of separate treatises, the faculty proposes that all of the papers are submitted to peer-reviewed journals or conferences.

6 The research committee

The research committee of the faculty (*Facultaire Onderzoek Commissie (FOC)*) is committed to empower the faculty's reputation in research. The FOC will foster a supportive ecosystem that empowers the faculties researchers and students to excel and make significant contributions.

6.1 Composition

The FOC is composed of five dedicated members: three representatives from the Faculty's departments, ensuring a the whole spectrum of the faculties disciplines are voiced; a secretary, who ensures the smooth administration and documentation of the committee's activities; a member responsible for impact and valorisation, focusing on enhancing the practical application and societal benefits of research; and a Chair, who serves as the Research Coordinator, steering the committee's strategic direction.

The FOC meets monthly to discuss and develop advice on issues regarding research within the Faculty and all policies and measures pertaining thereto.

The Chair of the Committee is Member of the OU Research Board and represents the research interests of the Faculty in that Forum. The Chair communicates developments at the Central level and discusses implications for the Faculty of Science within the Committee.

Body that informs the deans and she is invited to the meetings twice a year to discuss the PhD policy.

6.2 Objectives

The Research Committee develops, updates and implements the research strategy and policies. The committee advocates the importance of research at the Faculty of Science, both within and outside the OU. More specifically, it has the following objectives:

1. Streamline research assessments.
2. Enhance our faculty's success in securing funding.
3. Stimulate the culture of collaboration.

4. Improve the research visibility.
5. Improve the success of the PhD programme.

6.3 Streamline research assessments

Our aim is to ensure the continuous evaluation and enhancement of research quality and effectiveness across the faculty. This will be done at two levels.

The national level, i.e. the planning and coordination of regular research assessments (visitaties) following the Strategy Evaluation Protocol (SEP[1]) established by the VSNU, the NWO and the KNAW to evaluate the quality, relevance and viability of research in public institutions in the Netherlands. The NWO signed the Declaration on Research Assessment (DORA[2]) and will gradually implement these more into the SEP.

At the faculty level, we will create a more simplified and comprehensible process for the evaluation interviews (R&O gesprekken) that department heads have with the members every year. Including research assessment into these interviews has several advantages. First, it enables us to obtain an overview of research output that will translate into annual faculty research reports. Second, it will familiarise the members with evidence-based curricula that is promoted by DORA. Last, but not least, it will encourage people to keep their PURE pages updated.

6.4 Enhance success in securing funding

Our strategic vision for enhancing our faculty's success in securing funding from European (e.g. EU Horizon, Interreg, etc.) and national (NWO, NRO, NGF) calls the research committee will:

1. streamline the collaboration with the OU's project office and grant officers of the research support office
2. actively observe and communicating funding opportunities.
3. be the faculty's main point of contact for inquiries and guidance on funding
4. organise peer review processes for proposals upon request
5. organise a series of targeted courses

The targeted courses will address the specific challenges and opportunities presented by these funding mechanisms. These courses are aimed at empowering our researchers with the knowledge and skills necessary to craft compelling project proposals.

[1] storage.knaw.nl/2022-06/SEP_2021-2027.pdf

[2] www.nwo.nl/dora

We will cover a wide range of critical topics, including:

- understanding the funding landscape
- navigating the application processes (e.g. evidence-based curricula from NWO, lump sum funding in EU Horizon, etc.)
- project development as a preparatory step before writing a grant application (e.g. using the Project Logic Tree like Erik Prins' clinic workshops)
- how to build a compelling consortium
- mastering the art of persuasive and clear writing tailored to the expectations of European and Dutch funding bodies, where they will learn to articulate their research goals and impact, develop effective project plans.

Through this initiative, we aim to significantly increase our faculty's competitive edge in securing external funding, thereby fostering research excellence and innovation.

6.5 Stimulate the culture of collaboration

To foster a culture of collaboration in the faculty, we will organise a faculty research meeting (BW Horizons) every 3 months together with the heads of the three departments. Besides discussing themes that are relevant to researchers for the whole faculty we will encourage interaction and partnership among faculty members and departments with the aim to expand an environment where collaborative spirit thrives. This will be done for example through break out sessions where members from different departments will work on some collaborative assignment.

Moreover, we will organise an annual call for proposals that will award faculty initiatives to start interdisciplinary collaboration across the departments of the Faculty.

6.6 Improve the research visibility of the faculty

Our scientific output through articles, doctoral theses and conference contributions are visible through the regular scientific channels. However, improving the visibility of our faculty's research is crucial to attracting talent, funding, and partnerships. Our strategy includes the following activities:

- beter smanewerken met wetenschappescommunicatie (voor beta Emmy) research communication.
- social media, more specifically on Linked-In, researchgate, etc.
- an enhanced faculty website
- OU presence at events organised by Dutch organisations like NWO, IPN (e.g. ICT

with industry, ICT.OPEN, I/O Magazine, SEN symposium, NWA-ORC etc.)

- contribute more in the SIGs like VERSEN, SIGAI, SIGCS, etc.
- contribute more in research schools (IPA, SIKS, SENSE).
- participate in professional associations like for example, KIVI[3] (Royal Dutch Institute for Engineers), sourcing Nederland[4], VVM - netwerk van milieuprofessionals.
- participate in advisory boards.
- engage in proactive media relations to highlight our research achievements and stories in the broader media like popular magazines, newspaper,s radio and television.

Training sessions for researchers will be organised at our research events, ensuring our faculty members are well-equipped to showcase their work. This will include training on effective science communication for researchers, encouraging them to actively participate in disseminating their work online through research blogs and video content.

6.7 Improve the success of the PhD programme

The Research Committee plays a crucial role in assisting the dean with the implementation and oversight of the policies outlined for PhD student education and training (explained in Section 5.6). The committee's involvement is particularly significant in enhancing the quality assurance and support mechanisms for PhD trajectories, optimising the on-boarding process, streamlining first-year evaluations, and coordinating the organisation of PROMISES. By working closely with the dean, the Research Committee ensures that PhD students not only meet the scientific requirements within a timely manner but also foster a strong bond within the Science Faculty, ultimately contributing to a thriving academic community that supports its members' professional and personal growth.

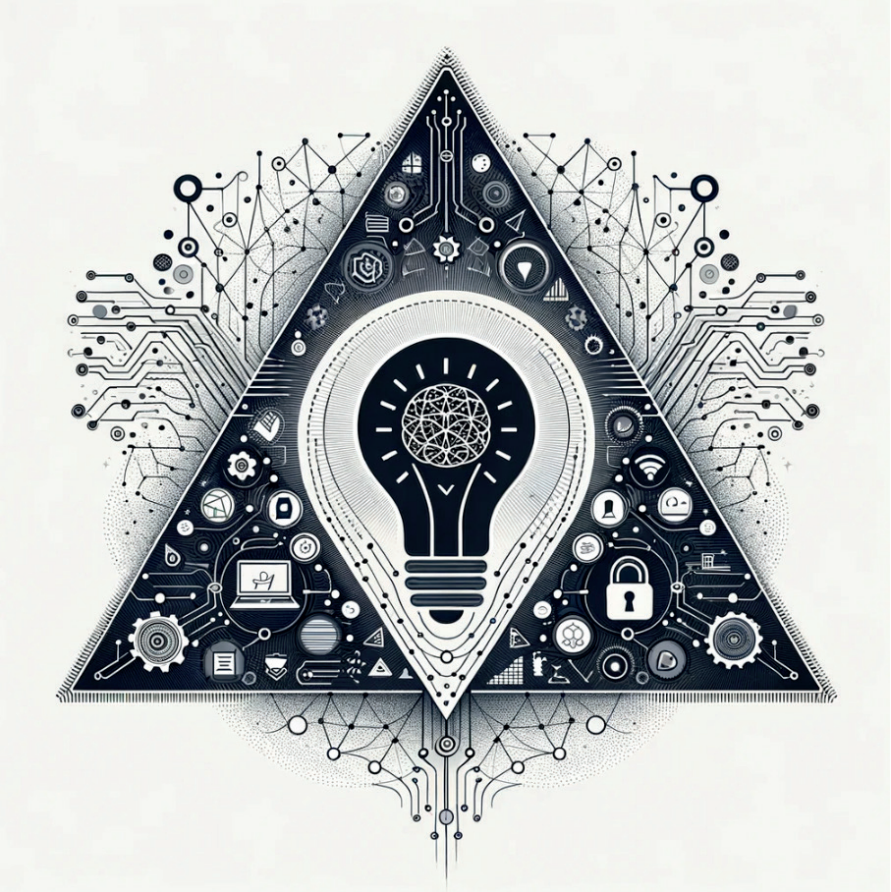
[3] www.kivi.nl/

[4] www.sourcingnederland.nl/

7 Computer Science Research Program 2023-2027

THIS

Towards High-quality and Intelligent Systems



Department of Computer Science, Open Universiteit

7.1 Overview of the department

7.1.1 History

The first research plan of the computer science department was created by the School of Computer Science at the OU in May 2011: *Software Technology Research Plan 2010-2015* [30]. This research program contained two research lines on software technology: *Software Technology for Teaching and Learning* and *Software Technology for Quality Improvement*.

In 2014 the School of Computer Science was integrated into the Faculty of Management, Science & Technology (MST), and renamed to the Department of Computer Science. The MST research committee created an interdisciplinary research program in December 2014: *Learning and Innovation in Resilient Systems: MST Research Program 2015-2020* [22].

In 2017, the MST research program on *Learning and Innovation in Resilient Systems* was assessed in a midterm review over the period 2014-2016. A self-evaluation of the research program was written [23]. The midterm review followed the SEP 2015-2021 'Protocol for Research Assessments in the Netherlands' (amended version, September 2016). The assessment committee considered three assessment criteria: research quality, relevance to society, and viability. Furthermore, three additional aspects were considered: PhD programs, research integrity, and diversity. The assessment outcome was very positive [1].

In 2020 the structure of the OU was reorganized. Since then, the Department of Computer Science became part of the Faculty of Science. A research plan was created for 2020-2025 [29] and, together with the department of Information Science, i.e. C&IS was assessed in 2022 in a National Computer Science Research Assessment following SEP 2021-2027 together with all Dutch universities except Delft (TUD) and Groningen (RUG). The same three assessment criteria were considered: research quality, relevance to society, and viability. Other additional aspects were considered: Open Science, PhD Policy and Training, Academic Culture, and Human Resources Policy.

The outcome was positive, summarizing that C&IS is recognized for emphasizing practical relevance, particularly through engaging a significant number of external PhD and master's students and collaborating with industry partners. The review committee applauds C&IS for undertaking the assessment process despite the department being relatively new to research. The committee notes that C&IS's willingness to embrace scrutiny and feedback is fundamental for its research growth and advancement.

Taking these observations into account, the current document is the update of the research of the Computer Science department for 2023-2027.

7.1.2 Research focus of the department

The Department of Computer Science at the Open University is researching a multi-faceted approach based on four research lines. Each line, while distinct, interconnects to form a comprehensive strategy (see Fig. 1).

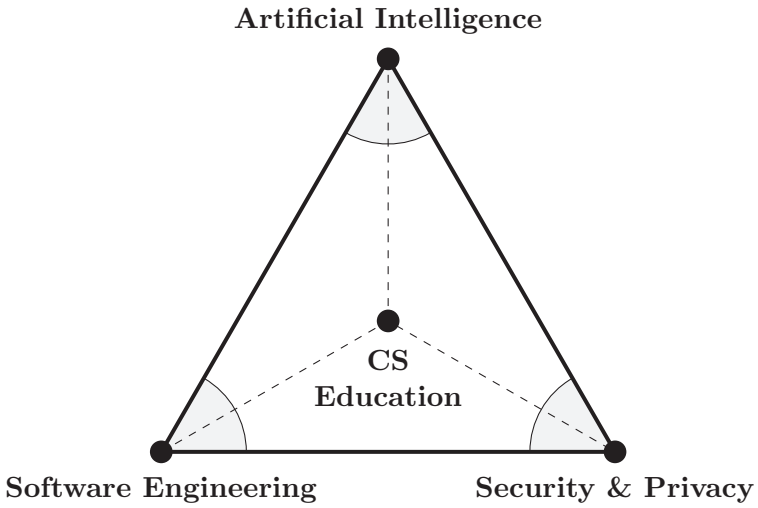


Figure 1: The four research lines at the Computer Science department

- *Software Engineering*, led by Prof. Dr. Tanja E.J. Vos, concentrates on enhancing software reliability through rigorous testing and formal verification methods.
- *Security & Privacy*, steered by Prof. Dr. Ir. Harald Vranken, aims to fortify software and computing systems against breaches, emphasizing measures for preventing, detecting and defending against security and privacy threats.
- *Artificial Intelligence*, under the guidance of Prof. Dr. Natasha Alechina, explores responsible, safe and efficient development of AI systems, in particular exploring how AI can further support and automate aspects of software engineering and security.
- *Computer Science Education*, led by Prof. Dr. Erik Barendsen, works on research supporting teaching and learning of computer science and digital skills, focusing in particular on programming, student-related factors and digital literacy.

Together, these lines form a robust and interdisciplinary network, striving not only to advance the practical aspects of software engineering but also to ensure the safe, secure, and enlightened development of future computing systems. They are shaping a new generation of computer science professionals well-prepared in the latest technologies and methodologies.

7.1.3 Size

Table 1 provides an overview of the amount of FTE involved in the research program.

Table 1: FTE in research lines

Research line	Staff	PhD/Postdoc	Total
Software Engineering	7,1	6,8	13,90
Security & Privacy	4,1	0	4,10
Artificial Intelligence	8,8	4	12,80
Computer science education	1,85	0	1,85

7.1.4 Embedding in the landscape in the Netherlands

7.1.4.1 ICT Research Platform Netherlands (IPN)

The Dutch university Computer Science community has a long tradition of national cooperation. The computer scientists are organized within the ICT Research Platform Netherlands (IPN)[1]. The members of IPN, are the general universities (including the OU) and the universities of the 4TU federation that have a substantial focus on computer science research and/or education, and the Centrum Wiskunde & Informatica (CWI).

Within the IPN, there are intensive collaborations on specific sub-areas in the 'Special Interest Groups (SIGs)':

- VERSEN[2] (Vereniging voor Software Engineering)

  Most members of our department are members of VERSEN. Moreover, the department head (Bastiaan Heeren) chairs the Workgroup on Education by the Dutch National Association for Software Engineering (VERSEN).

- SIG-Cyber Security (ACCSS)[3]
- SIG-Artificial Intelligence (SIGAI)[4]
- Data Science Platform Nederland (DSPN)[5]
- SIG- Future Computer Systems and Networking (FCSN)[6].

The annual national ICT.Open conference aims to bring together scientists from all ICT research disciplines and industries to meet, learn, and exchange ideas. It is jointly

[1] https://ict-research.nl/
[2] https://www.versen.nl
[3] https://accss.nl
[4] https://ict-research.nl/groups/special-interest-groups/sigai/
[5] http://www.datascienceplatform.org/index.shtml
[6] https://ict-research.nl/groups/special-interest-groups/fcsn/

organized by IPN, the HBO-ICT lecturers' network PRIO, and NWO. The department tries to assist these events yearly.

An exceptional initiative is the IPN EDI Working Group that strives to improve equity, diversity and inclusion in the Dutch ICT community. The group organizes concrete actions and events in this area and actively discusses EDI-related topics with policy makers, heads of departments and other relevant stakeholders. The working group holds plenary meetings four times per year. It includes representatives from all Dutch universities as well as CWI and NWO. In the year 2023, Prof. Dr. Tanja Vos from our department has taken on the role as chair of that working group.

7.1.4.2 Research schools

The three national computer science research schools (ASCI[7], IPA[8], SIKS[9]) collaborate closely. The PhDs of the department are member of the research schools that best fit their research topic.

7.1.4.3 Sectorplannen Informatica

In the Netherlands, plans for the sector of computer science, known as 'sectorplannen informatica'[10], have been developed as part of broader initiatives to enhance the quality of higher education and scientific research. These plans are part of a structural investment by the Dutch Government in scientific research across various science and engineering disciplines, including computer science, with a specific focus on strengthening the foundations of basic research.

In 2019, a concise computer science image was published for the Beta and Engineering domains. Within the Beta domain, the disciplines of Mathematics, Computer Science, Physics, and Chemistry were prioritized to participate in the first Beta and Engineering sector plan for 2018-2025 (referred to in the document as SectorPlan 1). The computer science department of the Open University did not participate in these sector plans.

The sector plan committee reported in an interim evaluation report at the end of May 2022 on the progress of this sector plan, which was then halfway through, to the Minister of Education, Culture, and Science (OCW). The conclusion was that due to the developments in society, science and innovation, and education, the joint efforts of Sector Plan 1 had not yet led to the desired stability and space for the sector. This was the reason for the Informatics Platform Netherlands (IPN), on behalf of the sector, to submit a second sector plan application to the Minister of OCW as part of the current round of national Sector Plans for 2023-2029. The computer science department of the Open University is participating in this sector plan for the first time.

[7] https://asci.tudelft.nl

[8] https://ipa.win.tue.nl/

[9] https://siks.nl

[10] https://www.nlsectorplannen.nl/bestanden-beta-ii

Within the 'Sectorplan Informatica' 2023, it is the intention to specifically strengthen research and education in the following key areas ('zwaartepunten'):

- Data Modeling and Analysis: This aims to address various fundamental questions concerning the modeling, organization, processing, storage, and analysis of big data. It also involves developing high-quality, flexible, and energy-efficient data-driven AI systems.
- Machine Learning: This involves the development of knowledge in learning computer systems that adapt their behavior based on data and have a wide range of industrial and societal applications. It covers learning patterns, large-scale energy-efficient machine learning systems, dealing with small datasets, and methodologies for fair, explainable, and reliable machine learning.
- Machine Reasoning and Interaction: The next step in the evolution of AI towards human-level intelligence is machine reasoning: the ability to apply learned knowledge to new situations. This enhances the quality of automated decision-making and enables AI systems to better support human intelligence.
- Algorithmics: This entails developing new methods to solve complex computational problems. New applications (energy networks, climate modeling, logistics, healthcare) and paradigms (quantum algorithms, programmable matter, distributed and streaming algorithms) present new fundamental challenges.
- Software: Software engineering is about systematically designing, developing, verifying, testing, and maintaining software. The four main challenges in this research area are: (1) how to guarantee the reliability of software systems, (2) how to improve the software development process, (3) how to enhance the flexibility, maintainability, and thus the sustainability of existing software systems, (4) how to train enough software engineers and scientists to meet societal needs.
- Security and Privacy: Within the sector plan, four fundamental research questions in cybersecurity and cryptography are central: (1) how can the (in)security of a system be (automatically) demonstrated, (2) how to design secure-by-design computer systems, (3) how to detect and repel attacks, and (4) how to ensure privacy and policy compliance in a rapidly developing digital world?
- Networked Computer and Embedded Systems: The scientific challenges here lie in the energy consumption, reliability, and sustainability of computer systems in cars, airplanes, medical equipment, smart buildings, robotics, etc. Their increasing complexity calls for the development of new, effective (software) solutions for the design, analysis, and optimization of these systems.

Table 2 shows how the research lines in the computer science research program at the OU correspond to the focus areas. Each line corresponds closely with one or two focus areas. The focus area on *Data modeling and analysis* is not covered by the program lines of the Department of Computer Science, but is covered by the research of the Department of Information Science and Business Processes at the OU. The focus area on *Software*

is covered by the lines *Software Engineering* and *Teaching & Learning*. The latter has a clear focus on education and also considers the application of software technology and programming languages, the development of a generic software framework, and the study of problem domains related to programming. The focus area *Networked computing and embedded systems* is not covered by the program lines, although some aspects are addressed, in particular, research on sustainability and energy analysis in the *Software Engineering* line.

Table 2: Mapping of program lines on focus areas

Focus area	**Program line**
Data modelling and analysis	-
Machine learning	Artificial Intelligence
Machine reasoning and interaction	Artificial Intelligence
Algorithmics	-
Software	Software Engineering, CS Education
Security and privacy	Security & Privacy
Networked computing and embedded systems	-

7.2 Research Line: Software Engineering

The research line in software engineering focuses on the quality of software. As the dependence on software in our society increases rapidly, its quality is crucial. However, this quality is not always evident. Unreliable and faulty systems cost money, can disrupt society, and, in critical sectors, may cause death. Our research contributes to high-quality software systems that underpin essential services in our society, from healthcare and finance to transportation and communication. By advancing software quality and addressing vulnerabilities, our research enhances the overall reliability of our digital infrastructure. We advance the quality of present-day systems, and also that of future software systems:

This gives rise to two sublines: *Software Testing and Analysis* described in Section 7.2.1 and *Programming Languages* described in Section 7.2.2.

7.2.1 Software Testing and Analysis

The "Software Testing and Analysis" research group is at the forefront of addressing a critical and contemporary challenge in the world of software engineering: the analysis and testing of *closed-source software*. In an era where legacy systems, proprietary third-party components, and intricate software architectures are ubiquitous, the unavailability of source code poses a formidable barrier to understanding, securing, and optimizing these systems. Our research encompasses a spectrum of vital topics, including scriptless testing, decompilation and reverse engineering, model learning, and verification of third-party libraries. These investigations share a common goal:

Slogan

Empower researchers and professionals to glean insights, detect vulnerabilities, and enhance the quality of real-life present software systems without requiring source code.

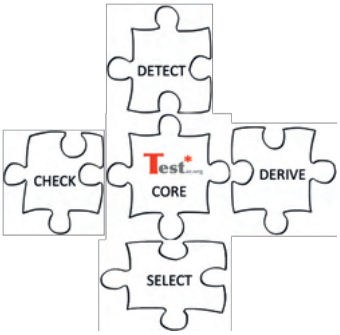
Our research group pioneers innovative, timely, and indispensable solutions to propel software engineering into the future, ensuring the integrity and resilience of software systems that underpin our digital world. In the next section, we describe each topic in more detail.

7.2.1.1 Scriptless test automation

End-to-end test automation at the Graphical User Interface (GUI) level is traditionally done by scripts that are designed to mechanize manual testing. However, conventional script-based tools are often rigid and fail to adapt to dynamic changes, necessitating substantial maintenance effort. In an era characterized by the accelerated development of applications, these limitations pose substantial challenges for testing teams, impeding their ability to stay aligned with the software developers.

Our research on *scriptless* end-to-end testing aims for a completely automated test approach. Instead of scripts, this approach is based on agents that implement various action selection mechanisms and test oracles. The underlying principle of this type of testing is very simple: generate test sequences of (state, action)-pairs by starting up the System Under Test (SUT) in its initial state and continuously selecting an action to bring the SUT to another state. The action selection characterizes the most basic problem of intelligent systems: what to do next.

We have implemented this approach in TESTAR. The tool implements the simple principle results in a core loop that continuously repeats:



- DETECT the GUI state
- DERIVE possible actions for the state
- SELECT an action to execute to go to the next state
- CHECK for failures

Research in this topic will concentrate on each of the 4 possible hooks that this simple approach can be extended and made more intelligent. This research will gradually shift the paradigm of end-to-end testing at the GUI level: from developing scripts to developing intelligent AI-enabled agents.

References and more

- Overview paper: Vos, T.E.J., Aho, P, Pastor, F, Rodriguez, O, Mulders, A. *TESTAR – scriptless testing through graphical user interface.* Software Testing Verification and Reliability 2021; 31:e1771. `https://doi.org/10.1002/stvr.1771`
- Open source repo: `https://github.com/TESTARtool/`

7.2.1.2 Decompilation

From legacy and abandonware to (smart) apps in virtual marketplaces, and from closed-source enterprise applications to embedded software; millions of binaries are being deployed and used daily, whose source code is inaccessible to stakeholders. Problematically, there is essentially nothing stakeholders can do to establish whether third-party binaries are indeed safe, except for just *believing* the original developers did a thorough job. But faith is brittle, and developers have shown—time and again—inadequacy in this area.

We aim to develop a novel holistic approach to decompilation and verification of binaries, by exploiting the synergy between new techniques for reverse-engineering and formal verification. To maximize impact, we are working on tools that target binaries originally written in C and C++. By placing particular emphasis on automation (the approach aims at minimal user interaction) and correctness (the produced result should be a

faithful semantic representation of the system under investigation), our vision is to allow *masses of stakeholders* to apply formal verification to *massively available binaries*.

References and more

- Freek Verbeek, Joshua Bockenek, Zhoulai Fu, Binoy Ravindran: *Formally verified lifting of C-compiled x86-64 binaries*. PLDI'22. `https://doi.org/10.1145/3519939.3523702`
- `https://ssrg-vt.github.io/FoxDec/`

7.2.1.3 Verification of standard libraries

Standard libraries are among the most commonly (re)used software components and a vital part of the ecosystem of any mainstream programming language. Yet, despite their importance, their safety and correctness are generally an open question.

Our initial work in this area has revealed uncovered decades-old bugs in the implementation of Java's sorting algorithm and list implementation. Our latest work has won an award from Google as part of a Google program that recognizes and rewards the often invisible and invaluable work of security researchers, such as finding and reporting programming bugs.

Research in this topic aims to develop new compositional techniques for deductive verification of (standard) libraries. Through the resulting provably safe and *massively used code*, our vision is to enable *masses of software engineers* to benefit from formal verification research, unbeknownst to them.

References and more

- First paper: Stijn de Gouw, Jurriaan Rot, Frank S. de Boer, Richard Bubel, and Reiner Hahnle. *Openjdk's java.utils.collection.sort() is broken: The good, the bad, and the worst case.* In CAV (1), volume 9206 of Lecture Notes in Computer Science, pages 273–289. Springer, 2015
- Google award winning paper: Hiep, H.D.A., Maathuis, O., Bian, J. et al. *Verifying OpenJDK's LinkedList using KeY (extended paper).* Int J Softw Tools Technol Transfer 24, 783–802 (2022). `https://doi.org/10.1007/s10009-022-00679-7`

7.2.1.4 Model learning

Model learning marks a major step forward to make formal verification methods more accessible to a wider range of researchers. Unlike traditional approaches where models are often handcrafted and may not accurately reflect the implemented system, model learning automates the creation of models that are consistent with the actual observable behavior of the system. These techniques are designed to facilitate researchers and

engineers in applying formal methods directly to actual systems without the laborious process of manual modeling. This is particularly relevant in our work on the analysis of attack surfaces within the Security & Privacy research line. Although this technique has been successful in small applications, it still requires expert knowledge about the system and it does not scale to larger systems.

The research in this topic, aims to address the above-mentioned limitations by improving and generalizing model learning techniques. The methodology we employ focuses on leveraging the modularity of the system under learning. By acknowledging and utilizing the modular design of systems (e.g., using communicating components), we aim to produce more scalable and accurate models. These models not only reflect the system more accurately but also align with the testing theories of finite state machines, enhancing the overall effectiveness of formal verification methods.

References and more

- Joshua Moerman. *Learning product automata*. In ICGI, volume 93 of Proceedings of Machine Learning Research. PMLR, 2018. `http://proceedings.mlr.press/v93/moerman19a.html`.
- SATUIO: Software tool for generating adaptive distinguishing sequences and unique input/output sequences for finite state machines, 2022. `https://github.com/Jaxan/satuio`

7.2.1.5 Formal methods in biology

In some contexts, an accurate correlation between model and reality is extremely difficult or even impossible to achieve. This occurs for example when trying to unravel the communication networks that can be found inside living beings. As biological networks were not engineered, we cannot refer to any existing description or technical paper to ensure that a "biological communication protocol" is accurately and completely modeled. Still, also in these cases we want to make formal verification methods applicable and accessible to domain experts.

The objective behind the research in this topic is to allow biologists to apply the concepts of (theoretical, formal) modeling in their daily research without the need for a rigorous mathematical training. Thanks to a structured modeling approach, biologists are able to more clearly organize their data and theories about specific biological networks, and use the resulting models as a guide in discussions. In addition, the formal foundations of the models allow for the application of so-called *in silico* experiments based on simulations and model checking. This way, biologists can more easily test hypotheses and understand emergent behavior in complex models.

ANIMO (Analysis of Networks with Interactive MOdeling), one of the tools resulting from this research, makes the analysis power of Timed Automata available to biology researchers and students without the need for a training in formal methods.

References and more

- S. Khurana, S. Schivo et al. *An ECHO of Cartilage: In Silico Prediction of Combinatorial Treatments to Switch Between Transient and Permanent Cartilage Phenotypes With Ex Vivo Validation.* Frontiers in bioengineering and biotechnology, 2021. https://doi.org/10.3389/fbioe.2021.732917
- S. Schivo, S. Khurana et al. *ECHO, the executable CHOndrocyte: A computational model to study articular chondrocytes in health and disease.* Cellular Signaling, 2020. https://doi.org/10.1016/j.cellsig.2019.109471
- S. Schivo et al. *Computational modeling of complex protein activity networks.* Phosphorylation, 2017. https://doi.org/10.5772/intechopen.69804
- S. Schivo et al. *Modelling with ANIMO: between fuzzy logic and differential equations.* BMC Systems Biology, 2016. https://doi.org/10.1186/s12918-016-0286-z
- ANIMO - Analysis of Networks with Interactive MOdeling
  https://www.utwente.nl/en/tnw/dbe/research/post_lab/animo/
  https://fmt.ewi.utwente.nl/tools/animo/

7.2.2 Programming Languages

Where the subline on testing takes current software systems as a starting point to improve software quality, the subline on programming languages starts with the ideal future software program in mind, and creates tools to develop such systems. Such an ideal program is fault-tolerant, error-free, robust, and scalable. The common goal is:

Slogan

Creating tools, novel programming language features, or design and implement whole new programming languages, to support developers write their software.

The solutions that are proposed in this subline share a common trait in that the tools will enable the formal, and hopefully automated, proofs of program correctness. In the next sections, we will describe each topic in more detail.

7.2.2.1 Advanced Programming Languages

Software applications pop up in many different contexts. Writing a program for a specific context in a general purpose programming language tends to be a hard task. Developers need to take many recurring programming activities into account when creating such applications.

Our goal is to ease this development process while taking program correctness into account. Instead of creating an one-size-fits-all programming language, we take general

techniques from programming language design and create languages that are specially tailored to their domain.

We thoroughly define a language's *syntax and semantics* using techniques discussed below in Section 7.2.2.3. We need to add enough language features to ease the creation of new software. However, by adding advanced *type and effect systems* on top of our language, we restricting it in such a way that we can guarantee proper behavior of written programs. We can give mathematical proofs on *program safety*, and verify program properties using *symbolic execution*. These properties can be mechanized in *proof assistants*.

