Design
Engineering
Sciences

Technology and Society in Equilibrium

Sector Portrait

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Engineering
Sciences

Technology and Society in Equilibrium

Sector Portrait

This sector portrait of the Design Engineering Sciences describes the common denominator of the various design disciplines in the Netherlands. In the process of writing this sector portrait, we jointly determined where our strength lies and where we can make a concrete contribution to solving social problems.

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Technologie en Maatschappij in Balans
Sectorbeeld Ontwerpende Ingenieurs Wetenschappen

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Contents

The embedding of technology in society encompasses a design challenge

"It can be valuable to listen to each other and consider alternative perspectives".

Iris Hendriksen [Source: https://2020.design-united.nl/day-2-eco-logica/perspective]

Ambition

The implementation of technological innovations aligned to societal issues encompasses a design challenge. This increasingly demands science-based design methodologies. The broad Dutch design landscape can fulfil the role of connector well in this regard.

In order to optimally strengthen this bridging function, three areas for further investment have been identified:

Research

More research and research funding are needed to meet the design challenges posed by Dutch societal missions, as well as for the further development of Key Enabling Methodologies (KEMs) as the basis for effective design.

Educational Capacity

Expanded teaching capacity and further development of design-driven didactics are needed to meet the growing demand for designers, This demand stems from the emerging need for design approaches in new research programmes within Horizon Europe and the Dutch Research Council (NWO).

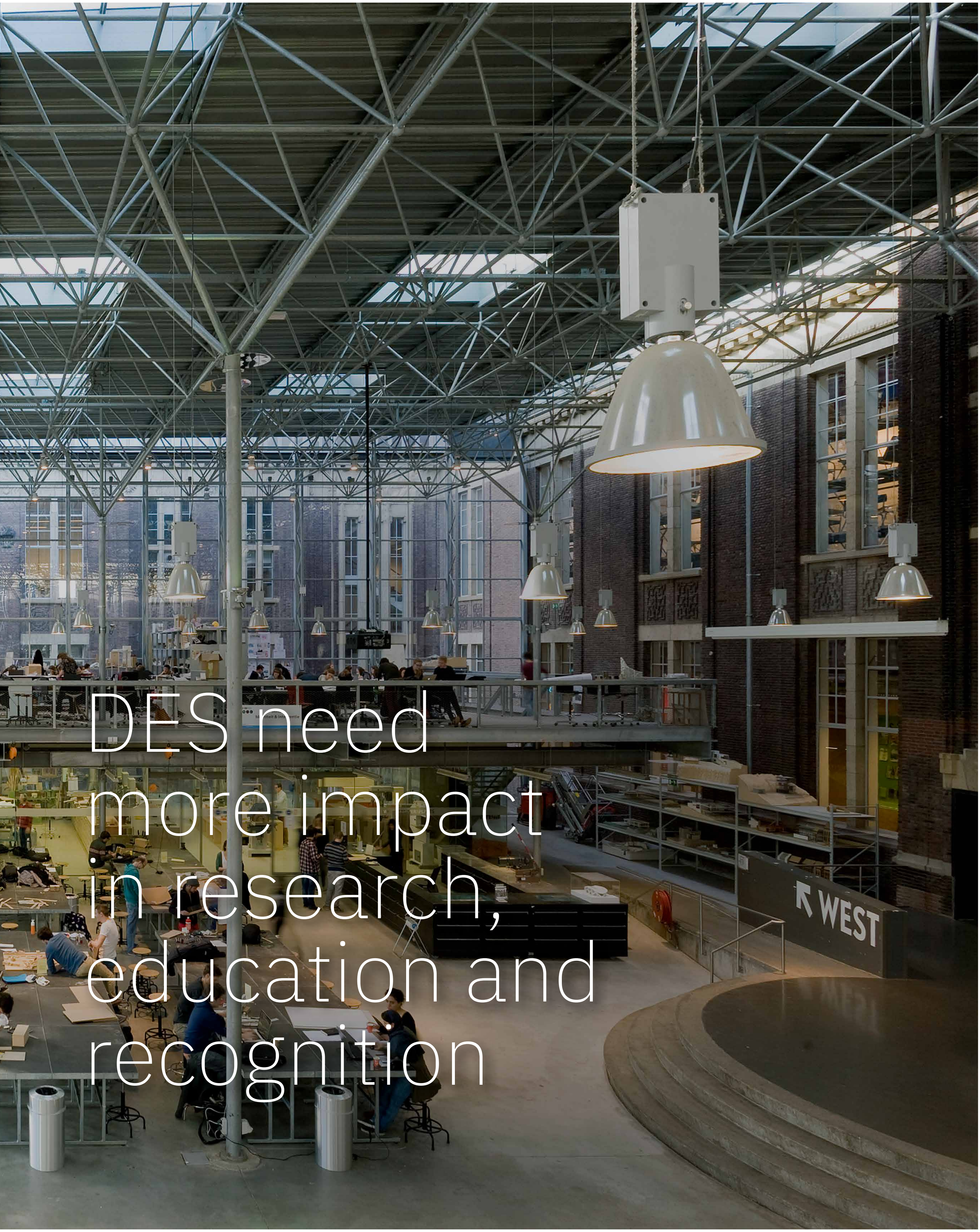
Access to Technology

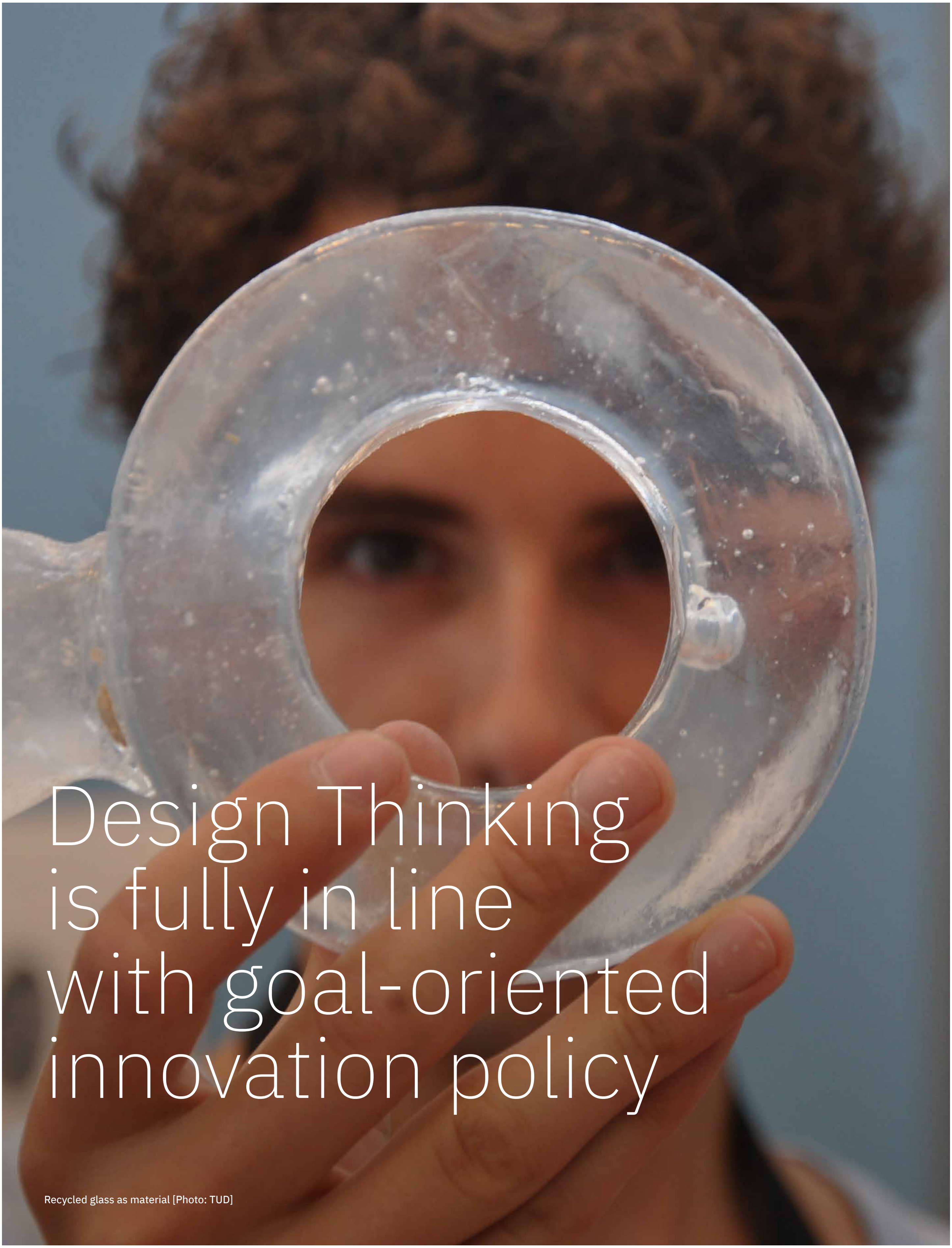
Continuous access to the rapidly evolving technological disciplines must be guaranteed for professionals who can both understand the technology and meet the investigative design challenge.

This sector portrait of the design engineering sciences describes the common denominator of the various design disciplines in the Netherlands. In a future sector plan, the above investment areas will be further explored and purposefully developed.

Physical modeling plays an important role in the design process. [Photo: TUD, Architecture and the Built Environment]

DES need more impact in research, education and recognition





Design Thinking is fully in line with goal-oriented innovation policy

Recycled glass as material [Photo: TUD]

1

Importance of design engineering sciences

Technology is becoming increasingly embedded in our daily lives: at home, at work, on the road, and even within our bodies. Technology is becoming smarter and is increasingly able to make independent decisions. In addition, the globally adopted 17 Sustainable Development Goals[1] require us to develop technical innovations that are linked to social innovations. These developments present us with complex design challenges and pose natural challenges for the designing engineer, who has a clear motive (purpose) with a focused and professional approach (competences), and is focused on concrete results (impact).

1 United Nations: Sustainable Development Goals. [https://sdgs.un.org/goals]

Mission driven with an integrated approach

An integrated way of doing science – from fundamental to practical application-oriented approaches – resonates ever more strongly. Science and science policy increasingly support this approach. This is evident from the government's mission-driven innovation policy[2]; the strategic planning process of Horizon Europe (EU); and also, various OECD publications[3] zoom in on tackling societal themes in a broad integrated way, focusing on actionable results.

Designing is matching technological capabilities and human needs

2 https://www.rijksoverheid.nl/documenten/kamerstukken/2019/04/26/kamerbrief-over-missiegedreven-topsectoren-en-innovatiebeleid

3 https://www.oecd.org/education/2030/E2030%20Position%20Paper%20(05.04.2018).pdf
https://www.oecd-ilibrary.org/science-and-technology/addressing-societal-challenges-using- transdisciplinary-research_0ca0ca45-en

Design Challenge

The complexity of social issues is driven by a combination of technical challenges, norms and values, laws and regulations and the way social groups are organised in society. These aspects play out on various levels, from personal to societal, from local to global. All these aspects together make the implementation of innovative technologies complex and need to be thought through thoroughly and integrally. Design engineers are indispensable for this.

Therefore, our society has an increasing need for professionals who see the opportunities technology offers and can seize them; who have an eye for the needs, desires and concerns of users; and who use the opportunities for creative and interdisciplinary cooperation to make innovations better suited to people and society. The design engineering sciences are uniquely qualified to meet these needs.

The design engineering sciences include the disciplines[4] of Industrial Design, Architecture, and Technology, Policy & Management. These branches of science are the engine for solving systemic problems that require a transdisciplinary and integrated approach. Society needs integrally developed, sustainable solutions to the challenges we face in the areas of: digitalisation;

- health care;
- energy transition;
- population structure;
- sustainable mobility;
- climate adaptation;
- and the food chain.[5]

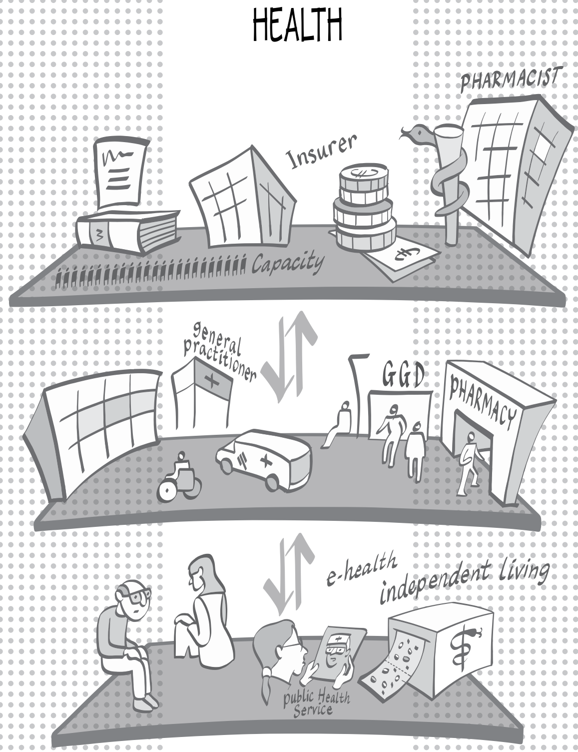
The design engineering sciences form an important link between knowledge from the fundamental sciences, knowledge from the technical engineering sciences and their implementation. Vice versa, they fulfil a unique role as translators of social bottlenecks into concrete (technological) directions for solutions.

This first sector portrait of design engineering sciences aims to make clear that improving our society by means of technology is in the first place a design challenge and that additional investments are indispensable to meet the challenges of our time by means of technology.

4 Design as included in this sector image is not yet a formally recognised discipline. One of the goals of this Sector image is to recognise design engineering as a stand-alone discipline.

5 *Dutch* Design has already made a name for itself in these areas. Driven by the Dutch culture that is focused on collaboration, giving *and* sharing opinions without barriers, teamwork provides added value for the realisation of more applicable solutions. The annual Dutch Design Week [https://ddw.nl/], with a more explicit role and position for Design Research (4TU), is evidence of this.

How to achieve the world's best organisation of care?

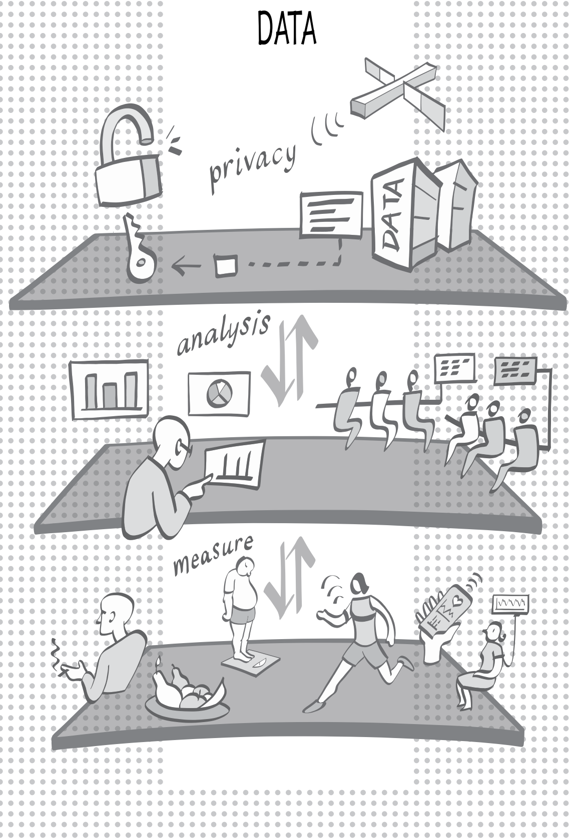


POLICY / LEGISLATION

ORGANISATION OF CARE

HOME HEALTHCARE

How to turn personal data into knowledge for health and treatment in a safe way?



POPULATION DATA

GROUP DATA

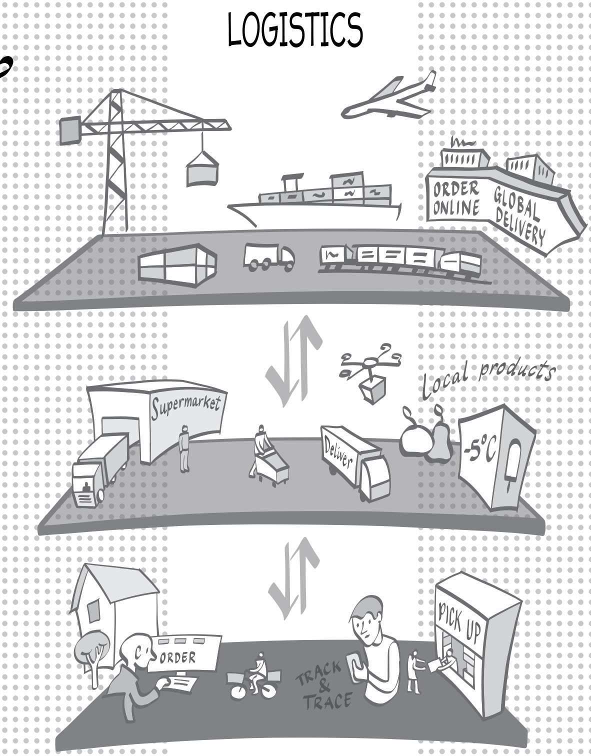
PERSONAL DATA

How to organise logistics eco efficiently and effectively?

DISTRIBUTION

STORE / RESTAURANT

ORDER ONLINE

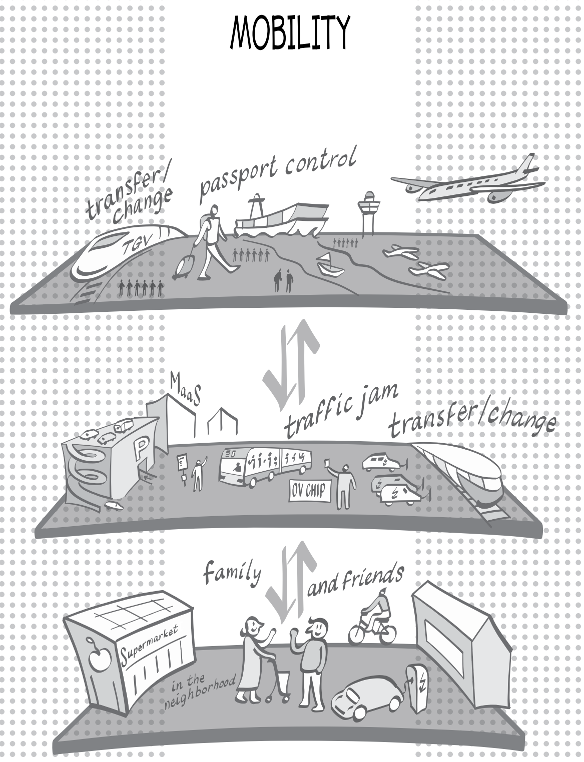


What does high quality personal mobility mean?

INTERNATIONAL

REGIONAL

LOCAL



DES visualise a scientifically based world of tomorrow

Minor Interactive environments [Source: https://interactive-environments.nl/polysense/]

2

Characteristics of design engineering sciences

Every discipline has a foundation: a shared way of working and thinking. For design as a research discipline and as a professional practice, this foundation involves the reasoned and substantiated design of the world of tomorrow. To achieve that, knowledge is needed, for example of psychology or materials, and technology is applied. In this way, designers contribute to small and large social issues.

Methodology

For this approach, designers have competencies[6] and – in addition to classical disciplinary knowledge – Key Enabling Methodologies or KEMs[7/8]:

- **Analysis & diagnosis –** the set of tools and methods to, for example, identify bottlenecks;
- **Vision & imagination –** to guide the change process;
- **Participation & co-creation –** involving stakeholders;
- **Monitoring & impact measurement –** to measure intended effects.

The KEMs connect four levels of application:

- The personal level;
- The level of interaction with the context;
- The organisational system level;
- The broad social and institutional level.

The approach moves iteratively between these levels from concrete to abstract and back again. In this way, concrete products or services can be critically examined from the perspective of social norms and values, but abstract concepts can also be translated into practical usability.

In essence, where the beta and engineering sciences push the boundaries of our knowledge of nature and the technical sciences translate scientific knowledge into skill, design-based engineering sciences bring the technical possibilities and challenges closer to social applications and acceptance by designing new technologies together with all stakeholders in realistic settings and/or future-oriented scenarios.

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6 Please visit the Knowledge and Innovation Agenda (KIA) of CLICKNL, chapter 2. [https://kia.clicknl.nl/deel-1-de-creatieve-industrie-kennis-en-kunde/2.-mens-maatschappij-en-betekenisgeving/2.1-meerwaarde-door-ontwerpen-kenmerkende-aanpak]

7 Key Enabling Methodologies (KEMs) for Mission-Driven Innovation, Research Agenda - Part of the KIA Key Technologies 2020-2023, June 2020. [https://kia.clicknl.nl/deel-1-de-creatieve-industrie-kennis-en-kunde/3.-character-and-knowledge-base-of-creative-industry/3.2-key-enabling-methodologies]

8 An overview of the KEMs is included in Appendix 2.

A stronger toolkit of methods, competencies and knowledge is needed

Tovertafel / PhD research Hester Anderiesen Le Riche [Source: https://www.tover.care/research/]

2.1

Joint approach

The design disciplines adopt a joint approach with the following common features:

— **Transdisciplinary –** Design is a transdisciplinary activity[9] where knowledge from STEM, economic, medical and social sciences come together in teams, processes and methods. Designers deploy the knowledge infrastructure from the outset for innovation and transformation, and in turn feed this knowledge chain with the new questions that arise in this process.

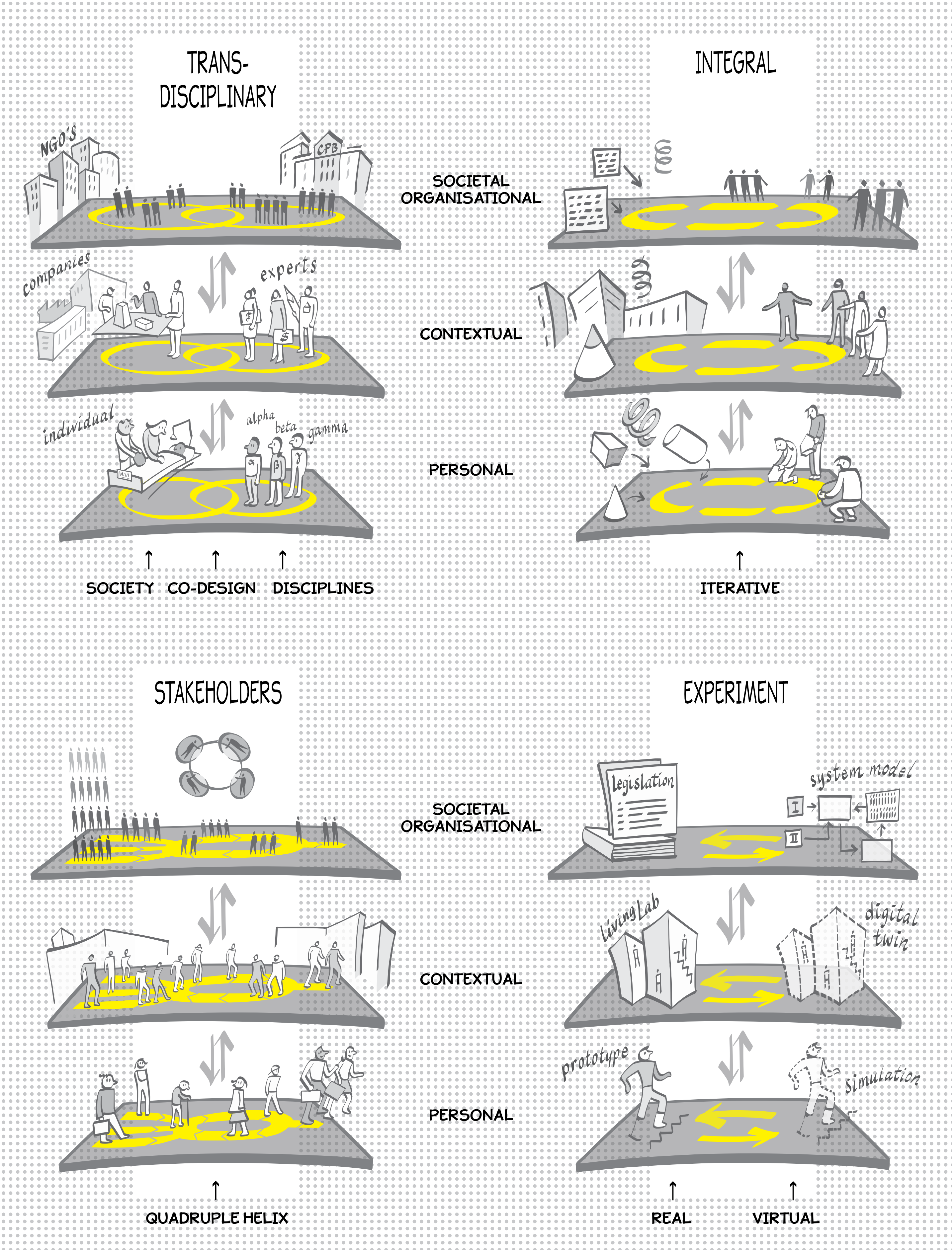
— **Integral and iterative –** Design processes work towards an integral design via a process of iterative creation, intervention and evaluation, also referred to as iterative design, which starts from a thorough diagnosis and analysis. This involves looking at the situation and the challenge from different relevant perspectives. In complex problems, this always involves issues that need to be solved at different levels of the system. In this process, designers work at different levels: the personal level; the level of interaction with the context; the organisational system level; and the broad social and institutional level.

— **Stakeholder Involvement –** Designing requires judgment because, by definition, it touches on public and private values. Designers are familiar with (designing arrangements for) involving all relevant stake holders such as users, suppliers, residents, and policy makers in the process. Driven by social questions, they have continuous collaborative relationships with organisations that design and implement change such as business, government, and civil society organisations.

— **Experimenting in a real context –** Designers search for possible solutions (and reflections on them) in experimental environments that are modelled on realistic situations.[10] In addition to the written word, images, mathematical simulations, prototypes and interventions, they make use of all kinds of communication. By shaping products, services, systems and scenarios, designers make the possibilities and effects conceivable, understandable, experienceable, verifiable and debatable.

9 Transdisciplinarity is understood as a higher stage of interdisciplinarity with a shared foundation and terminology for all sciences; differently put, co-design with other disciplines and stakeholders.

10 For example, living labs, field labs, virtual reality simulations, but also sketches, models, mock-ups, 3D renderings, videos, virtual reality applications, and computer models.


TRANS-
DISCIPLINARY
INTEGRAL
NGO'S
CPB
SOCIETAL
ORGANISATIONAL
companies
experts
CONTEXTUAL
individual
alpha
beta
gamma
PERSONAL
SOCIETY
CO-DESIGN
DISCIPLINES
ITERATIVE
STAKEHOLDERS
EXPERIMENT
legislation
system model
SOCIETAL
ORGANISATIONAL
LivingLab
digital
twin
CONTEXTUAL
prototype
simulation
PERSONAL
QUADRUPLE HELIX
REAL
VIRTUAL

In short, design engineers share the following general scientific and specific design competencies:

- Analysis and diagnosis (modelling and mapping, mathematical knowledge of laws in dynamic processes, data science competencies);
- (Re-)framing the design challenge in (future) context;
- Iteratively creating and evaluating, converging to the desired impact;
- Integrating an increasing number of relevant perspectives into a working whole;
- Actively engaging stakeholders and substantively driving the stakeholder process;
- Ideate, communicate, and make interventions to imagine new futures;
- Work at multiple system levels simultaneously.

These competencies have broader impact and meaning than just for design and research. Designers are often directional and leaders in the development of innovative educational methods, which are also increasingly accepted and applied within educational programmes of other disciplines. Consider, for example, design thinking methods and problem-based education. Students appreciate these forms of education that are at their core challenging, goal-oriented, and enable them to realise social impact.

Designed interventions can act as hypotheses and as objects of research

2.2

Design Research

Design research has two basic approaches: a theory-driven approach where interventions are used to test hypotheses and, as a counterpart, a phenomenon-driven approach where interventions are made to discover new possibilities.

FIG. 2.1
Schematic view of design research
Design research occurs in several variants. Horvath distinguished three versions situated between fundamental research from established disciplines, and applied research in industrial practice. Later, a further distinction was made between the central version in which doing design is part of the research method.
[Source: Based on Fig 7.1 in Stappers & Giaccardi (2017) Research through Design. The Encyclopedia of Human-Computer Interaction. https://www.interaction-design.org/literature/book/the-encyclopedia-of-human-computer-interaction-2nd-ed/research-through-design]

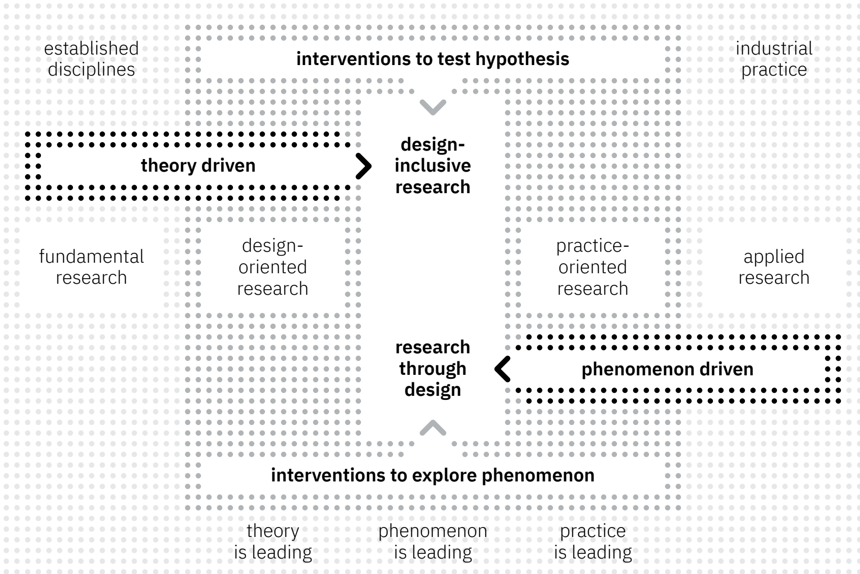


FIG. 2.1

Designing the world of tomorrow takes place at different levels that align with the domains of the following three disciplines involved:

- **Industrial Design –** The scientific discipline that studies design – both the product (artefact) and the activity – in all its manifestations with the aim of strengthening the knowledge base and improving design practice;

- **Architecture –** Design of buildings and our spatial environment, both at the scale of the building, the neighbourhood, the city, and at the regional and (inter)national level;

- **Technology, Policy & Management –** Design of business and administrative processes, of organisations, and of complex systems and regulations.

Within these three disciplines, the application of technology and its connection to societal goals and values plays a major role. With their design approach, the three design disciplines support the whole range of Key Enabling Methodologies and thus form an essential link to address the major societal challenges and strengthen the role of science, technology and innovation in societal transitions. Table 2.1 provides an overview of these KEMs.[11]

TABLE 2.1

	KEMs / Key Enabling Methodologies	
1	**Vision & imagination**	Realise inspiring visions of the future to make the goal tangible, thereby giving direction to change in which technology is embedded in society in a socially responsible and sustainable manner.
2	**Participation & co-creation**	Engage diverse stakeholders in a systematic process to arrive at new propositions through context analysis.
3	**Behavioural change & empowerment**	Generate methods that help develop interventions to change people's behaviour directly or indirectly.
4	**Experimental environment**	Experiment with uncertainties and ambiguous information to test and adjust effects of interventions in their natural context.
5	**Value creation & scaling up**	Test and validate in a process-oriented manner in an early phase aimed at effective interventions and rapid scaling up of innovations.
6	**Institutional change**	Gain insight into the behaviour of institutions and develop rules and procedures for the desired changes.
7	**System change**	Develop ways to work in a systemic and forward-looking way, and to provoke debate and feedback on changes.
8	**Monitoring & effect management**	Measure and monitor interventions and their effects to support iterative development and adjustments to the system.

Research and education form the breeding ground for the three disciplines. Research strengthens the designer's knowledge base through disciplinary knowledge and methods.[12]

That knowledge base is different for the three disciplines but has overlap. Chapter 4 gives an overview of the different types of research and knowledge belonging to the disciplines. Appendix 2 provides a more comprehensive overview of the KEMs and associated scientific questions.

However, the designer's knowledge base is not only formed by the design sciences. Other fields of science such as psychology, communication sciences, spatial sciences, social sciences, humanities, material sciences, and computer science also contribute essential knowledge that designers apply. Conversely, designers play specific research questions back to these areas of science through the stakeholders involved or the results of experiments.

11 Key methodologies (KEMs) for mission-driven innovation. [https://assets.ctfassets.net/h0msiyds6poj/6Oi6G5Mqob-cgNkA1qdWYmQ/e6dfa8991df936ef2f755fd08a6614e2/ Sleutelmethodologie__n__KEM_s__voor_missiegedreven_innovatie_v20200612_FINAL.pdf]

12 Character and knowledge base of the creative industry, agenda KIA KLICKNL, Chapter 3. [https://kia.clicknl.nl/deel-1-de-creatieve-industrie-kennis-en-kunde/3.-karakter-en-kennisbasis-van-de-creatieve-industrie]

2.3

Societal challenges

The disciplines contribute to knowledge for, and the training of, future generations of (academic) professionals with a mindset that is essential to be able to contribute decisively to the challenges of our complex socio-technical society. To address these major societal challenges the Dutch government has formulated a mission-driven innovation policy[13] that focuses on four societal missions.

FIG. 2.2
Relationship between Key Enabling Technologies (KETs) and Key Methodologies (KEMs) for mission-driven innovation
Representation of the current overview of Key Enabling Technologies. Emerging new technologies will follow, such as Urban Metabolism Technologies.
[Source: https://www.clicknl.nl/onderzoeksagenda-kems-missiegedreven-innovatie/ en https://www.hollandhightech.nl/sites/www.hollandhightech.nl/files/Documenten/KIAs/20191015%20KIA-ST.pdf]

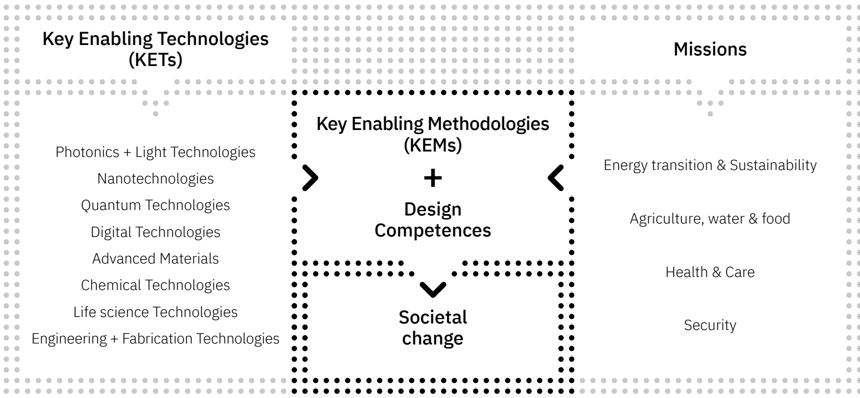


FIG. 2.2

The design sciences perform an indispensable bridging function to fulfil these four missions by seeking answers to questions of how to deploy the Key Enabling Technologies (KEMs[14]) in a focused and effective manner:

— **Energy transition and sustainability –** How do we shape the energy transition and the sustainable development of our living environment in such a way that technology, policy, economics, acceptance and behaviour go hand in hand in a major change?