An example of our approach is a formal specification and programming language for task-oriented systems. The resulting language TopHat aids in faithfully and understandably modeling collaboration of people in the real world. It does so while taking away recurring programming activities for distributed and fault-tolerant applications with persistent data and interactive user interfaces.

Next steps are to apply similar techniques to design and create a programming language to write kernel extensions for the Linux operating system. These programs need to be correct by compilation, provably terminating, and provably run in a limited amount of memory space.

References and more

- First paper: Tim Steenvoorden, Nico Naus, and Markus Klinik. TopHat: A formal foundation for task-oriented programming. In *Proceedings of the 21st International Symposium on Principles and Practice of Programming Languages, PPDP 2019, Porto, Portugal, October 7-9, 2019*, pages 17:1–17:13, 2019.
- Idris proofs: `https://github.com/timjs/tophat-proofs`

7.2.2.2 Program generation

Problems with large IT projects persist in today's world despite technological advancements. We believe that formal methods can automate software design, development, and engineering, offering solutions to these persistent issues. Our focus is on languages that can specify business problems in such a way that they directly facilitate the generation of corresponding information systems. Our interest in such languages is motivated by practice, so collaboration with non-academic partners is imperative.

The research objective of this topic is to develop a comprehensive theory of information systems centered around the principle that business semantics alone should form the basis of system specifications. These specifications would then be used to automatically generate the system, aiming to reduce software errors and enhance project success rates.

Our methodology involves advancing the existing Ampersand framework, a platform already capable of generating information systems. We are working on enhancing this

framework with additional tooling for challenges such as data migration under evolving schemas and enabling incremental changes for more frequent releases.

Key to our implementation strategy is the development of systems that are composable, scalable, and cloud-native. We aim to introduce an associative, commutative, and idempotent union operator for system composition. Furthermore, we intend to validate our theory and tools through case studies in practical environments, emphasizing collaboration with non-academic partners to ensure real-world applicability.

References and more

- Stef Joosten, Relation Algebra as programming language using the Ampersand compiler, Journal of Logical and Algebraic Methods in Programming, Volume 100, 2018, Pages 113-129, ISSN 2352-2208, https://doi.org/10.1016/j.jlamp.2018.04.002.
- The Ampersand project: `https://ampersandtarski.github.io/`
- The tool: `https://rap.cs.ou.nl`
- The course: `https://www.ou.nl/-/IM0403_Rule-Based-Design`
- A blog `https://sjcjoosten.nl/1-research/information-systems/`

7.2.2.3 Metatheory

This topic delves into the mathematical underpinnings or metatheory of programming, a crucial aspect of understanding and advancing programming languages. It encompasses the study of the fundamental properties and theories that govern programming languages.

Semantics There are many different ways to formally define the semantics of a programming language. One approach that has proved to be quite effective is *operational semantics*, which describes the program behavior in terms of an abstract machine. Each flavor of semantics has its advantages, and studying those can yield insights about how to formalize existing languages, or develop new ones.

Program equivalence When the semantics of a programming language has been formalized, we can compare and analyze programs. We are particularly interested in *program equivalence*, i.e., whether or not two programs exhibit the same behavior. The ability to prove or automatically verify this is important, for instance, to check whether an optimized version of a program still calculates the same result.

Axiomatisation When proving facts about programs, we can start with several facts or *axioms* that we accept as true, and reason from there. When a set of axioms is sufficient to prove all semantically valid properties, it is called *complete*. Completeness is very

powerful because it means that no further primitive properties need to be considered when writing a proof. Nevertheless, establishing completeness for new systems remains hard, and so we study techniques that can help accelerate this process.

References and more

- Schmid, Todd, Tobias Kappé and Alexandra Silva. "A Complete Inference System for Skip-free Guarded Kleene Algebra with Tests." European Symposium on Programming (2023). https://doi.org/10.1007/978-3-031-30044-8_12
- Kappé, Tobias. "Completeness and the Finite Model Property for Kleene Algebra, Reconsidered." International Conference on Relational and Algebraic Methods in Computer Science (2023). https://doi.org/10.1007/978-3-031-28083-2_10
- Mohan, Anshuman, Yunhe Liu, Nate Foster, Tobias Kappé, and Dexter Kozen. "Formal abstractions for packet scheduling." Proceedings of the ACM on Programming Languages 7, no. OOPSLA2 (2023): 1338-1362. https://doi.org/10.1145/3622845

7.2.2.4 Code generation

Today, Large Language Models (LLMs) are mostly used as *databases*. Users ask questions, which the model answers based on their compressed world knowledge encoded in the model's weights. One popular application of LLMs as databases is to generate code, ranging from contemporary programming languages such as Java, Python, etc, to database queries in various dialects of SQL or other query languages. With the advent of multi-modal models, it is even possible to ask questions by drawing a picture of a UI and have the model generate all the necessary HTML, CSS, and JavaScript to create a full application.

However LLMs are increasingly supplied with tools that they can invoke to access real-time data such as Web search, or to perform actions such as looking up flights, order food, or in general run arbitrary code. By combining tool use with the code generation abilities, LLMs can be viewed as powerful *neural computers*.

The aim of this research topic is to create a powerful natural language-based programming language for these AI-powered neural computers, by adding functionalities for users to, for example, name and parameterize prompts. Programming AIs faces all the same Software Engineering challenges as programming traditional binary computers, including quality, correctness, and robustness. A key aspect of our implementation is the incorporation of *proof carrying code* where the model generates both code as well as a proof that the generated code is safe, correct, and efficient.

References and more

- J. Bader, S. Seohyun Kim, F. Sifei Luan, S. Chandra and E. Meijer, "AI in Software Engineering at Facebook," in IEEE Software, vol. 38, no. 4, pp. 52-61, July-Aug. 2021, doi: 10.1109/MS.2021.3061664.
- Max Tegmark and Steve Omohundro, "Provably safe systems: the only path to controllable AGI", arXiv:2309.01933, 2023

7.3 Research line: Security & Privacy

We live in a digital society, which brings huge advances and benefits to all aspects of our daily lives. This however makes us dependent on Information and Communication Technologies (ICT), and hence vulnerable to threats. Managing security and privacy risks is essential to safeguard our ICT infrastructures and data from malicious actors, which range from script kiddies to organized cybercriminals and even state actors. The impact of attacks affects individual citizens (eg., in banking fraud), companies and institutions (eg., in ransomware attacks), and even our national safety (eg., attacks on control systems for critical infrastructures such as the electricity grid or water barriers).

The research challenges on security and privacy in the Netherlands have been formulated in the National Cyber Security Research Agenda (NCSRA) in five pillars:

1. Design: applying security-by-design to prevent security problems of systems and services before they are deployed
2. Defence: taking measures to protect deployed systems through identifying assets, preventing and detecting attacks, responding to incidents, and mitigating the impact of attacks and recovery
3. Attack: understanding the attack surface of systems
4. governance: addressing (conformance with) policies and national and international regulatory frameworks
5. Privacy: addressing how to protect sensitive and personal data.

Our research mainly addresses technical aspects of security and privacy in the pillars design, defence, attack, and privacy. The governance pillar is addressed mainly by the Department of Information Science, with whom we closely cooperate.

The research line Security & Privacy focuses on three sub-lines:

1. analysis of attack surfaces: What are vulnerabilities that cause security and privacy threats, and when and why do they occur?
2. mitigation of security and privacy threats: How to prevent or defend against the identified threats?

3. the human factor, education and ethics: This sub-line addresses non-technical aspects. The human factor is the Achilles-heel of security, and we address this by studying human behaviour and useability aspects of security and privacy, supporting education on security and privacy, and considering ethical aspects.

7.3.1 Analysis of attack surfaces

We analyse the attack surfaces of ICT systems to better understand threats on security and privacy. These attack surfaces comprise all potential entry points and vulnerabilities that can be exploited by attackers to compromise systems, involving the hardware and software that build these systems as well as the people that use them. We consider this both at the level of the system design and architecture, as well as at the system implementation level.

Slogan

Analysing the attack surface of ICT systems to identify threats on security and privacy.

Our research addresses the attack surfaces of systems, software and computer networks in general, and the attack surfaces of AI systems, distributed systems, and the World-Wide Web as specific instances.

Systems We develop formal models of real-life systems and describe how they can be disrupted by malicious actors. Using an abstract model as a reference for a more complex system lets us understand its most important aspects. The use of formal models allows us to apply formal verification methods such as model checking, to obtain useful insights into how system weaknesses can be exploited and how the security of systems can be strengthened. We develop software tools for this purpose using advanced software engineering techniques, making the power of formal methods available to security experts without the need for additional formal training. An example is the modelling and verification of attack trees. (This research has close relations with topics on formal verification of standard libraries and model learning in the Software Engineering research line.)

References and more

- R. Kumar, S. Schivo, E. Ruijters, B. Yildiz, D. Huistra, J. Brandt, A. Rensink and M. Stoelinga, "Effective Analysis of Attack Trees: A Model-Driven Approach", in Fundamental Approaches to Software Engineering, Lecture Notes in Computer Science 10802, pp. 56-73, 2018, doi:10.1007/978-3-319-89363-1_4
- N. Dong, H. Jonker and J. Pang, "Formal modelling and analysis of receipt-free auction protocols in applied pi", Computers & Security 65, 2017, pp. 405-432, doi:10.1016/j.cose.2016.09.002

Software We analyse the source code of software to identify vulnerabilities. We apply state-of-the-art AI methods to improve static code analysis. The main challenge is how to transform source code into a representation that can be input to an AI model. This transformation typically considers combining abstract syntax tree, control flow, and data flow representations into a graph model, and subsequently transforming the graph model into a numeric representation. This transformation should maintain sufficient information about the syntaxis and semantics related to vulnerabilities.

References and more

- J. Kronjee, A. Hommersom and H. Vranken, "Discovering software vulnerabilities using data-flow analysis and machine learning", in Proceedings of the International Conference on Availability, Reliability and Security, 2018.

Computer networks We analyse computer network traffic to detect anomalies and traces of malicious activity (such as botnets). We apply state-of-the-art AI methods to train classifiers that can distinguish anomalies and malicious traffic from regular network traffic. The challenge is to analyse network traffic in real time. This requires small models that operate at high speed and that also can be retrained quickly. Using small models also facilities explainability of the model and reducing false positive detections.

References and more

- D. Willems, K. Kohls, B. van der Kamp and H. Vranken, "Data Exfiltration Detection on Network Metadata with Autoencoders", in Electronics 2023, 12(12), 2584, doi:10.3390/electronics12122584.

AI systems We analyse security and privacy aspects that arise in the development and deployment of AI systems. We consider the security and privacy of both data and AI models. Data poisoning is an example of a data security threat, in which attackers attempt to bias or deceive AI systems by manipulating training data or injecting malicious training data. Protecting data privacy is needed to protect the privacy of individuals and sensitive data, and avoiding inadvertent disclosure or data breaches that can lead

to privacy violations and legal consequences. We address robustness of AI models by making them resistant to adversarial attacks during inference, in which attackers try to manipulate inputs to mislead the AI system. (This research has close relations with robust, safe and trustworthy AI in the AI research line.)

References and more

- M. Alishahi, V. Moghtadaiee and H. Navidan, "Add noise to remove noise: Local differential privacy for feature selection", in Computers & Security 123, 2022, 102934, doi:/10.1016/j.cose.2022.102934

Distributed systems We analyse security and privacy aspects of distributed systems. We focus on distributed systems in which consensus algorithms are used to agree on a global state. Prime examples are decentralized Web3 applications that are built on blockchain, and decentralized systems such as cryptocurrencies and distributed storage systems. Consensus mechanisms such as proof-of-work and proof-of-stake provide security by validating and authenticating transactions, that are next stored on a blockchain. We study the electricity consumption and environmental footprint due to consensus algorithms, as well as incentive mechanisms to reduce this footprint. We also study other aspects, such as the security of smart contracts, and tracing transaction flows on blockchains.

References and more

- A.R. Sai and H. Vranken, "Promoting rigor in blockchain energy and environmental footprint research: A systematic literature review", in Blockchain: Research and Applications 2024, 5(1), 100169, Elsevier, doi:10.1016/j.bcra.2023.100169

World-Wide Web We analyse the security and privacy of the world-wide web. We focus on digital fingerprinting, which is used to uniquely identify and track devices that connect to a website or online service. Digital fingerprinting considers various device characteristics and configurations, such as IP address, browser type and version, screen resolution, time zone, installed fonts, and language settings. The combination of these attributes creates a unique identifier for the device. Digital fingerprinting offers a means to track or identify visitors across websites and services, enabling the creation of user profiles. Although digital fingerprinting can improve security by identifying suspicious or potentially fraudulent activities, it also raises privacy concerns as it can be used to track users without their consent, even when they disallow cookies or use private browsing modes. We study fingerprinting techniques and countermeasures, their spread and impact, as well as ethical and regulatory aspects. For example, we investigate how the reliability of web measurements through web scrapers is affected by browser fingerprinting that detects web scrapers. To improve upon this, we design and implement countermeasures that enable large-scale web measurements whose results are not marred

by scraper detection.

References and more

- S. Calzavara, H. Jonker, B. Krumnow and A. Rabitti, "Measuring Web Session Security at Scale", in Computers & Security 111, 2021, 102472, doi:10.1016/j.cose.2021.102472

7.3.2 Mitigation of security and privacy threats

We apply methods and techniques in computer science to mitigate security and privacy threats. We provide security-by-design and privacy-by-design to prevent threats, and we provide methods and techniques to defend against threats. Our research focuses on the application of AI and cryptography to address threats, and on mitigating threats for AI systems.

Slogan

Providing security-by-design and privacy-by-design to mitigate threats on security and privacy.

Application of AI for security and privacy We apply AI methods and techniques to improve security and privacy in several different ways. AI has been applied in the last decades by both academic researchers and industry practitioners to address security challenges and problems related to security and privacy. This ranged from proactively protecting and defending systems and services to responding to security incidents after their occurrence, as well as analysing their impact and decision-making support. On the technical level, we study how AI can help in automated repair and patching of software vulnerabilities, and analysis of anomalies in computer network traffic. On the operational and management levels, we study the application of hybrid AI techniques, which combine human expertise with machine learning and deep learning, for improving security, such as structuring information on threats and solutions, metadata analysis, impact assessment and decision-making support for military Cyber/Information Operations, and assessing and strengthening user's security behaviour in relation to different types of security incidents.

References and more

- H. Vranken and H. Alizadeh, "Detection of DGA-Generated Domain Names with TF-IDF", in Electronics 2022, 11(3), 414, doi:10.3390/electronics11030414
- W. de Kraker, H. Vranken and A. Hommersom, "GLICE: Combining Graph Neural Networks and Program Slicing to Improve Software Vulnerability Detection", in Proceedings IEEE European Symposium on Security and Privacy, 2023, doi:10.1109/EuroSPW59978.2023.00009
- A. Chockalingam and C. Maathuis, "Assessing Cascading Effects of Cyber-Attacks in Interconnected Critical Infrastructures", in Proceedings European Safety and Reliability Conference, 2022, doi:10.3850/978-981-18-5183-4_S23-04-521-cd

Mitigating threats of AI systems Ensuring the robustness of AI models involves a combination of techniques, including data preprocessing, model design, regularization, training with adversarial examples, and monitoring. Furthermore, trained AI models may be considered as intellectual property, and hence AI models themselves should be secured against stealing, while also the usage of AI models by unauthorized parties may lead to information leaks. We study scenarios for differential privacy in which training data is distributed among multiple entities without entities sharing their original data. To achieve this, we explore the usage of federated learning, in which each participant locally trains an AI model using its own data and sends model updates to a central server that aggregates the model updates from all participants. This ensures that raw data stays locally with each participant, avoids the need for transferring large volumes of data to the central server, and is robust to dropout or failures of participants. Additionally, we study how to incorporate fairness considerations into AI systems.

References and more

- M. Sheikhalishahi and F. Martinelli, "Privacy preserving clustering over horizontal and vertical partitioned data", in IEEE Symposium on Computers and Communications, 2017, doi: 10.1109/ISCC.2017.8024694

Cryptography We study real-world application of cryptography to improve security and privacy. We focus on the development and implementation of privacy-enhancing technologies (PETS) to protect information related to a person's identity. A first research topic is the usage of attributes to generalise identities in attribute-based authentication, signature, and access control. We contribute to the implementation of attribute-based credentials in the IRMA and Yivi applications. A second research topic is the usage of polymorphic pseudonymisation to hide identities in the context of big data. A third research topic is practical cryptographic protection of medical data (PEP), and attribute-based encryption schemes to protect data stored at cloud services.

References and more

- G. Alpár, F. van den Broek, B. Hampiholi, B. Jacobs, W. Lueks and S. Ringers, "IRMA : practical , decentralized and privacy-friendly identity management using smartphones", in Proceedings Workshop on Hot Topics in Privacy Enhancing Technologies, 2017
- F. van den Broek, B. Hampiholi and B. Jacobs, "Securely Derived Identity Credentials on Smart Phones via Self-enrolment", in Security and Trust Management, Lecture Notes in Computer Science 9871, 2016, Springer, doi:10.1007/978-3-319-46598-2_8

7.3.3 Human factor, ethics, and education

The human factor is considered to be the Achilles-heel of security. We address this by studying human behaviour and useability aspects of security and privacy, by supporting education on security and privacy, and by considering ethical aspects.

Slogan

Addressing the human factor and ethics in security and privacy by considering how humans interact with ICT systems, and how to educate students and users.

Attention for the human factor and ethics plays an important role in all our research activities in the analysis- and mitigation-sublines. In addition, we carry out small case studies on topics related to the human factor and ethics, such as security of digital exams, privacy in digital forensics, compliancy with security and privacy regulations, and fraud in scientific publishing.

In education, we recognise that beyond teaching theoretical concepts and principles of security and privacy, equipping students with hands-on experience in labs enhances their understanding and deepens their knowledge. We provide this by researching, developing, and applying virtual labs, in which students can practice both defensive and offensive techniques in a realistic yet simulated environment. We conduct research not only about the technical infrastructure of distributed virtual labs to enable groups of remote students working together, but also about the way such labs can be applied for security education in distance teaching.

We explore the challenges and possibilities offered by generative AI. We build tools for comprehensive and active defence solutions that combine the generation and detection of mechanisms like disinformation for security awareness and learning purposes. In addition, for educational purposes, we are building educational games for young students and non-STEM experts for raising security awareness and learning support in relation to social media manipulation mechanisms like disinformation and deep fakes.

References and more

- J. Haag, H. Vranken and M. van Eekelen, "A Virtual Classroom for Cybersecurity Education", in Transactions on Edutainment XV, LNCS 11345 (2019): 173–208, Springer, doi:10.1007/978-3-662-59351-6_13
- C. Maathuis and S. Chockalingam, "Responsible Digital Security Behaviour: Definition and Assessment Model", in Proceedings European Conference on Cyber Warfare and Security, 2022, doi:10.34190/eccws.21.1.203
- C. Maathuis and S. Chockalingam, "Modelling Responsible Digital Security Behaviour for Countering Social Media Manipulation", in Proceedings European Conference on Social Media, 2023, doi:10.34190/ecsm.10.1.1079

7.4 Research line: Artificial Intelligence

Artificial intelligence (AI) is acquiring increasing importance in society and in business, and research into AI is expanding in the computer science department. National and European research agendas in AI strongly promote both technical advances in AI (such as deep learning) and research that ensures that AI technologies are beneficial to society: that AI systems are robust, safe, trustworthy, and are developed and applied ethically and responsibly. At the CS department, we are actively involved in the technical development of AI, in conducting AI research involving both humans and AI in creating new systems and solutions, and in ensuring AI conformance to safety requirements and ethical values.

This research line can be subdivided into ensuring trustworthiness of AI systems, and improving their effectiveness in collaborating with humans. There are clearly interactions between the two research sub-lines.

7.4.1 Robust, safe and trustworthy artificial intelligence

Slogan

Develop techniques for safe, robust and trustworthy AI systems

Robustness and safety of artificial intelligence can be ensured by using verification techniques applied to already existing systems, or generating (synthesizing) systems that are guaranteed to be correct by construction. Transparent and explainable systems are more amenable to rigorous analysis and providing guarantees for the system's behavior. A significant amount of research in the AI group focuses on symbolic systems and explicit knowledge representation

References and more

- Natasha Alechina, Giuseppe De Giacomo, Brian Logan, and Giuseppe Perelli. Automatic synthesis of dynamic norms for multi-agent systems. In Gabriele Kern-Isberner, Gerhard Lakemeyer, and Thomas Meyer, editors, *Proceedings of the 19th International Conference on Principles of Knowledge Representation and Reasoning, KR 2022*, pages 12–21. ijcai.org, 2022.
- Raphaela Butz, Renée Schulz, Arjen Hommersom, and Marko C. J. D. van Eekelen. Investigating the understandability of XAI methods for enhanced user experience: When bayesian network users became detectives. *Artif. Intell. Medicine*, 134:102438, 2022.
- Giso H. Dal, Alfons W. Laarman, Arjen Hommersom, and Peter J. F. Lucas. A compositional approach to probabilistic knowledge compilation. *Int. J. Approx. Reason.*, 138:38–66, 2021.
- Jesse Heyninck, Gabriele Kern-Isberner, Tjitze Rienstra, Kenneth Skiba, and Matthias Thimm. Revision, defeasible conditionals and non-monotonic inference for abstract dialectical frameworks. *Artif. Intell.*, 317:103876, 2023.

7.4.1.1 Integration of symbolic and subsymbolic approaches

Our strategy for the future is to develop techniques for achieving robust and safe AI that combine symbolic and subsymbolic approaches, reasoning, and learning. Examples of existing work in this direction explain the behavior of learned systems; declaratively specifying constraints on the outcome of learning; and using symbolic techniques for ensuring safety in reinforcement learning.

References and more

- Raphaela Butz, Arjen Hommersom, and Marko van Eekelen. Explaining the most probable explanation. In *International Conference on Scalable Uncertainty Management*, pages 50–63. Springer, 2018.
- Giovanni Varricchione, Natasha Alechina, Mehdi Dastani, Giuseppe De Giacomo, Brian Logan, and Giuseppe Perell. Pure past action masking. In *Thirty-Eighth AAAI Conference on Artificial Intelligence, AAAI 2024, Safe, Robust and Responsible AI (SRRAI) Track*, 2024.

In order to make techniques from knowledge representation amenable to integration with sub-symbolic techniques, it is also important to investigate how to make the processing of symbolic knowledge more efficient (e.g. by breaking down the knowledge base in modular parts and to give a principled account of how to combine symbolic knowledge with sub-symbolic knowledge (e.g. in the form of probabilities, fuzzy values or plausibilities. Specifically, the interaction between symbolic and sub-symbolic systems, such as large language models (LLMs), we can reduce the knowledge engineering bottleneck associated with symbolic systems, while at the same time enhancing the capabilities of

LLMs towards performing higher-order reasoning and planning.

References and more

- Jesse Heyninck, Gabriele Kern-Isberner, Thomas Andreas Meyer, Jonas Philipp Haldimann, and Christoph Beierle. Conditional syntax splitting for non-monotonic inference operators. In Brian Williams, Yiling Chen, and Jennifer Neville, editors, *Thirty-Seventh AAAI Conference on Artificial Intelligence, AAAI 2023, Thirty-Fifth Conference on Innovative Applications of Artificial Intelligence, IAAI 2023, Thirteenth Symposium on Educational Advances in Artificial Intelligence, EAAI 2023*, pages 6416–6424. AAAI Press, 2023.
- Jesse Heyninck, Gabriele Kern-Isberner, Tjitze Rienstra, Kenneth Skiba, and Matthias Thimm. Revision, defeasible conditionals and non-monotonic inference for abstract dialectical frameworks. Artif. Intell., 317:103876, 2023.
- Vishal Pallagani, Bharath Muppasani, Biplav Srivastava, Francesca Rossi, Lior Horesh, Keerthiram Murugesan, Andrea Loreggia, Francesco Fabiano, Rony Joseph, Yathin Kethepalli. Plansformer tool: demonstrating generation of symbolic plans using transformers. In *IJCAI*, volume 2023, pages 7158–7162. International Joint Conferences on Artificial Intelligence, 2023.

7.4.1.2 Explainable AI

We aim to contribute to human-centered aspects of explainable-AI (XAI) methods, for example, by evaluating the understandability of explanations. This is for example very relevant in medicine, where there is an urgent need for better understanding the requirements of such XAI systems to obtain better user acceptability, actions taken based on the results from the system and overall impact on clinical practice.

References and more

- Raphaela Butz, Renée Schulz, Arjen Hommersom, and Marko C. J. D. van Eekelen. Investigating the understandability of XAI methods for enhanced user experience: When bayesian network users became detectives. *Artif. Intell. Medicine*, 134:102438, 2022.
- C. Combi, B. Amico, R. Bellazzi, A. Holzinger, J. H. Moore, M. Zitnik, and J. H. Holmes. A manifesto on explainability for artificial intelligence in medicine. *Artificial Intelligence in Medicine*, 133:102423, 2022.

7.4.1.3 Robust, private and safe AI

We develop robust models through Bayesian methods, that allows for including prior knowledge into the learning process. For example, such learning methods have been developed by our group in the context of continuous-time Bayesian networks, and we aim to further investigate this in dynamic systems, particularly by incorporating various

types of knowledge in dynamic treatment regimes. We are also addressing privacy aspects in machine learning and data analysis in general.

References and more

- Manxia Liu, Arjen Hommersom, Maarten van der Heijden, and Peter JF Lucas. Learning parameters of hybrid time bayesian networks. In *Conference on Probabilistic Graphical Models*, pages 287–298. PMLR, 2016.
- Milan Lopuhaä-Zwakenberg, Mina Alishahi, Jeroen Kivits, Jordi Klarenbeek, Gert-Jan van der Velde, and Nicola Zannone. Comparing classifiers' performance under differential privacy. In *SECRYPT*, pages 50–61, 2021.
- Mina Sheikhalishahi, Andrea Saracino, Fabio Martinelli, and Antonio La Marra. Privacy preserving data sharing and analysis for edge-based architectures. *International Journal of Information Security*, pages 1–23, 2022.

7.4.1.4 AI and Cybersecurity

AI is shaping the trajectory of progress in all societal domains by providing insights and decision-making support in a wide range of activities. A fundamental pillar of building robust, safe, and trustworthy AI systems is to assure their transparency in relation to data used, systems' behavior, and decisions made in a way that is explainable, interpretable, and human-centered to human needs, goals, and expectations. To this end, extensive research is conducted in the military domain for building safe, responsible, and trustworthy AI systems for conducting military operations in a way that accounts, respects, and protects civilian lives and infrastructure and provides relevant military decision-making support. We are also collaborating with the Security and Privacy research line on detection of software vulnerabilities using machine learning.

References and more

- Clara Maathuis. On explainable AI solutions for targeting in cyber military operations. In *International Conference on Cyber Warfare and Security*, volume 17, pages 166–175, 2022.
- Clara Maathuis. On the road to designing responsible AI systems in military cyber operations. In *European Conference on Cyber Warfare and Security*, volume 21, pages 170–177, 2022.
- Clara Maathuis. Human centered explainable AI framework for military cyber oper-ations. In *MILCOM 2023-2023 IEEE Military Communications Conference (MIL-COM)*, pages 260–267. IEEE, 2023.
- Clara Maathuis, Wolf Pieters, and Jan van den Berg. Decision support model for effects estimation and proportionality assessment for targeting in cyber operations. *Defence Technology*, 17(2):352–374, 2021.
- Wesley De Kraker, Harald Vranken, and Arjen Hommmersom. Glice: Combining graph neural networks and program slicing to improve software vulnerability detection. In 2023 IEEE European Symposium on Security and Privacy Workshops (EuroS&PW), pages 34–41. IEEE, 2023.

7.4.2 Effective Human-Centered AI

Open University places a strong emphasis on the concept of co-creation with stakeholders, including the context of human-AI collaboration in which pre-trained AI systems are leveraged to create new AI models for the sake of human knowledge advancement. Co-creation, in our context, also involves the active involvement of human stakeholders in defining research directions that revolve around methodologies for the practical application of AI in industry and society.

Slogan

Empower researchers and users to effectively co-create with AI systems

The co-creation aspect of our research line is built upon our extensive experience in applying AI within industrial environments, exemplified by partnerships with companies like DHL and APG through the experience of the Brightland Smart Services Campus AI hub as a community aiming at applied research with industry and society. This implies that, in addition to algorithmic development, our department is dedicated to developing methodologies for the practical application of AI technologies in the industry, by modeling systems that can create relevant insights and business value for industrial stakeholders. Human-centered AI will therefore be the preferred context of our efforts, to ensure that, following the European tradition concerning human values, AI systems are created to foster human rights, and to the benefit of human society as a whole, as opposed to a race towards the most advanced AI system, the focus will be on the

development of the fairest and most inclusive possible type of AI.

In the pursuit of such objectives, our research group plans to focus on topics such as deep learning natural language processing, reinforcement learning and neurosymbolic reasoning.

References and more

- Ben Shneiderman. Human-centered AI. Oxford University Press, 2022.
- Bea Waelbers, Stefano Bromuri, and Alexander P Henkel. Comparing neural networks for speech emotion recognition in customer service interactions. In *2022 International Joint Conference on Neural Networks (IJCNN)*, pages 1–8. IEEE, 2022.
- Thomas van Dongen, Gideon Maillette de Buy Wenniger, and Lambert Schomaker. Schubert: Scholarly document chunks with bert-encoding boost citation count prediction. In *Proceedings of the First Workshop on Scholarly Document Processing*, pages 148–157, 2020.
- Giovanni Varricchione, Natasha Alechina, Mehdi Dastani, and Brian Logan. Synthesising reward machines for cooperative multi-agent reinforcement learning. In *European Conference on Multi-Agent Systems*, pages 328–344. Springer, 2023.
- Jesse Heyninck, Gabriele Kern-Isberner, Tjitze Rienstra, Kenneth Skiba, and Matthias Thimm. Revision, defeasible conditionals and non-monotonic inference for abstract dialectical frameworks. *Artif. Intell.*, 317:103876, 2023.

7.4.2.1 AI and Digital Twins

Other examples of building such human-AI collaboration systems are digital twins, i.e., digital representations of physical objects, systems, and processes involved when conducting military operations in a safe and responsible way. Another example is building AI solutions that assess and enhance responsibility of digital security behavior in relation to social media manipulation mechanisms like disinformation and misinformation. Countering disinformation is another important line of research that is conducted at OU by means of both AI and gaming technologies. To this end, Maathuis et al. build a hybrid deep learning system for generating and detecting disinformation in relation to ongoing societal crises, such as pandemic and conflict.

References and more

- Clara Maathuis. An outlook of digital twins in offensive military cyber operations. In *European Conference on the Impact of Artificial Intelligence and Robotics*, volume 4, pages 45–53, 2022.
- Clara Maathuis and Sabarathinam Chockalingam. Modelling responsible digital security behaviour for countering social media manipulation. In *ECSM 2023 10th European Conference on Social Media*. Academic Conferences and publishing limited, 2023.
- Clara Maathuis, Iddo Kerkhof, Rik Godschalk, and Harrie Passier. Design lessons from building deep learning disinformation generation and detection solutions. In *European Conference on Cyber Warfare and Security*, volume 22, pages 285–293, 2023.

7.4.2.2 Decision making in Industry 4.0

Conventional planning models are strong considering the complexity of the problem they are tackle. However, these models have a common aspect of using strong assumptions and statistical parameters, since they lack tools to cope with intrinsic uncertainties of the processes. Fortunately, this does not become a bothering issue in long time horizons. However when it comes to plan in relatively shorter time horizon, as in case of make-to-order or just-in-time type production or service conventions, then relaxing the strong assumptions by learning the complex processing system parameters turns out to be the only way to generate realistic outputs. Here, AI comes as a crucial discipline to improve conventional planning methods in several ways. Sometimes AI tools work with conventional planning models as a component in the solution framework with both supportive and active roles. Predicting case-specific parameters is an example of former role and making real-time decisions is of latter. Some AI tools may also be embedded into planning models as one way of enhancing the capability of these models for more complex decisions.

References and more

- Murat Firat, Julie De Meyere, Tugce Martagan, and Laura Genga. Optimizing the workload of production units of a make-to-order manufacturing system. *Computers & Operations Research*, 138:105530, 2022.
- Murat Firat, Guillaume Crognier, Adriana F Gabor, Cor AJ Hurkens, and Yingqian Zhang. Column generation based heuristic for learning classification trees. *Computers & Operations Research*, 116:104866, 2020.
- D. Wely. Integrating machine learning in the project scheduling of a multi-skilled workforce. Master's thesis, Data Science in Business and Entrepreneurship, Jheronimus Academy of Data Science, 2022.

7.4.2.3 Interactivity

Interactivity plays a pivotal role in the development and deployment of machine learning models, particularly in the context of human-in-the-loop systems. There are two common avenues for incorporating interactivity into the model, interactivity during training and interactivity during inference.

Interactivity During Training One avenue for incorporating interactivity is during the training phase, exemplified by approaches like active learning or reinforcement learning with human feedback (RLHF). In active learning, the model actively selects the most informative instances to ask a human to label. This process optimizes the model's learning efficiency by focusing on challenging examples, thereby improving its performance with fewer labeled examples. Human input becomes an integral part of the learning loop, steering the model toward a better understanding of complex patterns and nuances in the data.

Another example, popularized by large language models, is RLHF. In this setting, humans provide additional feedback to guide the learning and outcomes of the model. This feedback can include reward shaping, preference information, or explicit corrections to the model's actions. It is powerful paradigm that bridges the gap between the capabilities of machine learning models and the nuanced, contextual understanding that humans bring to complex decision-making scenarios. It allows the model to adapt to human preferences as well as domain-specific knowledge, making it well-suited for applications where human subjectivity or adherence to certain constraints is crucial.

References and more

- Gabrielle Kaili-May Liu. Perspectives on the social impacts of reinforcement learning with human feedback, arXiv:2303.02891, 2023.

Interactivity During Inference Another avenue of interactivity arises during inference time, where models are endowed with control mechanisms that enable users to influence or steer the outputs. This interactive paradigm empowers users to guide the model's decision-making, fostering a collaborative and adaptive system that aligns more closely with user preferences and requirements. These control mechanisms can take on various forms of user inputs, such as text prompts, point clicks, constraint specification, and preference indication. This transforms machine learning models from static tools to adaptive systems that respond to user needs in real-time. Users become active participants in the decision-making process, leveraging the model's capabilities while retaining control over the final outcomes. This collaborative approach ensures that AI systems are not black boxes but rather tools that users can shape and trust.

Together, these dual facets of interactivity reinforce the symbiotic relationship between human intelligence and machine learning models. By involving human input during both

training and testing, we move beyond traditional one-size-fits-all models to more flexible, adaptive, and user-centric AI systems that better serve the diverse and evolving needs of users in various domains. We have been active in this area for example for interactive object counting, image retargeting, and style transfer.

References and more

- Tadhg McCarthy, John Jethro Virtusio, Jose Jaena Mari Ople, Daniel Stanley Tan, Divina Amalin, and Kai-Lung Hua. Macnet: Mask augmented counting network for class-agnostic counting. *Pattern Recognition Letters*, 169:75–80, 2023.
- Adrienne Francesca O Soliven, John Jethro Virtusio, Jose Jaena Mari Ople, Daniel Stanley Tan, Divina Amalin, and Kai-Lung Hua. Conconet: Class-agnostic counting with positive and negative exemplars. *Pattern Recognition Letters*, 171:148–154, 2023.
- Jilyan Bianca Dy, John Jethro Virtusio, Daniel Stanley Tan, Yong-Xiang Lin, Joel Ilao, Yung-Yao Chen, and Kai-Lung Hua. Mcgan: mask controlled generative adversarial network for image retargeting. *Neural Computing and Applications*, 35(14):10497–10509, 2023.
- John Jethro Virtusio, Jose Jaena Mari Ople, Daniel Stanley Tan, Muhammad Tanveer, Neeraj Kumar, and Kai-Lung Hua. Neural style palette: A multimodal and interactive style transfer from a single style image. *IEEE Transactions on Multimedia*, 23:2245–2258, 2021.
- John Jethro Virtusio, Daniel Stanley Tan, Wen-Huang Cheng, Mohammad Tanveer, and Kai-Lung Hua. Enabling artistic control over pattern density and stroke strength. *IEEE Transactions on Multimedia*, 23:2273–2285, 2020.

7.5 Research line: Computer Science Education

The Computer Science Education research field focuses on teaching and learning of CS-related topics, from the perspective of both teachers and learners. The field investigates education on a wide range of computing topics, including (but not limited to) programming education, design, discrete mathematics (e.g. propositional logic), algorithms, and software engineering. Traditionally, much attention is focused on introductory programming courses, since writing code is a notoriously hard skill to master, which often makes these courses a major stumbling block for students. Compared to other educational research fields such as mathematics education and science education, CS education is relatively young.

The international CS Education research community has organized itself into a Special Interest Group on Computer Science Education (SIGCSE) hosted by ACM, with associated conferences that are held annually, a newsletter, and a list of topics. Table 3 lists the four topic areas that are defined, which are used by the OU researchers for

Topic areas	*Description*	*5.1*	*5.2*	*5.3*
Computing Topics	These topics relate to different content areas within computing education.	×		
Broadening Participation in Computing	These topics relate to efforts to make CS education a more equitable space for all and improve diversity and inclusion in computer science.		×	
Education and Experience	These topics relate to different pedagogical concerns in the teaching and learning of computing.	×	×	×
Curriculum	These topics address different programmatic themes.			×

Table 3: Four topic areas that are defined by the ACM's Special Interest Group on Computer Science Education (SIGCSE). The last three columns indicate how the three sublines (5.1 to 5.3) are connected to these topic areas.

positioning the departmental research line.[11]

Several reasons motivate having a CS education research line in the CS department. Firstly, it connects the department's research activities with educational programs. Teaching practices inspire new research goals to pursue. Reversely, research outcomes such as tools, instructional designs, and best practices can be included in CS courses or inform CS curricula. Secondly, a substantial part of the MSc students works as CS teacher in higher education, generally for a university of applied sciences. This group is often interested in selecting an educational topic with an element of computing for their graduation assignment. Thirdly, the OU has a long-standing tradition in research on educational technology, with research groups that are located in different faculties. This research line connects disciplinary practices with this tradition.

The research line consists of three sublines that are interrelated. The first subline (Section 7.5.1) studies several aspects of programming education including the design, construction, refactoring, and testing of programs, as well as tool support for each of these aspects (e.g. for generating automated feedback). The second subline (Section 7.5.2) explores human factors that influence CS education: this includes collaborative and socio-technical learning, but also efforts to improve diversity and inclusion in computer science. The third subline (Section 7.5.3) focuses on digital literacy.

7.5.1 Programming education

Programming is one of the core areas of Computer Science. Although introductory programming courses are typically positioned in the first semester of CS curricula, research shows that many students struggle with completing these courses [18]. This makes programming education, which focuses on learning and teaching how to program, an important research area. The emphasis of our department's research line is on higher education, even though many excellent initiatives exist that target young kids and teenagers [35, 10].

[11] See `https://www.sigcse2024.org/info/topics`: a fifth topic area that is used for identifying research methods of submitted papers is excluded here.

Writing a program consists of several phases, including problem analysis, design, coding, testing, and debugging. From a research perspective, each phase introduces challenges and new concepts that have to be learned. Also combining these phases adds complexity for students and teachers. In this research line, we consider multiple programming paradigms, each with their unique characteristics: imperative programming (at the method level), object-oriented programming (at the class level), and functional programming. For example, the correct application of OO-patterns can be investigated for the design phase, code-quality issues can be raised at the method level and may lead to refactorings, and program synthesis techniques can assist programmers in completing their code.

In particular, the research group studies tool support and technology-enhanced learning, often in the context of programming education. We develop automated feedback and analysis tools, and we investigate what the effects of such tools are in a classroom setting. These tools can support students with step-wise feedback for solving a problem, detect misconceptions and common mistakes, and provide a personalised and adaptive learning environment (also called "Intelligent Tutoring System").

Slogan

We explore tools and investigate teaching practices and students' learning, thus supporting the teaching and learning of all phases associated with program development.

Refactoring. Refactoring is the process of enhancing the structure of software, preserving the observable behavior, to make it easier to understand, modify, and extend [8]. With a growing volume of program code and an increasing demand for new functionalities, the importance of refactoring is also on the rise. The question of how to guarantee behavior preservation [31] still remains unresolved to a satisfactory degree [19].

One way to ensure behavior preservation is by formally proving the program's semantics in advance. In the case of languages with formally defined semantics, it is possible to demonstrate that certain refactorings maintain the program's semantics [34]. However, for highly complex languages such as Java, accomplishing this task is exceedingly challenging, if not infeasible [40].

Another well-known technique is 'testing' [19]. With testing, predefined tests that specify the desired behavior are used to determine whether the intended relationship between input and output remains intact during and after the refactoring process [8]. One problem with testing is that verification occurs after the refactoring has been executed, errors can go unnoticed if the test cases do not sufficiently cover all the desired behaviors, or if the behavior is not adequately specified. Furthermore, existing test code must be in sync with the refactored code to be tested [32]. Moreover, while failed test cases do indicate the absence of certain desired behaviors, they do not always provide a clear indication of the specific code location responsible for the issue.

A third known technique for achieving behavior preservation is by specifying 'refactoring preconditions' that must be satisfied before a refactoring is executed [31]. This approach is employed in various refactoring engines, including Eclipse and NetBeans. However, issues arise with this method, as refactoring engines may impose preconditions that are either too lenient or excessively restrictive, leading to situations where incorrect transformations are permitted while correct ones are hindered [21]. Furthermore, when potential problems arise, the range of available solutions is often limited.

In this research, we try to develop a technique that allows for an identification of risks before carrying out refactoring and presenting them to the programmer. In the second step, we aim to create a mechanism that provides recommendations for preventing or resolving these risks. Instead of the necessity of initially establishing specifications for a program to be refactored, such as defining input-output tests or refactoring preconditions, the technique examines the smallest changes at the code level (microsteps) and derives conclusions about potential changes in behaviour.

The tool we want to develop is interesting for both experienced programmers as well as computer science students.

References and more

- Ebrahim Rahimi, Harrie Passier and, Sylvia Stuurman, Exploring Factors Influencing the Satisfaction of Adult Software Engineering Students with Teamwork in Distance Education, 23rd Koli Calling International Conference on Computing Education Research, Helsinki, Finland
- Sylvia Stuurman, Harrie Passier, Erik Barendsen, Analyzing Students' Software Redesign Strategies, in Koli Calling '16: Proceedings of the 16th Koli Calling International Conference on Computing Education Research, Finland, ACM, 2016
- Lex Bijlsma, Arjan Kok, Harrie Passier, Harold Pootjes and Sylvia Stuurman, Evaluation of design pattern alternatives in Java, in Software: Practice and Experience, 2021 (12), Wiley Online Library.
- M. Lawende, H. Passier, G. Alpár. Reproduction for Insight: Towards Better Understanding the Quality of Students Tests. In Proceedings of ITiCSE 2021. ITiCSE 2021

Program synthesis. The goal of program synthesis is to automatically construct (part of) a program that satisfies a given specification. Such a specification can be a combination of different forms: a formal specification expressed in logic, input-output examples that illustrate the program's desired behaviour, a type signature, etc. Program synthesis is essentially a search problem, where the large search space makes the problem difficult. Two approaches exist and both are studied:

- using the programming language's semantics and type system for propagating top-level specifications to sub-parts, and to reason with these local properties;
- using generative-AI technology on big data of programming solutions for finding

candidate programs (e.g. GitHub's Copilot).

For both cases, a valid research question is how such technology can be applied usefully to support learning.

Automated feedback. We continue the long-standing research line on automated feedback generation, which has resulted in the IDEAS framework[12] and several intelligent programming tutors that are based on this framework and that have been tested in class (e.g., Ask-Elle [9], the collection of Logic Tools [17], and the Refactor Tutor [15]). The framework offers several advanced concepts that allow for rapid prototyping and extend the general knowledge of building intelligent tutoring systems (ITS): the specification of problem-solving procedures as a domain-specific language for generating step-wise feedback, hybrid solutions that mix the model tracing and and constraint-based modeling ITS paradigms, and buggy rules for describing common mistakes.

The IDEAS framework is based on state-of-the-art knowledge about ITSs. It supports VanLehn's inner and outer feedback loops that structures the sequencing of tasks and the step-wise feedback within such a task [42]. It also follows the traditional four-component architecture [28], which prescribes how the system should be decomposed into smaller parts. One such component, which is the domain reasoner or expert module, has received ample attention so far. We plan to investigate how the student model component can add to the feedback possibilities (e.g. by supporting an Open Learning Model) and make the system more adaptive. Computations by these components are offered to front-end UI systems as feedback services: these services are typically modelled after feedback types found in literature [25].

References and more

- Hieke Keuning, Johan Jeuring, and Bastiaan Heeren. A Systematic Literature Review of Automated Feedback Generation for Programming Exercises. ACM Transactions on Computing Education, 19(1):1–43, 2019.
- Bastiaan Heeren and Johan Jeuring. Automated feedback for mathematical learning environments. Proceedings of the 14th International Conference on Technology in Mathematics Teaching – ICTMT 14: Essen, Germany, 17-25, 2020.
- Alex Gerdes, Bastiaan Heeren, Johan Jeuring, and L. Thomas Binsbergen. Ask-Elle: an Adaptable Programming Tutor for Haskell Giving Automated Feedback. International Journal of Artificial Intelligence in Education, 27(1):65–100, 2017.

Software Testing. Testing is regarded as a crucial activity in software development. It is unclear, however, how acquisition of testing skills can be combined with learning how to program. The inherent complexity of programming, together with known conceptual and strategic difficulties of novice programmers, makes the integration of testing in an early stage of computer science curricula a non-trivial issue. We develop and analyze

[12] The software framework has been released at `https://hackage.haskell.org/package/ideas`.

testing education approaches aiming to align seamlessly with early steps in introductory programming. Moreover, we investigate how to foster an inquiry-based approach to testing in programming education, in line with strategies applied by testing professionals.

References and more

- Doorn, N., Vos, T., Marín, B., & Barendsen, E. (2023). Set the right example when teaching programming: Test Informed Learning with Examples (TILE). In 2023 IEEE Conference on Software Testing, Verification and Validation (ICST) (pp. 269-280). IEEE.
- Doorn, N., Vos, T., Marín, B., Bockisch, C., Dick, S., & Barendsen, E. (2023, May). Domain TILEs: Test Informed Learning with Examples from the Testing Domain. In International Conference on Research Challenges in Information Science (pp. 501-508). Cham: Springer Nature Switzerland.

7.5.2 Human factors in CS education

Software is produced by people for people. We investigate and facilitate human and social factors in Computer Science and programming education. We approach human factors in CS education from three perspectives: social and collaborative learning, personalized learning, and diversity and inclusion.

Slogan

We introduce and implement progressive educational methods and tools in programming education, emphasizing human factors such as social learning, personalization, and diversity recognition.

Social and collaborative learning. Our approach to social and collaborative learning in CS education is multi-faceted, including:

- investigate how students co-learn the CS and programming topics;
- encourage teamwork and peer-based learning and incorporate group projects; and
- fostering a supportive and motivating learning environment.

By researching and addressing these aspects, we aim at harnessing the potential of social and collaborative learning to create interactive learning environments for programming education. In these learning environments, students learn from and help each other, improving their programming as well as soft skills and problem-solving skills through (co-)development of team-based programming projects. This process provides them with ample opportunities to share their ideas, problems, solutions, and exchange feedback.

Personalized learning. Regarding personalized learning, our goal is to facilitate and motivate a more student-centered learning experience for CS students. This includes identifying and catering to individual learning needs, interests, difficulties, and competencies of students in the context of CS education. To this end, we intend to explore and leverage the potential of game-based learning, technology-enhanced learning, and generative AI to support and motivate a more student-centered approach to learning programming and computer science.

Diversity and inclusion. Diversity and inclusion are becoming essential principles in computer science education. These principles aim to ensure fair access, learning experience, participation, and success for all CS students, regardless of their gender, educational background, race, or other individual differences and characteristics. Supporting these principles in CS and programming education calls for a multi-faceted approach, encompassing various aspects. This includes designing and implementing an inclusive curriculum and developing inclusive teaching methods and course materials, taking into account the diverse learning needs of underrepresented students.

7.5.3 Digital literacy

Digital literacy refers to knowledge, skills and attitudes necessary to apply digital technology in a variety of contexts, including daily life, other (non-computing) subjects, and professions. There are several ways to characterize digital literacy skills. A framework currently used in Dutch primary and secondary educational settings distinguishes basic digital skills, media literacy, information literacy and computational thinking.

Slogan

We investigate students' learning, instructional strategies and teachers' knowledge and skills in order to support teaching and learning of digital competencies across curricula in a variety of contexts.

Computational thinking. The term Computational Thinking refers to a set of problem solving skills that make use of concepts and methods stemming from computer science. Computational Thinking is the thought process used to understand and formulate problems in such a way that they can be solved in terms of computations. Common elements in characterizations of Computational Thinking are decomposition, abstraction, algorithmic thinking, evaluation and generalization. We investigate students' understanding and instructional strategies for Computational Thinking, especially with respect to abstraction skills of primary school students. Special attention is given to teachers' knowledge and skills required for incorporating Computational Thinking in their lessons.

References and more

- Kallia, M., van Borkulo, S. P., Drijvers, P., Barendsen, E., & Tolboom, J. (2021). Characterising computational thinking in mathematics education: a literature-informed Delphi study. *Research in Mathematics Education*, 23(2), 159-187.
- Yeni, S., Grgurina, N., Saeli, M., Hermans, F., Tolboom, J., & Barendsen, E. (2023). Interdisciplinary Integration of Computational Thinking in K-12 Education: A Systematic Review. *Informatics in Education*.
- Faber, H. H., Koning, J. I., Wierdsma, M. D., Steenbeek, H. W., & Barendsen, E. (2019). Observing abstraction in young children solving algorithmic tasks. In *International Conference on Informatics in Schools: Situation, Evolution, and Perspectives* (pp. 95-106). Cham: Springer International Publishing.
- Yeni, S., Nijenhuis-Voogt, J., Hermans, F., & Barendsen, E. (2022). An Integration of Computational Thinking and Language Arts: The Contribution of Digital Storytelling to Students' Learning. In *Proceedings of the 17th Workshop in Primary and Secondary Computing Education* (pp. 1-10).
- Barendsen, E., Gorissen, P., Van Rens, C., & Coetsier, N. (2023). *Computational thinking: veelzijdiger dan enkel programmeren*. Onderwijskennis, NRO. `https://www.onderwijskennis.nl/kennisbank/computational-thinking-veelzijdiger-dan-enkel-programmeren`

Information literacy. A key competence to prepare students to deal with complex problems in a professional or learning context is information problem solving (IPS), also known as information literacy (IL), commonly defined as the ability to find, access, evaluate, synthesize, and use information. Despite its significance, research has repeatedly shown that many students are underdeveloped in IPS. This lack of IPS can be problematic for students in terms of accessing information and knowledge. It can result in them making decisions based on inaccurate, one-sided, or out-of-date information. On the other hand, information literate students know how to use and produce digital information to actively support their learning, further increasing their chances of academic and societal success. We investigate learning environments aimed to foster IPS in a higher education setting.

7.6 Impact

The research lines of the department are strategically positioned to make a profound impact on various fronts, including technological, educational, industrial, and societal.

7.6.1 Technological impact

Advancements in technology are at the core of our research. We aim to drive technological impact by creating and extending publicly available **tools, systems and libraries**. Our research results in the development of new tools, systems, and methodologies for software testing, analysis, and verification. For example:

- The TESTAR tool is an open source BSD3 tool (`https://github.com/TESTARtool`) for scriptless testing at the GUI level. In our pursuit of industrial impact, we organize hands-on sessions, or inspiration sessions, to provide companies with firsthand experience in using our specialized testing tool. This approach not only fosters a deeper understanding of our tools but also encourages industries to integrate them into their testing workflows.
- FoxDec is an open-source disassembler and decompiler (`https://ssrg-vt.github.io/FoxDec/`) that aims at retrieving a model from a binary that has been formally proven correct. FoxDec has been used to address challenges created by Raytheon BBN (`https://www.rtx.com/who-we-are/we-are-rtx/transformative-technologies/bbn`) for the DARPA research institute. These challenges have been used for the evaluation of FoxDec in an industrial setting.
- TopHat [39, 38] is a domain specific programming language (DSL) to describe workflow systems and business processes in a paradigm we call task-oriented programming. These specifications can be visualized and introduced a structured way to gradually develop such visualizations. It allows us to symbolically execute workflows to verify their correctness [27]. We also use this symbolic execution engine to generate next-step hints for end users [26]. Besides that, we developed a way to reason about the equivalence of task-oriented programs [16].
- The Ampersand project has yielded a compiler that generates information systems based on a formal specification (`https://ampersandtarski.github.io/`). It solves the problem of large IT projects by automating the design of information systems. Ampersand [13] takes a semantic approach by formalizing the semantics of the business (domain semantics) and generating fully functional prototypes from it. This facilitates incremental design and build approaches such as DevOps. Making an Ampersand model has proven useful in the requirements elicitation stage for yielding conceptual models that are ready to build. Generating systems has proven useful in the design stage for making prototypes that allow co-creation with users. Generating functional specifications has demonstrated its use in relieving architects from unpopular documentation work.
- Satuio is a (prototype) tool for generating adaptive distinguishing sequences and unique input/output sequences for finite state machines (`https://github.com/Jaxan/satuio`). It can generate short tests which verify in which state a system is. Such tests can also be used as a basis for conformance testing of finite state machines.

- We develop new techniques and extensions to the open-source KeY theorem prover (`https://www.key-project.org/`). KeY is tailored for formal verification of Java programs. New techniques are needed to optimize and make scalable the activities of the human proof architect and further enable verification of complex software written in the Java programming language.
- Library functions are used as the building blocks for millions of programs. If our analysis of these libraries reveals bugs, we will publish a fixed (and verified) version of the library and aim to incorporate this new version in the standard library. This way, all programs that use these libraries and the software engineering community at large benefit automatically from our new technology.
- We expect to be contributing to the development of state of the art AI technologies by e.g. developing new types of neural networks, new approaches to logic programming with predicates defined through representation learning, the definition of new approaches to training neural networks, to reinforcement learning conforming to declarative specifications, the specification of neurosymbolic models for planning in industry settings is also an area where we expect we can create impact.
- The educational tools that we develop advance the technological state-of-the-art and are often based on programming language technologies. For example, the intelligent tutoring systems that are based on the Ideas framework use techniques from generic programming (e.g. for rewriting and traversals), domain-specific languages, and advanced type system extensions. Similarly, the refactoring tool uses program analyses and is offered as a plug-in for integrated development environments (IDEs).

7.6.2 Academic impact

We aim to publish high-impact scientific papers on conferences and journals. In addition, we seek collaboration with academic research partners, both in the field of computer science and other disciplines including information science, law, and social sciences. For proof of work show a graph from PURE showing the publications starting from 2016?

7.6.3 Educational impact

The educational impact is reached by incorporating our research findings, expertise and tools into our educational programs. Especially the tools we develop have impact on our education. Moreover, graduation assignments help to further improve the tools. For example:

- Logic Tools for practicing equational, axiomatic, and inductive proofs: these tools are used in bachelor and premaster courses.
- The virtual security lab, of which we researched both the technical infrastructure

and application for education, that is used in the bachelor course on security.

- The TESTAR tool is used in our course on Software verification and testing (`https://www.ou.nl/opleiding?sku=im0903`).
- The course Rule Based Design [14] (`https://www.ou.nl/-/IM0403_Rule-Based-Design`) teaches how to design information systems with rules rather than code. Students are exposed to Ampersand as an example of a tool that does rule-based design. It uses a platform called RAP (`https://rap.cs.ou.nl`), which has been built in Ampersand itself [20]. RAP is the first application that Ampersand has generated to run in production.
- The ANIMO tool [36], [37] is being used in biomedical education at the University of Twente and at the Leiden University Medical Center as an instrument to model and analyze complex biological networks.
- The KeY tool (`https://key-project.org/`) for which we developed extensions and applications to major case studies, is used extensively in different universities in several countries, such as TU Darmstadt, Karlsruhe Institute of Technology, Chalmers, Carnegie Mellon, Uppsala and Oslo. In Germany alone, yearly more than 500 students learn to use KeY.

Moreover, we want to improve the success we have had with publishing Bachelor and Master thesis results, i.e. [6], [2], [41], [24], [4],[33], [3], [11], [5], [7], [12].

7.6.4 Industrial impact

Our research does not stop at academia; it has significant practical applications within companies and industries. The industrial impact of our work includes:

- **Software development:** Our research contributes to the development of better software products, benefiting software companies, startups, and tech industries.
- **Process optimization:** We provide insights and tools for optimizing software development and testing processes, reducing costs and development time.

This industrial impact is achieved through close collaboration with industry partners, technology transfer, and the incorporation of our research findings into industrial practices. We will actively engage with industry partners to collaboratively address real-world software quality challenges, making our research industry-driven.

Ampersand has been used in practice in various places, most notably at Ordina and TNO-ICT. Ordina uses Ampersand as a prototyping tool and a tool for semantic analysis of information systems. In the past, Ordina has used it during the design of large information systems in the public sector, e.g. INDIGO (Dutch Immigration Authority, IND) and DTV (Dutch Food Authority, NVWA). TNO-ICT, a major Dutch industrial research laboratory, has used Ampersand for research purposes, patent research, and demonstrator software. TNO-ICT has built several information systems that it now

maintains in production, in the context of the Semantic Treehouse project (`https://www.semantic-treehouse.nl/`).

The libraries that we analyze and improve are mainly developed in industry. For example, the Java Collection Framework is under development by Oracle and Google (for use in their Android platform). We will engage directly with industry by reporting discovered bugs, fixes, enhancements and test cases to the libraries to the official channels, such as the Java bug tracker. This way our improvements can be incorporated in the standard libraries that are in control and use by these companies and have direct impact on their software development, as well as millions of other software developers worldwide.

Another example is the Dagobert-project in which we researched the detection of botnets by analyzing network traffic by applying AI. This was done in cooperation with internet service providers and network infrastructure providers.

7.6.5 Social impact

Our Software Engienering research is dedicated to improving software quality, which directly translates to positive effects on society, communities, and specific groups. By providing insights and best practices for software quality, our research could influence policy decisions related to technology standards and regulations, ensuring that software systems are developed to the highest standards. Moreover, our work could directly contribute to preventing issues related to system failures and disruptions that could impact people's lives.

More specifically, society today relies on software, in particular the software libraries that form the building blocks of programs. For instance, the Java Collection Framework is used as the standard library on Android and cloud services and programs written in the mainstream Java programming language, which means that its library functions run on the devices of billions of users every day. By analyzing and improving such libraries, society thus directly benefits from using rigorously verified, trusted software components.

Our research on privacy directly relates to the privacy of citizens and organisations. We also research the impact of security measures, such as the electricity consumption and environmental footprint of security mechanisms in cryptocurrencies. Our research results has raised awareness, are being applied to enhance blockchain-based applications, and are used by governments and institutions to define legislation and policies. For instance, in our Econsensus project, we defined a code of conduct for researchers, we provided input for the US policy on cryptocurrency mining, and co-authored a report of the World Economic Forum.

The focus on both robust and safe AI, and co-creation with humans seeks to bridge the gap between theoretical advancements and real-world AI integration, ensuring that our research not only contributes to both academic knowledge but also the practical evolution of AI technologies in society and industry. It is therefore only natural that the approach taken by the Open University concerning AI research and education is that of

Open Science. This means that OU will focus on working with naturally replicable and open approaches to data and AI models, allowing open access to the publications, and working with open source as the preferred software development methodology.

The impact on society of the CS education research line consists of multiple aspects:

- Barendsen chaired the committee that was responsible for designing a new curriculum for the final exam subject Computer Science for secondary education (havo/vwo).
- Barendsen acts as an expert advisor in national curriculum revision and monitoring on digital literacy in primary and secondary education. He chairs the advisory board for the core curriculum ('kerndoelen') with respect to digital literacy.
- By publishing books on guidelines for inclusive education and autism (Autisme is geen puzzel [2021], Autisme-inclusief hoge onderwijs [to appear]), Stuurman informs a diverse audience about neurodiversity and helps teachers to make their education more accessible.

7.7 Organization of the department and meetings

The organizational structure of the department is depicted in Figure 2. It is a multifaceted structure consisting of several interconnected components that define the institution's governance and operational dynamics.

At the head of the department is the Department Management Team, which is lead by Dr. Bastiaan Heeren. This core team includes specialized roles such as the Faculty's Research Coordinator and the program leaders of the departments educational programs.

Diverging from the management core are two primary branches: Research Lines and Educational Programs, each with its own set of leaders and agendas. This structured approach not only emphasizes the institution's commitment to a broad spectrum of research but also underscores the foundational layer of education.