— **Agriculture, water & food –** How do you realise the actual application of innovations in this field? For example, social innovation and acceptance is needed to implement new food patterns and eating habits.

— **Health & Care –** How can technology as part of a design process make the health spectrum of prevention, cure and care more efficient, effective and empathetic?

— **Security –** How do we deal with (key) technologies to keep the Netherlands a safe country in which to live, work and play?

13 For this, see Parliamentary letter on mission-driven top sectors and innovation policy. [https://www.rijksoverheid.nl/documenten/kamerstukken/2019/04/26/kamerbrief-over-missiegedreven-topsectoren-en-innovatiebeleid].

14 These questions are from the Sector Plan Technology.

The knowledge of the designing disciplines and the designing approach are the key to successfully deploying KETs in society and thereby catalysing societal transitions. The main challenges lie in the further development of knowledge-based Key Enabling Methodologies. The combination of societal challenges, emerging KETs, and the design approach that is essential in this regard is the common focus for the future.

Key Enabling Methodologies (KEMs) connect societal challenges and technological capabilities (KETs)

2.4

Power, recognition and impact

The scientific, but even more so, the *social* recognition of designs is growing rapidly. This can easily be placed within several social changes, the interpretation of which has already been described many times scientifically.

Transition

From a psychosocial view of change processes, one can generally distinguish several phases that must be gone through to be able to accept and embrace the benefits of a change. The phases run from denial (*you are not bothered by it yet, so you experience no urgency*), to resistance (*fed by interests, doubts and fear of the new*), via self-examination (*uncertainty: the new is unavoidable, what role can I play in it?*) to acceptance and connection (*understanding and behavioural change*).

Many social bottlenecks encounter resistance: people see the bottlenecks but do not know how they can contribute, and this is coupled with fear of losing the benefits of the ‘old’.

The importance of design and the power of persuasion of designers lies in a thorough knowledge of change processes. Throughout the design process, the designer consciously builds with innovative techniques to deal with resistance, from the brainstorming/drawing board phase to the implementation/execution phase.

The added value of design becomes concrete by creating safe situations (e.g., living labs or field labs) where a new approach or technology can be experienced by testing new methods or interventions.

In addition to this psychosocial process, which is also a moral process because people’s experience is guided by a set of norms and values that are collectively shared socially, a second process unfolds. Here the experiences of users are taken into account by designers in the development of new interventions within the design process or additional wishes are incorporated into the design of technology. Technology and experience thus move towards each other, aiming for the most seamlessly connected result. This alignment of processes is based on trust, listening, empathy, experimentation and learning. That’s what makes designers strong. And it’s why we need more knowledge, more experience and more educated professionals in many parts of society.

Scientific impact and recognition

The added value of the design engineering sciences is evident from numerous scientific references. In addition to the more traditional scientific parameters such as publications, citation indexes and rankings, Dutch designers increasingly score high on indicators for societal impact.

Science policy (NWO, EU) and quality assessment of research (Strategy Evaluation Protocol 2021 – 2027[15] and 'Recognition and Appreciation'[16]) follow this movement by adapting and expanding the instruments and approach. These are signs of recognition and mean a boost for the development and assessment of competences and skills that are necessary to be able to translate research results into practice in addition to scientific excellence and thus strengthen the impact.

The demand for the application value of scientific output is becoming increasingly articulated. Society expects concrete added value from investments in research. This is what design also stands for and what the discipline wants to be valued for. Valued for its implementation strategies for scientific/technological innovations, which are essential for generating impact. That are purpose-driven with a broad integrated approach, focused on actionable results. The following are highlights of both scientific and social impacts of design sciences.

Highlights

— In the field of industrial design, the Netherlands is among the world's scientific leaders. To summarise, over the past 10 years (2010 - 2020), the Netherlands holds the third position with 127 publications in the authoritative journals Design Studies (Elsevier), International Journal of Design (Full Open Access), and Journal of Engineering Design (Taylor & Francis).[17]

— In the various rankings, the subdisciplines all score highly. 'Urban Planning' scores first place in the University Ranking by Academic Performance (URAP) Field Based Ranking 2019-2020 and the subject 'Architecture' is in sixth place.

15 The SEP 2021-2027 also states: "*The research unit should take into account that the use of the Journal Impact Factor is not allowed. The use of individual bibliometric indicators such as the h-index is strongly discouraged.*" In concrete terms: in addition to the existing criteria of scientific quality, social relevance and viability, attention is also paid to aspects such as open science, PhD policy & training, academic culture (inclusivity, research integrity) and human resources policy (diversity, talent management). [https://vsnu.nl/en_GB/sep-eng.html].

16 Here – in addition to, or even in place of, the more traditional forms such as publications and h-index – there is increasing recognition of training people, methods, developing new networks, team performance, and knowledge dissemination. [https://www.vsnu.nl/Erkennen-en-waarderen-van-wetenschappers.html].

17 The Netherlands follows the United States (178) and Britain (164), and China (86) at four and Denmark (69) at five. Looking at the university rankings, the top five are TU Delft (91), Cambridge (34), Denmark Technical University (32), Eindhoven University of Technology (29), and Aalto (22).

— In the QS World University Rankings by Subject 2020, TU Delft is the third university among Dutch universities for Arts & Humanities thanks to its performance in the field of architecture/built environment. TU Delft is also included in the QS Rankings for Art and Design for the first time in 2021 and comes in at 11th place.[18] TU Delft occupies third place worldwide in the QS Rankings by Subject 2021 in the subject Architecture/ Built Environment. Finally, Wageningen University occupies first place in the QS ranking within the domain of Agriculture & Forestry.[19] For Business and Management Studies, the QS World University Ranking with the subject Statistics & Operational Research is a good measure to use for the recognition that researchers working in this field receive. TU Eindhoven ranks 29th, TU Delft 38th and RUG 51-100th.[20]

— Both the quality and relevance of design engineering sciences research are highly rated. Industrial Design Engineering at the University of Twente was awarded an 'excellent' for societal relevance in the most recent accreditation (2020) (in combination with Mechanical Engineering).[21] The CHOIR research group of Industrial Engineering at the University of Twente is world renowned and a unique research group in the Netherlands in the area of healthcare logistics/operations management in healthcare.

— The research groups related to Engineering and Business Administration from the five universities involved work together in the field of research and graduate education. Many projects are collaborations between two or more research groups within top sectors such as HTSM, logistics and energy, and for healthcare within ZonMW. The 'captain of science' of the HTSM top sector and two of the three theme leaders of the logistics top sector come from different Technology, Policy & Management research groups.

— Education: The University of Twente's Industrial Engineering and Management BSc and MSc programmes have received the 'Top Programme' quality seal within the Keuzegids for years. The Keuzegids 2021 has named University of Twente the 'Best Technical University' in the Netherlands.

— Finally, the design engineering sciences have a strong collaboration with universities of applied sciences (e.g., Hogeschool van Amsterdam, Haagse Hogeschool, Windesheim, Saxion), which strongly promotes the translation of developed knowledge and methods to design practice. Doctoral research by teachers is an important example of this. In many cases the design practice is also a direct partner in these collaborations.

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18 QS World University Rankings for Art and Design 2021. [https://www.topuniversities.com/university-rankings/university-subject-rankings/2021/art-design].

19 QS World University Rankings for Agriculture & Forestry 2021. [https://www.topuniversities.com/university-rankings/university-subject-rankings/2021/agriculture-forestry].

20 The focus areas chosen for TBB overlap very much with Operations Research. TU Eindhoven ranks highest among Dutch universities in the Statistics & Operational Research topic, followed by EUR (31), TU Delft (38), Tilburg University (51-100), RUG (51-100), VU (51-100). [https://www.topuniversities.com/ university-rankings/university-subject-rankings/2021/statistics-operational-research].

21 The Product-Market-Relationship chair at the University of Twente has been repeatedly recognised as a "Highly Cited Researcher" according to Clarivate/Web of Science (2017, 2018, 2019).

Societal impact and recognition

The design engineering sciences are strong in direct valorisation of their (research) results through close collaboration within the quadruple helix. The private partners with whom they collaborate include not only large companies, but also explicitly SMEs and interest groups, which promotes the direct application of results.

For example, TU Delft's Faculty of Architecture is founding partner of the BauHow5 alliance, together with UCL Bartlett, Chalmers, TU Munich, and ETH Zurich, which deals with topics such as circularity, Inclusion-Diversity-Equality (IDE), and education for PhD students. The same faculty is affiliated with highly prominent international architecture firms with home-grown founders such as Mecanoo, Kaan Architects and MVRDV.

There is also frequent collaboration with social partners in various projects within all sub-disciplines.[22]

Finally, designers also appear on television. Examples are the programme 'We gaan het maken' (BNNVARA) in which DesignLab Research Fellows from the University of Twente designed products for people with disabilities. In addition, designers contribute to the series 'Abstract, The Art Of Design', a 14-part Netflix series about important designers and their impact on society.[23] And there is the Dutch series 'Voor de Vorm', in which designers investigate the shape of everyday utensils.[24] The value of good design is also reflected in competitions such as 'Het beste idee van Nederland' or the recent TV programme 'Briljant!' in which people are looking for ideas that make the Netherlands better, cleaner, and more social.

Finally, designers are often asked to interpret and clarify the issues surrounding various themes related to news items.

22 This is evidenced by frequent invitations of collaborators as referees and advisors; the inaugurations of exceptional teachers and researchers funded by community partners as well as co-funding of projects by community partners, and finally the implementation of design ideas and guidelines in real-world projects.

23 NETFLIX, series 1: 2019, series 2: 2020.

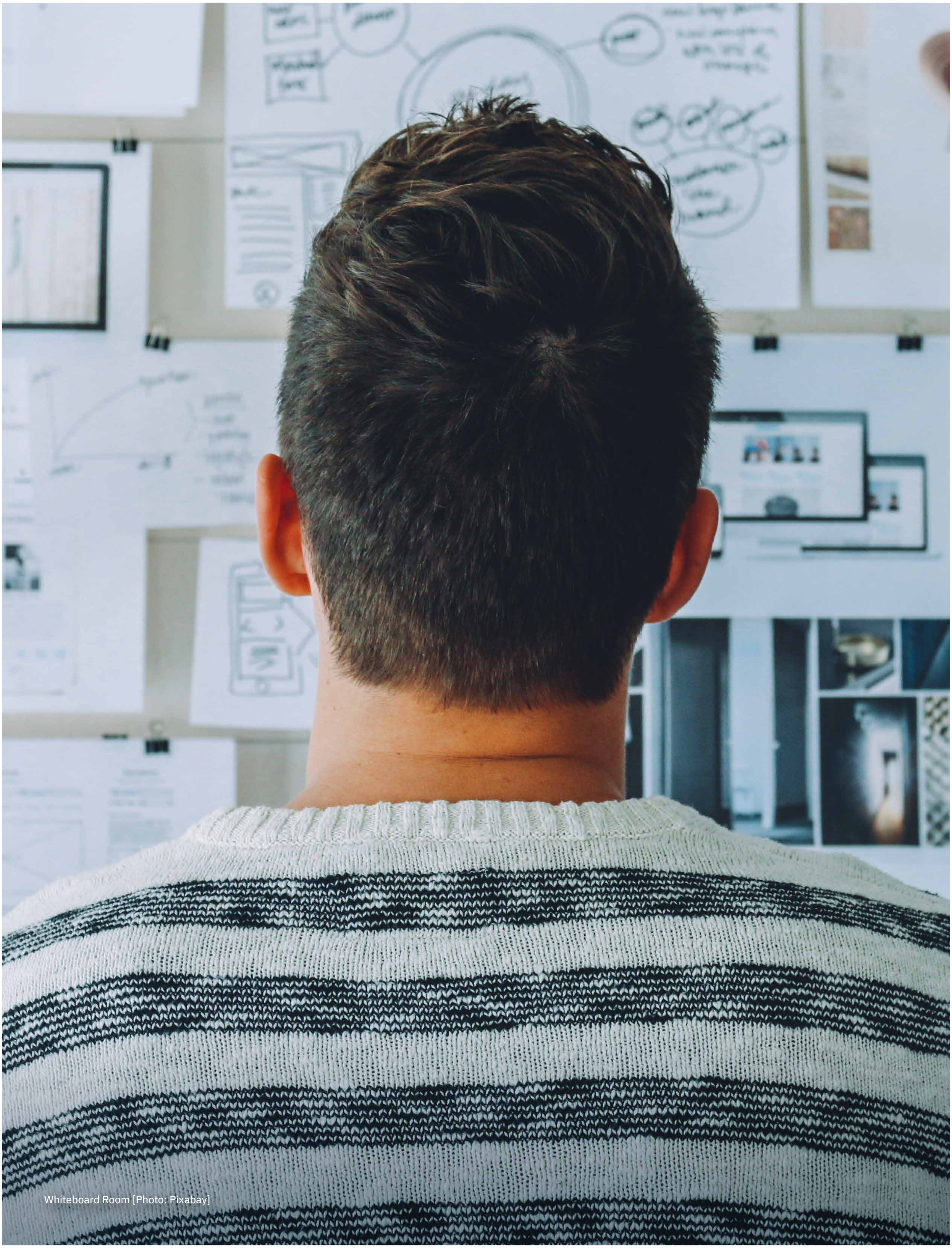
24 https://www.npostart.nl/

Students, labour market and alumni

On an annual basis over 4,000 students nationwide graduate with an MSc degree in design, or closely related fields. The student numbers are rising, despite the fact that TU Delft and TU Eindhoven have a numerus fixus on acceptance for the bachelor's programme. Graduates in Engineering and ICT have very good job-market prospects.[25] Statistics indicate that there are about 18,000 more positions vacant than new design engineers entering the labour market. The VSNU's National Alumni Survey 2019 indicates that graduates find employment broadly in the labour market with a slight preference for industry, trade and transportation. This broad labour market perspective is in line with the broad application framework of the design phenomenon. Data on labour market perspectives are included in Appendix 4.

Science policy strengthens both societal and academic foundations

25 https://arbeidsmarktinzicht.nl/ & Researchcentrum voor Onderwijs en Arbeidsmarkt (ROA) / Arbeidsmarkt Informatie Systeem (AIS).


Whiteboard Room [Photo: Pixabay]

3

Scientific questions and application areas

The three disciplines that make up the field of design engineering sciences can be seen as three dimensions along which different design challenges are addressed. The discipline of Industrial Design has placed its emphasis on the scientific methodical knowledge base. The other two disciplines have already defined a field of work from their focus, namely Architecture, and Technology, Policy & Management.

3.1

Industrial Design Engineering

This is the scientific discipline that studies design – both the product (artefact) and the activity – in all its manifestations in order to strengthen the knowledge base and improve design practice. The field is multidisciplinary by nature: it integrates knowledge about people, technology, and design and innovation processes.

The core disciplines of Industrial Design Engineering are:

- **Human-centred design –** Perspectives from ergonomics, psychology, informatics, humanities, technology acceptance, ethics of form and interaction, aesthetics, sociology and user experience, including new and innovative research-through-design processes;

- **Technology-inspired design –** Consider manufacturing technology, informatics, artificial intelligence, data science, electronics, mechatronics, and new materials;

- **Design and innovation strategy –** Consider design thinking, future scenarios, strategic design of design, organisational, and innovation processes, as well as validation of mindsets and solutions.

IDE = Knowledge about people, technology and design

Core disciplines and research areas

The science of Industrial Design has five areas of knowledge and related types of research:

- **Design as an activity –** Research into how designers act, analyse and (technologically) support their process. Research questions cover topics such as how teams work together; how design(-ers) can have strategic impact on an organisation; how stakeholders and end-users are engaged; and the way of conceptualising and integrating disciplinary perspectives in creating solutions.

- **Human-design interaction –** Examining how people interact with results of design. The main focus is on human perception of product use. How do people experience everyday objects? When and how do people accept and use innovations? How can design outcomes promote well-being? What design mechanisms help motivate people to move more? Designing complex hybrid human-technology systems (autonomous intelligence); designing the interface between humans and artificial actors.

- **Creating to realise –** How can we realise new designs (materials, technology integration and new production processes)? Future research directions include designing complex hybrid human-tech systems; designing with new materials (smart materials, biomaterials); designing from and with smart, flexible manufacturing processes (prototyping techniques) and designing with data.

- **Future Worlds –** Researching the design of the future. Exploring and researching alternative speculative designs of the future. How can we make interactive technology and concepts more tangible? What role will bio-based materials play within designs? What might responsible Artificial Intelligence (AI) look like? How can designs strengthen inclusion and connectivity? How can we design for a circular economy?

- **Design, culture and society –** Research into the role of design results in our culture and society. What has been the social impact of historical design movements? How has an invention like the microwave changed our family routines? What values are at stake when we “design for safety”? How do we imagine a sustainable society?

- **The system level –** Investigating design outcomes within a socio-technical system. How can we understand the dynamics of a system with multiple actors and elements? How can we translate systems thinking into socio-technical issues? How can we predict behaviour based on research findings? Where can we best intervene to change the system and avoid unintended consequences? Can we distinguish different transition paths?

Results

- Generating knowledge and insights in the field of designing interventions and gaining knowledge based on interventions;
- Realising models/prototypes, interventions and frameworks;
- Drawing up, applying and evaluating specific and generic design methods;
- Developing new realisation techniques based on new materials (smart manufacturing, biomaterials), artificial intelligence and data;
- Establishing and making explicit (ethical) principles, classifications, strategies, tools (e.g., through map sets, canvases, technology tools).

Thematic application areas.