Strategic Meetings form the backbone of the department's communication and decision-making processes, fostering an environment of regular reflection and strategic planning. The department organizes different research meetings to achieve engagement and cohesion between the members of the department and their research results.

OUrsi is a two-weekly research seminar that aims to provide a platform for the researchers in the CS group as well as visitors to share their preliminary as well as mature research results with each other in an informal setting. The seminar seeks a balance between presentations from each of the research lines, as well as balancing talks from more senior group members with presentations from more junior members.

GenAI in CS Education is a quarterly symposium that aims to provide a platform for

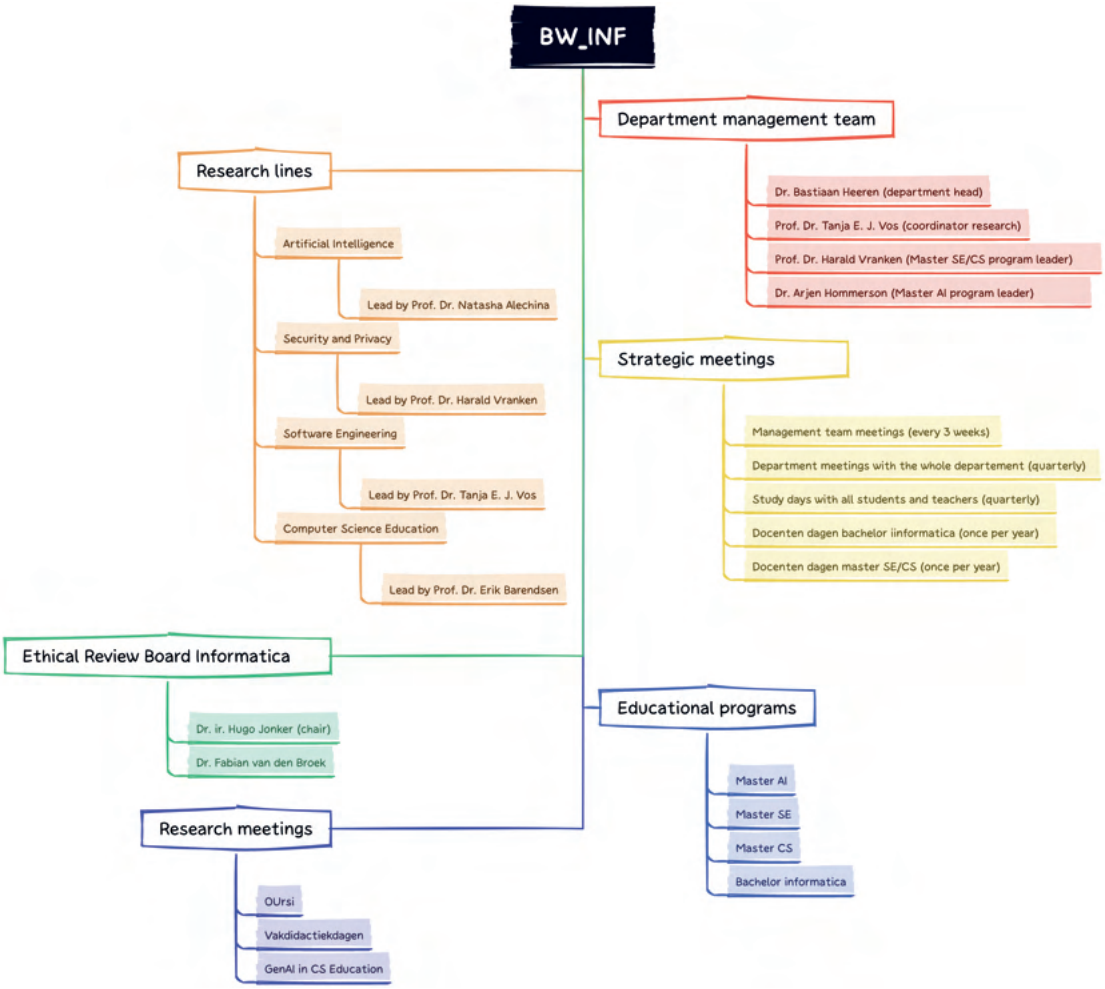


Figure 2: Organizational structure of the department

researchers and educators in computer science, software engineering, and programming education in higher education who are active or interested in the educational application of GenAI and ChatGPT within these disciplines. It is designed for them to share their research findings and good educational practices, collaborate on writing research proposals and grants, contribute to policymaking and regulations, and seek synergies with similar initiatives in GenAI within higher education.

Network meetings on Computing Education research ('Vakdidactiekdagen') These network meetings are organized four times a year. They connect a broad country-wide community of researchers with interests in computing education. The events serve as a platform to share research results, get in touch with colleagues and potential project partners, and to pitch new ideas. Moreover, the meetings offer a safe and constructive environment in which beginning researchers (in particular bachelor's and master's students and PhD candidates) benefit from feedback on their plans and preliminary work. Traditionally, for each event a recent research paper is selected to be read by the participants and discussed during the event, thus contributing to the role of the network as a learning community.

Finally, following the advice from the KNAW report "Ethical and Legal Aspects of Computer Science Research" (2017), the Computer Science department has established an Ethical Review Board for Informatics (ERBi). This body aims to provide easily accessible ethical advice on computer science-related research. The procedure for formal ethical approval for research remains unchanged and goes through the CETO.

7.8 Scientific and societal partners and collaborations

We have a strong collaboration with some entities that we would like to enforce and extend in the future.

7.8.1 Radboud University

We are closely connected with the Institute for Computing and Information Sciences (ICIS) at Radboud University. This holds in particular for the Digital Security group in ICIS: about 10 of our researchers have a position as guest researcher or have a secondment in this group. Of these researchers, some visit Radboud University regularly, while others even have their office at Radboud University. This strong physical presence facilitates contacts and cooperation, both for research and education. These researchers also act as supervisors for thesis projects at Radboud University. Since these projects are often done externally with industry or governmental institutions, this also provides a direct connection for researchers to private and public organisations.

To add: there are also links with the software science and data science groups at ICIS.

7.8.2 Virginia Tech

An active and fruitful collaboration has been maintained with Virginia Polytechnic Institute and State University (Virginia Tech) for years. The SSRG research group op prof. Ravindran has close ties to several researchers of the OU computer science group, which has lead to collaborative research, resource sharing, and joint funded research proposals. Most notably, Virginia Tech and OU share a funded DARPA proposal, and a funded NSF proposal. The objective of this research is to combine knowledge available at a US technical university (low-level OS programming, detailed hardware knowledge) with the mathematical and formal knowledge available at OU. This has lead to several joint publications, exchange of personnel and sharing of ideas and funding opportunities.

7.8.3 Technical University of Valencia

The collaboration with the Technical University of Valencia (Universidad Politécnica de Valencia (UPV)) is part of the Software Testing research led by Tanja Vos. This collaboration is unique in that this group is spanning two locations in two countries: the Open Universiteit (OU) in Heerlen and the Universidad Politécnica de Valencia (UPV) in Spain. The group was portrayed in the July edition of the I/O magazine[13] published by the ICT Research Platform Nederland (IPN).

7.8.4 University of Twente

An ongoing research collaboration with the University of Twente focuses on the application of formal modeling techniques in the field of biomedical research. The work is part of a larger quantitative biology research effort aimed at understanding cell fate decisions, with diagnostic and therapeutic applications. Teams from Leiden University Medical Center and Radboud University are also integral part of the research effort, which has been leading to a number of joint publications. Ideally, in the future the collaboration would entail shared research projects including funding and PhD supervision.

References

[1] Assessment Committee (Rik Leemans, Jos Benders, Michel van Eeten, and Wim Lambrechts). Midterm review Learning and Innovation in Resilient Systems 2014-2016. Technical report, Open Universiteit, October 31, 2017.

[2] Axel Bons, Beatriz Marín, Pekka Aho, and Tanja E.J. Vos. Scripted and scriptless gui testing for web applications: An industrial case. *Information and Software Technology*, 158:107172, 2023.

[13] https://ict-research.nl/wordpress/wp-content/uploads/2023/06/IO-magazine-NR2-2023_vWEB.pdf

[3] Jelle Bouma, Stijn de Gouw, and Sung-Shik Jongmans. Multiparty session typing in java, deductively. In Sriram Sankaranarayanan and Natasha Sharygina, editors, *Tools and Algorithms for the Construction and Analysis of Systems - 29th International Conference, TACAS 2023, Held as Part of the European Joint Conferences on Theory and Practice of Software, ETAPS 2022, Paris, France, April 22-27, 2023, Proceedings, Part II*, volume 13994 of *Lecture Notes in Computer Science*, pages 19–27. Springer, 2023.

[4] Hatim Chahim, Mehmet Duran, Tanja E. J. Vos, Pekka Aho, and Nelly Condori Fernandez. Scriptless testing at the gui level in an industrial setting. In Fabiano Dalpiaz, Jelena Zdravkovic, and Pericles Loucopoulos, editors, *Research Challenges in Information Science*, pages 267–284, Cham, 2020. Springer International Publishing.

[5] Martin de Boer, Stijn de Gouw, Jonas Klamroth, Christian Jung, Mattias Ulbrich, and Alexander Weigl. Formal specification and verification of jdk's identity hash map implementation. In Maurice H. ter Beek and Rosemary Monahan, editors, *Integrated Formal Methods - 17th International Conference, IFM 2022, Lugano, Switzerland, June 7-10, 2022, Proceedings*, volume 13274 of *Lecture Notes in Computer Science*, pages 45–62. Springer, 2022.

[6] F. de Gier, D. Kager, S. de Gouw, and Tanja E. J. Vos. Offline oracles for accessibility evaluation with the testar tool. In *2019 13th International Conference on Research Challenges in Information Science (RCIS)*, pages 1–12, May 2019.

[7] Erwin de Jager and Stijn de Gouw. Hybrid analysis of BPEL models with grammars. In Yannis Manolopoulos, George A. Papadopoulos, and Theodoros Tzouramanis, editors, *Proceedings of the SOFSEM 2020 Doctoral Student Research Forum colocated with the 46th International Conference on Current Trends in Theory and Practice of Computer Science (SOFSEM 2020), Limassol, Cyprus, January 20-24, 2020*, volume 2568 of *CEUR Workshop Proceedings*, pages 73–84. CEUR-WS.org, 2020.

[8] Martin Fowler, Steven Fraser, Kent Beck, Bil Caputo, Tim Mackinnon, James Newkirk, and Charlie Poole. *Refactoring: Improving the Design of Existing Code*. Addison-Wesley Longman Publishing Co., Inc., Boston, MA, USA, 1999.

[9] Alex Gerdes, Bastiaan Heeren, Johan Jeuring, and L. Thomas Binsbergen. Ask-elle: an adaptable programming tutor for haskell giving automated feedback. *International Journal of Artificial Intelligence in Education*, 27(1):65–100, 2017.

[10] Felienne Hermans. Hedy: a gradual language for programming education. In *Proceedings of the 2020 ACM conference on international computing education research*, pages 259–270, 2020.

[11] Hans-Dieter A. Hiep, Olaf Maathuis, Jinting Bian, Frank S. de Boer, and Stijn de Gouw. Verifying openjdk's linkedlist using key (extended paper). *Int. J. Softw. Tools Technol. Transf.*, 24(5):783–802, 2022.

[12] Hans-Dieter A. Hiep, Olaf Maathuis, Jinting Bian, Frank S. de Boer, Marko C. J. D. van Eekelen, and Stijn de Gouw. Verifying openjdk's linkedlist using key. In Armin Biere and David Parker, editors, *Tools and Algorithms for the Construction and Analysis of Systems - 26th International Conference, TACAS 2020, Held as Part of the European Joint Conferences on Theory and Practice of Software, ETAPS 2020, Dublin, Ireland, April 25-30, 2020, Proceedings, Part II*, volume 12079 of *Lecture Notes in Computer Science*, pages 217–234. Springer, 2020.

[13] Stef Joosten. Relation algebra as programming language using the ampersand compiler. *Journal of Logical and Algebraic Methods in Programming*, 100:113–129, 2018.

[14] Stef Joosten, Lex Wedemeijer, and Gerard Michels. *Rule Based Design*. Open Universiteit, Heerlen, 2013.

[15] Hieke Keuning, Bastiaan Heeren, and Johan Jeuring. A tutoring system to learn code refactoring. In *Proceedings of the 52nd ACM Technical Symposium on Computer Science Education*, SIGCSE '21, pages 562–568, New York, NY, USA, 2021. Association for Computing Machinery.

[16] Tosca Klijnsma and Tim Steenvoorden. Semantic equivalence of task-oriented programs in tophat. In Wouter Swierstra and Nicolas Wu, editors, *Trends in Functional Programming - 23rd International Symposium, TFP 2022, Virtual Event, March 17-18, 2022, Revised Selected Papers*, volume 13401 of *Lecture Notes in Computer Science*, pages 100–125. Springer, 2022.

[17] J.S. Lodder. *The Design and Use of Tools for Teaching Logic*. PhD thesis, September 2020.

[18] Michael McCracken, Vicki Almstrum, Danny Diaz, Mark Guzdial, Dianne Hagan, Yifat Ben-David Kolikant, Cary Laxer, Lynda Thomas, Ian Utting, and Tadeusz Wilusz. A multi-national, multi-institutional study of assessment of programming skills of first-year cs students. In *Working group reports from ITiCSE on Innovation and technology in computer science education*, pages 125–180. 2001.

[19] Tom Mens and Tom Tourwé. A survey of software refactoring. *IEEE Trans. Softw. Eng.*, 30(2):126–139, February 2004.

[20] Gerard Michels. *Development Environment for Rule-based Prototyping*. PhD thesis, Open University of the Netherlands, June 2015.

[21] Melina Mongiovi, Rohit Gheyi, Gustavo Soares, Márcio Ribeiro, Paulo Borba, and Leopoldo Teixeira. Detecting overly strong preconditions in refactoring engines. *IEEE Transactions on Software Engineering*, 44(5):429–452, August 2018.

[22] MST Research Committee (Carolien Kroeze, Marjolein Caniëls, Dave Huitema, and Harald Vranken). Learning and Innovation in Resilient Systems: MST Research Program 2015-2020. Technical report, Open Universiteit, December 18 2014.

[23] MST Research Committee (Petru L. Curseu, Marjolein Caniëls, Dave Huitema, Harold Krikke, Harald Vranken, and Annemarie Cremers). Learning and Innovation

in Resilient Systems 2014-2016. Technical report, Faculty of Management, Science and Technology (MST), Januari 10, 2017.

[24] Ad Mulders, Olivia Rodriguez Valdes, Fernando Pastor Ricós, Pekka Aho, Beatriz Marín, and Tanja E. J. Vos. State model inference through the gui using run-time test generation. In Renata Guizzardi, Jolita Ralyté, and Xavier Franch, editors, *Research Challenges in Information Science*, pages 546–563, Cham, 2022. Springer International Publishing.

[25] Susanne Narciss. Feedback strategies for interactive learning tasks. In J.M. Spector, M.D. Merrill, J.J.G. van Merriënboer, and M.P. Driscoll, editors, *Handbook of Research on Educational Communications and Technology*. Mahaw, NJ: Lawrence Erlbaum Associates, 2008.

[26] Nico Naus and Tim Steenvoorden. Generating next step hints for task oriented programs using symbolic execution. In Aleksander Byrski and John Hughes, editors, *Trends in Functional Programming - 21st International Symposium, TFP 2020, Krakow, Poland, February 13-14, 2020, Revised Selected Papers*, volume 12222 of *Lecture Notes in Computer Science*, pages 47–68. Springer, 2020.

[27] Nico Naus, Tim Steenvoorden, and Markus Klinik. A symbolic execution semantics for tophat. In Jurriën Stutterheim and Wei-Ngan Chin, editors, *IFL '19: Implementation and Application of Functional Languages, Singapore, September 25-27, 2019*, pages 1:1–1:11. ACM, 2019.

[28] Hyacinth S. Nwana. Intelligent tutoring systems: an overview. *Artificial Intelligence Review*, 4(4):251–277, 1990.

[29] Department of Computer Science. Computer science research program 2020-2025. Technical report, Open Universiteit, 2020.

[30] School of Computer Science. Software Technology Research Plan 2010-2015. Technical report, Open Universiteit, May 9, 2011.

[31] William F Opdyke. *Refactoring object-oriented frameworks*. University of Illinois at Urbana-Champaign, 1992.

[32] Harrie Passier, Lex Bijlsma, and Christoph Bockisch. Maintaining unit tests during refactoring. In *Proceedings of the 13th International Conference on Principles and Practices of Programming on the Java Platform: Virtual Machines, Languages, and Tools*, PPPJ '16, pages 18:1–18:6, New York, NY, USA, 2016. ACM.

[33] Fernando Pastor Ricós, Arend Slomp, Beatriz Marín, Pekka Aho, and Tanja E.J. Vos. Distributed state model inference for scriptless gui testing. *Journal of Systems and Software*, 200:111645, 2023.

[34] Maurizio Proietti and Alberto Pettorossi. Semantics preserving transformation rules for prolog. *ACM SIGPLAN Notices*, 26(9):274–284, 1991.

[35] Mitchel Resnick, John Maloney, Andrés Monroy-Hernández, Natalie Rusk, Eve-

lyn Eastmond, Karen Brennan, Amon Millner, Eric Rosenbaum, Jay Silver, Brian Silverman, et al. Scratch: programming for all. *Communications of the ACM*, 52(11):60–67, 2009.

[36] Stefano Schivo, Jetse Scholma, Paul E van der Vet, Marcel Karperien, Janine N Post, Jaco van de Pol, and Rom Langerak. Modelling with ANIMO: between fuzzy logic and differential equations. *BMC Systems Biology*, 10, July 2016.

[37] Jetse Scholma, Stefano Schivo, Ricardo A Urquidi Camacho, Jaco van de Pol, Marcel Karperien, and Janine N Post. Biological networks 101: computational modeling for molecular biologists. *Gene*, 533(1):379–84, January 2014.

[38] Tim Steenvoorden. *TopHat: Task-Oriented Programming with Style*. PhD thesis, Radboud University, Nijmegen, the Netherlands, 2022.

[39] Tim Steenvoorden, Nico Naus, and Markus Klinik. Tophat: A formal foundation for task-oriented programming. In Ekaterina Komendantskaya, editor, *Proceedings of the 21st International Symposium on Principles and Practice of Programming Languages, PPDP 2019, Porto, Portugal, October 7-9, 2019*, pages 17:1–17:13. ACM, 2019.

[40] Lance Tokuda and Don Batory. Evolving object-oriented designs with refactorings. *Automated Software Engg.*, 8(1):89–120, jan 2001.

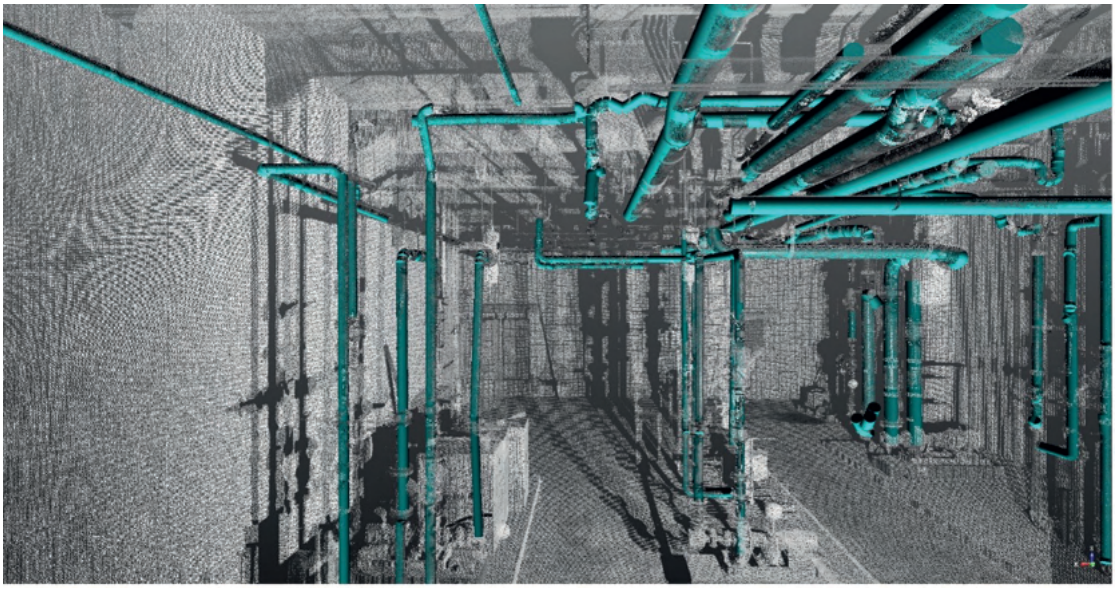
[41] Aaron van der Brugge, Fernando Pastor Ricos, Pekka Aho, Beatriz Marín, and Tanja E.J. Vos. Evaluating TESTAR's effectiveness through code coverage. In S. Abrahão Gonzales, editor, *XXV JISBD*. SISTEDES, 2021.

[42] Kurt VanLehn. The behavior of tutoring systems. *International Journal of Artificial Intelligence in Education*, 16(3):227–265, 2006.

8 Information Science Research Program 2023-2027

CAMINO

Creating, Analyzing and Managing high-quality Information



Department of Information Science, Open Universiteit

8.1 Overview of the department

This strategic research plan of the Information Science (IS) Department in the Faculty of Science represents a next step in the evolution of information science practised by this research group. Besides some quite fundamental developments in the way in which individual researchers and research teams are being assessed, a much stronger focus on societal relevance next to scientific excellence characterises this update of our research plan (see version 1.0 [1]). In addition, first steps have been taken to map the rich variety in individual expertise in our group to take into account, both the scientific foundational domains as well the individual experience in various actual application areas.

Besides the continuous effort to further the academic IS domain, researchers in our IS department embrace their mission to "bridge" the gap between the academic IT community and the various stakeholders in practice. Therefore, much of our research takes place in a multi-disciplinary setting in which practitioners may participate actively to create relevant high impact research and to shorten the adoption time of scientific innovation.

In this document the various research lines, the structure, future developments and our ambitions will be explained.

8.1.1 History

The IS department has grown substantially in recent years. This growth necessitates a strong structured approach to organise our research capacity. As will be demonstrated in coming paragraphs, the research capacity is quite diverse, not just on the departmental level but also on an individual level. We hope and expect that this strategic plan will be equally interesting for academics and practitioners. In particular growth was made possible through a growing popularity of the "Business Process Management and IT" scientific master program.

Typically for the Open University, the vast majority of students are in the middle of their career tracks and have regular jobs in a broad variety of organisations, employed mostly in positions closely related with IT development in relation to business development. They seek further academic sophistication and professionalism in the emerging field of information science and become leaders in innovation. In a sense, this interest demonstrates the relevance of the departments knowledge and innovational prowess for actual IT business challenges many modern organisations have to deal with.

Being in the forefront of information science innovations necessitates a strong information science research effort to facilitate a quick and direct influx of new ideas, concepts, instruments and methods into our educational programs.

In our department we strongly believe that scientific excellence and societal relevance go hand in hand. It may come as no surprise then, that we not only have a strong following of master students but also a growing group of external PhD students, having

professional daytime jobs. At the time of this writing, the number of PhD students grew from a handful to over thirty in just a few years' time. Our success on the educational side very much motivates our staff to innovate further to invest in IS novel research and learning approaches to facilitate a quick adoption into practice.

8.1.2 Research focus of the department

The Information Science discipline can be considered a research domain which unites computer science (the enabling IT technology) and management science (users seeking effective and efficient application of IT technology). In a sense, the information Science (IS) discipline is a response to the inability on, both practical as well as on a scientific level, to realise the envisioned success of IT applications in a straightforward way. The inherent complexities of combining technological excellence with organisation design and governance is seen as a key problem area in the research efforts in our IS department. In addition, the many different application contexts in which IT technology can be studied are sheer endless. The Information Science Group has defined its mission as follows:

The mission of the IS group is to foster the co-evolution of the application of Information Systems in its environment to the greater benefit of the value creation of organisations, networks and society in general

The IS group is a young dynamic group of researchers with a wide interest in various aspects in information science. In our view, information science should aim to bridge the gap between rather generic information technology and its real world application to the benefit of individuals operating in various social settings and constructs such as organisations. To develop expertise in this particular area a researcher has to connect with traditional scientific disciplines such as computer science, economics and social sciences, etc. as well as the countless application areas in which real world information systems are being developed and used. In all, this requires a multidisciplinary mindset and a mental flexibility to team up and cooperate with various academic and non-academic groups. Our researchers combine solid scientific methodological research with situational awareness, sensibility and stakeholder requirements in real world situations in which productive, safe and sustainable information systems are paramount.

To summarise our expertise we decided to make use of a two-dimensional matrix (the IS expertise matrix in Figure 1) in which we categorise our more generic disciplinary knowledge on one hand, i.e. the classic research lines (i.e. the horizontal rows, the first axis), with our situational application knowledge component (i.e. the vertical columns, the second axis) on the other hand.

The researchers in Information Science are active in research projects on both axis simultaneously and in multiple cross-sections shown in Figure 1. E.g. a research project may concern the improvement of ethically sound business processes in a hospital environment in which data security is highly valued.

Because the diversity of expertise is rather large in the IS group, it is rather difficult

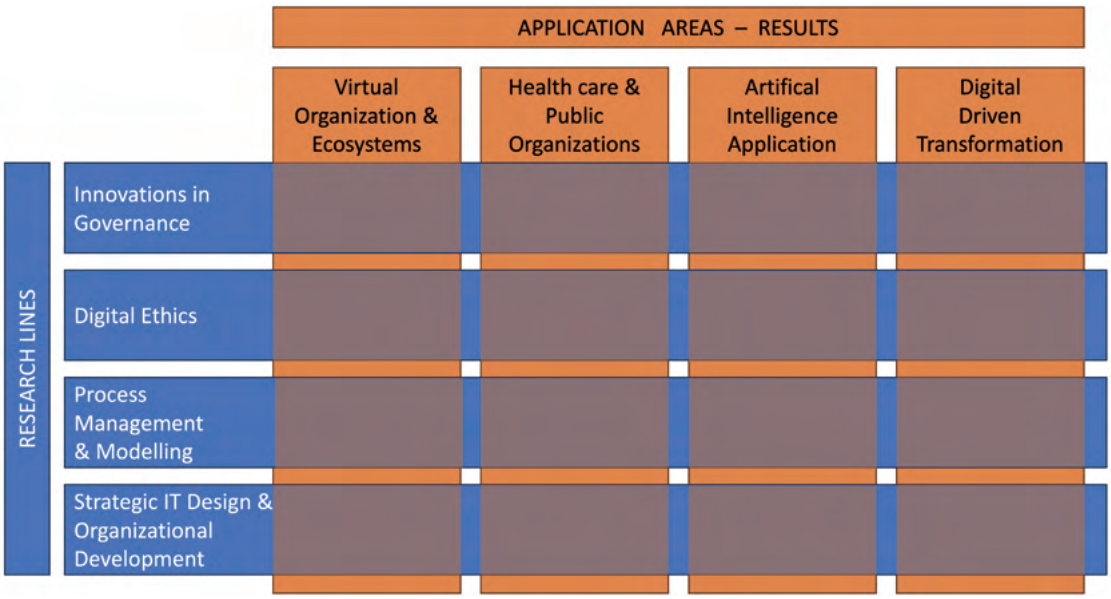


Figure 1: The IS expertise matrix

to position everyone's knowledge in a compact and insightful way on paper, a special experimental Web-application has been developed that provides an interactive and visual way to drill down from the global matrix axes, via the matrix cells down to the individual researchers (The link will be made available via the Information Science research portal, see contact section in this report). The various research lines and application areas will be explained below.

8.1.3 Size

The total capacity as per January 2024 is listed in table 1. The 4 research lines will be explained in the sections below.

Table 1: FTE in research lines

Research line	**Capacity**
Innovations in Governance	9,6
Digital Ethics	2,6
Process Management & Modelling	3,7
Strategic IT Design & Organisational Development	6,8
Total	**22,7**

8.1.4 Embedding in the landscape in the Netherlands

8.1.4.1 Research schools

From the three national computer science research schools (ASCI[1], IPA[2], SIKS[3]), the PhDs of the department IS are all member SIKS.

8.1.4.2 Sectorplannen Informatica

The sectorplannen, as discussed before also include key areas ('zwaartepunten') related to the IS department. Table 2 shows how the research lines in the information science research program at the OU correspond to the focus areas.

Table 2: Mapping of IS research lines on the Sectorplan focus areas

Focus area	**Program line**
Data modelling and analysis	Strategic IT design & organisational development
	Digital Ethics
Machine learning	Digital Ethics
Machine reasoning and interaction	-
Algorithmics	-
Software	Process Management & Modelling
	CS Education
Security and privacy	Innovations in Governance
	Digital Ethics
Networked computing and embedded systems	-

8.2 Research Line: Innovations in Governance

Nowadays, organisations heavily leverage digital technologies for strategic purposes, accompanied by fundamentally reshaped (digital) business strategies. This widespread adoption of information technology (IT) has resulted in organisational decision-makers encountering crucial IT-related decisions across operational, tactical, and strategic levels. Fields such as IT management, which focuses more on operational aspects, and IT governance, which concentrates more on strategic aspects, have emerged to support

[1] https://asci.tudelft.nl
[2] https://ipa.win.tue.nl/
[3] https://siks.nl

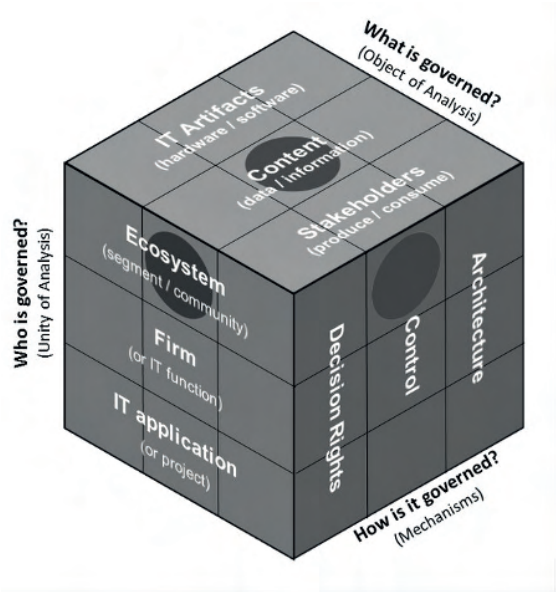


Figure 2: IT governance cube (Tiwana et al., 2013)

organisations in addressing these challenges and to ensure effective control over their current and future IT use.

It has been stressed many times that the achievement of IT business value relies heavily on good IT governance. As Weill & Ross (2004, pp. 3–4) already put it: *"[. . .] effective IT governance is the single most important predictor of the value an organization generates from IT."* Aside from the potential benefits of good IT governance, there are also potential risks of non-existent or inappropriate IT governance. For example, instances of IT governance failure have been linked to incidents such as information security breaches and inefficient allocation of IT resources. In summary, organisations have clear incentives to strive for effective IT governance, as this enables the creation and protection of IT business value.

The issues related to ensuring appropriate control over IT to enable the creation and protection of IT business value fall under the umbrella of the 'IT governance' concept, which can be defined as: *"[. . .] an integral part of corporate governance for which, as such, the board is accountable. It involves the definition and implementation of processes, structures, and relational mechanisms that enable both business and IT stakeholders to execute their responsibilities in support of business/IT alignment, and the creation and protection of IT business value."* (De Haes et al., 2020, p.3).

There are numerous ways to classify IT governance research. Initially, the focus was on two concurrent research pathways, which are considered foundational to subsequent IT governance studies (Brown & Grant, 2005). The first pathway delves into different forms

of IT governance (and is concerned with the locus of IT decision-making authority and the types of IT decisions), while the second pathway explores IT governance contingency analysis (and is concerned with understanding the factors that influence the choice for a structural form of IT governance). While these initial pathways remain relevant to this day, later research has converged and aggregated these two initial research streams, and tried to better connect to practice. In that regard, research focused on how IT governance can be implemented in practice (e.g., through structures, processes, and relational mechanisms), and on the organisational effects of effective IT governance.

Figure 2 presents the IT Governance Cube (Tiwana et al., 2013), providing a straightforward framework to classify IT governance research. It comprises three dimensions that delineate the scope of IT governance research. First, the 'Who is governed?' dimension signifies the breadth of governance and roughly maps to the unit of analysis. Second, the 'What is governed?' dimension concerns what is being governed. Third, the 'How is it governed?' dimension represents the mechanisms used to govern.

The research line on IT governance can be divided into four research sub-lines. These sub-lines can be related to the dimensions in the IT Governance cube in the following way:

IT Governance Dimension	**Research Sub-line**
Who is governed	1. Digital platform governance
What is governed	2. Information security governance
	3. Data governance
How is it governed	4. Agile and adaptive IT governance

In the following sections, each of the research sub-lines will be described briefly.

8.2.1 Digital platform governance

With the ongoing rise of digital platforms, it is becoming clear that traditional IT governance mechanisms used in an intra-corporate setting are challenged and may be less adequate in a platform setting. Consequently, governance frameworks must be redeveloped using the elements of existing frameworks centred around creating an agile governance structure where business and IT are operating closer than ever.

Slogan

Forging trust in digital frontiers: shaping governance for platform success

Specific projects within this topic focus on (1) governmental platforms for digital citizen services and (2) data-sharing platforms.

Governance models for governmental platforms for citizen services are needed for governments all around the world since are going digital and are using technology like the

Internet, AI, or social media to improve citizen services. Citizens are evolving into digital users and increasingly expect the same level of proactive and personalised services from governments like they enjoy in banking, financing, or shopping online.

Part of the challenge for governments to deliver on these digital expectations is how administrations operate, including political and legal constraints. For decades, citizens must request each service directly to the relevant administration, supply proof – often in paper form - and wait for approval. Governments have been experimenting with personal budgets that citizens that can use at their discretion. Using the platform approach, governments now take this one step further. Next to the personal budget, they provide a marketplace with a series of trusted providers where the personal allocated budget is to be spend. This approach is based on the business platform model. Many consumers are quite familiar with this approach, for example using Uber and/ or Airbnb to travel. The benefits for the providers are agility, efficiency, and increased service quality.

Platform models require agility from an organisation to engage successfully. Because many governments still operate in a decade old approach, traditional IT governance frameworks can be used and seem effective. But as we require more agility to operate a platform model, using traditional IT governance is not a recipe for success anymore. Therefore, the objective of this research is to design an IT governance framework for government organisations that want to embrace the platform model to improve citizen services and that allows governments to become agile in redesigning citizen services using the digital platform model and using an ecosystem of industry suppliers as partners to deliver the service directly to the citizen. With digital expectations from citizens rising, governments can no longer just wait and see how the platform economy will develop. As more and more bottom-up inspired government agencies start launching platform models without decent control mechanisms in place, there is a sense of urgency to define a new IT governance framework to manage government platform models and provide consistency and trust to all stakeholders involved.

Data-sharing platforms need governance: striking the balance between openness and control. In the increasingly pervasive landscape of data platforms, where business data is exchanged and monetised among various user groups like data providers and users, establishing a robust governance framework is paramount. These platforms essentially function as marketplaces facilitating data trading. However, ensuring the success of these platforms and their surrounding ecosystems presents challenges, particularly in the domain of governance.

Although governance is extensively studied in digital platform literature, existing governance frameworks cannot be directly applied due to unique characteristics such as data sovereignty loss and privacy concerns. Current research predominantly focuses on digital platform governance, neglecting the specific requirements of data platform ecosystems.

One significant challenge that data platform ecosystems encounter is the delicate balance between openness and control. Striking the right governance mechanisms to reconcile these tensions becomes imperative for their success.

Therefore, navigating the governance landscape of data platform ecosystems requires a tailored approach that addresses their specific needs and challenges, while effectively reconciling the tensions between openness and control.

References and more

- Bagheri, S. Towards a Governance Framework for Data Platform Ecosystems in the Construction Industry. ICEIS (2), 2023. 566-574.
- Yves Vanderbeken, Tim Huygh, Laury Bollen, Adopting the business platform model for Citizen Services – from lean to platform organization', paper presented at the 31st European Conference on Information Systems (ECIS), Christiansand, 2023
- Bagheri, S., Brandt, T., Sheombar, H. & Van Oosterhout, M. 2021. Value Creation through Urban Data Platforms: A Conceptual Framework. Proceedings of the 54th Hawaii International Conference on System Sciences.

8.2.2 Information security governance

With increased reliance on digital technologies, businesses must develop and evolve digital strategies that closely integrate business and technology considerations. The digital strategy shows organisations' direction and tactics to achieve competitive advantages with technology. Using this direction and tactics will create new products or re imagine current organisational processes. With "digital" being put on the agendas of business strategies more frequently, organisations are required to be aware of the risks that come with embedding IT into the business. Decision makers within organisations need to take account of the increasingly sophisticated threat environment following this digital agenda. As such, the organisation must govern information security by implementing the required information security components from a holistic perspective to minimise the risks arising from the use of IT and digital assets.

The present research focuses on helping organisations prevent the materialisation of security risks by ensuring a sound information security governance and management approach.

Slogan

Steering trust in the digital age: empowering boards, empowering security

Due to the evolution in the deployment of information security and the role of every employee in every department in keeping the company secure, merely focusing on technical aspects does not work anymore, and shifting towards a holistic and multidisciplinary people-orientated and governance-orientated approach is required. Therefore, knowledge related to information science as well as an understanding of organisational behaviour theories, is necessary to enable a better understanding of the phenomenon.

The role of the board in security governance. In this era of increasingly complex and interconnected technologies, addressing InfoSec issues requires more senior management and board involvement. The ability of senior managers and boards to assess a company holistically and implement new processes in a timely manner has led academics to advocate that effective security policies should be developed at the top rather than by the Chief Information Security Officer (CISO). Although several papers argue for the importance of an InfoSec-minded board, little is known about its specific role in the available literature. It is not explicitly discussed how the board should act or what its role is. To understand the board's potential role in InfoSec holistically applying theoretical pluralism is necessary, as this role may span technology, human behaviour, legal and regulatory aspects, risk management, and more. In this project, we are defining the various roles board roles in the context of information security based on extant corporate governance literature, and empirically validating (1) the decision to be made, (2) the information required and (3) the availability of this information, within the context of each of these roles.

Counteracting biases in IT risk management communication. Even though cyber risk has been promoted as an important focus for IT governance, that should as such be on the radar of the board of directors, many boards are still not well-equipped to perform their strategic roles related to cyber risk. In order to be able to take responsibility for cyber risk in the boardroom and ask the right questions to the expert IT managers within the organisation (e.g., CIO, CISO, senior IT management), adequate measures of IT governance should be in place. This involves two pillars: (1) proper information about cyber risks coming from the organization and (2) board composition and expertise to be able to make an appropriate assessment of cyber risks.

Cyber risks are becoming increasingly complex and dynamic. While most research has focused on the technical aspects of cyber risks and security, a broader approach, including behavioral perspectives, would certainly be beneficial. This is because the course of risks is subject to our own behavior and how we personally assess risk. Risks can be captured less and less in "probability x impact",but are much more ambiguous. This raises the question of whether the current way of reporting cyber risks (in the form of traffic light reports) needs improvement.

In an ongoing PhD project, we focus on three objectives. Firstly, we examine biases in the use of traffic light reports (green – yellow- red) to communicate cyber risks. Secondly, we probe an enriched and refined language for communicating cyber risks by using metaphors that capture the dynamics of cyber risks and could serve as an instrument for communicating cyber risks between IT experts and C-level executives. Thirdly, we place these insights in the context of a move beyond 'traditional' cyber risk management towards cyber resilience to assess their relevance and implications.

References and more

- Sara Nodehi, Tim Huygh, Laury Bollen, Six board roles for information security governance, paper presented at the International Conference on Enterprise Information Systems (ICEIS), Angers (Fr), 2024.
- A. Joshi, M. van Peteghem, L. Bollen, S. de Haes, S. Mithas, Board IT competence and firm performance, paper presented at ICIS conference, Munchen, 2019
- Joshi, L. Bollen, H. Hassink, W. van Grembergen, S. de Haes, "Explaining IT Governance Disclosure through the Constructs of IT Governance Maturity and IT Strategic Role", Information & Management, Vol. 55, Issue 3, 2018, pp. 368-380; Impact factor 3.317 (A)

8.2.3 Data governance

Data governance research is part of the IT governance research line and focuses particularly on data assets. Due to heavily digitised processes, each organisation has become dependent on having timely and accurate data available for their business operations and as a result also generates huge amounts of data. Furthermore, more and more organisations realise that this data can also be analysed, with the use of machine learning and AI, to discover new insights to improve business processes and decision making. In the data governance research line, we address both aspects of the data asset. First, the management of the data asset, and second the analytical processes that transform data into valuable information and insights.

Slogan

Guiding data, empowering organisations: the path to insightful governance

In our research we aim to develop frameworks to better understand the structural, relational and procedural mechanisms that underpin good practices for data and analytical governance. Such frameworks are helpful for organisations to design their governance practices. To further enable organisations, we develop maturity models based on the frameworks. A maturity model considers several phases in which an organisation can develop their governance practices, i.e. going from basic to more advanced. Using a maturity model, an organisation can measure its current maturity and define the next steps to further advance it data and analytics governance practices. Besides research that summaries overall governance mechanisms for data and analytical processes, we also seek to understand how these mechanisms affect organisational members. Current research has shown that while big data is generally useful for innovative processes at the organisational level, it also prone organisational members to information overload and technological stress. We generally propose that strong data governance will allow organisations to select the right systems and approaches that are more likely to benefit employees by providing them with valuable business insights from massive data. In particular, our research delves into the interaction of various elements constituting big

data systems and employees. We aim to shed light on how the characteristics of big data systems might augment or limit employees' productivity and well-being, thereby informing governance researchers and practitioners on the role of governance in technological selection, adoption, and investment.

References and more

- Merkus, J., Helms, R. W., & Kusters, R. (2023). Data Governance Capabilities; Empirical validation in case studies of large organizations. In proceedings: 36th Bled eConference Digital Economy and Society: The Balancing Act for Digital Innovation in Times of Instability, 35.
- Baijens, J., Huygh, T., & Helms, R. (2022). Establishing and theorising data analytics governance: a descriptive framework and a VSM-based view. Journal of Business Analytics, 5(1), 101-122.

8.2.4 Agile and adaptive IT governance

Extant research has recognized IT governance as a crucial factor in facilitating organizational performance by ensuring appropriate control over IT use. While many studies have surfaced over time that provided descriptive accounts of IT governance, the evolutionary dynamics of IT governance are largely neglected. However, given the fast-changing nature of IT and the way it is developed and adopted within organizations, these issues are undoubtedly relevant in practice. Indeed, organizations have to tailor their IT governance to their own specific context (which is shaped by several external and internal factors). Moreover, a change in this context (by virtue of these external and internal factors - e.g. threat landscape, compliance requirements, or the role of IT for the organization) might warrant a change to the organization's IT governance. In short, the evolutionary dynamics of an IT governance arrangement should be considered. This will ensure that the IT governance arrangement is able to control the (current and future) IT use effectively, i.e. that it has the capacity to continue creating and protecting IT business value, despite a changing environment.

Slogan

Navigating change, empowering success: agile IT givernance in action

Research in this sub-line can deal with a contingency view on IT governance. In other words, how does the context (which is shaped by several external and internal factors) influence (the design of) IT governance within organisations. As an example, we focus on how organisations combine different IT governance process capabilities to create and capture business value via strategic alignment, as well as how such combinations perform under internal and external contingency factors. As another example, we focus on how the increasing adoption of agile development practices influences program and portfolio management (which are IT governance processes) - i.e., scaled agile. Moreover, our

research focuses on the governance of elite members in the organisations to guide their behaviours toward effective IT use and subsequently business value creation. These governance mechanisms are often relational aspects, corresponding to power distribution and/or characteristics of elite members. For instance, we examine the relative power of IT executives in the top team as an effective governance mechanism for stimulating digital innovation. We also explore the characteristics of managers that influence how they adopt digital technologies, thereby informing organisations to select change agents when attempting digitalisation.

References and more

- Merkus, J., Helms, R. W., & Kusters, R. (2023). Data Governance Capabilities; Empirical validation in case studies of large organizations. In proceedings: 36th Bled eConference Digital Economy and Society: The Balancing Act for Digital Innovation in Times of Instability, 35.
- Baijens, J., Huygh, T., & Helms, R. (2022). Establishing and theorising data analytics governance: a descriptive framework and a VSM-based view. Journal of Business Analytics, 5(1), 101-122.

8.3 Research Line: Digital Ethics

Development of Information Systems & Information Technology (IS/IT) should not be executed by technology-push only. Derived from the Resource-Based View economics theory, research studies have indicated that organisational and digital (dynamic) capabilities (Wernerfelt, 1984; Barney, 1991; Teece et al., 1997; Teece, 2007; Van de Wetering et al., 2022) are essential for organisations to succeed in their markets. However, successful and sustainable IS/IT development requires more than this: it needs to be done responsibly for all stakeholders involved and affected. Digital innovation can go easily wrong if it takes place without adequate moral considerations, illustrated by e.g. the Volkswagen Diesel Scandal, the Dutch 'Toeslagenaffaire' and Roermond's Sensing-project. Personal data can be easily misused, even unintentionally. The need for trustworthy and responsible digital solutions becomes even more apparent in the age of AI and large language models, as human values are often affected by the application of these new technologies (Dignum, 2020).

Slogan

Empowering responsible digital futures: ethical horizons in technology

Arising from the research field of user experience (UX), the Value Sensitive Design (VSD) approach deals with responsible IS/IT development. Notably, Friedman has provided a research legacy for VSD (Friedman & Hendry, 2019). The approach stimulates a responsible way of decision-making in not only the design, but also the situational

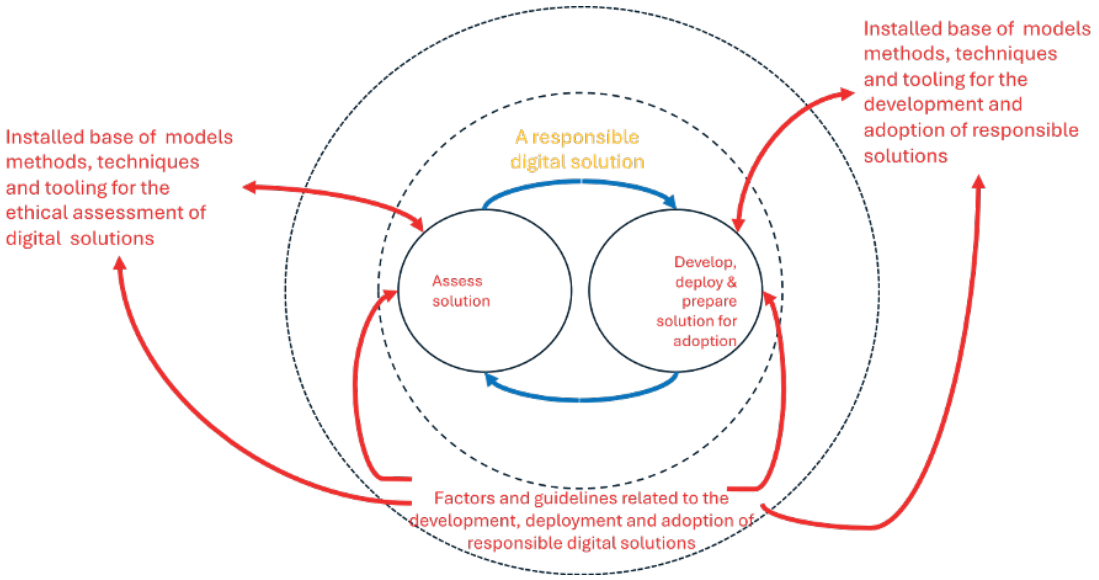


Figure 3: Context of the research of the Digital Ethics research line

implementation, deployment and further up-scaling of digital technologies. But still a number of research gaps exist in value sensitive design:

- Scarcity of standardised and reproducible methods for conducting VSD;
- Application of VSD in an agile way is not obvious;
- Dealing with value tensions (like privacy and transparency at the same time) is underexposed;
- Limited attention to the technical phase (defining requirements),
- Empirical proof of the effectiveness of applying VSD, and,
- Lack of support for professional practice.

At the same time increasing research efforts are being put on the ethical assessment of digital solutions. This comes to no surprise as one sees new laws coming from the EU, national governments, as well as codes of conduct, etc. More specifically, nationally and internationally, ethical considerations are increasingly paid attention to in the digital innovation and coincides with the development of EU regulations (e.g. GDPR and the AI Act of the European Union). We see the methodological development and – validation, as well as the deployment in practice of such assessment models as a primary focus of our research. It is in this context that the research of the research line Digital Ethics is situated (see Figure 3).

Responsible digital solutions can be developed, deployed, prepared for their adoption and assessed, as depicted in the centre of the figure. Our research contributes specifically to

the red-texted and -arrowed parts of the figure. This implies that in the Digital Ethics research line three types of research are executed:

- Research related to the development, deployment and adoption of digital solutions in any kind of context (e.g. within an organisation, in a network or ecosystem, or for society). Here, particularly methods like VSD and ethical guidelines are leveraged for our research, but also extended (in case we contribute to theory and practice): the bi-directional red arrow on the top right depicts this.
- Research related to the assessment of existing digital solutions, or digital solutions in development, deployment and/or adoption. Here, e.g. the socio-technical method of the Trustworthy AI-lab will be leveraged, legislation can be used, etc. Also the existing body of knowledge on assessing existing digital solutions from an ethical perspective can be extended by our research, in which case we contribute to theory and practice (the bi-directional arrow on the left depicts this). Note that assessment can take place during development (& deployment & adoption) as well assessment (see the text "Assess during development").
- Research related to the identification of barriers, impediments, determinants, success factors and situational factors that contribute to the success of the development, deployment, adoption and assessment of responsible digital solutions. For both the development, deployment, adoption, and assessment research of a descriptive or explanatory nature is necessary. Through this type of research new knowledge can be brought into the installed bases of models as well as the responsible development (& deployment & adoption) and the assessment of responsible digital solutions.

Many digital ethics research gaps exist in the domain of AI solutions. Therefore we explicitly address AI-based solutions, generative AI and large language models in an organisational context. Among others risk management and impact management are subject of our research.

AI risk management and impact assessment. The rapid advancement and widespread adoption of Artificial Intelligence (AI) technologies introduces substantial challenges and risks. These challenges encompass both technical issues, such as a lack of transparency, and explain ability, as well as non-technical risks, including the potential violation of human rights and ethical concerns. In response, effective risk management strategies are imperative, aimed at identifying, analysing, and mitigating AI-related risks.

In addition, to navigate this complex landscape, organisations increasingly rely on AI impact assessments as a complementary approach to risk management, aiming to ensure trustworthy AI development and deployment. Various AI impact assessment frameworks, including AI ethical guidelines, have been proposed. Despite the growing recognition of their importance, there remains a lack of consensus on the essential components and assessment methods for AI impact assessments. Additionally, the practical application of these assessments is challenging, particularly under new regulatory frameworks like the EU AI Act.

As such there arises a pressing need to delve into the intricacies of AI risk management and impact assessment, seeking to address both technical and non-technical concerns while advancing the responsible development and deployment of AI technologies. Anticipatory practices are typically put in place to assess future risks.

Organisational readiness for AI adoption. Despite the widespread uptake of AI in practice and the prospective benefits it offers to organisations, many organisations still struggle to create business value from AI initiatives. To fully harness the benefits of AI, organisational readiness for AI adoption is a prerequisite. Therefore identifying organisational AI readiness factors, the common challenges encountered by organisations when adopting AI, and their mitigation strategies becomes imperative for their successful adoption and use to create value for organisations.

References and more

- Arnoldi, E., Bosua, R. & V. Dirksen (2021). Mapping themes for the wellbeing of low-skilled gig workers: Implications for digital platform design, Transitions: Journal of Transient Migration 5(1), pp. 55–75.
- Butseraen, J. (2023). Artificial Intelligence challenges and impacts in the public sector: evidence from law enforcement. [Master Thesis, Open University of the Netherlands]. Open Universiteit.
- Hadžiarapović, N., Versendaal, J., van Steenbergen, M., & Ravesteijn, P. (2023). The Economics of Collective Management in the Music Copyright Industry in The Netherlands: Digital Transformation and Equitable Remuneration, Review of Economic Research on Copyright Issues, 20, 38-75.
- Neumann, M., Dirksen, V. & Dickel, S. (2024). On the Construction of Plausible Futures in Interpretive Agent-Based Modelling, in: M. Neumann (ed.), An Interpretive Account to Agent-based Social Simulation: Using Criminology to explore Cultural Possibilities. pp. 170-188. London: Routledge.
- Versendaal, J., van Steenbergen, M., Smit, K., van Ginkel, S., de Haas, M., Peters, R. & Govers, S. (2024). Responsible software development through situational method engineering: Building a metamodel for method fragments. [Manuscript submitted for journal publication]

8.4 Research Line: Process Management & Modelling

Work is done in processes. So here the actual added value provided by IT is realized. This explains the focus we place in our research on the process aspect.

Slogan

Empowering business through process excellence: leading the wat in process management & modelling

IT, as a fast-changing basic production technology, is impacting business process on a continuous basis. At a strategic level this impact is looked at in the previous research lines. At a more operational design level, this issue is researched here. For this, three perspectives are explored. The first takes a model view and explores relevant modelling approaches. The second explores Business Process Management, gaining a deeper understanding of how processes are designed, how they are executed and the difference between the two. The final perspective focuses on the application of technology to support these processes operationally, for instance hyper-automation and robotic process automation, to name just two. In all three views, we decide to focus on the human perspective: developing human-centric business information technology, tools and techniques to support design, analysis, execution, and innovation of business processes, driven by challenges from practice.

Enterprise and process modelling.– The often-heard creed "Our business is IT and our IT is the business" captures precisely what we see happening in our field. Developments in Artificial Intelligence, Machine Learning, Semantic Technologies, Cloud Software Engineering (to name just a few) are taking away the focus from alignment, because the difference between business and IT is felt much less in our heavily digitalised society. To manage businesses from an information perspective, we develop and apply modelling techniques to enable the creation of value in today's enterprises by applying IT inside business processes.

Enterprise Modelling is oriented towards the systematic analysis and modelling of strategies, business models, processes, business policies and rules, information systems and any other relevant business perspective. Within this domain, process modelling can be situated on the operational layer of the organization, with the aim of analyzing and communicating about internal activities. Enterprise modelling efforts are particularly useful to analyze the current and desired future state of enterprises, which enables them to faster react on external changes and developments.

Business Process Management.– Business process management (BPM) is the art and science of overseeing how work is performed in an organisation to ensure consistent outcomes and to take advantage of improvement opportunities (Dumas et al, 2018). It studies business processes from a holistic point of view involving the people, organisations, applications, documents and other sources of information, to produce business outcomes in support of a business strategy (Gartner, 2020). Various methods, tools and techniques are used to elicit, discover, model, analyse, measure, improve and optimise business processes. The focus in this research theme puts special attention on human aspects of BPM.

More specifically, the research addresses process model quality, focusing on how the structure and aesthetics of a model influence its understandability. The theme also explores ontology design patterns for legal concepts and aims to extend these patterns beyond law, emphasising constraints over data models. Another topic is the process of process modelling, which involves understanding how modellers create models, their common mistakes, and methods for better training. Continuous process improvement

methods are also discussed, alongside advancements in task/resource allocation in BPM systems and the application of BPM technology in various domains. Lastly, data analytics for BPM is explored, focusing on applying analytics to create and evaluate new process analysis and improvement methods.

Process supporting technologies. – Both (enterprise) process modelling and business process management are well recognized scientific domain, with their own body of knowledge, conferences, journals etc. In the third perspective, we focus on the range of technologies that have been developed or adopted to facilitate business process management. In industry, the term "hyperautomation" has been coined by Gartner Consulting in 2019, referring to the "the orchestrated use of multiple technologies, tools or platforms, including: artificial intelligence (AI), machine learning, event-driven software architecture, robotic process automation (RPA), business process management (BPM) and intelligent business process management suites (iBPMS), integration platform as a service (iPaaS), low-code/no-code tools, packaged software, and other types of decision, process and task automation tools."

Across the application areas in our "matrix", we can identify relevant challenges for the organizations involved and solutions offered by science; our interest in this perspective is the translation process into working solutions in practice. We aim to intensify our applied research in this field by investigating the critical success factors and identifying best practices for achieving the organizational goals of process automation through the application of such technologies.

References and more

- Rutledge, L., Berghuis, B., Lim, K. & Soerokromo, A Web-Based Approach for Traceability in Rule-Based Business Information Systems. M., Jul 2023, Business Modeling and Software Design: 13th International Symposium, BMSD 2023, Proceedings
- Roubtsova, E. (2015). Advances in behavior modeling. In Advances in Computers (Vol. 97, pp. 49-109). Elsevier

8.5 Research Line: Strategic IT design & organisational development

In the rapidly evolving business ecosystem and technology landscape, digital transformation has emerged as a pivotal concept, reshaping modern industries and societies worldwide (Vial, 2019). Global technology trends like big data, the Internet of Things, and the rise of artificial intelligence are making firms' ability to change and adapt their organisations' structure, architecture, and people as crucial as their competitive strategy. In this day and age, firms, therefore, need to embrace the digital transformation journey to become top performers in the digital economy. Hence, they can leverage new IT resources and innovations, (data and IT-driven) organisational capabilities, business

models, and value networks to facilitate new, better, and more effective ways of working, enhance service delivery to customers (and patients), and reduce cost. The key to success is the seamless interaction between IT systems and humans, aka the work system, and to do this securely. In essence, digital transformation involves the integration of digital technologies and innovation into diverse aspects and dimensions of business models and the organisation's operations. It fuels organisational growth, efficiency, and competitiveness (Kraus et al., 2022; Vial, 2019). While digital transformation has been a driving force in information science research, the accelerating pace of change and the emergence of unforeseen disruptions necessitate a more dynamic and responsive approach.

Slogan

Empowering organisational evolution: strategic IT design for dynamic growth.

We defined four core research focuses that particularly apply as well within the application areas Digital-Driven Transformation (see Figure 4).

The first area, *enterprise architecture*, concerns the blueprint of an organisation's structure and operations (Grave, van de Wetering, & Kusters, 2021). We examine how a well-defined enterprise architecture can serve as the backbone for digital transformation, enabling flexibility and providing a framework to integrate new technologies seamlessly into existing business models.

Dynamic capabilities form our second area of focus. These are the skills, processes, and routines that enable organisations to adapt and thrive amidst market and technological changes (D. Teece, Peteraf, & Leih, 2016; van de Wetering, de Weerd-Nederhof, Bagheri, & Bons, 2023; Rogier van de Wetering & Johan Versendaal, 2021). Our research delves into how organisations can cultivate these capabilities to not only react to changes but also anticipate and shape them. Also, we concentrate on the business value of digital innovations. This encompasses assessing how digital advancements can be translated into tangible business outcomes, such as revenue growth, increased efficiency, and enhanced competitiveness. We explore how digital innovations can be leveraged to catalyse organisational development, transform business practices, and drive sustained value creation.

The last two focus areas, work towards the understanding the *business value* of virtual organisations as integral part of the *collaborative ecosystem* in times of AI and digital transformation.

Together, these four areas form our core focus of research that aims to empower organisations with the insights and tools necessary to navigate and capitalise on the digital landscape. Through this comprehensive approach, this research line aims to contribute to a deeper understanding of how digital transformation can be a leveraged asset for strategic advantage in a rapidly evolving world. We will describe each in more details in the next sections.

Figure 4: Research agenda overview

8.5.1 Enterprise architecture

Enterprise architecture (EA) is a family of guidelines and artifacts (concepts, models, policies, principles, rules, patterns, interfaces, and standards) to build organizational capabilities (Foorthuis, Van Steenbergen, Brinkkemper, & Bruls, 2016; Gong & Janssen, 2019; Grave et al., 2021; Kotusev, 2019). As a result, EA is a practice that, on an ongoing basis, fosters business/IT-alignment, and creates value for key stakeholders (Hinkelmann et al., 2016; Pattij, van de Wetering, & Kusters, 2022; Szabó & Öri, 2017; van de Wetering, 2021). EA is a valuable research discipline for effectively navigating digital and adaptive transformations (Bocken & Geradts, 2020; Pattij et al., 2022; Van de Wetering, 2022b; Vial, 2019). It provides a strategic lens, aligning strategies, business objectives, and IT landscape, organisations can leverage EA to orchestrate their information technology (IT) portfolio and business landscape, including processes, (big) data, information, systems, resources, and capabilities. In other words, EA is crucial for the organisation's design and the process of orchestrating and restructuring the organisation's resources when needed. However, the extant literature does not provide convincing evidence on how EA contributes to this, leaving a critical knowledge gap in understanding the concrete ways EA creates a road-map for the digital journey, fosters agility, innovation, and continuous improvement (Korhonen & Molnar, 2014; Shanks, Gloet, Someh, Frampton, & Tamm, 2018; Van de Wetering, 2019). Thus, we will explore and advance our understanding of how organisations can effectively deploy EA artefacts and EA modelling practices. Research in this area can help uncover best practices, case studies, and methodologies that effectively leverage EA for successful digital and adaptive transformations.