Industrial designers address societal challenges by always deploying design competencies, methods and knowledge towards a combination of technical feasibility, economic viability and human desires. This is aimed at making the world a better and more efficient place to live. They focus on the following themes:

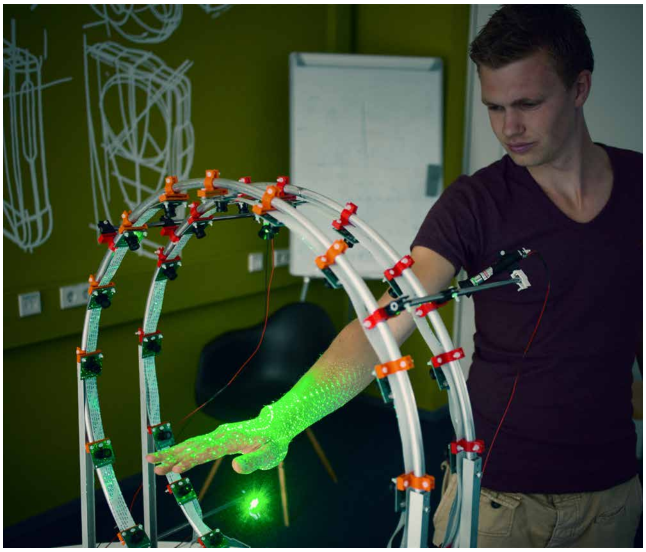


FIG. 3.1

FIG. 3.2

FIG. 3.1
Hand scanner
Graduation project by Pieter Smakman in 2014. Currently a company that makes orthoses for the polyclinic for the hand of the Reinier de Graaf hospital. www.manometric.nl
[Photo: Pieter Smakman]

FIG. 3.2
Half of the Green Team Industrial Design
Students give advice on how we can become 'greener' ourselves.
[Photo: Nathan Douenburg, Green Team]

Design for health and well-being

For a society to function optimally, vital and resilient residents are crucial. Lifestyle, healthy food, mental well-being, quality of care and optimal treatments are some of the crucial elements for a healthy society. New technologies can ensure that people are healthy and stay healthy for longer. Design can, with a unique approach, understand the core of the challenges in the health ecosystem and uses a human-centred and dynamic process to achieve the desired transformations such as addressing challenges like the aging society and the pressure on care. Insights and knowledge gained through the design methodology then lead to meaningful impact on our society.

Sustainable design & circular economy

The ubiquitous linear economy of 'take-make-waste' is unsustainable and in dire need of renewal. This is a big task because realising a circular economy requires a fundamental system change. It means incorporating circularity into all aspects of design, with value retention and reuse of products, components and materials being paramount. But also, the business model within which all this happens must be right. Innovative models are needed for this. Finally, social embedding and acceptance are important themes: how do we ensure a transition that is inclusive?

FIG. 3.3

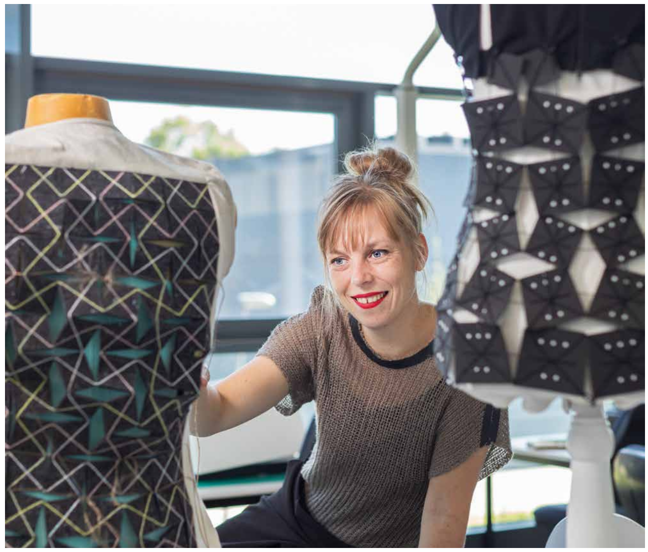


FIG. 3.4

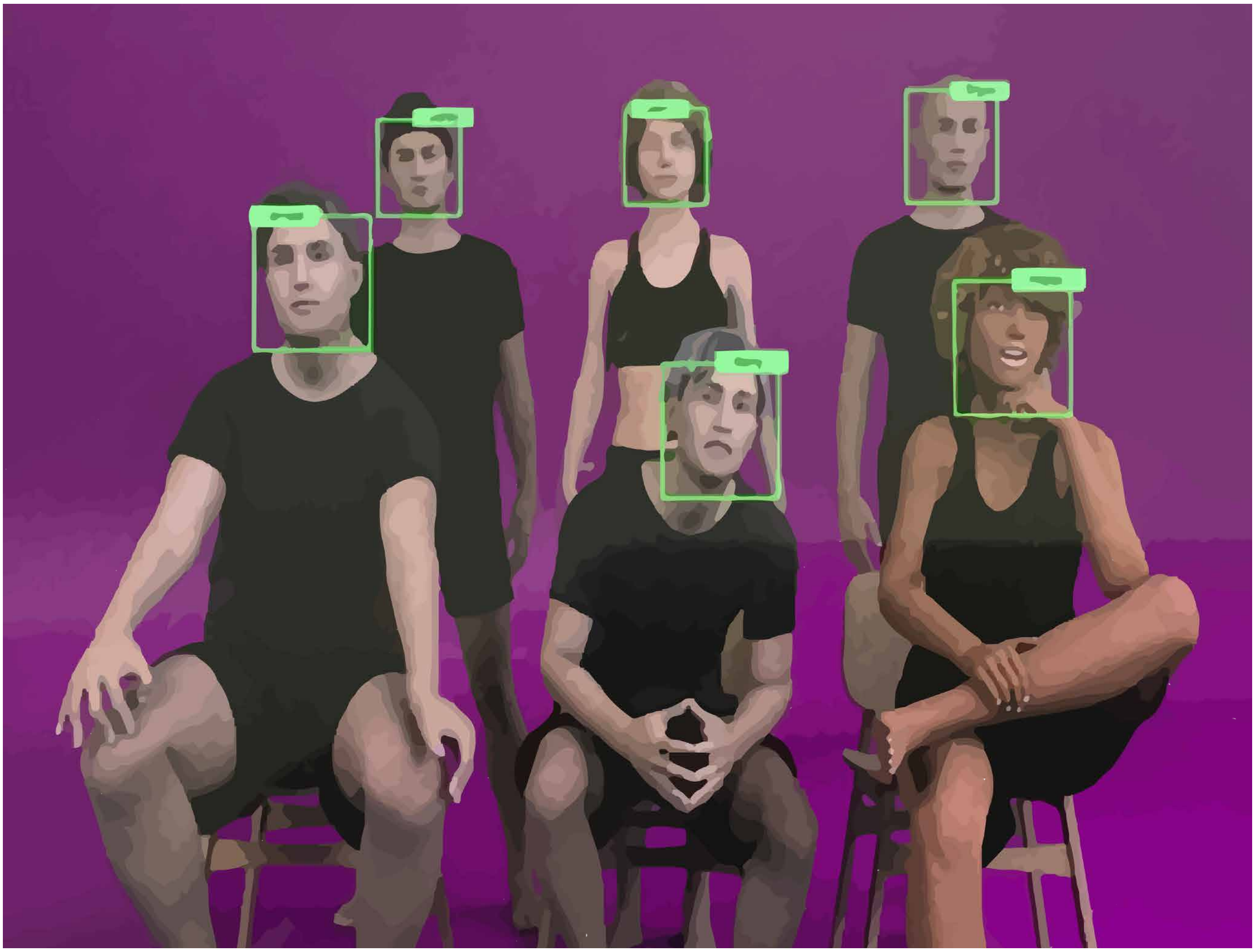


FIG. 3.5

FIG. 3.3
Designscapes:
Training on Participatory Evaluation
Part of H2020 project
CO-CREATION-02-2016
User-driven innovation: value creation through design enabled innovation.
[Source: https://designscapes.eu/]

FIG. 3.4
Wearable Technology
Vest that helps children with breathing difficulties. By Hellen van Rees.
[Source: https://www.hellenvanrees.com, Photo: Annabel Jeuring]

FIG. 3.5
ParadizeD
Creating awareness about the possibilities of digital surveillance technology.
By Simone Ooms. [Source: https://2020.design-united.nl/day-4-silent-power/paradized/]

Design & social transformation (systemic design & participation).

Social issues or transitions in the field of energy, food and health require a systemic perspective that not only looks at the end user, but also at how he or she operates within a complex system of actors and institutions. Only by looking at the system as a whole is it possible to determine where the best intervention can be made to get the system moving in the desired direction. Such an intervention is more and more networked (Internet of Things) and, due to the unpredictability of the system, must be adaptive and move with it. Furthermore, such a system often involves conflicting interests of various stakeholders. All this calls for the design of smart interventions that involve and connect individual and collective values.

Designing for behavioural change

Designing for behavioural change is a growing theme for the design sciences. It finds application in the fields of health, safety and sustainability, among others. Within this theme, researchers explore the influence of design on our behaviour in many ways. This may involve design at various levels: from the products and services we use, to our environment. Within the theme, design methodologies and tools are developed that are based on models and theories from various disciplines, such as social, cognitive and environmental psychology, organisational psychology, communication sciences and sociology. What is still lacking is knowledge about when which method/intervention works best and why. There is also still relatively little knowledge about how the design sciences can contribute to sustainable behaviour change.

Human-centred Artificial Intelligence (AI).

Design and design research play a vital role in developing a “human-centred” approach to Artificial Intelligence, whereby: 1) AI complements and enhances (rather than replaces) human intelligence; 2) the design and development of AI systems are based on a deep understanding of and appreciation for human characteristics, values, intentions, and behaviours; and 3) the success of AI systems is measured by the impact they have on society.

Basic design research on human-centred AI systems provides the knowledge base necessary for the successful embedding of Artificial Intelligence in organisations and society. The development and application of human- and society-oriented KEMs in the field of Artificial Intelligence is necessary to ultimately achieve better outcomes for people and organisations consistent with fundamental values of Dutch society.

3.2

Design of the Built Environment

The field of architecture and the built environment encompasses the full spectrum of analysis, design, engineering, planning and management of our everyday living environment. Research and education within this domain are specifically focused on improving the design and performance of buildings, neighbourhoods, cities and regions to better meet the requirements and expectations of their users and communities. From this perspective, much can be understood as applied science, appealing to the curiosity and needs of other researchers, students, practitioners and the wider public. The field includes a mix of humanities, social sciences and engineering. The humanities are most strongly represented in architecture; the social sciences in management and urban planning, while the engineering sciences are most strongly represented in structural engineering and building technology.

Design of the Built Environment focuses on adapting the spatial design and organisation of the Netherlands to social needs and desires at *various levels*: from the appearance, interior and construction of a residential house or store to entire office towers or stations as part of city centres, shopping areas and residential neighbourhoods, which are then connected to transportation, water and energy infrastructure, natural and recreational areas and rural areas. The architectural design determines the physical conditions for each activity in the immediate living environment and the climate in which those activities take place. In addition, design ensures the safety and functionality of the structures to facilitate these activities. For the more classic design professions in the built environment, professionalism is guaranteed by the Architectural Title Act (WAT = Wet op de Architectentitel), thanks to a system of title protection through a register of architects; only those registered as architects, urban designers, garden and landscape architects or interior architects may use the relevant title.

DBE = Designing, planning, making and managing our living environment

Core disciplines and research areas

Related to the Architectural Title Act, the following core disciplines and research areas are distinguished:

- **Interior Architecture –** Interior architecture is the area of research that studies the design of spaces delineated by structural elements, and that studies human interaction within those boundaries. This includes the study of the original design, the use phase, as well as redesign to accommodate a new interpretation of an object or space.

- **Architecture –** Architecture (which includes architectural theory, architectural and urban building history, real estate heritage, and building technology) is the discipline that deals with the design, transformation, and interpretation of the built environment, and articulates space at various scales. It encompasses the knowledge, history, heritage, planning, realisation, management and practice of architecture, and addresses issues of ethics, aesthetics, culture and society.

- **Urbanism –** Urbanism (including urban design, urban renewal, spatial planning, land-use planning, area development) focuses on the configuration of the city, the ensembles of buildings in conjunction with public space, infrastructure, the urban programme and the associated governance (institutional and organisational design). In addition to the physical component – the infrastructure and the design of public spaces – the focus is on the way in which urban planning organises spatial patterns: everyday living patterns, lifestyles, the transport of people and goods, which in turn influence factors such as public health, economic efficiency, sustainability et cetera.

- **Landscape Architecture –** Landscape architecture focuses on the design of outdoor spaces, in urban and rural contexts and at different scales from garden or park to regional design. It includes the systematic examination of existing social, ecological, and soil conditions and processes in the landscape, and the design of interventions based on these conditions that provide solutions that are functionally, aesthetically, and ethically weighted.

Within each of these core disciplines, careful attention is paid to the governance and institutional context – the planning and decision-making process in which the design is created – and the embedding of the design in the existing situation, physically, institutionally and organisationally at various levels. Spatial design and institutional design are closely intertwined. The interaction between them is increasingly recognised, both in practice and in the scientific community.

Results

— Adapting the quality of the living environment to the use of the future through creative (re)design;
— Prioritisation of interventions from limited (public) financial resources available for the built environment in the coming years through evaluation of use using design methodologies;
— Meeting the current circular building challenge with the limited supply of building materials through smart design;
— Design explorations of housing typologies and sustainability options in the existing housing stock;
— Spatial scenarios for urbanisation, multifunctional use of space and the integration of infrastructure systems;
— Serious gaming for resident participation in the context of energy transition and climate adaptation.

Thematic application areas

In addition to the worldwide Sustainable Development Goals, there are challenges that are articulated in national policy, such as the National Environmental Vision[26], with which the government gives direction regarding major challenges for the next 30 years. Other policy frameworks include the Delta Programme, the Panorama of the Netherlands by the Board of Government Advisors, the housing market policy of the Ministry of the Interior and Kingdom Relations, the Spatial Design Action Agenda of the Ministers of the Interior and Kingdom Relations and Education, Culture and Science, or the call in the Davos Declaration for a high-quality Baukultur. In summary, this leads to seven important themes for Design of the Built Environment:

26 The National Environmental Vision (De nationale Omgevingsvisie/NOVI) describes the major challenges facing the Netherlands: the construction of 1 million new homes, sustainable energy generation, climate change and the transition to a circular economy. This requires more space than is available in the Netherlands. [https://www.denationaleomgevingsvisie.nl/default.aspx].

FIG. 3.6

FIG. 3.6
Passive Renovation
Renovation of a Dutch terraced house into a home that requires virtually no energy for space heating. De Kroeven in Roosendaal. [Source: DAT, The Architects Workshop Tilburg]

Energy transition and climate adaptation

Climate change will increasingly lead to extremes in terms of heat, drought, and flooding, each of which will require radical solutions for water and energy use. This requires innovation in physical and institutional design with respect to buildings, outdoor space, infrastructure and landscapes.

Both energy transition and climate adaptation create major spatial demands and require a spatial transition. The Netherlands has limited room to manoeuvre in implementing the guidelines. This translates into challenging targets for existing buildings, new construction, the social and private rental sector, and the total building-related energy consumption. Design plays a central role in this.

FIG. 3.7

FIG. 3.8

FIG. 3.7
Prêt-a-Loger
Student project as part of the 2014 Solar Decathlon Europe Challenge.
[Photo: TUD]

FIG. 3.8
Masterplan Rijnhaven, Rotterdam
A wide esplanade with urban functions and special high-rise projects will soon border on a large-scale city park, an attractive public area with a permanent city beach and an educational 'tidal park'.
[Photo: Barcode Architects]

Circularity and sustainability of the existing housing stock and infrastructure

Dutch government policy aims to have a circular economy by 2050. This assumes that there will be no more waste and that all materials can be reused. A large part of the infrastructure (roads, railroads, canals, dikes, artworks) was built some time ago and is approaching the end of its life. Both the environment of this infrastructure and the requirements of its users have changed. Climate change, energy transition and sustainability make the replacement of outdated infrastructure a major, challenging design and planning challenge for the coming decades.

Sustainable and smart urbanisation

By far, the largest part of the Dutch population lives in an urban environment. The spatial and ecological footprint of our cities has increased enormously over the past century. Every hectare in the Netherlands is functionally invested and has an effect on its immediate environment. A cultural change is needed to organise our cities in such a way that they do not cause any further burden on people and the living environment and at the same time continue to offer sufficient space and functionality for everyone. A special effort is needed to digitise the mostly analog design process over the entire trajectory from concept to production, so that building processes become more sustainable, efficient and effective. On top of this comes a whole new field of artificial intelligence that can optimise the use of the built environment.

FIG. 3.9

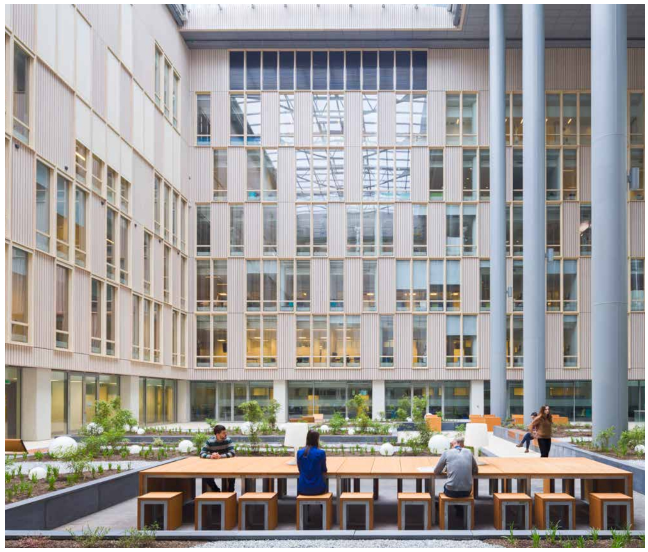


FIG. 3.10

FIG. 3.9
Digital nature
How patients feel affects their recovery. The physical environment plays an important role. [Source: Kim et al. https://2020.design-united.nl/day-2-eco-logica/digital-nature-designing-a-healing-environment-to-prevent-icu-delirium/]

FIG. 3.10
Atrium in the new Erasmus Medical Centre
Plenty of daylight and green plants make the entrance pleasant and the interior gives it a human scale. [Photo: Erasmus MC Rotterdam]

Healthy living environment

Within our cities, sharp contrasts exist between the health and life expectancy of citizens. These differences are partly due to air quality, noise nuisance, housing quality and outdoor space. From the point of view of social justice, there is a task to combat this inequality wherever possible. Even more important than its physical quality is the way in which the living and working environment promotes or inhibits healthy lifestyles: the possibilities for active exercise (walking, cycling), access to safe and inviting (programmed) greenery, social hubs and other destinations that entice people to leave their homes and enter the public domain. These and many other facets are determined to a great extent by the urban design of town and country.