References and more

- Van de Wetering, R., Roelens, B., & de Langen, F. (2023). Improvisational and Dynamic Capabilities as Drivers of Business Model Innovation: An Enterprise Architecture Perspective. Pacific Asia Journal of the Association for Information Systems, 15(1), 1.
- Pattij, M., van de Wetering, R., & Kusters, R. (2022). Enhanced digital transformation supporting capabilities through enterprise architecture management: A fsQCA perspective. Digital Business, 2(2), 100036.
- Van de Wetering, R. (2022). The role of enterprise architecture-driven dynamic capabilities and operational digital ambidexterity in driving business value under the COVID-19 shock. Heliyon, 8(11).
- Kotusev, S., Kurnia, S., Dilnutt, R., & van de Wetering, R. (2023). The Structuring of Enterprise Architecture Functions in Organizations: Towards a Systematic Theory. Business & Information Systems Engineering, 1-24.
- Roelens, B., Ebben, R., & de Wetering, R. V. (2023, July). Composing an Initial Domain-Specific Modeling Language Notation by Reusing Icons. In International Symposium on Business Modeling and Software Design (pp. 245-255).

8.5.2 Dynamic capabilities and organizational development

The second key area of this research line concerns dynamic capabilities and organisational development. Modern organisations must be agile, responsive, and capable of adapting to new challenges, opportunities, and demands of the business environment (Abou-Foul, Ruiz-Alba, & López-Tenorio, 2023; D. J. Teece, 2007), which is characterised by predictable patterns or 'waves,' as Pavlou and El Sawy call them (2010). Dynamic capabilities broadly reflect the organisation's ability to orchestrate and renew internal and external resources and competencies to address rapidly changing conditions and business environments (Felin & Powell, 2016; Kay, Leih, & Teece, 2018; Mikalef, Pateli, & van de Wetering, 2020; Van de Wetering, 2022b; Wang & Ahmed, 2007). Digital innovations (e.g., digital platforms, the Internet of Things, data analytics, and AI) play an instrumental role in developing and enhancing an organization's dynamic capabilities (Mikalef et al., 2020; van de Wetering, Mikalef, & Dennehy, 2022; Warner & Wäger, 2019). For instance, they can have a monumental impact on how organisations respond to changes in the marketplace and customer needs, wishes, and preferences using real-time customer data. Also, they can facilitate flexible allocation and reconfiguration of resources. However, many questions still remain. By examining the concept of digital-driven dynamic capabilities, we can contribute to a better understanding of how organisations can cultivate different capabilities not only to survive but thrive in rapidly evolving industries, identify business opportunities and transform digital disruptions into competitive advantages and ensure long-term resilience. Also, the Chair and his team will investigate how these capabilities depend on the combination of digital assets and resources, activities, and people, connecting a firm's day-to-day activities with its

strategic ambitions (Canhoto, Quinton, Pera, Molinillo, & Simkin, 2021; Puliga & Ponta, 2022; Van de Wetering, 2022b; Van de Wetering, Roelens, & de Langen, 2023). This is particularly relevant in knowledge intense industries like healthcare, where the ability to anticipate patient demands and needs, i.e., patient agility, is crucial (Broekharst, van de Wetering, Ooms, Helms, & Roijakkers, 2023; Kraus, Schiavone, Pluzhnikova, & Invernizzi, 2021; Rogier Van de Wetering & J Versendaal, 2021). Collaborating with industry partners and academia, the Chair can contribute to the collective understanding of digital-driven dynamic capabilities' impact on organisations, ultimately fostering a more informed approach to adaptive and digital transformations in the modern era.

References and more

- van de Wetering, R., de Weerd-Nederhof, P., Bagheri, S., & Bons, R. (2023, July). Architecting agility: Unraveling the impact of AI capability on organizational change and competitive advantage. In International Symposium on Business Modeling and Software Design (pp. 203-213). Cham: Springer Nature Switzerland.
- Bagheri, Samaneh and Dijkstra, Jesse, "Capailities For Data Analytics in Industrial Internet of Things (IIOT)" (2023). ECIS 2023 Research Papers. 416. `https://aisel.aisnet.org/ecis2023_rp/416`
- Walraven, P., van de Wetering, R., Helms, R., Caniëls, M., & Versendaal, J. (2022). Evolving competencies to align electronic medical records–a dynamic resource-based perspective on hospitals' co-evolutionary information systems alignment capability. Journal of Health Organization and Management, 36(9), 112-132.
- Mikalef, P., Pateli, A., & van de Wetering, R. (2021). IT architecture flexibility and IT governance decentralisation as drivers of IT-enabled dynamic capabilities and competitive performance: The moderating effect of the external environment. European Journal of Information Systems, 30(5), 512-540.

8.5.3 Collaborative Ecosystems

The evolution of collaborative patterns within diverse sectors of industry reflects a significant shift from fleeting trends to enduring structures. Departing from internal innovation confined to large enterprises, the paradigm now embraces open innovation with external partners. Over the decades, collaborations have transitioned from ephemeral alliances in the 1980s to more strategic and structured alliances in the 1990s. A pivotal moment in collaboration occurred with the introduction of alliance portfolio management, expanding collaborations to include diverse partners such as universities and startups. This development coincided with the formation of dense networks, giving rise to ecosystems characterised by self-governance and sustained collaboration aimed at addressing societal challenges.

Simultaneously, the concept of the "virtual organisation" encapsulates the evolving perception of traditional workplaces. Information Technology's transformative impact facilitates close collaboration without rigid physical proximity requirements, fostering in-

novative working conditions. In its extreme form, an organisation may fully transition into a virtual entity, enhancing mobility and flexibility while potentially affecting social connections and loyalty. This virtualisation dimension mirrors the ecosystem model. Another facet of virtualisation arises from increased organisational specialisation, where entities extensively depend on other organisations' structural contributions. This trend fosters agility, innovation within ecosystems, and reduced financial investments, aligning with the augmented reliance on advanced information systems. However, similar to the ecosystem model, the cross-border flow of information in this virtualisation dimension carries inherent risks related to information security.

Slogan

Synergies unleashed: transforming collaborative ecosystems and virtual organizations

The parallels between these dimensions underscore intricate organizational evolution dynamics, emphasizing the necessity for comprehensive research exploring intersections and synergies between collaborative ecosystems and virtual organizational transformations. Recognizing virtual organizations as integral to the ecosystem model provides a holistic understanding of the evolving collaborative landscape:

- At a comprehensive level, research at the level of ecosystems centres on generating societal value and health through collaborative and innovative efforts, emphasising the creation of knowledge-oriented jobs. Ecosystems actively leverage voluntary knowledge sources, addressing challenges with intensive interactions and long-term commitment. The dynamics of internal and external connections are crucial for shaping enduring functionality. In this digitally interconnected landscape, the integration of information security becomes paramount. Researchers focus on measuring societal value, considering socio-cultural, sustainability, and environmental aspects. Studies explore the influence of real-time governance dashboards, collaborative platforms, and knowledge-sharing systems on ecosystem health, with a parallel emphasis on implementing robust information security measures. The inclusion of information security safeguards helps protect sensitive data, mitigate cyber risks, and build trust among ecosystem participants. This comprehensive research provides valuable insights for facilitators, guiding partners toward shared goals in the evolving virtual landscape, underscoring the integral role of technology, including information security, in optimising collaborative innovation efforts and navigating the complexities of the digital era.
- Within technology-driven innovation ecosystems, a diverse array of organisations actively engages, highlighting the role of information science in fostering preparedness for meaningful involvement. This readiness sparks transformative structural changes, shaping organisations into nimble, virtual entities. Leveraging cross-functional teams equipped with digital collaboration tools, these entities refine core competencies while seamlessly engaging with others for non-core resources.

Cultural shifts prioritise values like trust, innovativeness, open communication, risk tolerance, inclusivity, customer orientation, and a dedicated commitment to collective goals. This cultural evolution harmonises with the adoption of agile and asynchronous work practices, seamlessly facilitated by information technologies. Simultaneously, ecosystem preparedness requires a refinement of processes related to knowledge management, learning, agility, collaboration, and intrapreneurship. In this paradigm shift, performance measurement takes centre stage, employing analytics, data measurement tools, and dashboards to focus on innovation, ecosystem contribution, and learning. Research underlines the significance of diverse ecosystem partners, each offering varied insights. Scientists explore the intricate relationship between unique partner characteristics and the internal organisational changes essential for effective ecosystem engagement. They delve into the dynamic roles of ecosystem facilitators, subtly emphasising the need for adaptability in fostering collaborative innovation. Research consistently underscores the importance of maintaining diversity for adaptability and resilience, particularly during challenging situations, with a dedicated focus on the facilitator's role. Critical questions emerge, subtly probing into aspects such as skills, role evolution, and the delicate balance between guidance and allowing for self-direction.

References and more

- Cobben, D., Ooms, W., Roijakkers, N., & Radziwon, A. (2022). Ecosystem types: A systematic review on boundaries and goals. Journal of Business Research. Advance online publication. https://doi.org/10.1016/j.jbusres.2021.12.046
- Ooms, W., Caniëls, M. C. J., Roijakkers, N., & Cobben, D. (2020). Ecosystems for smart cities: Tracing the evolution of governance structures in a Dutch smart city initiative. International Entrepreneurship and Management Journal, 16(4), 1225-1258.
- Pullen, A. J. J., de Weerd-Nederhof, P. C., Groen, A. J., & Fisscher, O. A. M. (2012). Open innovation in practice: Goal complementarity and closed NPD networks to explain differences in innovation performance for SMEs in the medical devices sector. Journal of Product Innovation Management, 29(6), 917-934.
- Skute, I., Zalewska-Kurek, K., Hatak, I., & de Weerd-Nederhof, P. (2019). Mapping the field: A bibliometric analysis of the literature on university–industry collaborations. The Journal of Technology Transfer, 44, 916-947.

8.5.4 Business value of digital innovations

The business value of digital innovation, particularly AI, has garnered considerable attention due to its transformative potential. AI, or the 'next era of analytics', as Davenport denotes it (Davenport, 2018, p. 74), is not just a technology but a foundational element that enables firms to carve out new value paths and evaluate perspectives from a competitive stance. AI is a broad term encompassing various advanced analyses, applications, and logic-based techniques that mimic human behavior, decision-making, learning, and

problem-solving (Brynjolfsson & Mcafee, 2017). AI can bring substantial benefits to firms. However, when a major transformation is required, firms must articulate a compelling shared vision to adopt AI and enable a high impact that does not derail all the investments and effort (Dwivedi et al., 2019; Haefner, Wincent, Parida, & Gassmann, 2021; Wamba-Taguimdje, Wamba, Kamdjoug, & Wanko, 2020a). Moreover, firms must leverage innovative and distinctive technologies like AI to develop dynamic capabilities to drive innovation, improve service levels and customer experiences, and foster competitive performance (Davenport, 2018; Haefner et al., 2021; Majhi, Mukherjee, & Anand, 2021; Van de Wetering, 2022a; Wamba-Taguimdje, Wamba, Kamdjoug, & Wanko, 2020b). Also, while AI's capability to imitate human cognition in decision-making, learning, and problem-solving paves the way for operational and strategic advantages, currently, little is known about the innovative and routine deployment and use of AI (AI ambidexterity) in firms and how this supports dynamic capabilities and an organisation's strategic flexibility (Van de Wetering, 2022a), triggering how an organisation determines the most effective way to execute its strategy through its people and other business and IT resources (Miroshnychenko, Strobl, Matzler, & De Massis, 2021). To harness AI's full potential, organisations must traverse beyond mere adoption to a state where AI is deeply embedded in the business fabric, driving the evolution of value chains and customer interactions. Therefore, we demystify the operationalization of AI ambidexterity within firms, revealing how it contributes to business agility and the execution of strategy in the digital age. Such insights will be invaluable for organisations looking to navigate the complexities of digital innovation. We can play a pivotal role in contributing to this research area using a business value lens. The business value of digital innovations lies in their transformative potential to redefine how organisations operate and compete. Therefore, the process of capturing this particular value requires an approach that encompasses not just the adoption of technology, but also the cultivation of an ecosystem conducive to innovation. Evaluating the impact of digital innovations involves not only assessing their direct contributions to efficiency and performance but also understanding their role in empowering human capital, driving customer satisfaction, and creating new market opportunities. This research is, especially relevant in healthcare, where, for instance, the rapid spread of AI is seen as a means to support faster and improved decision-making processes, reshape the patient experience, and deliver value-based care. However, its specific contributions and role in shaping healthcare business ecosystems, especially within and between hospitals, remain unclear, leading to an incomprehensive view (Chen & Decary, 2020).

References and more

- van de Wetering, R., Mikalef, P., & Dennehy, D. (2022, September). Artificial intelligence ambidexterity, adaptive transformation capability, and their impact on performance under tumultuous times. In Conference on e-Business, e-Services and e-Society (pp. 25-37). Cham: Springer International Publishing.
- Van de Wetering, R. (2022). The impact of artificial intelligence ambidexterity and strategic flexibility on operational ambidexterity. In Pacific Asia Conference on Information Systems (pp. 1-17). AIS Electronic Library.
- Papagiannidis, E., Mikalef, P., Conboy, K., & Van de Wetering, R. (2023). Uncovering the dark side of AI-based decision-making: A case study in a B2B context. Industrial Marketing Management, 115, 253-265.
- Doe, J. K., Van de Wetering, R., Honyenuga, B., & Versendaal, J. (2022). Extended contextual validation of stakeholder approach to firm technology adoption: moderating and mediating relationships in an innovation eco-system. Society and Business Review, 17(4), 506-540.

8.6 Impact

8.6.1 Introduction

An important dimension in IS research concerns the situational expertise (i.e. depicted as the Application Areas in the IS expertise matrix in Figure 1) in which the generic traditional research lines, described in the previous sections, can be studied and applied. Situational expertise is essential in bridging the gap between science and actual systems in which practitioners have learned with guidance and sometimes through active research participation to quickly adopt new insights. Both, academics and practitioners can learn in their own way by careful observation of current practices, by testing new approaches and by creating new working systems. Recognition of this second perspective also facilitates a strong potential for impactful cooperation, co-development with various external parties. Also, a rich variety of research methodologies and approaches such as action research, design science and citizen science to name a few, are being used. As such, the second axis can be seen as a necessary precursor to the build-up of generic knowledge in the first axis. Although, the list is open-ended, we will focus here on the more prevalent topics.

8.6.2 Application Area: Virtual Organisation & Ecosystems

The term “virtual organisation” refers here to the increasingly blurred perception of the classic “brick-and-mortar” organisation, where employees go to work to each day. Information technology has revolutionised communication and in many situations people can work closely without the strict need to be physically together. This physical

independence has led to the emergence of new types of organisations (e.g. platform organisations) or ways to organise work (e.g. crowd science), and to the creation of new working environments and conditions for employees (e.g. telework). Virtual organising increases our mobility and overall flexibility, encourages the development of new working and learning modes that need to be facilitated and it also poses challenges on the social interaction.

A different form of virtualisation is driven by the increased specialisation of organisations. To function as "complete" organisations, they become increasingly dependent on the structural contribution of other organisations offering complementary services. Organisations increasingly source essential parts of their operations in- and out in order to increase their agility, to bolster innovation (in innovation ecosystems) and to lessen financial investments. Depending on the tightness of integration of operations a higher reliance on advanced information systems is to be expected. Naturally, a "cross-border" information flow also imposes risks in terms of information security. Since a few years, the IS department is closely connected with Sourcing Nederland, an independent association whose members include all parties involved in IT sourcing activities. This association aims at sharing sourcing knowledge in order to realise better practices. Currently a research project on IT sourcing is envisioned in which members of Sourcing Nederland as sourcing actors will actively participate.

8.6.3 Application Area: Health Care & Public Organisations

In particular, the healthcare sector suffers from a workforce drain and steady cost increases, making it increasingly difficult to provide the much-desired high-quality health services. Whilst various reasons attribute to the problems in this sector, a consensus exists in that the health sector is lagging in the transformation of their business processes and the information systems that go with it. Similar problems exist in other public sectors due to limited budgets, slow decision-making structures, strict requirements regarding data privacy and security, and political and regulatory challenges. Addressing these challenges requires an approach that involves strategic planning, stakeholder engagement, investment in information technology and infrastructure, and a commitment to fostering a culture of digital innovation and continuous improvement. Currently, research projects are running in collaboration with the national tax, justice, defence and police departments, a waste processing company, and an electricity grid operator.

8.6.4 Application Area: Artificial Intelligence Application

Research on artificial intelligence in the Information Science department is mainly focused on the effective and trustworthy development of actual operational systems, whereas the foundational research line is placed in the computer science department. All four research lines in our department have to play a role in this application area, as the application of AI impacts governance, process and organisational strategy, while ensuring

that ethical concerns are met, preferably by design. So typically, the AI systems we are interested in support humans in performing their jobs more intelligently, effectively, with more confidence, less error-prone, faster. Needless to say, that to develop such AI tooling, intricate situational knowledge of the actual processes and (stakeholder) requirements is essential besides a sound basis of foundational AI research.

As such, the societal impact we expect from our research is a combination of realising the transfer of our research into applied AI technologies in practice, as well as assistance in the verification of the trustworthiness of AI in specific practical contexts, both within a single company or in entire ecosystems. In this section, we focus on two specific types of examples the department is involved in.

The first initiative is in the application area of "affective computing". If AI is to be continuously aligned with human values, empathy becomes a crucial element of it. We engage in the development of systems that can recognise, interpret, and simulate human emotions, feelings and mood. Together with partners from the Brightlands ecosystem, as well as other national and international partners, we focus on facial emotion recognition, speech-emotion recognition and their multimodal combinations. Projects, in which we play a leading role, include the MAI-HOME project (Interreg Flanders-Netherlands) on the application of AI to reduce "energy poverty" and CO2 emissions. Another example is the GO-KIT project, funded by several regional entities, which also looks at the application of AI combined with domestic sensoring to make homes smarter and reduce energy consumption with minimal impact on the people living there.

The second initiative we want to highlight here is our participation in the Z-Inspection initiative and the network of "trustworthy AI labs", as mentioned in our presentation of the digital ethics research line. To cope with the ethical assessment challenge, the Open University has become a member of the Z-inspection® Trustworthy AI Labs community. The mission of the Trustworthy AI Lab at the Open University is to bring together a community of experts to promote AI research, education, and policy development. We aim to support society by establishing and sharing best practices in the design, implementation, and oversight of ethical, responsible, thoughtful, sustainable, and reliable AI applications.

The lab is located in the Faculty of Science but has an interdisciplinary focus, including computer science, information science, law, cultural studies, business administration, and psychology. Multiple international researchers from various disciplines are involved, providing a forum for academic and industrial research and applications. We collaborate closely with national and international networks, such as the Brightlands AI Hub.

Z-Inspection[4] is a holistic process used to empirically evaluate the reliability of AI-based technologies at various stages of the AI lifecycle. It focuses particularly on identifying and discussing ethical issues and tensions by developing socio-technical scenarios. It adheres to the general guidelines for trustworthy AI from the High-Level Expert Group of the European Union (EU HLEG). Z-Inspection® is distributed under the terms of the

[4] https://z-inspection.org/

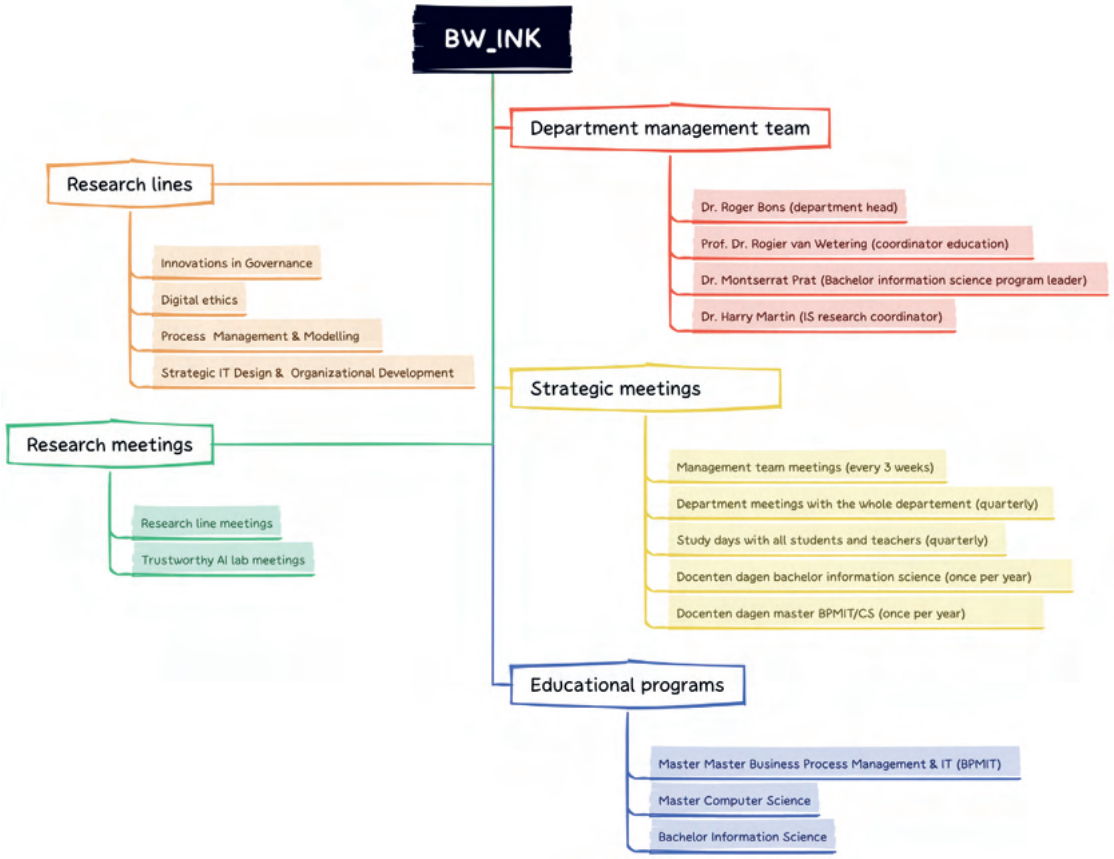
Not only do we need to gain experience with Z-Inspection®, but also we can leverage other, empirical and conceptual evaluation methods.

8.6.5 Application Area: Digital Driven Transformation

Many organizations struggle with the adoption of new (information) technologies, which potentially could boost their organizational performance in almost every aspect. For most organizations information technology is not an integral part of their primary business function (at least not momentarily) and may represent a blank page in their knowledge arsenal. Such organizations can be easily overwhelmed by the choices they have to make and dealing with the associated risks. Where and how to begin? Which organizational capabilities can to be developed, and how? What is the role of digital innovation (e.g., AI, analytics, platforms) in this context? Which other organizational factors and contingency factors play a key role in digital-driven transformation? What is the best path towards maturity? These and other related questions are very situation-specific. Digital-Driven Transformation embraces the idea that simply adopting and using digital technologies is insufficient to stay competitive. Rather, this concept provides a strategic framework for integrating digital technologies and innovations with organizational structures, processes, and capabilities and could offer organizations a practical toolbox to identify and capitalize upon market and technology opportunities effectively. Modern organizations must be agile, responsive, and capable of adapting to new challenges, opportunities, and demands of the business environment. Contemporary society demands the urge for sociotechnical transformations of organizations and anticipatory practices are proliferating as enablers of such transformations in various industrial sectors and for different goals (environmental and social sustainability e.g., energy transition, climate change, inclusion, social equality and diversity).

The application contexts described here, are not mutually exclusive, but just characterize well-recognizable actual points of interest in practice our research group has been active in recent years. E.g. hospitals may strive for the application of artificial intelligence to understand patient needs better as a part of their journey in the digital-driven transformation.

8.7 Organisation of the department and meetings



8.8 Scientific and societal partners and collaborations

It goes without saying that due to the large diversity in academic expertise and a strong orientation with actual societal challenges, the IS group is well connected and has many active relationships with institutions in various sectors, academic and non-academic, governmental and commercial, etc.. Partly, these relationships occur more or less naturally since e.g. our master students already have daytime jobs in regular organizations and very often use their connections within their own employer to facilitate their master thesis projects under close guidance of our research staff. Up to some extent this is also the case with (external) PhD students. Although most of these relationships are fleeting, still, the student-employer relationships have proven to be very valuable for our research in providing a basis for data collection and analysis, validation and testing and implicitly demonstrates the commitment and confidence several hundreds of organizations have in our research. This close interaction between science and practice, in essence, can significantly boost the adoption of newly discovered scientific insights with the involved

organizations.

Relations/affiliations with scientific institutes:

1. Katholiek Universiteit Leuven, Afdeling Industrieel Beleid/Verkeer Infrastructuur, Belgium
2. Utrecht University, Department of Information and Computing Sciences
3. Utrecht University of Applied science, Digital Smart Services
4. Universiteit Utrecht, department for Social and Economic History, Institutions for Collective Action
5. Maastricht University, School of Business and Economics, dep. Organisation, Strategy and Entrepreneurship (OSE)
6. Maastricht University, Department of Accounting and Information Management
7. The University of Melbourne, Computing and Information Systems, Melbourne School of Engineering
8. National Research University Higher School of Economics, Moscow, Russia
9. Norwegian University of Science and Technology, Department of Computer Science
10. Radboud University, Social Cultural Research
11. NIVEL, Netherlands Institute for Health Services Research
12. Erasmus University, Erasmus School of Accounting and Assurance
13. Georgia State University, department of Computer Information Systems
14. Ghent University, Faculty of Economics and Business Administration, UGentMIS Research Group
15. Antwerp Management School, Research Group Digital Innovation
16. University of Antwerp, Department of Management Information Systems
17. UTwente, sectie ETM, afd. HBE, faculteit Behavioural, Management and Social Sciences, PhD-program
18. Novel T and PLD UTwente, Panther-Program in cooperation with KU Leuven, Fontys Hogeschool and Flanders Business School
19. Faculteit Militaire Wetenschappen and TNO Defensie, joint PhD-program.

References

Arnoldi, E., Bosua, R. & V. Dirksen (2021). Mapping themes for the wellbeing of low-skilled gig workers: Implications for digital platform design, Transitions: Journal of

Transient Migration 5(1), pp. 55–75.

Bagheri, S. Towards a Governance Framework for Data Platform Ecosystems in the Construction Industry. ICEIS (2), 2023. 566-574.

Bagheri, S., Brandt, T., Sheombar, H. & Van Oosterhout, M. 2021. Value Creation through Urban Data Platforms: A Conceptual Framework. Proceedings of the 54th Hawaii International Conference on System Sciences.

Bagheri, Samaneh and Dijkstra, Jesse, "CAPABILITIES FOR DATA ANALYTICS IN INDUSTRIAL INTERNET OF THINGS (IIOT)" (2023). ECIS 2023 Research Papers. 416. https://aisel.aisnet.org/ecis2023_rp/416

Baijens, J., Huygh, T., & Helms, R. (2022). Establishing and theorising data analytics governance: a descriptive framework and a VSM-based view. Journal of Business Analytics, 5(1), 101-122.

Butseraen, J. (2023). Artificial Intelligence challenges and impacts in the public sector: evidence from law enforcement. [Master Thesis, Open University of the Netherlands]. Open Universiteit.

De Haes, S., Van Grembergen, W., Joshi, A., Huygh, T., De Haes, S., Van Grembergen, W., ... & Huygh, T. (2020). Enterprise governance of IT, alignment, and value. Enterprise Governance of Information Technology: Achieving Alignment and Value in Digital Organizations, 1-13.

De Moor, T., Rijpma, A., & Prats López, M. (2019). Dynamics of Engagement in Citizen Science: Results from the "Yes, I do!"-Project . Citizen Science: Theory and Practice, 4(1), 1-17. Article 38. https://doi.org/10.5334/cstp.212

Doe, J. K., Van de Wetering, R., Honyenuga, B., & Versendaal, J. (2022). Extended contextual validation of stakeholder approach to firm technology adoption: moderating and mediating relationships in an innovation eco-system. Society and Business Review, 17(4), 506-540.

Hadžiarapović, N., Versendaal, J., van Steenbergen, M., & Ravesteijn, P. (2023). The Economics of Collective Management in the Music Copyright Industry in The Netherlands: Digital Transformation and Equitable Remuneration, Review of Economic Research on Copyright Issues, 20, 38-75.

Huygh, T., & De Haes, S. (2019). Investigating IT governance through the viable system model. Information Systems Management, 36(2), 168-192.

Huygh, T., & De Haes, S. (2020). Towards a Viable System Model-based Organizing Logic for IT Governance. In Proceedings of the International Conference on Information Systems (ICIS).

Joshi, A., Benitez, J., Huygh, T., Ruiz, L., & De Haes, S. (2022). Impact of IT governance process capability on business performance: Theory and empirical evidence. Decision Support Systems, 153.

Joshi, A., van Peteghem, M., Bollen, L., de Haes, S., Mithas, S., Board IT competence and firm performance, paper presented at ICIS conference, Munchen, 2019

Joshi, L. Bollen, H. Hassink, W. van Grembergen, S. de Haes, "Explaining IT Governance Disclosure through the Constructs of IT Governance Maturity and IT Strategic Role", Information & Management, Vol. 55, Issue 3, 2018, pp. 368-380; Impact factor 3.317 (A)

Kotusev, S., Kurnia, S., Dilnutt, R., & van de Wetering, R. (2023). The Structuring of Enterprise Architecture Functions in Organizations: Towards a Systematic Theory. Business & Information Systems Engineering, 1-24.

Merkus, J., Helms, R. W., & Kusters, R. (2023). Data Governance Capabilities; Empirical validation in case studies of large organizations. In proceedings: 36th Bled eConference Digital Economy and Society: The Balancing Act for Digital Innovation in Times of Instability, 35.

Mikalef, P., Pateli, A., & van de Wetering, R. (2021). IT architecture flexibility and IT governance decentralisation as drivers of IT-enabled dynamic capabilities and competitive performance: The moderating effect of the external environment. European Journal of Information Systems, 30(5), 512-540.

Mourits, R., Prats López, M., van Oort, T., Ganzevoort, W., & van Galen, C. (2023). Engaging the Crowd: Citizen Science for Historical Demography. Abstract from European Social Science History Conference, Gothenburg, Sweden.