Buildings for health(care)

The corona pandemic reinforces the realisation that radical innovations in the built infrastructure of health care – hospitals, psychiatric clinics, facilities for the elderly – are inevitable if the quality of care is to be maintained. In addition to reconstruction of large-scale, outdated facilities, this calls for the development of new methods and new technologies that allow for a fundamentally different, personalised relationship between care providers and care recipients.

FIG. 3.11

FIG. 3.12

FIG. 3.11
Renovation of Sanatorium Zonnestraal, Hilversum
World Monuments Fund/Knoll Modernism Prize 2010. [Photo: WDJArchitecten]

FIG. 3.12
Dealing with natural systems in the river area
In the river area, we need to deal with water safety, water quality, navigability, freshwater availability, nature and spatial and economic quality in conjunction. [Photo: NOVI]

Future-proof heritage

Heritage in the built environment was long limited to relatively compact historic inner cities. In the meantime, post-war building production is also counted as heritage. The challenge is to find a new approach to the reuse and redevelopment of this extensive building stock. In addition, landscape elements and sometimes entire landscapes increasingly have a cultural-historical value.

Sustainable design of the rural area

In the rural area there is great pressure on space because not only does sustainable agriculture have to be practiced, but also the use of space for water storage, renewable energy and recreation is increasing. In addition, major problems such as the nitrogen crisis, diseases spreading between humans and animals and declining biodiversity must be tackled. New plans are needed that take an integrated approach to these problems and opportunities. In addition, circularity in agriculture plays a major role: how are we going to organise the agricultural landscape with a view to the circularity of materials, manure/residues, energy and water flows, aimed at a better quality of soil, air and water?

3.3

Technology, Policy & Management

Core disciplines and research areas

The core of Technology, Policy & Management (TPM) is the design and quantitative analytical approach to organisations, processes, governance structures and systems. This discipline is concerned with the design, implementation, evaluation and subsequent optimisation – through targeted intervention – of technology development, systems and governance structures. The focus is on social systems in which (semi-) public authorities and companies cooperate and compete.

Technical management and business experts use mathematical models and technical tools such as data analytics and artificial intelligence methods, gaming, visualisation, scenario development and simulation for their analyses and designs, which they create in collaboration with companies, governments, civil society organisations and public-private partnerships. The goal is to achieve sustainable solutions for society by making the best possible use of technological possibilities and embedding them in complex social systems.

TPM = Designing and analysing organisations, processes, structures and systems

Results

- Passing on of circular economy concepts and design of earning models for these concepts;
- Design of data-driven tools for monitoring performance in healthcare networks;
- Design of decision support tools to support decisions and policy around critical infrastructures;
- Serious games that can be used for security training;
- Policy advice regarding ethical implications in design issues, such as in geoengineering;
- Design of tools for understanding the long-term impact of decisions and policy scenarios;
- Design of new data-driven coordination mechanisms, leading to higher capacity of supply chains;
- Quantitative analyses of the interaction between policy and the actions of companies with respect to CO_2 emission regulations;
- Design of artificial intelligence-based planning and control models in services and manufacturing;
- Design of tools for monitoring and analysing large policy-relevant datasets;

Thematic application areas

Technology, Policy & Management designs sustainable solutions in which Key Enabling Technologies (KETs) are best utilised and embedded in complex social systems. In this way, insights and methods – KEMs – are provided, which are indispensable to make technology work for and in society. This is also reflected in modern forms of education. The focus is particularly on four domains that require competencies in problem diagnosis, analysis, and creation:

FIG. 3.13

FIG. 3.13
Linking with physical internet
A new logistics paradigm.
[Photo: Reyer Boxem]

Global supply chain and logistics

The ambition is to use a holistic systems approach to design solutions for the sustainability of global supply chains and their logistics operations. Digitalisation and hyper-transparency play an important role in this, as does the deployment of key technologies around obtaining secure, transparent and resilient chains. New societal trends such as the sharing economy and circularity require both radically new concepts for chain direction and for its governance. It also involves designing logistics systems that facilitate other sectors in their sustainable transitions, such as the energy or agriculture sectors.

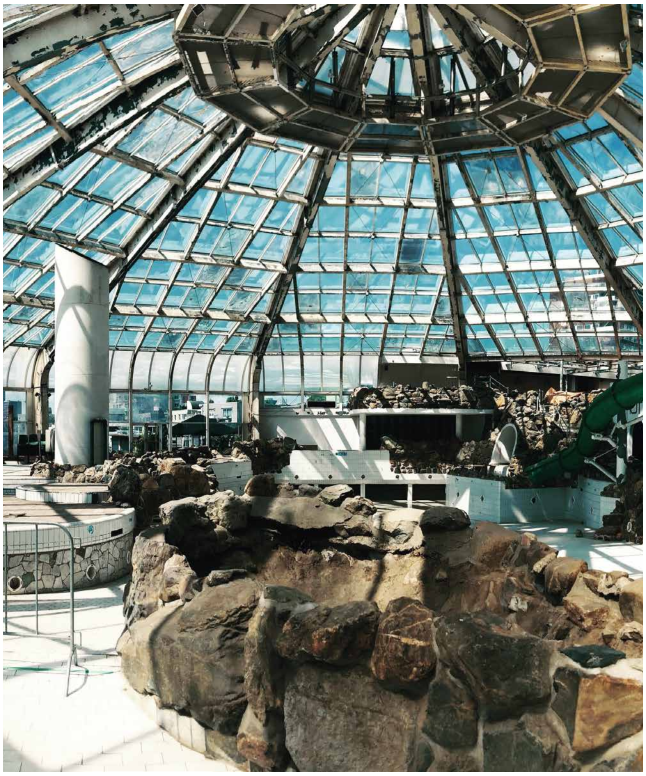


FIG. 3.14

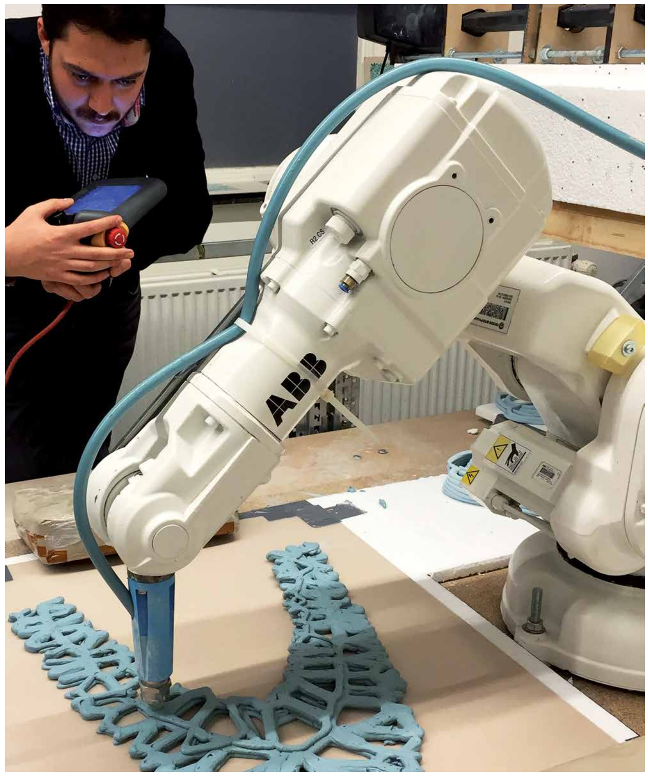


FIG. 3.15

FIG. 3.14
BlueCity
Pioneers of the circular economy gather in the former Tropicana. A dynamic community of like-minded entrepreneurs is flourishing there. www.bluecity.nl [Photo: Maarten Scheer, Unsplash]

FIG. 3.15
3D printing as a basis
Research on the use of Robotics and additive manufacturing.
[Source: TUD]

Smart industry and sustainability

In order to change into a climate-neutral society, it is essential that industry is transformed into a local-for-local industry and that raw materials and products are reused as much as possible. New technologies such as robotics, 3D printing, Internet of Things, and artificial intelligence make it possible to form more flexible and efficient factories and to set up smart, remote maintenance processes. New business models for both manufactured products and capital goods are needed to maximise reuse.

Healthcare operations management

The enormous pressure on healthcare spending and healthcare capacity, the many technological and medical innovations, and developments such as concentration of care and shifts to primary care create the need for a transformation of the healthcare landscape. There is a need for management solutions that facilitate the transformation to an integrated system in which care units cooperate better, innovations are implemented cost-effectively and the desired quality for patients is delivered. The specific characteristics of healthcare necessitate a different approach to operational optimisation that does justice to the inherently complex care processes, the stake-holder interests, and the desired autonomy of healthcare professionals.

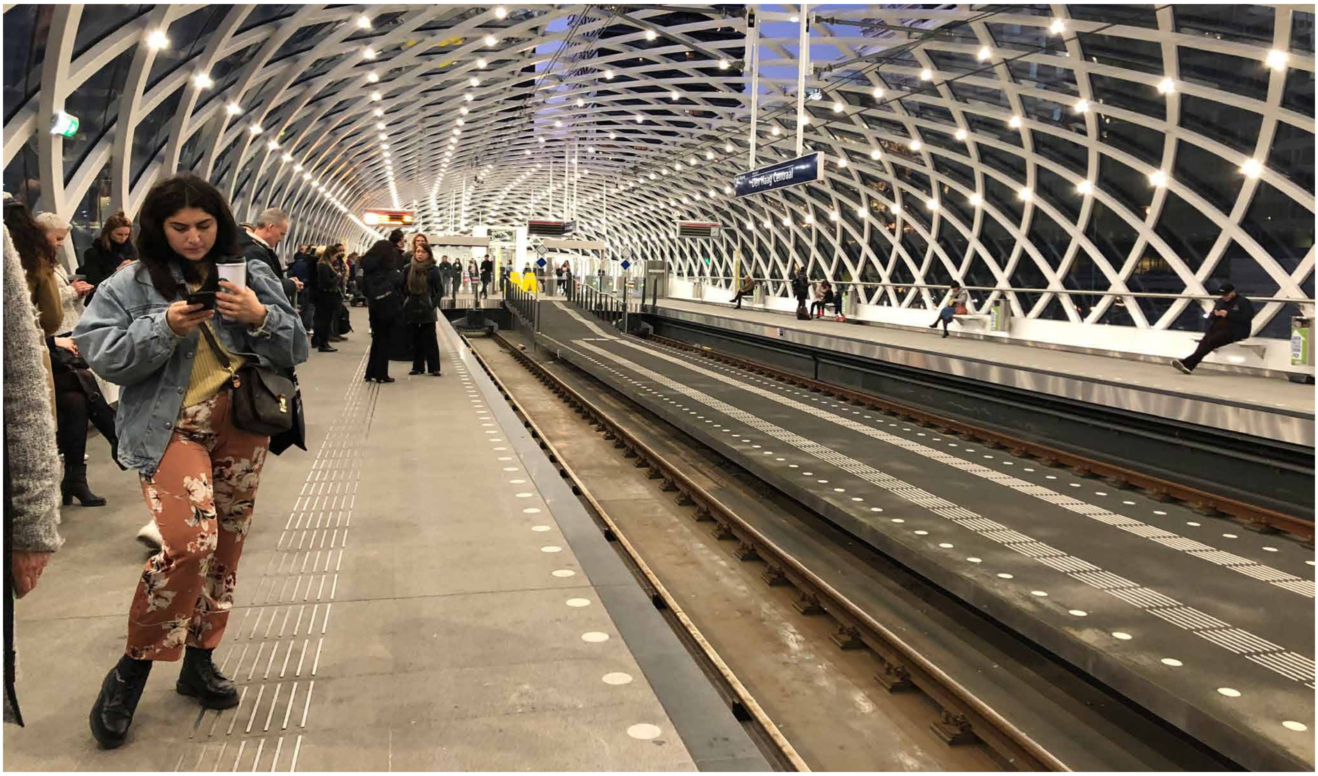


FIG. 3.16

FIG. 3.16
The Hague Central Station metro station
The eye-catcher of the station is the roofing of the platforms, which consists of curved glass and steel. The station's design is slender in order to keep the impact on the surroundings to a minimum. [Photo: Frank van der Hoeven]

Vital infrastructures

Resilient and robust vital infrastructures are important for the safety of society and will be a key focus area in the coming years. In addition, as a result of the energy transition, structural changes are taking place in the various energy networks, such as the (partial) transition from the natural gas network to a hydrogen network. The strong interdependency between the vital infrastructures, managed by various parties, requires a holistic approach from both a system and an actor perspective.

3.4

Societal focus

Design research often takes place within the context of technological (artificial intelligence, digitisation, new materials) and societal challenges. This is also evident in the application themes of the three disciplines. In general, almost all of the themes mentioned touch on sustainability, health and safety. These overarching themes form the basis for prosperity and well-being. As such, they are closely aligned with the objectives of the Dutch missions and the Sustainable Development Goals of the United Nations.

FIG. 3.17

FIG. 3.17
UN Sustainable Development Goals
This overview of the 17 UN SDGs indicates the 7 (framed) themes on which the three OIWs jointly focus.
[Source: https://sdgs.un.org/goals]

Waterplein Benthemplein: An innovative way to prevent urban flooding in Rotterdam. Design by De Urbanisten [Photo: C40 Cities]

DesignLab [Photo: UT]

4

The Dutch Landscape

Design-oriented education and research manifest themselves in a variety of ways. In the Netherlands, there are five university institutions that teach and conduct research in the field of design

Delft University of Technology (TU Delft)

TU Delft's mission 'Impact for a Better Society' is based on a broad palette of technical disciplines along the lines of science, engineering, and design. The faculties of Industrial Design, Architecture, and Technology, Policy and Management fall under the heading of design. TU Delft combines its research capacity in a number of university-wide institutes: the TU Delft Institutes.[27] This bundling of high-quality capacity puts TU Delft in an even better position to link up with national and international consortia and networks and to attract scientific talent. TU Delft is also a partner in a number of strategic alliances in the Netherlands, such as TU Delft/ErasmusMC/EUR Convergence[28], Medical Delta[29], and the Leiden, Delft and Erasmus collaboration (LDE).[30] Within the EU, the IDEA League[31] and CESAER[32] are the most important alliances.

Eindhoven University of Technology (TU/e)

The mission of TU Eindhoven is to educate students and promote knowledge in science and technology for the benefit of mankind. The university is located in the centre of one of the most powerful technology hubs in the world, Brainport Eindhoven, and stands out worldwide for its collaboration with advanced industries. Three faculties are associated with the design engineering sciences: Industrial Design, Architecture, and Industrial Engineering & Innovation Sciences (IE&IS). The latter has a programme in engineering business administration and a programme on human-engineering interaction, including ethical design. TU/e Innovation Space is responsible for interdisciplinary hands-on challenge-based learning, engineering design and entrepreneurship, and is thus also directly linked to the design engineering sciences. Within the Netherlands, TU Eindhoven is a partner in the 4TU Alliance and in the Utrecht-TU/e-Wageningen Alliance. In the EU, it is one of the six closely cooperating partners of EuroTech University Alliance.

27 https://www.tudelft.nl/onderzoek/samenwerking/delft-institutes.

28 Convergence: joining forces of TU Delft, Erasmus University Rotterdam & ErasmusMC aimed at problem driven collaboration across disciplines and institutions in the field of healthcare. https://convergence.healthandtechnology.nl/].

29 Medical Delta: three renowned universities, two university medical centres, four colleges, governments, businesses, health care institutions and other parties in South Holland work together in scientific programmes in the field of healthcare. https://www.medicaldelta.nl/].

30 LDE is a partnership between TU Delft, Leiden University, and Erasmus University Rotterdam. https://www.leiden-delft-erasmus.nl/en/home].

31 https://idealeague.org

32 https://www.cesaer.org/about/mission-and-aims/

University of Twente (UT)

The mission of the University of Twente – '(be) The ultimate people-first university of technology. We empower society through sustainable solutions'- is based on the powerful presence of both technical and social sciences. The unique combination of fundamental technological and social science research within one university strengthens the 'High Tech, Human Touch' profile of the University of Twente. In Twente, the engineering design sciences are housed in the faculties of Engineering Technology (Industrial Design & Design of the Built Environment) and Behavioural, Management & Social Sciences (Design of Business and Administrative Processes), in close connection with the faculties of EEMCS and ITC (respectively host of the Creative Technology, Interaction Technology and Spatial Engineering programmes).

The design engineering sciences are also closely linked to DesignLab, the experimental ecosystem that with its Responsible Futuring approach strengthens the connection between society, science, technology and design. Research institutes such as the Digital Society Institute, MESA+ and the TechMed Centre also ensure a connection to both (international) academic networks and societal issues.

Within the Netherlands, the University of Twente is a partner in the 4TU Alliance. And within Europe, the university chairs The European Consortium of Innovative Universities (ECIU).

Wageningen University & Research (WUR)

Wageningen University's mission is 'To explore the potential of nature to improve the quality of life'. Wageningen University takes a multi-, inter- and transdisciplinary approach to social issues. Its strength lies in the combination of specialised research institutes and the university. This close cooperation in various natural, technological and social science disciplines ensures that scientific breakthroughs are quickly translated into practice and education.[33] Many different studies at BSc and MSc level offer courses that revolve around the design of new technological and spatial solutions. In particular, chair groups in food technology and food design work on tasks typical of the design engineering sciences, but they also include the spatial design disciplines such as landscape architecture and spatial planning, and international land and water management.

33 The "Wageningen approach" focuses on the clustering of specialised research institutes. This close cooperation in various natural, technological and social science disciplines ensures that scientific breakthroughs are quickly translated into practice and education by involving the triple helix (research, companies and public) throughout the design process. [https://www.wur.nl/en/show/dossier-urban-agriculture.htm].

University of Groningen (RUG)

The spearheads of the University of Groningen (RUG) are: Energy, Healthy Ageing, Sustainable Society, and Digital Society. Schools linked to the aforementioned spearheads promote interdisciplinary cooperation between the alpha, beta and gamma disciplines established at the university. Within the University of Groningen, the Groningen Engineering Center (GEC) provides a unique platform for interdisciplinary design-oriented research and education. Four faculties are involved: the Faculty of Science and Engineering (FSE), the Faculty of Economics and Business Administration (FEB), the Faculty of Spatial Sciences (FRW), and the Faculty of Arts. Researchers from these faculties collaborate on research projects and in teaching. The ambition of the university is to further expand the national cooperation with 4TU and to strengthen the contacts with the four technical universities. In this way, the University of Groningen wants to contribute to the strengthening and bundling of technological knowledge, conduct internationally leading and socially relevant research together, and promote collaboration between research institutions and companies.

The university houses the interfaculty knowledge centre Architecture, Urban Planning and Health, which studies the influence of architectural and urban design on public health and works closely with (inter)national experts in this field. For example, it is working on a ZonMw-funded project studying the health effects of a typical post-war residential neighbourhood, and has published a Hospital Design Manual.

Number of students and academic staff

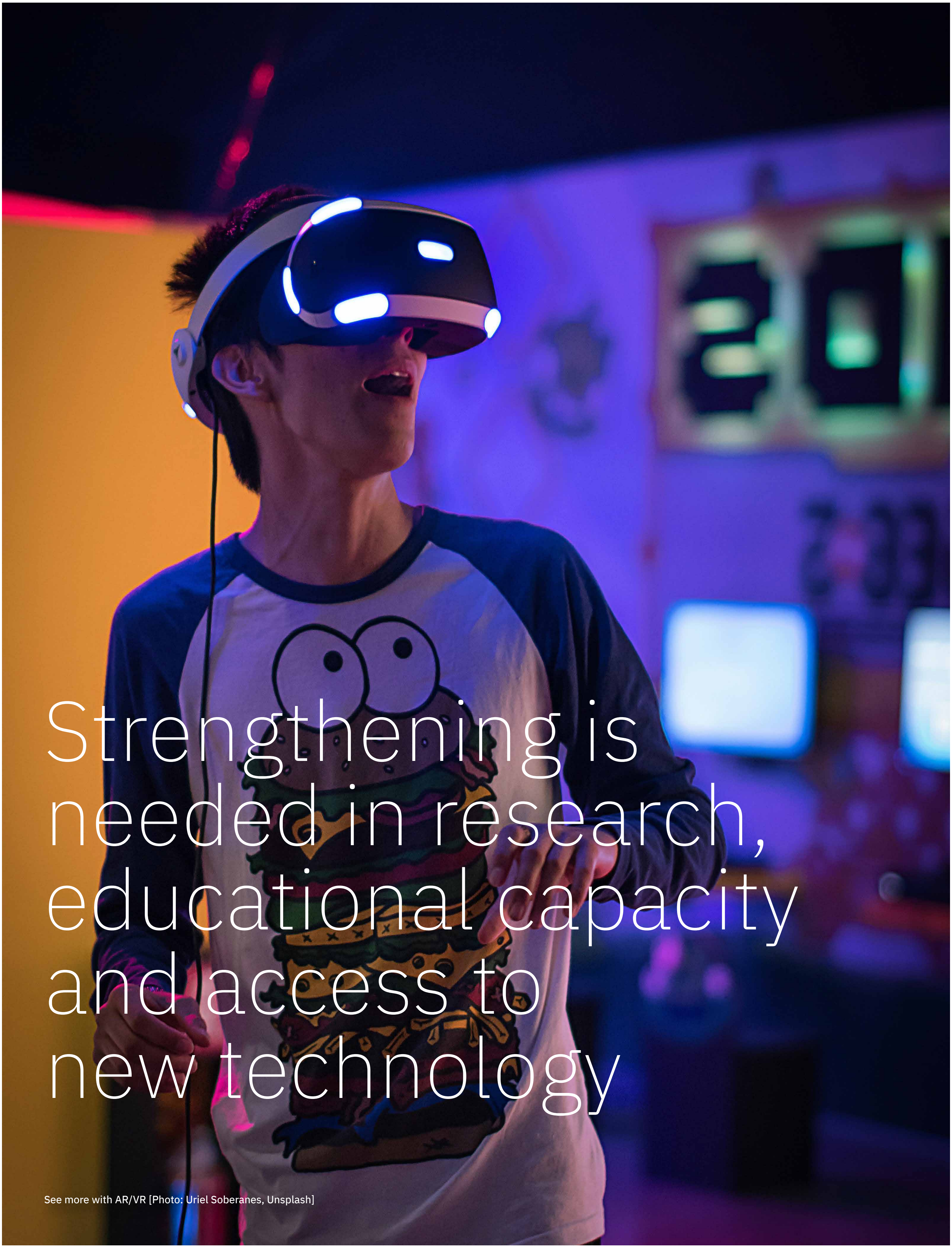
Table 4.1 summarises the numbers of students being trained as design engineers (or who have received a solid component of design *thinking* in the programme, expressed in credits/ECTS obtained), and the number of staff members within the institutions involved. The underlying data can be found in Appendix 3.

TABLE 4.1

NUMBERS OF STUDENTS BEING TRAINED AS DESIGN ENGINEERS & STAFF

	Students	EC/std/yr.	Female students	Scientific staff permanent (fte)	(Of which) Female staff
TUD	6818	46	47%	316	37%
TU/e	3826	49	38%	143	36%
UT	2011	47	37%	89	26%
WUR	4685	34	58%	67	46%
RUG	1200	43	27%	28	36%

Female engineer. They increase the labor market potential [Photo: ThisisEngineering RAEng, Unsplash]



Strengthening is needed in research, educational capacity and access to new technology

See more with AR/VR [Photo: Uriel Soberanes, Unsplash]

5

What is needed now?

This moment in time is ripe for real and achievable policies for inclusive and sustainable growth, coupled with concern for the climate, based on innovation.[34] The Key Enabling Technologies[35], given their expected major impact on society, will play a crucial role in addressing these challenges. However, to realise this promise, thoughtful *design processes* are needed that ensure a seamless connection of potentially innovative technologies to our social environment.

34 https://www.oecd.org/naec/NAEC_Mazzucato.pdf

35 These are: advanced manufacturing, advanced materials, life-science technologies, micro/nano-electronics and photonics, artificial intelligence & security and connectivity.

5.1

Strengthen Design Engineering Sciences

The design engineering sciences are the essential bridging link in the engineering chain. To strengthen them, the following is needed:

Invest in scientific personnel.

- To adequately equip the current staff in this field, both financially (funding) and in time (staff/student ratio), to realise the full potential of good design;
- To cope with the increasing teaching load, as well as to realise the international research connection. The staff-student ratio is too high. This is due to education-intensive curricula and an increasing student intake. For several programmes there is already a numerus fixus, while society demands more engineers with design qualities;
- To strengthen the research base regarding design methodology for a better understanding of how these methodologies work in design and research processes and how and when to apply them;
- To realise a larger and broader palette of cultural and gender backgrounds. A representative gender and diversity balance in design education helps strengthen social impact;
- To be able to subscribe in a targeted way to the rapidly growing number of research calls that require a transdisciplinary, design-oriented approach. This includes, for example, the new EU Horizon Europe second pillar[36] but also the imminent new KIC Culture and Creative Industries[37], the JPI Urban Europe initiatives[38] and the New European Bauhaus initiative[39] that connects the European Green Deal with our living spaces.

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36 Horizon Europe is the European Union's new research and innovation programme. Pillar 2 – Global Challenges and Industrial Competitiveness – supports direct research related to societal challenges, strengthens technological and industrial capabilities, and establishes EU-wide missions. It also includes activities of the Joint Research Centre that supports EU and national policy makers. [https://ec.europa.eu/info/horizon-europe_en].

37 The Knowledge and Innovation Community (KIC) cultural and creative industries (CCIs) are the heart and soul of Europe. They highlight both our diversity and unity, and inspire us to innovate. The cultural and creative industries are key drivers of economic growth and employment across Europe, but have been hit hard by the COVID-19 pandemic and the subsequent crisis. [https://eit.europa.eu/our-activities/call-for-eit-communities/2021].

38 The JPI (Joint Programming Initiative) Urban Europe is an international network that joins forces to strengthen research from across Europe on the vitality, liveability and accessibility of European cities. [https://www.nwo.nl/onderzoeksprogrammas/jpi-urban-europe].

39 The New European Bauhaus initiative calls on all Europeans to work together to imagine and build a sustainable and inclusive future that is attractive to all senses. [https://europa.eu/new-european-bauhaus/index_en].

Recognising the Design Engineering Sciences as a discipline in its own right

— The design sciences are traditionally housed within other disciplines or have their origins in applied professions. This sector portrait on the design engineering sciences expresses the solidarity and joint organisation of the scientific field of the design engineering sciences and thus aims at recognition as an independent discipline;

— Recognition of the interdisciplinary and integral character in funding and policy instruments: design engineering sciences are at their core interdisciplinary and integrated. However, calls and criteria from the NWO schemes are often still disciplinary oriented. This results in a weak connection of this discipline to the regular Dutch funding and policy instruments such as TTW, SGW and the Vernieuwingsimpuls (Innovation Impetus).[40] The design sciences are also represented to a limited extent in the NWO discipline codes. Recognition and understanding of the design sciences requires a broader assessment framework and appropriate policy instruments that do justice to the relevance of the discipline;

— Measuring the quality and impact of design sciences is a source of ongoing debate. Formal and informal systems in science are not always set up for the recognition of bridging functions. Also, at the KNAW and to a lesser extent KIVI and other institutional networks, the designing engineer still has insufficient prestige. Reasoning from the perspective of the social relevance of science, a more differentiated classification of the scientific disciplines within the scientific system would be justifiable. This is in line with the new policy of the VSNU 'Recognise and Appreciate', in which new assessment frameworks are put forward that emphasise the social relevance of research.

40 However, there is some shift of attention: the NWA and KIC are very open to multidisciplinary research, and within NWO's committees, space is increasingly provided for scientists with a design background.

The protein transition calls for new nutrition and adapting to new flavours

How do we design this change? [Photo: Getty Images]

Industrial Design

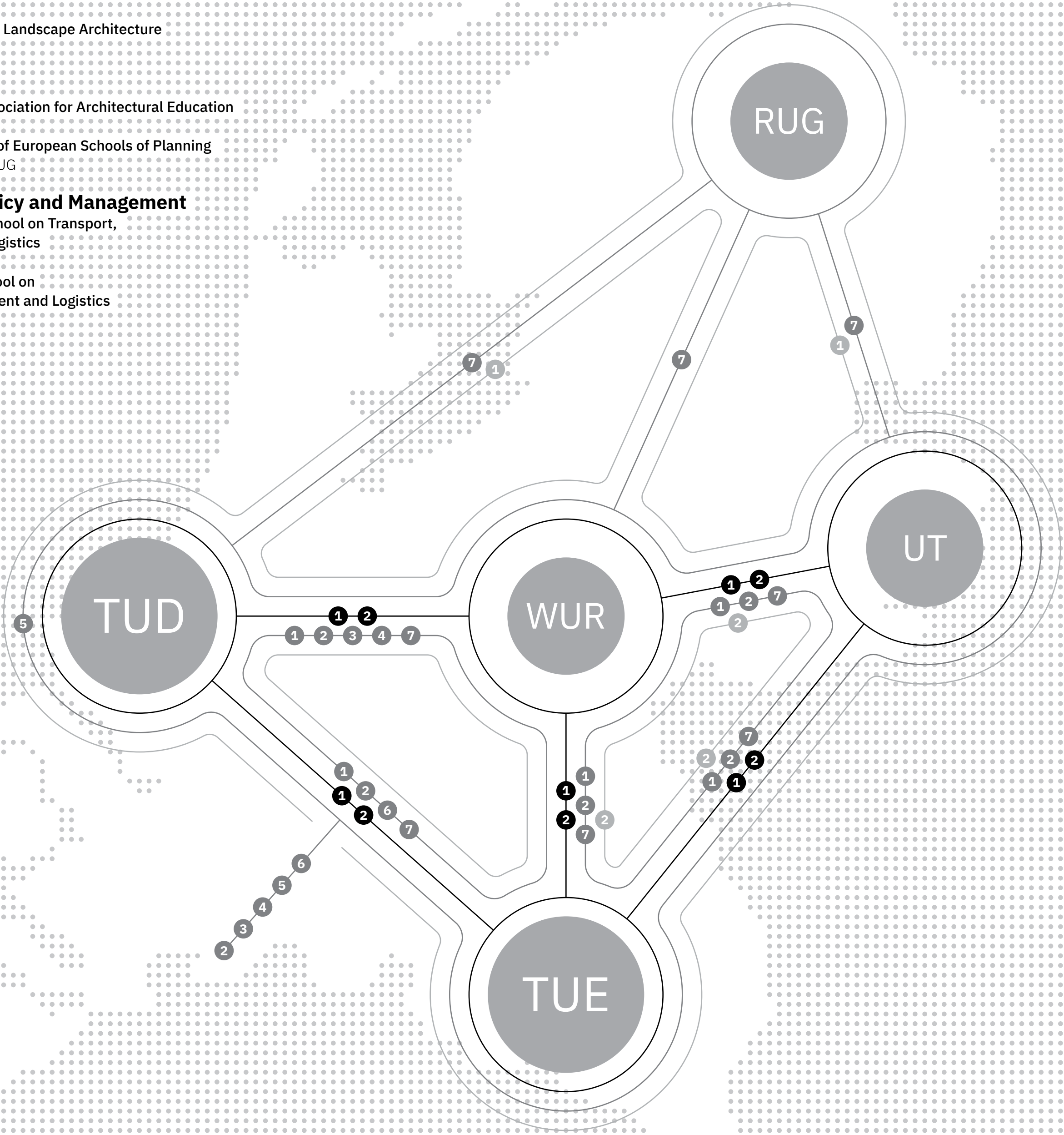
1. 4TU Design United
   TUD, TUE, UT, WUR
2. CLICKNL
   TUD, TUE, UT, WUR

Design of the Built Environment

1. 4TU Bouw
   TUD, TUE, UT, WUR
2. BTIC / Building and Technology Innovation Centre
   TUD, TUE, UT, WUR + extern
3. AMS / Amsterdam Metropolitan Solutions
   TUD, WUR + extern
4. DSL / Dutch School of Landscape Architecture
   TUD, WUR + extern
5. BauHow5
   TUD + extern
6. EAAE / European Association for Architectural Education
   TUD, TUE + extern
7. AESOP / Association of European Schools of Planning
   TUD, TUE, UT, WUR, RUG

Technology, Policy and Management

1. TRAIL / Research School on Transport, Infrastructure and Logistics
   TUD, RUG, UT
2. BETA / Research School on Operations Management and Logistics
   TUE, WUR, UT



TUD Delft University of Technology

TUE Eindhoven University of Technology

UT University of Twente

WUR Wageningen University & Research

RUG University of Groningen

APPENDIX 1

National Profile of the Three Disciplines for Education, Research, and Networking

B.1.1

Industrial Design in The Netherlands

Industrial Design is taught at Delft University of Technology (TU Delft), Eindhoven University of Technology (TU/e), and the University of Twente (UT) at both bachelor and master levels. After obtaining the master's degree, the three institutions also provide PhD programmes, substantively and administratively organised within a Graduate School.

The members also reinforce each other in the training and coaching of scientific talent by sitting on appointment advisory committees (BACs) for academic staff and on promotion committees for PhD students. Finally, employees take part in visitations aimed at evaluating education, research and research policy.

Industrial Design at TU Delft

In Delft, Industrial Design is housed within one faculty with three departments that jointly provide one bachelor's and three master's programmes. Consistent thought is given to this from three perspectives, namely the desirability from the human side, the functionality from the technology side, and the long-term workability from the organisational side. Each department and each master's programme focuses on one of the perspectives, but the research and teaching is at all times done in collaboration with others from the faculty.

The departments have the following designations: Human Centred Design, Sustainable Design Engineering, and Design, Organisation and Strategy. The master's programmes are called Design for Interaction, Integrated Product Design, and Strategic Product Design.

Industrial Design at TU/e

Eindhoven has a Faculty of Industrial Design that conducts research and provides specific education. There is one bachelor and one subsequent master within which the emphasis lies on Future Everyday and Systemic Change.

Industrial Design at the UT

The Bachelor's and Master's of Industrial Design Engineering (IDE) at the University of Twente are embedded in the Engineering Technology faculty. In the bachelor, education is provided through the Twente Education Model (TOM), which means that students design and learn the design process and their role as designers within design projects, which are organised around themes. In addition to the design projects, the bachelor's programme offers a broad introduction to the various aspects of Industrial Design, ranging from human-centred design, technical design, production, design to marketing. Whereas the bachelor lays a broad foundation, the three master's tracks provide specialisation within the Industrial Design Engineering field. These three master's tracks are: Management of Product Development (MPD), Emerging Technology Design (ETD), and Human Technology Relations (HTR). MPD focuses on studying and supporting the product development and manufacturing process. ETD focuses on how new technology can be integrated into products for the consumer market. HTR focuses on exploring and designing products that address the problems and aspirations of people at the individual, social and societal levels. Both the bachelor's and master's programmes in Industrial Design Engineering at Twente have a strong interdisciplinary character.