Neumann, M., Dirksen, V. & Dickel, S. (2024). On the Construction of Plausible Futures in Interpretive Agent-Based Modelling, in: M. Neumann (ed.), An Interpretive Account to Agent-based Social Simulation: Using Criminology to explore Cultural Possibilities. pp. 170-188. London: Routledge.

Nguyen, D. K., Broekhuizen, T., Dong, J. Q., & Verhoef, P. C. (2022). Power Distribution of IT Executives in the TMT: When Should It Be Equal?. In Proceedings of International Conference on Information Systems 2022

Papagiannidis, E., Mikalef, P., Conboy, K., & Van de Wetering, R. (2023). Uncovering the dark side of AI-based decision-making: A case study in a B2B context. Industrial Marketing Management, 115, 253-265.

Pattij, M., van de Wetering, R., & Kusters, R. (2022). Enhanced digital transformation supporting capabilities through enterprise architecture management: A fsQCA perspective. Digital Business, 2(2), 100036.

Prats López, M., Rijpma, A., De Moor, T., & Reijerink, J. (2023). Behind the Crowdsourcing Platform: Assessing Volunteer Recruitment and Engagement Instruments. Nonprofit and Voluntary Sector Quarterly. Advance online publication. https://doi.org/10.1177/08997640231212839

Prats López, M., Soekijad, M., Berends, H., & Huysman, M. (2020). A Knowledge Perspective on Quality in Complex Citizen Science. Citizen Science: Theory and Practice,

5(1), 1-13. Article 15. https://doi.org/10.5334/cstp.250

Puthenpurackal, J., Huygh T., & De Haes S. (2022). Portfolio Management Agility – Deriving Design Goals. In Proceedings of the Pacific Asia Conference on Information Systems (PACIS) 2022.

Roelens, B., Ebben, R., & de Wetering, R. V. (2023, July). Composing an Initial Domain-Specific Modeling Language Notation by Reusing Icons. In International Symposium on Business Modeling and Software Design (pp. 245-255). Cham: Springer Nature Switzerland.

Roubtsova, E. (2015). Advances in behavior modeling. In Advances in Computers (Vol. 97, pp. 49-109). Elsevier Rutledge, L., Berghuis, B., Lim, K. & Soerokromo, A Web-Based Approach for Traceability in Rule-Based Business Information Systems. M., Jul 2023, Business Modeling and Software Design: 13th International Symposium, BMSD 2023, Proceedings

Sara Nodehi, Tim Huygh, Laury Bollen, Six board roles for information security governance, paper presented at the International Conference on Enterprise Information Systems (ICEIS), Angers (Fr), 2024. Science Faculty, "New Horizons for Science: Research Strategy of the Faculty of Science 2020 - 2025", Heerlen, January 2022

Tiwana, A., Konsynski, B., & Venkatraman, N. (2013). Information technology and organizational governance: The IT governance cube. Journal of management information systems, 30(3), 7-12.

Van de Wetering, R. (2022). The impact of artificial intelligence ambidexterity and strategic flexibility on operational ambidexterity. In Pacific Asia Conference on Information Systems (pp. 1-17). AIS Electronic Library.

Van de Wetering, R. (2022). The role of enterprise architecture-driven dynamic capabilities and operational digital ambidexterity in driving business value under the COVID-19 shock. Heliyon, 8(11).

van de Wetering, R., de Weerd-Nederhof, P., Bagheri, S., & Bons, R. (2023, July). Architecting agility: Unraveling the impact of AI capability on organizational change and competitive advantage. In International Symposium on Business Modeling and Software Design (pp. 203-213). Cham: Springer Nature Switzerland.

van de Wetering, R., Mikalef, P., & Dennehy, D. (2022, September). Artificial intelligence ambidexterity, adaptive transformation capability, and their impact on performance under tumultuous times. In Conference on e-Business, e-Services and e-Society (pp. 25-37). Cham: Springer International Publishing.

Van de Wetering, R., Roelens, B., & de Langen, F. (2023). Improvisational and Dynamic Capabilities as Drivers of Business Model Innovation: An Enterprise Architecture Perspective. Pacific Asia Journal of the Association for Information Systems, 15(1), 1.

van Galen, C., van Oort, T., Prats López, M., Ganzevoort, W., & Mourits, R. (2023). Creating user profiles based on citizen scientists' engagement patterns. In Book of

Abstracts: Digital Humanities Conference 2023 (pp. 108-109). Austrian Centre for Digital Humanities. https://zenodo.org/records/7961822

Vanderbeken, Yves, Huygh, Tim & Bollen, Laury, Adopting the business platform model for Citizen Services – from lean to platform organization', paper presented at the 31st European Conference on Information Systems (ECIS), Christiansand, 2023

Versendaal, J., van Steenbergen, M., Smit, K., van Ginkel, S., de Haas, M., Peters, R. & Govers, S. (2024). Responsible software development through situational method engineering: Building a metamodel for method fragments. [Manuscript submitted for journal publication]

Walraven, P., van de Wetering, R., Helms, R., Caniëls, M., & Versendaal, J. (2022). Evolving competencies to align electronic medical records–a dynamic resource-based perspective on hospitals' co-evolutionary information systems alignment capability. Journal of Health Organization and Management, 36(9), 112-132.

Weill, P., & Ross, J. W. (2004). IT governance: How top performers manage IT decision rights for superior results. Harvard Business Press.

9 Environmental Sciences Research Program 2023-2027

GREAT

Governance Research and Environmental Sciences for Action and Transitions

Department of Environmental Science, Open Universiteit

9.1 Overview of the department

The Department of Environmental Sciences is part of the Faculty of Science at the Open Universiteit (OU). The Department embodies the commitment of the OU to excellence in the environmental sciences, science for impact, and lifelong learning in the sustainability domain. The Department brings together people working on integrated environmental modelling, human health and the environment, learning for sustainability, and environmental governance and has about 20 team members. The Department has long recognised that solutions to environmental problems require interdisciplinarity between various natural sciences, and with the social sciences. Reflecting this, the Department holds chairs in Integrated Environmental Modelling, Natural Sciences, Technology-enhanced Learning for Sustainable Development, Data-driven decision making in healthcare, and it holds the longest standing Chair in Environmental Governance in the Netherlands. The Department of Environmental Sciences has a strong track record in research, as witnessed by its publication record in outstanding academic outlets and its acquisition of prestigious grants.

9.1.1 Research focus of the department

The research of the Department aims to contribute to the understanding of social-ecological systems, the development of solutions for environmental and conservation issues, and to the wider body of knowledge that helps societies to reach their sustainability goals. There is a close link between the research and the education programs of the Department – our students are actively encouraged to get involved in our research program, and in turn, our research helps us maintain the level and currency of our education programs to the benefit of these same students. Collaboration within a growing network of universities and societal partners, both nationally and internationally, ensures state of the art research and the continuous alignment of research efforts with societal needs.

The department has a very strong interdisciplinary focus that brings together four distinct research lines:

1. Integrated Environmental modelling,
2. Human Health & Environment,
3. Learning for Sustainability, and
4. Environmental Governance.

These research lines indicate the academic domains to which we seek to contribute with our research. The research concerns many different environmental issues, with a particular emphasis on three main themes:

1. pollution,

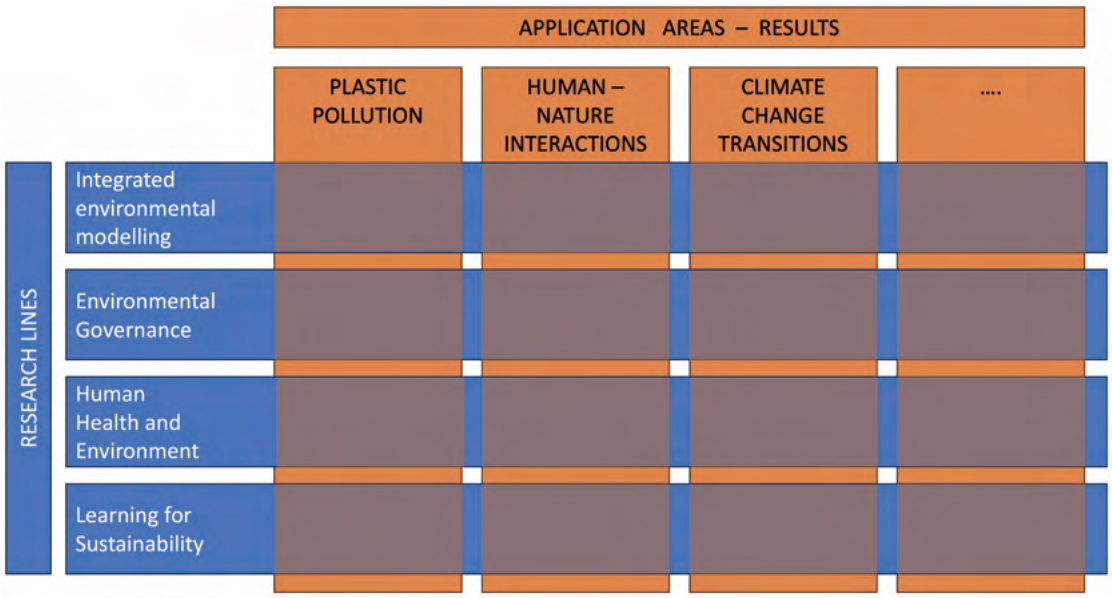


Figure 1: The ES expertise matrix

2. human-nature interactions, and
3. climate change transitions.

The relation between the research lines and the themes is shown in Figure 1. This figure also includes an open theme, as not all research fits neatly in the figure, as the themes will evolve over time, and as new themes might be included in the future.

9.1.2 Size

In the beginning of 2024, the department included 4 full professors, 1 special professor, 3 Associate professors, 10 assistant professors, 1 teacher, and 2 junior researchers with a total of 15.9 FTE. Staff at the department typically has 30% of their time available for research. In addition, there were 6 internal PhD students (PhD students with a contract at the OU) and 11 external PhD students (PhD students without a contract and often employed elsewhere).

9.2 Research Lines

9.2.1 Integrated Environmental Modelling

Environmental sciences focus on the functioning of social-ecological systems, with a specific focus on the complex interactions between natural systems and humans which has

become increasingly important in the Anthropocene. Particularly while undergoing increasingly rapid changes, it is key to understand the resilience and self-regulations in these systems but also the tipping points and the potential cascading effects. A better understanding allows for an ex ante assessment of e.g. environmental changes and environmental policies. But at the same time the environmental sciences help us to design and evaluate alternative interventions like nature-based solutions. The Department of Environmental Sciences at the OU aims to achieve this understanding through Integrated Environmental Modelling. These models can function as digital twins of a social-ecological system to support e.g. stakeholder discussions and informed decision making. Within our research we do not make a priori decisions on the type of models, but rather let the case determine the type of model. As such we develop and make use of a wide range of modelling approaches that can range from rather simple back-of-the-envelope calculations, and flow mapping (often based on structured literature reviews), to more complex mechanistic models, neural networks, agent-based modelling and artificial intelligence. Within the research line on Integrated Environmental Modelling, we are specifically searching for tools to develop parsimonious models with the right level of complexity to deal with the social-ecological system and to answer the specific question at hand. In addition, we study the role that these models can play in facilitating stakeholder discussions.

References and more

- Hoeke S, van Wijnen J, Krikke H, Löhr A, Ragas AMJ (2024) Mapping the tire supply chain and its microplastics emissions using a multi-stakeholder approach. Resources, Conservation and Recycling 203, 107389
- van Wijnen J, Ragas AMJ, Kroeze C (2019) Modelling global river export of microplastics to the marine environment: Sources and future trends. Science of the Total Environment 673: 392-401.

9.2.2 Human Health and Environment

Nature provides the basis for human health and well-being. Essential elements such as clean air, safe food and pure drinking water are vital to sustaining life. Additionally, natural environments offer opportunities for recreation, relaxation and social interaction, while raw materials support the comforts of modern life. Yet, environmental pollution persists, contributing significantly to the burden of disease and mortality. Fortunately, this burden can be significantly reduced through concerted efforts to improve environmental quality. Unfortunately, the burden of environmental diseases is not evenly distributed. The most vulnerable people in our society are most affected by environmental stress. Socially disadvantaged communities are exposed to higher levels of air pollution, noise and heat stress. In addition, children, pregnant women, the elderly and people with chronic diseases are more affected by environmental health risks than others. As a result, higher levels of exposure to environmental stressors and the greater burden of health impacts exacerbate existing health inequalities.

The human health and environment research line aims to contribute to a better understanding of the health impacts of environmental factors such as pollution, climate change and urban environments, while assessing the health benefits associated, for example, with the use of green spaces and climate mitigation measures. We focus on various exposures, including pollution, temperature and green space, and their potential impact on outcomes such as premature mortality, cardiovascular and respiratory health, and cognitive function. The research line is therefore closely aligned with the research themes of pollution and human-nature interactions, with a particular focus on vulnerable communities, and contributes to several Sustainable Development Goals, including SDG 3 (Good Health and Well-being), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action).

Moving forward, this novel research line will continue to evolve, refining multiple research paths and enhancing our comprehension of the dynamic interplay between the environment and human health. Our ambition is to deepen our understanding of environment-related health implications, with a focus on water quality, air pollution, food safety, temperature, and green spaces. By expanding the body of scientific knowledge in these areas, our research will provide valuable information that can serve as a basis for future studies, policies, and interventions aimed at mitigating environmental related health risks and promoting human well-being.

References and more

- Hantoro, I., Löhr, A.J. Van Belleghem, F.G.A.J., Widianarko, B., Ragas, A.M.J., 2019. Microplastics in coastal areas and seafood: implications for food safety. Food Additives & Contaminants: Part A, DOI: 10.1080/19440049.2019.1585581.

9.2.3 Learning for Sustainability

The research in the field of Learning for Sustainability aims at a better understanding of the role of learning processes in systemic sustainability transitions in our society. The research focuses on the study (of integration) of different types of knowledge (such as experiential knowledge, exact scientific knowledge, actionable knowledge), stakeholder perspectives (including values, norms and interests), and integrative knowledge concepts in science and sustainability. Current research themes include competences for sustainability professionals, social learning as a catalyst for building resilience among smallholder farmers, technology-enhanced action-oriented learning in higher education and (professional) practice (including MOOCs), action capacity development, learning of stakeholders in multilateral environmental treaty-making (specifically on plastic pollution), and transformative learning in neighbourhoods, cities, and regions including in the Global South. Specific attention is also paid to the theoretical understanding of the role and functioning of learning processes in governance.

The Department has over 30 years of expertise in (online) learning design, curriculum development and networked learning in higher education environmental sciences pro-

grammes. In the last years the focus has been broadened to social learning, learning regions, and transformative learning for sustainability in society.

The research is innovative and performed at the national and international forefront, often in consortia consisting of both scientific institutions and societal partners, such as the Dutch Climate Research Initiative (KIN), UNESCO and UNEP. Much of the work can be classified as transdisciplinary, since it is carried out collectively with stakeholders (co-creation with professionals, informal leaders, citizens, etc.). In addition, our students bring in experiential knowledge from their professional employment. Applied research methodologies include newly developed action research for sustainability transitions and action learning, combined with quantitative surveys, focus groups and interviews.

We envision that our research will inform and empower students and teachers, citizens, professionals and (informal) leaders in their understanding of sustainability and in achieving and accelerating sustainability transitions.

References and more

- Löhr A, Broers V, Tabuenca B, Savelli H, Zwimpfer T, Folbert M, Brouns F (2024) Informing and inspiring worldwide action against marine litter - The impact of the Massive Open Online Course (MOOC) on Marine Litter. Marine Pollution Bulletin Volume 198, 115811 https://doi.org/10.1016/j.marpolbul.2023.115811
- Venn, R., Perez Salgado, F., & Vandenbussche, V. (2022). Competencies of Sustainability Professionals: An Empirical Study on Key Competencies for Sustainability. Sustainability, 14(9), 1-22. https://doi.org/10.3390/su14094916
- Van Assche, K., Beunen, R., Verweij, S., Evans, J., & Gruezmacher, M. (2022). Policy Learning and Adaptation in governance; a Co-evolutionary Perspective. Administration & Society, 54(7), 1226-1254.
- Van Assche, K., Beunen, R., & Verweij, S. (2020). Comparative planning research, learning, and governance: The benefits and limitations of learning policy by comparison. Urban Planning, 5(1), 11-21.
- van Herten, S. M., & Perez, P. (2022). Ecocritical analysis of “glocal” essays on Lived Experiences of Climate Change in higher education. Frontiers in Sustainability, 3, Article 980530. https://doi.org/10.3389/frsus.2022.980530
- Dlouhá, J., Heras, R., Mulá, I., Perez Salgado, F., & Henderson, L. (2019). Competences to Address SDGs in Higher Education: A Reflection on the Equilibrium between Systemic and Personal Approaches to Achieve Transformative Action. Sustainability, 11(13), 3664. https://doi.org/10.3390/su11133664
- Tabuenca B, Kalz M, Löhr A (2019) Massive open online education for environmental activism: The worldwide problem of marine litter. Sustainability 11 (10), 2860
- Perez Salgado, F., Abbott, D. & Wilson, G. (2018). Dimensions of professional competences for interventions towards sustainability. Sustainability Science, 13(1), 163-177. https://doi.org/10.1007/s11625-017-0439-z

9.2.4 Environmental Governance

The research line Environmental Governance is dedicated to accelerating sustainability transitions. The aim of this research line is to develop and improve theoretical approaches for analysing and evaluating processes of stability and change in governance and contributing to the societal debates about current governance systems and the possibilities to transform and improve these systems through research, education, and capacity development.

Contemporary societies face a range of environmental problems and sustainability challenges. It has become clear that current ways of production, consumption and governing need to be changed to stay within planetary boundaries, while ensuring the minimal social standards necessary for human well-being, such as food, water or education. These ambitions and their interrelations are also reflected in the Sustainable Development Goals. Innovation, transition and transformative change are increasingly called for to realise these ambitions. At the same time, it has become clear that bringing about necessary changes is difficult and more research is needed to better understand the processes of stability and change in governance and the various factors that play a role in these processes. The research under this line therefore aims to enhance the understanding of the functioning and evolution of governance systems and their impact on the environment and sustainable development. It focuses on unravelling the pathways of stability and change, analysing the main drivers and mechanisms of transitions, and providing practical recommendations and solutions to improve environmental governance outcomes. It calls for holistic and integrative approaches that are increasingly developed and applied in cooperation with societal partners.

Societal engagement and stakeholder involvement are central themes in this research line. While there is some general agreement on the different environmental challenges and sustainable development goals, the perspectives on environmental issues and on the why, how and what of successful and just transformations can largely diverge. Informing the societal discussions about sustainability transformations therefor also calls for insights in these different perspectives and their impact on governance, as well as in the various ways to integrate stakeholders' perspectives and needs in the pathways of change.

The research line environmental governance builds on a long tradition of research in related domains like public policy and administration, environmental politics, nature resource management, international relations, sociology, philosophy, anthropology, etcetera. The scientific literature on environmental governance has gradually evolved into a set of inclusive and integrated approaches that recognise the complexity and interconnectedness of environmental challenges. It emphasises the need for participatory approaches, adaptive management, and global cooperation to address these challenges effectively. With this in mind, the group wants to be at the forefront of theoretical advancement as well as work on societal impact, by translating scientific insights for practical use and by actively contributing to societal debates. More specifically, three interrelated topics and their integration gain specific attention in the research of the group. These will be

described next.

9.2.4.1 Multi-actor governance

First of all, the literature shows a clear shift from public policy and administration towards more diverse forms of environmental governance that include a wide range of public and private actors and both formal and informal institutions. This shift emphasizes the involvement of multiple stakeholders in environmental governance, including governments at different levels, businesses, civil society organizations, and local communities. It brought attention to models of stakeholder involvement, capacity development, changing patterns of inclusion and exclusion, and the various ways in which different perspectives, forms of knowledge and ways of valuing can be brought together. Moreover, there has been a growing recognition of the importance of global environmental governance, as environmental issues have become increasingly transboundary in nature. The literature explores topics such as international environmental agreements, global environmental institutions, and is increasingly paying attention to the role of non-state actors in shaping global environmental governance beyond international environmental agreements and contributing to implementation. Multi-level and multi-actor governance have therefore become key concepts that address the interrelations between different levels of governance and the multiple actors that are involved in each level.

References and more

- Bisschops, S., & Beunen, R. (2019). A new role for citizens' initiatives: the difficulties in co-creating institutional change in urban planning. Journal of Environmental Planning and Management, 62(1), 72-87.
- Dahdouh-Guebas, F., Hugé, J., Abuchahla, G.M., Cannicci, S., Jayatissa, L.P., Kairo, J.G., Arachchilage, S.K., Koedam, N., Mafaziya Nijamdeen, T.W.G. F, Mukherjee, N. and Poti, M., 2021. Reconciling nature, people and policy in the mangrove social-ecological system through the adaptive cycle heuristic. Estuarine, Coastal and Shelf Science, 248, p.106942.
- Groen, L. (2020). Group Interaction in the UN Framework Convention on Climate Change. In Group politics in UN multilateralism (pp. 267-284). Brill Nijhoff.
- Taillandier, C., Cörvers, R., & Stringer, L. C. (2023). Growing Resilient Futures: Agroforestry as a Pathway towards Climate Resilient Development for Smallholder Farmers. Frontiers in Sustainable Food Systems, 7, 1260291.

9.2.4.2 Understanding the processes of change (and stability)

Secondly, one can witness a growing attention for the **process of change and stability** in environmental governance. Governance systems are always changing, but increasingly attention is given to the ways in which the processes of change can be understood, planned and steered. This brought attention to concepts like transitions, transforma-

tions and transformative governance. Within the literature attention is given to several of the main drivers of change that include social learning, politics, fairness concerns and changing societal views and paradigms, as well as for the obstacles for change, path-dependencies and lock-ins. Furthermore, some stability in governance is needed to stabilize expectations, enhance coordination over time, and to ensure that new policies persist over sufficient timeframes to bring about desired effects. More broadly, democratic political systems need to provide sufficient stability to uphold legitimate, fair, and accountable sets of rules, while also being flexible in adapting to economic, social, and environmental change over time. Within this context of change, scientific research can help to refine our understanding of the functioning of policy and planning and different forms of steering, and to better identify the possibilities for and limits to strategy to accelerate sustainability transitions.

References and more

- Beunen, R., & Kole, S. (2021). Institutional innovation in conservation law: Experiences from the implementation of the Birds and Habitats Directives in the Netherlands. Land Use Policy, 108, 105566.
- Groen, L., Alexander, M., King, J. P., Jager, N. W., & Huitema, D. (2023). Re-examining policy stability in climate adaptation through a lock-in perspective. Journal of European Public Policy, 30(3), 488-512.
- Löhr AJ, Van Belleghem F (2020) Sustainable Development Goals to Reduce and Prevent Marine Litter. Life Below Water, 1-12
- Oberthür, S., & Groen, L. (2020). Hardening and softening of multilateral climate governance towards the Paris Agreement. Journal of Environmental Policy & Planning, 22(6), 801-813.

9.2.4.3 Just transitions (quality of the process)

Thirdly, environmental problems and its governance create winners and losers, and if more leading to conflicts as well. Benefits and harms vary among stakeholders, different parties are involved in diverse ways, and diverse groups frame environmental controversies differently – all give rise to pleas for justice, equity, and inclusion. That makes there is inevitably a **normative dimension in environmental issues**. This goes against the idea that justice is a separate sphere or domain that can, for instance, be dealt with only through social policy or tax reforms. There is now a growing literature on just transition (climate change), environmental justice and inclusive conservation (nature conservation). Research tackles different dimensions: the mapping of inequalities (how are different groups affected or involved); explaining the mechanisms and processes behind such differentiation; distinguishing and applying different dimensions of justice, such as distributive (who gets what), procedural (who decides) and recognitive justice (how groups and value systems are treated); and examining assumptions, such as in narratives, policy tools and research approaches. Examining justice aspects in not inde-

pendent of legitimacy and public support. If processes, outcomes, and policy instruments are perceived as more just, fair, or inclusive, people often see these as more legitimate and tend to support these more. Understanding justice and pluralism claims requires involvement of local actors and citizens, since justice is context dependent. Increasing societal pleas for just transitions therefore demand for a better understanding of all these normative dimensions.

References and more

- Neuteleers, Stijn & Hugé, Jean (2021) Value pluralism in ecosystem services assessments: closing the gap between academia and conservation practitioners, Ecosystem Services, 49, 101293.
- Neuteleers, Stijn (2023). 'Environmental Justice', in Van Assche, Kristof, Beunen, Raoul & Duineveld, Martijn (eds.). Encyclopedia of Urban & Regional Planning & Design. Edward Elgar Press.
- Neuteleers, Stijn (2022) Trading nature: When Are Environmental Markets (Un)desirable? Journal of Political Philosophy, 30(1): 116-139.

9.2.4.4 Integrative approach to governance

The research line environmental governance integrates these three topics and their interrelations from a holistic perspective on governance. The focus of the research is on environmental governance in general, with more specific attention for environmental degradation, biodiversity loss, climate change mitigation and adaptation, and (plastic) pollution. The research therewith enriches empirical understandings of environmental governance, it contributes to the development and improvement of theories and methodologies for analysing environmental governance, while the transdisciplinary focus and outreach activities help to enhance societal impact and contribute to capacity development among relevant actors.

References and more

- Taillandier, C., Dijk, M., & Vialleix, M. (2023). Back to the Future: "De-Transition" to Low-Car Cities. Future Transportation, 3(2), 808-839.
- Van Assche, K., Beunen, R., Duineveld, M., & Gruezmacher, M. (2023). Adaptive methodology. Topic, theory, method and data in ongoing conversation. International Journal of Social Research Methodology, 26(1), 35-49.
- Van Assche, K., R. Beunen & M. Gruezmacher (2024) Strategy for Sustainability Transitions: Governance, Community and Environment. Edward Elgar Publishing.

9.3 Research themes

9.3.1 Pollution

The research on environmental pollution covers a wide spectrum, from the study of adverse effects on individual cellular components to broader considerations of human physical and even mental health, and from the development of innovative analytical methods to the implementation of comprehensive risk assessments. Projects in this thematic area range from overcoming technical challenges in detecting environmental pollutants in blood (including micro- and nanoplastics, regardless of whether they are free-floating in the plasma phase or associated with immune cells) to investigating their pathophysiological effects (e.g. uptake, translocation and effects of these micro- and nanoplastics in an intestinal system) and assessing their impact on different disease processes in humans (e.g. disruption of immunological to chronic inflammatory processes, cardiovascular abnormalities, or diabetes). In another project, the presence of microplastics in seafood from markets in Semarang, a coastal city in Java, Indonesia, will be linked to human exposure through a nutritional study, which will lead to a comprehensive risk assessment. Within the wider theme of pollution, the focus over the last decade has been on marine litter and plastic pollution. Research on this theme is carried out within all research lines.

9.3.1.1 Theme link with Integrated Environmental Modelling

Within the research line Integrated environmental modelling several studies are carried out dealing with tire particles, sea-based sources of plastics and solid waste management. The main aim of a large study on car tires is to contribute to our understanding of the accumulation of tire particles in the environment by examining the contribution of tire particle emissions from road wear, the presence of tire particles along the Dutch road network and the contribution of tire particle emissions from artificial turf. In addition, to place these findings in statutory context, the research project delves into the political process of enacting legislation to reduce tyre emissions.

Another study on car tires uses a transdisciplinary approach to mitigating tire microplastics in which we develop an effective tire microplastic mitigation strategy using environmental modelling. Mitigation strategies are developed and assessed involving various European stakeholders, e.g., from universities, industry and policy.

The contribution of sea-based sources such as shipping and fisheries has in specific geographical sea areas been identified as the dominating source. However, the sources and pathways of microplastic pollution from ships have not been systematically documented and quantitative data is lacking.

We use system dynamics to diagnose causes of failing waste collection in developing countries. Often 60% of the population in low-income countries is not serviced with

waste collecting and we investigate the main factors influencing this failing performance.

References and more

- Breukelman H, Krikke H, Löhr A (2019) Failing services on urban waste management in developing countries: a review on symptoms, diagnoses, and interventions. Sustainability 11 (24), 6977
- Breukelman H, Krikke H, Löhr A (2022) Root causes of underperforming urban waste services in developing countries: Designing a diagnostic tool, based on literature review and qualitative system dynamics. Waste Management & Research 40 (9), 1337-1355
- Folbert MEF, Corbin C, Löhr AJ (2022) Sources and Leakages of Microplastics in Cruise Ship Wastewater. Frontiers in Marine Science 9, 814
- Kole PJ, Van Belleghem FGAJ, Stoorvogel JJ, Ragas AMJ, Löhr AJ (2023) Tyre granulate on the loose; How much escapes the turf? A systematic literature review. Science of the Total Environment, 166221
- Löhr, A., Savelli, H., Beunen, R., Kalz, M., Ragas, A., & Van Belleghem, F. (2017). Solutions for global marine litter pollution. Current opinion in environmental sustainability, 28, 90-99.

9.3.1.2 Theme link with Human Health and Environment

The research on environmental pollution covers a wide spectrum, from the study of adverse effects on individual cellular components to broader considerations of human physical and even mental health, and from the development of innovative analytical methods to the implementation of comprehensive risk assessments. Projects in this thematic area range from overcoming technical challenges in detecting environmental pollutants in blood (including micro- and nanoplastics, regardless of whether they are free-floating in the plasma phase or associated with immune cells) to investigating their pathophysiological effects (e.g. uptake, translocation and effects of these micro- and nanoplastics in an intestinal system) and assessing their impact on different disease processes in humans (e.g. disruption of immunological to chronic inflammatory processes, cardiovascular abnormalities, or diabetes). In another project, the presence of microplastics in seafood from markets in Semarang, a coastal city in Java, Indonesia, will be linked to human exposure through a nutritional study, which will lead to a comprehensive risk assessment. The aim of this research is to determine the risks of exposure to microplastics through food and the environment. The presence of microplastics in various types of seafood from local markets in Semarang, Java, Indonesia, is studied and estimate residents' levels of exposure based on their diet. In line with this, as part of the MOMENTUM consortium, we are investigating the uptake, translocation and effects of microplastics in small intestinal cells in order to link the presence of microplastics to the molecular processes that cause the harmful effects. These results contribute to the development of an integrated risk assessment of microplastics for food safety.

References and more

- Hantoro, I., Löhr, A. J., Van Belleghem, F. G., Widianarko, B., & Ragas, A. M. (2019). Microplastics in coastal areas and seafood: implications for food safety. Food Additives & Contaminants: Part A, 36(5), 674-711.
- Saenen, N. D., Witters, M. S., Hantoro, I., Tejeda, I., Ethirajan, A., Van Belleghem, F., & Smeets, K. (2023). Polystyrene Microplastics of Varying Sizes and Shapes Induce Distinct Redox and Mitochondrial Stress Responses in a Caco-2 Monolayer. Antioxidants, 12(3), 739.

9.3.1.3 Theme link with Learning for Sustainability

The research aims to understand how technology can help to scale up and speed up learning for sustainability, by reaching and empowering a very large and diverse audience of motivated change-agents, and how the outcomes and impacts of this learning can be made deeper and longer lasting. The current research focus is on the learning ecosystem around the MOOC on Marine Litter and Plastic Pollution. Key questions concern its effectiveness and options to further enhance this, including options to help learners increase their impact, to identify and target specific key actors and their capacity development needs, and to make the MOOC-ecosystem more accessible to a larger and more diverse group of learners.

References and more

- Löhr A, Broers V, Tabuenca B, Savelli H, Zwimpfer T, Folbert M, Brouns F (2024) Informing and inspiring worldwide action against marine litter - The impact of the Massive Open Online Course (MOOC) on Marine Litter. Marine Pollution Bulletin Volume 198, 115811 https://doi.org/10.1016/j.marpolbul.2023.115811
- Tabuenca B, Kalz M, Löhr A (2019) Massive open online education for environmental activism: The worldwide problem of marine litter. Sustainability 11 (10), 2860

9.3.1.4 Theme link with Environmental governance

The effectiveness of multilateral environmental agreements, as in legal effectiveness, has been debated in recent years. However, effectiveness beyond legal bindingness has not yet been the subject of extensive research. This theme therefore considers multilateral environmental agreements and their ancillary functions (beyond legal bindingness) to identify how effective these are, and how they could potentially be further improved for more sustainable outcomes. More specifically a part of the research in the theme pollution focuses on the complex problem of nitrogen deposition and its adverse effects on biodiversity. This research integrates insights from environmental sciences, legal studies, public administration, and sociology to reflect on the evolution of governance

systems and their impact on biodiversity goals.

References and more

- Beunen, R., & Kole, S. (2021). Institutional innovation in conservation law: Experiences from the implementation of the Birds and Habitats Directives in the Netherlands. Land Use Policy, 108, 105566.
- Beunen, R., & Turnhout, E. (2019). 'Stikstof'als symbool voor een falende overheid: Essay voor het Montesquieu Instituut.
- Groen, L. (2019). Explaining European Union effectiveness (goal achievement) in the Convention on Biological Diversity: the importance of diplomatic engagement. International Environmental Agreements: Politics, Law and Economics, 19(1), 69-87.
- Oberthür, S., & Groen, L. (2020). Hardening and softening of multilateral climate governance towards the Paris Agreement. Journal of Environmental Policy & Planning, 22(6), 801-813.

9.3.2 Human-nature interactions

This theme focuses on a better understanding of the multiple dimensions through which human systems and natural systems interact. While humans are intrinsically interwoven into social-ecological systems and while human agency is now a potent force shaping landscapes and resource fluxes at a global scale in the Anthropocene, the term 'human-nature interactions' facilitates a pragmatic analytical approach. Human-driven modifications of nature trigger impacts on ecosystems, which have a direct impact on other living beings and a direct or indirect impact on human health and wellbeing. Mapping and understanding people's attitudes and behaviour towards nature is also key to foster sustainable social-ecological systems in which human and non-human entities can thrive sustainably. Our research aims to contribute to the growing evidence base of the diversity of human-nature interactions at different spatial and temporal scales and it wants to contribute to make these interactions more sustainable. In this research theme we propose a roadmap which zooms in on a range of specific topics and approaches which highlight the human dimension of nature conservation and environmental management.

9.3.2.1 Theme link with Integrated Environmental Modelling

Human-nature interactions are notoriously difficult to model due to the multiplicity of decision-makers involved. These include human decision-makers of course, but also animals which are decision-makers themselves. Agent-based modeling applied to human and animal decision-making is one of the themes in which we develop and apply new knowledge. This knowledge can be used directly to address human-wildlife conflict in Europe (e.g. human-carnivore conflict) and in Africa (e.g. human-elephant conflict). The environmental modeling of human-modified landscapes is another key element of

a better understanding of human-nature interactions. Modeling the carbon and water fluxes of landscapes and integrating stakeholders' views into this modeling approach yields applicable knowledge to improve the climate resilience of our landscapes and to learn with and from neighbouring European countries. Species distribution modeling allows us to understand and predict how human activities impact other species' living environments and distributional shifts. Co-creating actionable environmental knowledge is key to harnessing all the available types of knowledge and to strengthen the societal support base for necessary, socially robust societal transition. Hence our modeling research explicitly fosters social learning for better environmental outcomes.

References and more

- MacAfee EA, Löhr AJ (2023) Multi-scalar interactions between mismanaged plastic waste and urban flooding in an era of climate change and rapid urbanization. WIREs Water.2023;e1708 https://doi.org/10.1002/wat2.1708

9.3.2.2 Theme link with Human Health and Environment

As human forces increasingly impact the environment, negative health effects of a degraded environment impact human health and wellbeing. We study these health impacts at various scales, and propose solutions to address these challenges, from the potential effect of micro-plastics on human health to the negative impact of climate change on human livelihoods (such as slum inhabitants in Indonesia). However, humans and nature also interact in positive ways, as exposure to nature and green spaces positively impacts human health and wellbeing. Our research on this issue feeds into recommendations regarding land use and urban planning. Similarly, understanding the positive contributions of nature to people are an intrinsic part of ecosystem services assessment and form the basis of the One Health approach which stresses the interconnection between human, animal and ecosystem health, and which we contribute to make more tangible through our research.

Research associated with this theme focuses on the interaction of environment and health in vulnerable communities, focusing on literacy, education, income, access to health care, etc. Examples relating to this research line include investigations into the positive effects of green environments on human well-being, particularly in vulnerable neighbourhoods (e.g. part of the Heerlen Noord project). The aim of this project is to reveal citizens' preferences, needs, and desires in relation to their living environment, with a focus on green spaces, so that the living environment can be designed to provide the highest health benefits. This project bridges the gap between environmental sciences, health, and psychology. Another example is the connection between, for example, the patient's origin (e.g. living environment, socioeconomic status, type of work, etc.) and, for example, the occurrence of chronic (musculoskeletal) pain. This project thus directly addresses the adverse effects of the combination of increased exposure to environmental stressors and increased vulnerability.

References and more

- Saenen, N. D., Nawrot, T. S., Hautekiet, P., Wang, C., Roels, H. A., Dadvand, P., Plusquin, M., & Bijnens, E. M. (2023). Residential green space improves cognitive performances in primary schoolchildren independent of traffic-related air pollution exposure. Environmental Health, 22(1), 33. https://doi.org/10.1186/s12940-023-00982-z

9.3.2.3 Theme link with Learning for Sustainability

Improving the process and outcomes of dynamic human-nature interactions requires a learning mindset from all involved actors. Gaining and applying new knowledge is key especially at the collective level, which is why social learning is a leading concept in our research strategy. From social learning among smallholder farmers who are key actors in sustainable food production and climate resilience strategies to learning by using ecosystem services assessment tools and serious games related to human-wildlife co-existence, resource use and/or land use and forest management, our research strategy aims to feed into, and apply the 'green competences' any actor in a social-ecological system should ideally have. Learning is intrinsically linked to new ways of relating to nature, which is reflected in the concept of plural valuation of nature on which we focus in our research strategy. Attaching a range of values to nature, ranging from instrumental to intrinsic to relational values, is a first step into recognizing, assessing and realizing the diversity of human perspectives on nature. Ultimately this plural valuation of nature, which can be facilitated by citizen science initiatives, contributes to more sustainable human-nature interactions which benefit humans and nature alike. In our research, we map people's perceptions and valuation of nature, which contributes to fostering more inclusive land use planning (e.g. in port areas in the Low Countries or in Protected Areas in Africa).

References and more

- Vogel, S. M., Songhurst, A. C., McCulloch, G., & Stronza, A. (2022). Understanding farmers' reasons behind mitigation decisions is key in supporting their coexistence with wildlife. People and Nature, 4(5), 1305-1318.

9.3.2.4 Theme link with Environmental governance

Understanding and (re-)organizing the governance of human-nature interactions is key in order to keep human activities within the limits of Earth's planetary boundaries. This requires dealing with novel challenges at various scales: this includes plastic pollution and its (inter)national governance, among others through Multilateral Environmental Agreements; the governance of human-wildlife conflicts in Europe and beyond; the study of the effectiveness of protected areas (PAs) and how to improve their governance; the con-

ceptualization and implementation of environmental justice; and the application and effectiveness of (environmental/sustainability/social/biodiversity) impact assessment processes. Recognizing environmental governance as a multi-actor endeavour is key, which requires insight into people's knowledge, perceptions, attitudes and behaviour, to which our team contributes through our extensive experience in environmental social science methods.

References and more

- Batkai, Hugé, Huitema, Semeijn, Lambrechts, Stoorvogel. 2023 Social learning as a catalyst for building resilience among smallholder farmers: Exploring its role in promoting transformations. NJAS: Impact in Agricultural & Life Sciences 95 (1)
- Beunen, R., & Lata, I. B. (2021). What makes long-term perspectives endure? Lessons from Dutch nature conservation. Futures, 126, 102679.
- Bogatinoska, Lansu, Hugé, Dekker. 2022 Participatory Design of Nature-Based Solutions: Usability of Tools for Water Professionals Sustainability 14 (9), 5562.
- Broussard, A., Dahdouh-Guebas, F. & Hugé, J. 2023 Diversity of perspectives in biodiversity conservation: a case study of port land use in Antwerp & Rotterdam. Journal of Environmental Management 341: 117937
- Hugé, J. et al. 2020 Ecosystem services assessment tools for African Biosphere Reserves: a review and user-informed classification. Ecosystem Services 42: 101079
- Vogel, S. et al. 2023 Identifying sustainable co-existence potential by integrating willingness to co-exist with habitat suitability assessments. Biological Conservation 279 (109935).

9.3.3 Climate change transitions

This theme focuses on better understanding socio-ecological transition processes towards climate resilience. Terrestrial socio-ecological systems, such as river catchments, face challenges due to among others climate change. What are the key mechanisms in these socio-ecological systems for climate resilience? How does scale matter in these processes, both geographically and in terms of socio-economic and institutional proximity of actors? How do green climate adaptation interventions as nature-based solutions (NbS) interact with climate mitigation interventions in the landscape? And vice versa keeping in mind the multifunctionality of the landscape with its various ecosystem services? How can climate transitions be accelerated in urban regions, at neighbourhood level? There is a growing awareness that nature-based solutions (NbS) offer cost-effective solutions. Therefore, it is essential to identify key principles that promote societal support, economic viability of NbS and their impact on socio-economic resilience.

9.3.3.1 Theme link with Integrated Environmental Modelling

To reach a Net Zero ambition in Europe it is a challenge to link large scale data that points to good environmental decisions with local and regional practitioners who make the decisions and implement the policies that determine land use and land use dynamics (in IPCC LULUCF). The information may be available, for example free access earth observation data – but at the local level it may not be of use, applicable or understandable. Smart decision-making combining spatiotemporal modelling with GeoAI, AutoML and other novel tools could become more actionable, especially when the modelling is scaffolded by smart designing of the learning of these practitioners. The aim of this theme is to bring the data to those that can connect it to land and water management policies and interventions. This way of Integrated Environmental Modelling in co-creation with practitioners allows for scientifically backed decision-making and consistent monitoring of the outcomes.

References and more

- Bogatinoska, Lansu, Hugé, Ali, Dekker, Stoorvogel. 2024 Analysing Landscape Multi-Functionality by Integrated Modelling. `http://dx.doi.org/10.2139/ssrn.4705609`
- Bogatinoska, Lansu, Huge, Dekker, Stoorvogel. 2023 Water, Carbon, and Climate: An Integrated Modelling Approach to Nature-Based Solutions Wageningen Soil Conference, 112-113

9.3.3.2 Theme link with Human Health and Environment

While the health effects of climate change are increasingly being recognised and the Right to Health is embedded within the Paris Agreement, climate health impacts have received little attention to date. How practitioners at the local level can increase the pace of urban greening to make an urban environment more resilient to ecological climate risks such as the urban heat island effect, drought and flooding is one question that this theme addresses. The aim of this theme is to find out where there are opportunities to make greening policy more effective and socially just in order to ensure the desired acceleration. Increased awareness around the impacts of climate change and climate adaptive actions has an impact on participation and the success of greening. To this end, the relationship of greening actions with ecosystem services, social equality and participation is examined.

References and more

- Saenen, N. D., Nawrot, T. S., Hautekiet, P., Wang, C., Roels, H. A., Dadvand, P., Plusquin, M., & Bijnens, E. M., 2023 Residential green space improves cognitive performances in primary schoolchildren independent of traffic-related air pollution exposure. Environmental Health, 22(1), 33. https://doi.org/10.1186/s12940-023-00982-z
- MacAfee EA, Löhr AJ. 2023 Multi-scalar interactions between mismanaged plastic waste and urban flooding in an era of climate change and rapid urbanization. WIREs Water. 2023; e1708 https://doi.org/10.1002/wat2.1708

9.3.3.3 Theme link with Learning for Sustainability

The climate transition requires versatile sustainability practitioners with diverse types of knowledge and skills and attitudes (i.e. competences). They are confronted with major challenges in their daily work situations that come with the complexity of the climate transition. Weighing and bringing together various "justice claims" (interests and ideals) of different stakeholders and also involving colleagues within the organization are challenging processes. To manage this, there is a need for transformative formal and informal leaders with a broad and new set of leadership competences. In the transdisciplinary action research, the set of competences towards fair climate transitions is explored together with stakeholders and current and future sustainability professionals and informal leaders in urban regions. One of the aims of this research theme is to develop, test and improve the set of competences needed for just climate transitions, to be used by sustainability practitioners and informal climate leaders and for impacting academic programmes on networked learning hubs.

References and more

- 2022 Participatory Design of Nature-Based Solutions: Usability of Tools for Water Professionals. Bogatinoska, Lansu, Hugé, Dekker. Sustainability 14 (9), 5562.
- 2022 Competencies of Sustainability Professionals: An Empirical Study on Key Competencies for Sustainability. Venn, R., Perez Salgado, F., & Vandenbussche, V. Sustainability, 14(9), 1-22. https://doi.org/10.3390/su14094916
- 2018 Dimensions of professional competences for interventions towards sustainability. Perez Salgado, F., Abbott, D. & Wilson, G. Sustainability Science, 13(1), 163-177. https://doi.org/10.1007/s11625-017-0439-z
- 2017 International E-learning Programmes for Sustainable Development in Higher Education in Europe and Africa. Perez Salgado, F., & Rikers, J. H. A. N. In G. Michelsen, & P. J. Wells (Eds.), A Decade of Progress on Education for Sustainable Development: Reflections from the UNESCO Chairs Programme (pp. 48-58). Paris: UNESCO.
- 2013 Changing professional demands in sustainable regional development: a curriculum design process to meet transboundary competence. Lansu, Boon, Sloep, van Dam-Mieras. Journal of cleaner production 49, 123-133.

9.3.3.4 Theme link with Environmental governance

Preparing for and coping with the accelerating impacts of climate change requires adaptation in a wide range of policy areas. Yet, despite increasing calls for action, policy change to allow this is often slow. A range of counteracting forces and barriers can make it difficult to embed adaptation objectives into important policies and move them away from 'business-as-usual'. However, deeper dynamics are also at play, where self-reinforcing mechanisms, feedbacks and path dependencies interact across different spatio-temporal scales and coalesce to establish policy lock-ins. One of the aims of this research theme is to uncover these lock-in dynamics and examine the extent to which they account for varying levels of climate change adaptation in among others the Netherlands. More specifically the barriers and enablers for sustainability transitions are explored to identify effective and just strategies for changing governance systems.

References and more

- Batkai, Hugé, Huitema, Semeijn, Lambrechts, Stoorvogel 2023 Social learning as a catalyst for building resilience among smallholder farmers: Exploring its role in promoting transformations. NJAS: Impact in Agricultural & Life Sciences 95 (1).
- Groen, Alexander, King, Jager, Huitema 2023 Re-examining policy stability in climate adaptation through a lock-in perspective Journal of European Public Policy 30 (3), 488-512.
- Oberthür, Groen 2018 Explaining goal achievement in international negotiations: the EU and the Paris Agreement on climate change Journal of European Public Policy 25 (5), 708-727.

9.4 Impact

The impact of the department is made through collaboration in research projects, a diversity of research outputs, as well as via a range of dedicated dissemination activities, including the development of (online) teaching materials and training for professionals. For this section we distinguish between scientific, educational and societal impact, although many activities and output focus on all three in a more or less integrated manner.

9.4.1 Scientific impact

The department of Environmental Sciences aims to make a significant contribution to the advancement of theoretical and methodological perspectives in various domains of environmental sciences. For that purpose, we publish books and high-impact articles in scientific journals and regularly participate in academic conferences. We also seek collaboration with academic research partners in a wide range of disciplines.

9.4.2 Educational impact

Educational impact is first and foremost realized via the BSc and MSc programs on Environmental Sciences, in which teaching materials increasingly include theories, methodologies, illustrations and examples from our own research projects. Furthermore, we offer students in different ways the opportunity to participate in our research projects. The department furthermore develops and teaches online courses for other audiences. Examples include MOOCs on marine litter, climate adaptation and a Masterclass on Unnecessary, Avoidable and Problematic (UAP). We particularly support lifelong learning with the development and teaching of dedicated training for professionals in the domains of environment, sustainability and governance. Some key examples of educational impact include:

- Together with UN Environment Programme we have created a Massive Open Online Course (MOOC) on Marine Litter as a key activity of the Global Partnership on Marine Litter. It is also part of the Clean Seas Campaign. The course is free for all students and available in 10 different languages.
- Together with partners from the international network of excellence dedicated to understanding policy and governance innovation for climate change (INOGOV) we have developed the MOOC Polycentric Climate Change Governance[1]
- Together with partners from the Dutch network Kennis voor Klimaat we have developed a MOOC and related online teaching materials about climate adaptation.
- OUNL has a strong infrastructure in learning design to support the networked learning of the project partners and water/land practitioners in transformative spatial processes, with a series of online webinars and Open Access Learning Hubs, like Co-adapt[2] and MOOC Polycentric Climate Change Governance[3].
- OUNL has created an online active training in the use of Climate Impact tools, to develop Carbon LULUCF strategies at local level, The training is incorporated into academic degree programmes and in practitioners' learning hub[4]

9.4.3 Social impact

The department is highly committed to making societal impact. We deploy a range of strategies to achieve impact, including partnerships with societal partners, online education and training (see also education impact), professional and publications, presentations at conferences, webinars, and regular media coverage. Many of the research projects specifically focus on solving socio-environmental problems such as climate change, biodiversity loss, or pollutions and apply a transdisciplinary approaches whereby mutual learning and co-creation of solutions, tools, and transition pathways are key aspects. Training and education of professionals and wider audiences are also means to achieve and strengthen societal impact (see educational impact). A more particular strategy for societal impact follows from the involvement of students and the professional organizations many of them are working for in research and education. Therewith students help in making productive interactions with societal parties and to share research findings. Some key examples of societal impact include:

- Virtual Consultant Company (VMAB): In their BSc thesis project students engage actively with clients and stakeholders and therewith link our research with societal issues. This is a two-directional route, whereby the questions of client act as a means to voice societal needs and questions that we can address in our research agenda, while the projects also contribute to the dissemination of relevant research

[1] https://youlearn.ou.nl/web/espub-climate-change/course-preview/-/pagestructurenavigator/60454259

[2] https://youlearn.ou.nl/web/co-adapt/dashboard

[3] https://youlearn.ou.nl/web/espub-climate-change/course-preview/-/pagestructurenavigator/60454259

[4] https://youlearn.ou.nl/web/co-adapt/climate-adaptation

findings.

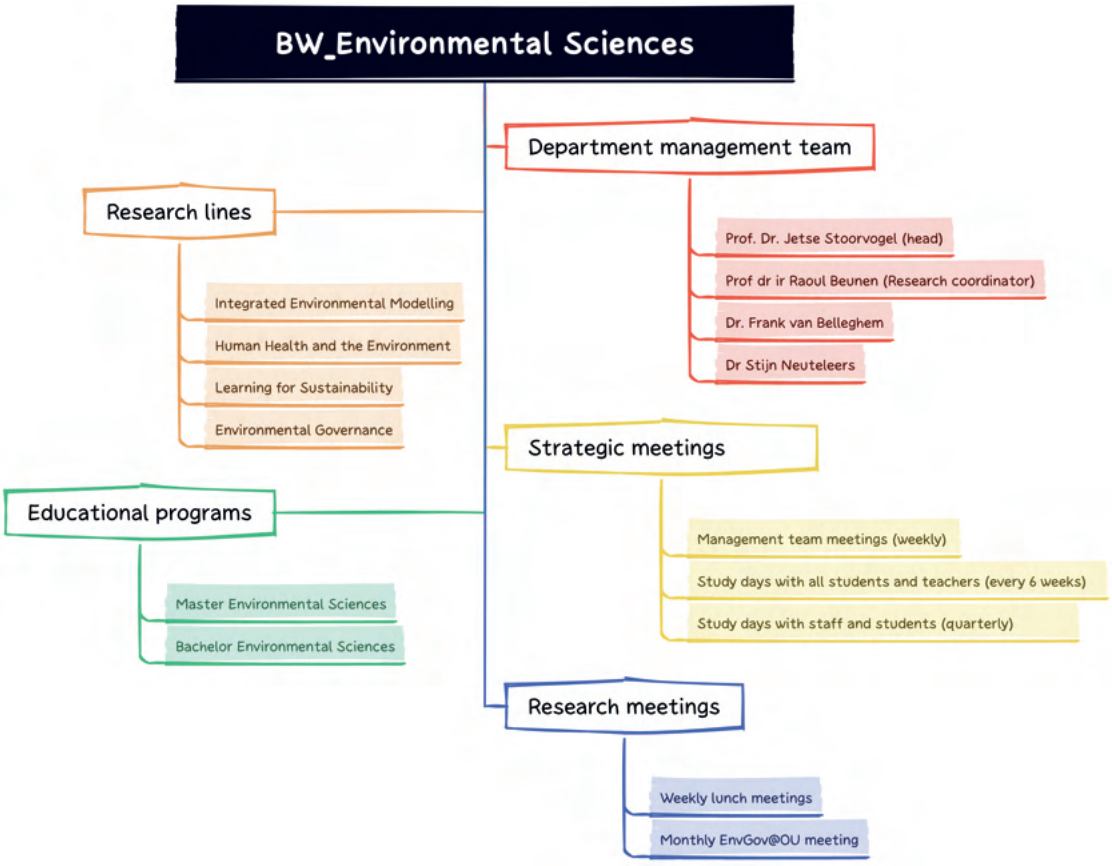
- Availability of spatial plans and GIS data(.shp) files of the territory - OUNL Hydrological, Soil, Land Use data coverage on coupled hydrological and carbon modelling in Brabant catchment Aa of Weerijs, cross border Netherlands and Belgium[5].
- Worldwide Capacity Development on Plastic pollution and Marine litter together with United Nations Environment Programme (UNEP) and the Global Partnership on Plastic pollution and Marine Litter (GPML) since 2014.
- Knowledge to Knowledge partner in Partners for International Business "Waste and Circular Economy Business Indonesia – Netherlands (since 2019) Waste and Circular Economy Business Indonesia - Netherlands — RVO.nl — Rijksdienst
- In the Resilient Indonesian Slums Envisioned (RISE) project (NWO - RISTEK-BRIN), led by Radboud University and Universitas Indonesia, our department leads the Knowledge Sharing and Capacity Building work package together with Yayasan Humanis dan Inovasi Sosial (HIVOS) Research: Resilient Indonesian Slums Envisioned (RISE) — Radboud University (ru.nl)
- ACT: Accelerating Just Climate Transitions in Urban Regions (2024-27), NWO-KNAW Dutch Climate Research Initiative (KIN). This work program aims to support the acceleration of just climate transitions in neighbourhoods in the Netherlands. We do so by developing local action pathways and agendas through collaboration between previously disconnected stakeholders: including residents, housing corporations, civil servants and sustainability professionals.
- Together with the Province of Zuid-Holland and the Ministry of Infrastructure and Water Management several workshops and multi-media[6,7] are developed to communicate and discuss the lessons learned on participation and trust in government to a wider audience of municipalities, provinces and waterboards.

[5] http://ssrn.com/abstract=4705609

[6] https://kennis.zuid-holland.nl/podcast/komt-te-voet-en-gaat-te-paard/

[7] https://www.ou.nl/en/-/webinar-terugkijken-over-relatie-participatie-en-vertrouwen-in-openbaar-bestuur

9.5 Organisation of the department and meetings



9.6 Scientific and societal partners and collaborations

The department collaborates with a wide range of societal and scientific partners. These partnerships are reflected in the research projects and participation in various regional, national and international networks of collaboration.

9.6.1 Research projects

- **ACT: Accelerating Just Climate Transitions in Urban Regions (NWO, 2024-2027)** – Klimaattransitie in stedelijk gebied door de lens van klimaatrechtvaardigheid, NWO-KNAW Dutch Climate Research Initiative (KIN). This work program aims to support the acceleration of just climate transitions in neighbourhoods in the Netherlands. We do so by developing local action pathways and agendas through collaboration between previously disconnected stakeholders: including

residents, housing corporations, civil servants and sustainability professionals.

- **EIFFEL4Climate[8] (Horizon Europe, 2021-present)** – Earth Observation applications for climate change adaptation & mitigation – Pilot 1 Water and Land Use Management, Brabant NL. Development of a framework, models and DSS for embedding co-design into spatial water and land management strategies to enhance climate resilience, focusing on water shortage, droughts and soil carbon sequestration. Regional stakeholders use climate impact atlases for testing adaptation measures.
- **Blue Green Governance[9] (BGG) (Horizon Europa, 2024-2028)** – BGG pursues an innovative approach to the governance of the seas and coastal areas that links marine policies with the management of the land and water. More precisely, BlueGreen Governance will develop evidence-based pathways for the design and implementation of innovative governance schemes around the land-sea connection that incorporates both the scientific predictions of future developments (about the biodiversity-water-climate nexus) and societal views on the most viable policy responses.
- **2seas Co-Adapt (Interreg 2019-2024)** – Co-Adapt: Climate Adaptation through Co-creation – We developed in co-creation a Guide and framework with tools for co-creation, adaptive pathways to Nature-based solutions, incl. e-Learning resources to support uptake of the Co-Adapt approach by professionals and organisations responsible for water and spatial management. Incl Crossborder strategy incorporating 2Seas vision, and regional transition roadmaps to replicate the Co-Adapt approach.
- **2023 PhD project on AutoML[10] in LUC (submitted)** – AutoML in land use change and effect on carbon sequestration. Nature-based solutions in brook catchments – Modeling land-use and its impact on terrestrial carbon pools. (with AutoML land use change tools): PhD-candidate Timmer, L., Supervisors: van Wijnen (OUNL), Lansu (OUNL), Fledderus (Windesheim), Stoorvogel (OUNL) elaboration on MSc thesis.
- **Resilient Indonesian Slums Envisioned[11] (NWO - RISTEK-BRIN) 2021-2025** – The project aims to develop an inclusive governance roadmap to transform Indonesian cities towards social-ecological resilience in the face of water-related disasters. The focus is on studying social-ecological interactions in slum areas in three different locations in Indonesia: Pontianak, Manado and Bima. Together, these represent most of the key social and water challenges that Indonesian cities face.
- **UNEP – Capacity development Marine Litter and plastic pollution**

[8] http://Eiffel4climate.eu

[9] https://www.cmcc.it/projects/bluegreen-governance

[10] https://research.ou.nl/en/studentTheses/nature-based-solutions-in-brook-catchments-modeling-land-use-and-

[11] https://www.ru.nl/en/research/research-projects/resilient-indonesian-slums-envisioned-rise

(since 2014) – Since 2014 the Department works in close cooperation with the United Nations Environment Programme (UNEP) and the Global Partnership on Plastic pollution and Marine Litter (GPML) on capacity development activities such as the Massive Open Online Course on Plastic pollution and Marine litter and the Community of Practice on Capacity Development.

- The Open University participates in the **European Horizon2020 project Labplas**, focusing on the sources, transport, distribution and impacts of plastic pollution in all environmental compartments. The Labplas project involves fieldwork in two contrasting case studies, collecting data that can serve as input for environmental modelling, identifying or predicting sources, transport among compartments and potential transfer of chemicals to biota. With this knowledge the project provides tools for environmental management and planning of effective mitigation measures. An action-oriented course will be developed to disseminate the results of the project to stakeholders.
- **ADAPT LOCK-IN[12] (DFG/ESRC/NOW)** –Understanding the impact of policy lock-ins on climate change adaptation. The aim of this interdisciplinary project is to uncover these lock-in dynamics and examine the extent to which they account for varying levels of climate change adaptation in Germany, the Netherlands and the U.K. (England).
- **E-SLP[13] European Short Learning Programmes (SLPs) for continuous professional development and lifelong learning. SLP 'Climate Change: from global to local Action' (Erasmus+ 2018-2020)** – In a cooperation between three distance learning universities, Universidade Aberta – UAb (Portugal), Open Universiteit in the Nederlands - OUNL and Universidad Nacional de Educación a Distancia – UNED (Spain), the project will develop an international Short Learning Program (SLP) 'Climate Change: from global to local Action', for professionals, managers and technicians from all type of organisations, from private and public sector. Output: learning materials, online courses, student guide, and video.
- The OU is a partner of the **MOMENTUM**[14] consortium that studies the effects of micro- and nanoplastics on human health on all levels. The MOMENTUM project aims to advance understanding of the internal exposure and kinetics of Micro- and Nanoplastics (MNPs) within the human body, focusing on lung, intestine, brain, and placental barriers. Additionally, it seeks to uncover the immunological hazards associated with exposure to plastic particles and MNP-linked pathogens. Building upon existing breakthrough projects, MOMENTUM will enhance knowledge on MNP formation and characterization, and develop a roadmap for comprehensive risk assessment.

[12] https://adaptlockin.eu/

[13] https://e-slp.eadtu.eu/

[14] https://momentummicroplastics.nl/

9.6.2 Partnerships

EcoBiose[15] is a regional partnership in the region of South Limburg focusing on biodiversity and a sustainable living environment. It connects governments, businesses and research and teaching institutions.

[15] https://www.linkedin.com/company/ecobiose1/


Faculty of Science