Networks

Design United

The design-oriented study programmes and research activities work together within 'Design United', as part of the 4TU research centre for design with the aim of strengthening the innovative power of the Dutch creative industry by building a bridge between design research and the design community and organisations/companies. Within Design United, several joint activities in the field of education and research are developed, such as the annual festival DRIVE[1] and the design research exhibitions, both within the Dutch Design Week (in cooperation with CLICKNL). Furthermore, scientists from Design United work closely together with scientists who are connected within the 4TU Humans & Technology Research Centre; this is another 4TU research centre for the strengthening of knowledge and implementation in the field of human-technology interaction and the ethical design thereof.

CLICKNL

The design faculties also make an active contribution to the Top Sector Creative Industry to increase the knowledge base of the creative professional and the innovation capacity of the Netherlands. CLICKNL draws up the Knowledge and Innovation Agenda (KIA) for the Creative Industry together with experts from the creative industry and knowledge institutions. In doing so, CLICKNL focuses on fundamental and practice-oriented research and applications.

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1 The Design Research & Innovation Festival (DRIVE) organises an annual event aimed at bringing together designers, scientists, companies and government within the framework of Dutch Design Week. The festival provides a platform for various programmes for design research and innovation in the Netherlands.

B.1.2

Design of the Built Environment in the Netherlands

Design of the Built Environment, which includes architecture, urban design, spatial planning and landscape architecture, is taught at TU Delft and TU Eindhoven, the University of Twente, Wageningen University and at the University of Groningen. The titles architect, urban designer and landscape architect are protected by the Architects Register. Conditions for registration in the Register are a qualifying Dutch (master's) degree and the completion of a so-called Professional Experience Period.

Design of the Built Environment at TU Delft

The Faculty of Architecture in Delft has four departments:

- Architecture, Architectural Engineering + Technology (AE+T);
- Management in the Built Environment (MBE);
- Urbanism.

The Department of Architecture holds a key position within the Faculty of Architecture. Architecture, as the art and doctrine of designing and (doing) building works, is an ancient science with its own tradition. The formation of theory is focused on the question of new correlations between the form, construction and function of buildings in their urban context. Through its range of high-quality courses, the department manages to attract an increasing number of students from home and abroad. Staff members and alumni play an active role in social and university networks and organisations.

The Architectural Engineering + Technology department focuses on the intimate relationship between design, its engineering and the inextricable link with technology. The social task requires an integral approach to design, including in the field of sustainability, climate, energy efficiency, shrinkage, transformation, redevelopment and health. The related issues are complex and require an approach in which fundamental and applied research and design are closely related.

The department Management in the Built Environment (MBE) strives for a sustainable built environment in which the interests of the end user and other stakeholders are the starting point. MBE focuses on solutions for the development and management of buildings, real estate portfolios and urban areas and on training the next generation of managers in the built environment.

The Urbanism department combines urban design, land use planning, landscape architecture and environmental modelling. The department is best known for its 'Dutch approach' to urbanism, which combines the creativity of design with academic research methods. This 'integral' urban construction enjoys high international prestige in professional practice, research and education.

Architecture has a joint Bachelor's of Architecture programme and three master's programmes:

- Architecture, Urbanism and Building Sciences;
- Geomatics;
- Metropolitan Analysis, Design and Engineering (MADE).

The master's programme in Architecture, Urbanism and Building Sciences is based on renowned Dutch practice in architecture, spatial planning and the built environment professions and is internationally oriented thanks to its multinational faculty of staff and students. The educational approach is based on the Dutch tradition of multi-disciplinary work, where students work in groups to develop integrated solutions for the built environment. This programme consists of five different tracks within which students can specialise: Architecture;

- Building Technology;
- Landscape Architecture;
- Management in the Built Environment; Urbanism.

The master's programme in Geomatics provides vital spatial knowledge about the built environment. Students learn to use advanced techniques in data collection and analysis, spatial information modelling, and data visualisation. They learn about the use, management, and application of geographic data to solve real-world problems in innovative ways.

And finally, MADE is an interdisciplinary programme of both Delft University of Technology and Wageningen University & Research. In this master, students work with complex problems resulting from urbanisation. These include mobility and logistics, water and waste management, and energy and food security.

Design of the Built Environment at TU/e

The Faculty of Architecture in Eindhoven consists of four departments, namely Architecture, Urban Design and Engineering; Building Physics and Services; Structural Engineering and Design; and Urban Systems and Real Estate. The last three are housed in the Civil Engineering Sector. The combination of architecture, urban design, civil engineering and planning makes the faculty unique. Both the master's and bachelor's programmes are taught in English and attract a wide range of students from home and abroad.

The Architecture, Urbanism and Building Sciences (AUBS) bachelor's programme is a faculty-wide programme in which architectural and urban design play a key role. Several projects are founded on the principles of Challenge Based Learning, through which students learn to communicate and collaborate with other disciplines on cross-disciplinary assignments with a socially urgent theme.

The Master's in Architecture Building and Planning (ABP) responds to the advancing globalisation of the world that poses increasing challenges to mankind in terms of nature, demography, society and space. In the various tracks of this master's programme, students are engaged in transforming these challenges into smart, healthy and sustainable solutions for the built environment.

The combination of science, technology and design makes it possible to guarantee the creative freedom of the design and to subsequently subject the design decisions to scientifically grounded analysis and criticism. Because of the close relationship with adjacent disciplines, the so-called double tracks are increasing in popularity among students. This allows students to combine a full-fledged education in architectural design with disciplines such as urban design, structural design, building physics design or urban planning.

Design of the Built Environment at the UT

At the University of Twente, a multidisciplinary design and problem-solving approach is central. This means that technology is always linked to people. This leads to the conviction that the only way to cope with problems such as climate change, the energy transition, increasing risks of water scarcity and overflows, ongoing urbanisation and the drive for circular materialisation is to rethink the way we plan, design, build, use and renew the built environment. The Construction Management & Engineering group plays a key role in dealing with these societal challenges through the design of new process approaches, methods and technologies. This can provide innovative solutions that make our critical infrastructure networks safer, more sustainable, more efficient, more effective and more resilient by improving the integration into and performance of the construction industry.

With several other programmes such as Spatial Engineering, UT focuses on addressing these problems by combining technical and socioeconomic knowledge with a strong foundation of spatial data analysis and modelling. Consider, for example, new design solutions for the distribution of limited natural resources; water, energy or food security; catastrophic impacts of natural and man-made disasters; or the unplanned development of megacities.

Design of the Built Environment at the WUR

Landscape architecture and spatial planning are taught at Wageningen at both the bachelor's and master's levels. Students study the intentional design and governance of landscapes at different scales. The programmes focus on the process and design of spatial interventions, accompanied by a thorough academic reflection on both process and results. The objectives of the programme are to create, improve, maintain and protect (urban) landscapes in order to make them functional, aesthetic and sustainable. The bachelor's and master's programmes have two majors, Landscape Architecture and Spatial Planning. Graduates of the Landscape Architecture major are skilled in architectural composition, the role of various means of representation, and the exploration of relevant reference situations. Graduates of the Spatial Planning major learn to generate problem solutions in interdisciplinary and multidisciplinary teams, and have knowledge of public planning management and communication with interested parties. They learn a variety of planning tools and are able to evaluate the consequences of their plans.

To respond to the great challenges of our time, such as climate change and biodiversity loss, landscape architecture and spatial planning focus their research on physical transformations of landscapes and cities through planning and design interventions. Landscape architecture and spatial planning cultivate a trans-disciplinary academic culture to integrate knowledge from multiple disciplines into projects around "real-world" situations. Major challenges occur simultaneously and require an integrated approach to ensure that a solution to one problem does not create or exacerbate other problems (so-called "wicked problems"). Evidence-based, technically and socially feasible solutions are sought. Spatial designs, design guidelines, policies or plans are the result of such research, as well as analysis of and reflections on such designs, policies and plans.

Design of the Built Environment at the RUG

The Faculty of Spatial Sciences offers three courses in which spatial issues are linked to solution-oriented interventions. To this end, both an understanding of space (technical, rational) and an understanding of the decision-making processes (institutional, communicative) are taught. After all, a spatial design is only effective if it convinces both the engineer and the politician and, through implementation, leads to actual improvement for society. Design and planning, and spatial and institutional design are thus united in the Bachelor of Spatial Planning & Design, the Master of Society, Sustainability & Planning and the Master of Environment & Infrastructure Planning. This line is continued in the Graduate School, where PhD research takes place at the interface of spatial and institutional design, both from an architectural/urban/landscape design perspective, and from an institutional administrative and planning perspective.

The Faculty of Spatial Sciences, together with the University Medical Center Groningen and the Faculty of Arts, carries the Knowledge Center for Architecture, Urban Planning and Health (organisationally housed with the latter), which offers a master's programme in the field of Healthy Cities and the architecture of health care.

The Faculty of Spatial Sciences also distinguishes itself in research by connecting spatial and institutional design. The research theme Spatial & Institutional Design falls under the umbrella of the faculty research programme tWIST – Towards Wellbeing, Innovation and Spatial Transformation. This programme focuses on urban planning and policy making, investigating on the one hand processes of spatial design (including the analysis and design of the physical environment and its social use), and on the other hand institutional design (including the analysis and adaptation of regulations, organisation and governance). For example, research is being done into the role and position of spatial design(ers) in complex planning and design processes; into methods and techniques for analysing spatial and institutional issues; and into the organisation and influence of public-private partnerships and citizen participation in spatial planning. The research in the field of spatial analysis and design is bundled in CASUS – Centre for Advanced Studies in Urban Science and Design – to which about 10 researchers, full/associate/assistant professors, and about eight PhD students are connected.

Networks

RUG/WUR research

Research into spatial quality takes place within the Flood Protection Program, in collaboration with – and financed by - 12 water boards, STOWA, Deltares, consulting firms, and the College of Government Advisors (CRA). WUR and RUG also work together in the field of nature-inclusive agriculture. In addition, the Faculty of Spatial Sciences has a number of special cooperative relationships with a number of Dutch civil society partners in its research on spatial/institutional design: the Directorate-General for Public Works and Water Management, the Kadaster, and the Special Envoy for International Water Affairs.

International collaborations: Ensystra and Making City

Examples of international collaborations include the Marie Curie ITN programme 'Energy Systems in Transition' (a collaboration of RUG with the University of Edinburgh, Aalborg University, Europa-Universitaet Flensburg, Chalmers Technical University, Offshore Renewable Energies Catapult (Scotland), World Wind Association (Germany), Norwegian Energy Partners, Engie Energie Nederland, and the Swedish Energy Agency), and the Horizon 2020 project 'Making City' in which 5 European universities (including RUG), 4 research institutes, 9 cities, 4 housing cooperatives, and 12 companies and organisations are researching CO2-neutral neighbourhoods.

4TU.BOUW, Center of Excellence for the Built Environment

The 4TU.BOUW is the research cooperation between the technical universities in the field of construction. The 4TU.BOUW is a collaboration between designing and constructing technical sciences. Architecture Delft brings in things like architecture, urban planning, construction technology and management. Wageningen contributes with landscape architecture, urban design and spatial planning. The University of Twente focuses on the design, digitisation and realisation of the underlying infrastructure.

Building and Technology Innovation Centre (BTIC)

In 2018, the Building and Technology Innovation Centre[2] was initiated to organise and stimulate the necessary innovation in the building and technology sector to achieve the 2050 goals in the built environment. These goals include a CO2-free, circular and climate-adaptive building environment. The BTIC stimulates and facilitates the initiation of long-term, broad integrated research and innovation programmes on:

- Energy transition of existing buildings;
- Circular building economy; Digitisation;
- Infrastructure renewal;
- Climate adaptation.

2 BTIC is a collaboration between knowledge institutions (4TU Bouw, Universities of Applied Sciences, TNO), the construction industry (Bouwend Nederland, Techniek NL, Koninklijke Ingenieurs NL) and the government (Ministries of the Interior, Infrastructure and Water and Economic Affairs). [https://btic.nu/]

Amsterdam Institute for Advanced Metropolitan Solutions (AMS)

AMS Institute is an Amsterdam-based knowledge institution dedicated to metropolitan solutions. The institute was founded in 2014 by TU Delft, Wageningen UR and MIT. It brings forth talent, technology-driven concepts and partnerships to address issues around mobility, energy transition, circularity, food systems, climate resilience and responsible digitalisation in the metropolitan context. Located at the Marineterrein, the institute has urban experimentation as a common thread in all its activities. With a two-year engineering and professional education programme; a research and innovation portfolio of EUR 100 million; a start-up programme; and strategic collaboration partners, AMS Institute is the place to make a difference for our cities with talent, ideas and partners.

BauHow5

Internationally, TU Delft's Faculty of Architecture is a founding partner of the BauHow5 alliance between TU Delft, UCL Bartlett, Chalmers, TU Munich, and ETH Zurich, with active groups on topics such as circularity, inclusion, diversity and equality, and doctoral education.

Dutch School of Landscape architecture (DSL)

The Dutch School of Landscape architecture is a platform of all Dutch educations teaching landscape architecture: Wageningen University (WO, BSc and MSc); TU Delft (MSc); Academy of Architecture Amsterdam (HBO MA); Van Hall Larenstein and HAS Den Bosch (HBO BA). Within the DSL, experiences about education are exchanged and efforts are made to streamline courses, as well as the organising of national network meetings on current topics.

EAAE

TU Delft and TU Eindhoven are active members of the European Association for Architectural Education (EAAE). The EAAE is an international non-profit membership organisation for European schools of architecture, registered in Belgium. The association's mission is to build a network of European architecture schools, to promote discussions, exchanges and a common policy in Europe to improve the quality of architecture education. The EAAE represents the interests of its member schools as institutions and academic environments.

AESOP

The Association of European Schools of Planning (AESOP) is an organisation similar to the EAAE but with a specific focus on spatial planning. TU Delft, TU Eindhoven, Wageningen University, University of Twente and the University of Groningen are all members.

B.1.3

Technology, Policy and Management in the Netherlands

Technology, Policy & Management at TUD

The faculty of Technology, Policy & Management (TPM) at TU Delft combines governance with an engineering and values perspective on socio-technical systems. The faculty aims to contribute to sustainable solutions to complex societal problems through the analysis of socio-technical systems and the design of interventions in these systems. Empirical and model-based techniques are combined in qualitative and quantitative research on such interventions. The ambition is to train students to be engineers who combine their technical skills with a solid background in social sciences and humanities. In addition, TPM provides service education to virtually all degree programmes in Delft in the areas of ethics and methodology, entrepreneurship, and language and academic skills. This service education complements the disciplinary knowledge and skills taught by the various monodisciplinary engineering programmes, and contributes to the 'T-shaped' profile[3] of TU Delft graduates.

Technical Business Administration at TU/e

Technical Business Administration at TU Eindhoven aims to deepen knowledge within the fields of operations management, innovation management, information systems, work psychology and business economics with a view to applying that knowledge to current industrial design problems. The faculty has a bachelor's programme in Industrial Engineering and master's programmes in Operations Management & Logistics and Innovation Management, where students use disciplinary knowledge to design solutions in integration courses and in bachelor's and master's final projects. Most of the research and these final projects are conducted in collaboration with companies and other organisations and therefore deal with current design problems from the field.

3 A graduate with T-shaped profile possesses, on the one hand, in-depth skills and knowledge in a specific subject (the vertical leg of the T) coupled with more general broader skills and knowledge (the horizontal leg of the T).

Industrial Engineering and Management at the UT

Industrial Engineering and Management at the University of Twente is called Industrial Engineering & Management (IEM). The relevant bachelor's and master's programmes have been assessed as the best Industrial Engineering and Management programmes for several years, and carry the distinction of TOP programme. The bachelor is characterised by challenge-based/project-driven education, in which students are presented with challenging design issues by a company/organisation as a project assignment, around which the education is organised. Knowledge and skills gained are applied immediately. Many projects are interdisciplinary – students work together with other engineering students from e.g., Industrial Design, Mechanical Engineering, Civil Engineering and Technical Mathematics. The master's programme in Industrial Engineering & Management at the University of Twente has the graduation specialisation in Production and Logistics Management (PLM), as well as the Financial Engineering & Management (FEM) and Healthcare Technology and Management (HCTM) specialisations, which are unique in the Netherlands. Financial Engineering & Management focuses on identifying, analysing and managing financial risks, by designing financial products and funding models for a wide range of industries. Healthcare Technology and Management focuses on the optimisation of healthcare processes through health economic evaluation of healthcare innovations and healthcare logistics/operations management. The programme maintains close cooperation with the (manufacturing and service) industry, financial sector and healthcare sector. Entrepreneurship is strongly encouraged. This has resulted in many successful spin-offs, such as Booking.com, Thuisbezorgd.nl, and SciSports. Graduation projects in the bachelor and master take place in residence in the aforementioned industries. The programme encourages students to gain an experience abroad in the bachelor and master phase, and the programme facilitates this without study delay in the bachelor-minor and master elective (both one semester). This elective space is also often used to broaden by taking a semester of master's courses from another engineering programme (from University of Twente or from other universities at home and abroad).

Technical Management and Business Administration at the WUR

Technical Administration and Business Administration at Wageningen University consists of two chair groups in the Social Science Group (SSG), namely Public Administration & Policy (PAP) and Business Management & Organisation (BMO). According to the Wageningen way, PAP and BMO education contribute not only to the Social Science Group programmes but also to STEM programmes. Research is embedded with research school WASS, and is focused on developing fundamental insights that have social impact. The Business Management & Organisation chair group has a leading role in setting up and rolling out the 'entrepreneurship' programme through which all students – bachelor, master, PhD – learn at least some and possibly a lot about entrepreneurship in a technical environment.

Engineering Management and Technology & Operations Management at RUG

The design component of the Bachelor of Industrial Engineering & Management (IEM) provides a unique focus within the Faculty of Science and Engineering (FSE). The fundamentals of natural sciences, engineering and management in the programme are rooted in the disciplines within the Faculty of Science and Engineering and the Faculty of Economics and Business (FEB). Subsequently, students learn to bridge to applications in business in a number of steps through specific design methodology courses within Industrial Engineering & Management, three in the bachelor's and three in the master's programmes. Design is thus anchored in the programme, something that alumni still recognise after years as an added value. An important design-oriented track within the Bachelor and Master of Industrial Engineering & Management is the track Production Technology & Logistics with the specialisations Production Logistics Engineering and Systems, Control and Automation.

The Faculty of Economics and Business Administration offers several programmes that focus on technology, policy and management. In the Bachelor of Business Administration, students can choose the Technology Management specialisation. The Master of Technology and Operations Management (TOM) focuses on designing processes and operations and making decisions in complex environments in which the latest technologies, digitisation and data play an important role.

There are two research groups within the Faculty of Science and Engineering that conduct research within the domain of technical business administration, namely (i) optimisation and decision systems and (ii) smart manufacturing systems. These groups – within the broad areas of smart transportation and logistics, smart grid and energy systems, socio-technical behavioural systems – conduct research on science challenges arising from the coexistence of physical-technical components and socio-economic components.

Within the Faculty of Economics and Business Administration, the OPERA research programme focuses on modelling, analysing and designing processes and operations, bringing together knowledge from operations management, operations research and industrial engineering. This involves intensive collaboration with other research groups, for example in the fields of HRM and innovation. The two research groups involved within the Faculty of Science and Engineering participate in research collaborations with international partners and with partners at technical universities in the Netherlands.

Networks

TRAIL and BETA

The research groups related to Technical Management and Business Administration from the five universities involved cooperate in the field of research and graduate education. In the interuniversity research schools TRAIL and BETA and within the graduate programme Operations Management and Logistics the research groups cooperate in the field of research and in education for PhD and master's students. TRAIL is the research school on Transport, Infrastructure and Logistics in which six Dutch universities participate, including TU Delft, TU Eindhoven, University of Twente and the University of Groningen. BETA is the research school on Operations Management and Logistics, in which six Dutch and two Belgian universities participate, including TU Eindhoven, Wageningen University, and the University of Twente. TRAIL and BETA have the joint graduate programme Operations Management & Logistics in which courses for PhD and master's students are offered in the field of operations management and logistics. BETA also organises a biennial conference for the field of operations management and logistics. In addition, many projects are done in a cooperation between two or more research groups within top sectors such as HTSM, Logistics and Energy, and for Care within ZonMw. The 'captain of science' of the HTSM top sector and two of the three theme leaders of the logistics top sector come from different Technical Management and Business Administration research groups.

APPENDIX 2

The eight categories of Key Enabling Methodologies

These eight categories of KEMs are indispensable in the context of addressing societal challenges and shaping transitions. Each category represents a collection of methods, processes, strategies, and research questions that are related because of the purpose for which they are deployed[4].

4 https://kems.clicknl.nl/inleiding-op-de-agenda-1/1.-inleiding/1.3-categorieen-van-kems

Vision and Imagination

Any mission requires that we know what we are heading for. Sometimes that goal is obvious, but more often it requires designing that goal, making an inspiring vision of the future visible and tangible through the use of imagination, and thereby providing direction for change. KEMs in this category help map the current world, imagine new worlds, and see phenomena and problems differently.

Research Questions
How is a vision or imagination shaped? Does that say anything about its quality? How does a desirable vision contribute to social change processes? How can visions of the future be linked to decision-making?

Participation and co-creation

Missions involve many players with divergent interests, from citizens and companies to government agencies and domain experts. You want to involve them in the process because of the knowledge and experience they bring to the table, to enable them to take the initiative, and to achieve commitment and support. KEMs in this category help to involve stakeholders, to go through the process systematically, to analyse and understand the context of issues, and to develop new propositions.

Research Questions
What do these methods deliver socially and is it possible to demonstrate this? What do individual methods deliver and especially which combination/approach works, why and in which situations? Who do we need on board when and what is their input, expectation, responsibility and connection? How should various methods be adapted to the specific context in which they are used?

Behaviour and empowerment

For a transition to be successful, a change in behaviour is often required. For example, to eat less meat or fly less. In addition, people must be empowered to make conscious choices and be offered the opportunity to take charge themselves. KEMs in this category help to develop, test and validate an intervention to change people's behaviour directly (through motivation) or indirectly (through influence).

Research Questions
What does it take to motivate people to adopt interventions? Which method works best and why? What is the underlying mechanism? When is personalisation effective? Can we combine interventions at the individual level with interventions at the environmental level? What moral aspects play a role? For whom are what data available?

Experimental environments

Transitions are not easy to manage and related issues are often surrounded by uncertainties and ambiguous information. Room for experimentation is needed in the early stages of the development process of innovations. Further in the process, there should be room to test and adjust the effects of developed interventions in simulated and/or real-life contexts. KEMs in this category help set up these experimental environments and provide methods of working and experimenting.

Research Questions

What conditions must an experimental environment meet to generate new routes and directions? How are actors encouraged to contribute and provide feedback? How is information secured, clustered and made accessible? How do we ensure that (different) public values are safeguarded? How are constants and variables determined in an experimental environment under development? How do you gain insights about experiences aimed at unknown future contexts? What is the design, establishment and validation of interdisciplinary and trans-disciplinary methodologies and practices when so many stakeholders are involved in the research process?

Value creation and scaling up

Current societal challenges require effective interventions and scaling up of innovations in a relatively short period of time. The speed with which transitions can be realised goes hand in hand with the ability and speed to create new value for society. The (changing) relationships in terms of ownership and profit play a role in this, and issues surrounding steering and governance come into the picture. KEMs in this category help to structure this process and to validate and test it at an early stage.

Research Questions

How can economic, cultural, social and environmental value creation be combined? What does a minimal viable proposition look like? Which methods are suitable to better understand and learn about the diffused process of scaling up? What are performance indicators for the design and realisation of collaborative business models aimed at social transitions? How can alignment of stakeholders be achieved? What collaborations and alliances of knowledge disciplines and research traditions are necessary? In what way can value created within the process of social transitions be cashed in? And who will receive the profits from this, and when, and in what way?

Institutional Change

In addition to the desires and capabilities of citizens and stakeholders, the organisation in and around the contexts of transition issues has a crucial influence on the desired changes. Institutional change is a response to technical and societal change, and at the same time, these changes can in turn bring about institutional change. KEMs in this category provide insight into the behaviour of institutions and help to develop structures and procedures appropriate to the changes.

Research Questions

What is the role of new organisational forms in mobilising resources, commitment, and knowledge about social problems and possible innovative solutions? What is the role of leadership in bringing about institutional change, and what new forms of leadership are needed to do so? How can a radically new solution to a social problem gain support among stakeholders? What can lead to breaking through existing power structures that have an interest in maintaining the status quo? What methods can integrate the insights of emergence and design methodology?

System Change

Transitions require a transformation or tilting of an existing system. A characteristic of systems is that they are difficult to define and unpredictable. Furthermore, systems have a multitude of elements and (mutual) relationships, creating a complexity that is difficult to manage or change. Developing for and on systems is therefore a dynamic issue. KEMs in this category help to work in a system-oriented and future-oriented way, and to elicit debate and feedback.

Research Questions

How do we deal with issues in "chaos" where there are various interests competing over where to go within a system? What is an appropriate participation model? Which actors should be involved at what stage? What are appropriate methods for designing systemic interventions that focus on the social and emotional dimensions of change, e.g., influencing mental models, paradigm shifts, and human relationships? How do we encourage transdisciplinary action research and make science more entrepreneurial? How can we better monitor systemic change? How can we understand long-term change and develop indicators of change? How can we help system actors develop skills that encourage dialogue and adaptive leadership? How do we help system actors be reflexive about how they engage with system change?

Monitoring and effect measurement

Because of the long horizon and the unpredictable nature of systems (and changes to them), it is especially relevant to transition issues to monitor and (interim) evaluate the effects of interventions. In this way, knowledge is gained about the possible effects of the way in which the intervention was carried out, which can then be fed back into the process in order to support iterative development and adjustment. KEMs in this category help to measure effects of interventions and monitor the impact on the system.

Research Questions

How can we formulate output, outcome, and impact indicators relevant to the transition goal and intermediate goals that are tailored to the mission as much as possible? What is the effect of the measurable and available indicators on the shape and direction of our interventions? How can we test the effectiveness and efficiency of our design process? What methods do we need to apply and/or develop in order to make appropriate estimates (prognosis) and classifications (diagnosis, screening, monitoring) from new types (diverse, new, unstructured, incomplete) of data? How to identify relevant data sources and data types for monitoring and evaluating transitions, including validating data/information? How to ensure that information generated by AI and big data is explainable, understandable and accepted?

APPENDIX 3

Underlying data of students and staff within designing disciplines

Education: Scope and credits earned (ECs)

UNI	DESIGN PROGRAMME	BACHELOR'S STUDENTS	MASTER'S STUDENTS	ECTS/YEAR	% FEMALE	STAFF/STUDENT RATIO
TUD	Industrial Design	1151		51795	54%	1 / 25
	Design for Interaction		289	13005	65%	1 / 25
	Integrated Product Design		301	13545	39%	1 / 25
	Strategic Product Design		308	13860	52%	1 / 25
	Architecture	1360		61200	50%	1 / 22
	Architecture, Urbanism and Building Sciences		1389	69165	50%	1 / 22
	Geomatics		65	2925	48%	1 / 22
	Geographical Information Management and Applications		36	1620	44%	1 / 22
	Metropolitan Analysis, Design and Engineering		82	3690	43%	1 / 22
	Technical Management	938		42210	34%	1 / 17
	Complex Systems Engineering and Management		234	10530	31%	1 / 17
	Engineering and Policy Analysis		175	7875	35%	1 / 17
	Management of Technology		268	12060	23%	1 / 17
	Industrial Ecology (shared with Leiden)		222	9990	50%	1 / 17
	Total	**3449**	**3369**	**313470**		

>>>

Education: Scope and credits earned (ECs)

UNI	DESIGN PROGRAMME	BACHELOR'S STUDENTS	MASTER'S STUDENTS	ECTS/YEAR	% FEMALE	STAFF/STUDENT RATIO
TU/e	Industrial Design	568	258	37420	47%	1 / 22
	Architecture	609	462	56950	40%	1 / 36
	Technical Business Administration	714	662	69000	25%	1 / 26
	Human-Technology Interaction and Ethics	385	168	25000	55%	1 / 23
	Total	**2276**	**1550**	**188370**		
UT	Industrial Design	461	262	33310	45%	1 / 25
	*Creative Technology**	*417*		*20650*	*36%*	
	*Interaction Technology**		*178*	*7140*	*54%*	
	Industrial Engineering & Management	435	258	33160	25%	1 / 15
	Total	**1313**	**698**	**94260**		
WUR	Business & Consumer Sciences	506		20240	48%	
	Biotechnology	320	405	11600	30/40%	
	Communication & Health		159	6360	88%	
	Development & Rural Innovation		74	2960	65%	
	Economy & Policy	190		7600	32%	
	Geo-Information Science		145	2900	34%	
	Health & Society	185		7400	91%	
	International Development Studies		283	11320	75%	
	International Land & Water Management	292	151	8860	42%	
	Landscape Architecture & Planning		134	5360	54%	
	Landscape Architecture & Spatial Planning	293		11720	45%	
	Management, Economics & Consumer Studies		353	14120	50%	
	Metropolitan Design, Analysis & Engineering (joint degree)		82	3280	43%	
	Nutrition & Health		502	20080	88%	
	Urban Environmental Management		128	5120	59%	
	Food & Health	483		19320	89%	
	Total	**2269**	**2416**	**158240**		
RUG	*BSc* Spatial Planning & Design	307		13815	33%	
	MSc Environmental & Infrastructural Planning		95	4295	30%	
	MSc Society, Sustainability & Planning		35	1575	51%	
	Architecture, Urbanism & Health	50	10	3000	70%	
	Industrial Engineering & Management	**49	**20	**2685	23%	
	Business Administration *(Technology Management profile)*	291		13882	30%	
	Technology & Operations Management		140	5017	21%	
	Total	**697**	**503**	**51829**		

1 *Definition: number of students enrolled as of 1 October 2019.*

2 *Definition: number of students x average number of credits obtained in the curriculum or design-related subject.*

3 *Definition: number of students per design study programme per permanent staff member. Only indicated where permanent staff is fully employed in the relevant design programme concerned.*

* *The programmes Creative Technology & Interaction Technology are mentioned because in terms of content they belong to the design engineering sciences sector portrait; however, they have already been included in the earlier sectoral portraits of Technology and Beta, which is why we do not include the number of students here.*

** *A large proportion of the students have already been counted in other sector plans. We therefore present here only 10% of the total number of students. However, the entire programme tackles design in the same way as other programmes mentioned in this sector portrait.*

Scientific Staff (permanent & temporary)

UNI	UNIT				STAFF *(IN FTE)*
			Permanent		**Temporary**
		Total	**% Female**	**Total**	**% Female**
TUD	Industrial Design	81	*45%*	100	*40%*
	Architecture	135	*37%*	156	*37%*
	Technology, Policy & Management	100	*30%*	148	*45%*
	Total	**316**		**404**	
TE/e	Industrial Design	37	*39%*	73	*63%*
	Architecture	30	*35%*	90	*37%*
	Technical Business Administration	52	*40%*	203	*37%*
	Human-Technology Interaction & Ethics	24	*21%*	63	*60%*
	Total	**143**		**429**	
UT	Industrial Design	29	*21%*	16	*51%*
	DesignLab			4	*64%*
	Construction Management & Engineering	15,2	*21%*	16,1	*45%*
	Industrial Engineering & Management	45	*30%*	15	*40%*
	Total	**89,2**		**51,1**	
WUR	Business Management & Organisation	7,9	*38%*	8,5	*91%*
	Environmental Technology	12,2	*20%*	32,9	*55%*
	Human Nutrition & Health	27,2	*64%*	71,4	*86%*
	Landscape Architecture & Spatial Planning	11,6	*33%*	20,5	*58%*
	Public Administration & Policy	7,60	*47%*	9	*39%*
	Total	**66,5**		**142,3**	
RUG	Spatial Sciences and Architecture, Urbanism and Health	14	*57%*	10	*90%*
	Technical Business Administration and Technology & Operations Management	13,9	*14%*	7,4	*31%*
	Total	**27,9**		**17,4**	

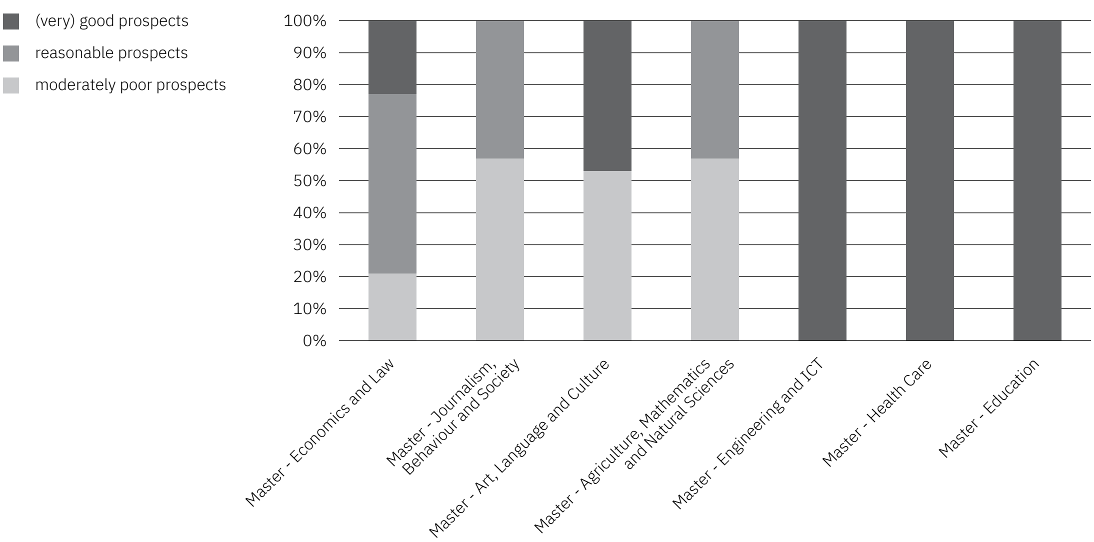
1 *Definition: faculty+ = Assistant, Associate and Full Professor & Tenure trackers (with permanent prospects); reference date 31-12-2020.*

2 *Definition: temporary WP: PhD's, PDEng & postdocs; reference date 31-12-2020.*

APPENDIX 4

Labour market perspective

Distribution of labour market perspectives within scientific education, EN (2024)



Source: ROA (POA)

Labour demand for university graduates

	JOB OFFERINGS UNTIL 2024	INFLOW UNTIL 2024
Economics and Law	75100	92800
Journalism, Behaviour and Society	29700	38600
Art, Language and Culture	27900	27100
Agriculture, Mathematics and Natural Sciences	25600	31400
Engineering and ICT	**50800**	**32600**
Health Care	48900	30000
Education	17600	13600

Source: ROA (AIS)

Colophon

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We face major design challenges

Design
Engineering
Sciences

DES

This sector portrait of the Design Engineering Sciences describes the common denominator of the various design disciplines in the Netherlands. In the process of writing this sector portrait, we jointly determined where our strength lies and where we can make a concrete contribution to solving social problems.