SELF-EVALUATION REPORT

Research Assessment 2016-2021

TU/e
EINDHOVEN UNIVERSITY OF TECHNOLOGY

DEPARTMENT OF THE BUILT ENVIRONMENT

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Preface

It is with appropriate pride that we present here to you the self-evaluation report written by the Department of the Built Environment of Eindhoven University of Technology (TU/e), as part of its research assessment over the period 2016-2021.

Looking back, it was quite an eventful period, characterized by financial concerns as a result of declining student numbers in the preceding years. This urged the department to make firm strategic choices in order to guarantee its continuity in the long term. As dean and vice-dean, we both started our terms halfway through the evaluation period, after which we quickly had to shift into crisis mode because of the global covid-19 pandemic. The focus on crisis management, strategic adjustments and the efforts as a new department board to get a grip on the situation and do the right things at the right time, explain why the research assessment was eventually pushed past the 2022 year mark. Also, halfway through the current evaluation period, the TU/e presented and rolled out its strategy for the new decade and the department adjusted its course accordingly as can be read in the Built Environment Strategic Plan 2020-2030.

Now we are in the next phase, and the report in front of you exudes the atmosphere of a department in transition, with more than enough material for reflection on the policy pursued and plenty of room for discussion on the most desirable further developments on the way to a bright future, we believe.

The thread running through the report is the strategic choice to strengthen the department's **research profile** from 2014 on (and even already in the years before). And with this, an improved balance between education and research and, ultimately, an adjustment of the educational curriculum. This includes the ambition to be internationally recognized for high quality research and academic excellence. The numbers and facts presented in the self-evaluation report show that the course has indeed been changed successfully, and we scheduled ample time for the peer review committee to verify this during the site visit. The department was able to achieve its strong performance because we managed to strengthen our groups with a pool of young academic talents and we invested in additional unique and large-scale research facilities. This impetus was made possible largely because of our efforts to maximize opportunities provided by the government, the university and industry. While this has ensured a solid foundation for the research in the department, it has to be said that there is still a degree of imbalance in the contributions to education and research between the four disciplinary groups within the department. Precisely this will have our attention in the coming period.

Another clearly identifiable thread in the report is that we increased the department's focus on valorization and impact, by grouping ourselves around a selected number of **societal themes**. The objective was, and still is, that such themes will increase the visibility of the department. The original approach to embed the themes in the department had the characteristics of a matrix organization. Despite the energetic start, however, due to many reasons this did not bring the results we aimed for. In the past years, the department has taken a different approach by building strategic collaborations and thus creating incentives for bottom-up initiatives. As part of this, we have taken active roles in the regional Urban Development Initiative and the TU/e's new institutes in the fields of energy and artificial intelligence, aligning the institutes' roadmaps with our own ambitions related to the energy transition, sustainability (with a focus on circularity as a tool) and inclusiveness.
By doing so, we have been able to position ourselves in strong ecosystems both within and outside the university.

As department we strive for **one united built environment**. Uniting the rich variety of excellent disciplinary foundations in our department, encouraging cross-disciplinary connections and team science, and at the same time uniting all our colleagues in the sense of a one-community feeling.

We hope that the self-evaluation report is engaging and brings the committee inspiration for the site visit in March 2023. We are very much looking forward to it!

Prof.dr.ir. Theo Salet, dean
Prof.dr.ir. Maarten Hornikx, vice-dean

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1. Introduction

1.1. THE DEPARTMENT IN A NUTSHELL

The Department of the Built Environment (established 1967) is one of nine departments of Eindhoven University of Technology. From its foundation, the department focuses on engineering and technology of civil structures and materials and architecture. In terms of education, the department educates cross-disciplinary engineers with strong collaborative skills. Over the decades, the department has developed and has distinguished itself both nationally and internationally, being a department aiming at the built environment where engineering and technological disciplines work together with design and human behaviour disciplines under one roof. The department virtually harbours all built environment disciplines in one house, ranging from building physics, building services, building materials, structural design and construction technology, to architecture, urban planning, planning and management. This unique profile is reflected by both the research and the education of the department.

1.2. ORGANIZATION AND GOVERNANCE

1.2.1. DEPARTMENTAL BOARD

The Board of the department is responsible for the general management of the department and reports to the university Executive Board. It is responsible for the organization of the education and research programs in the department. The department board consists of 3 members, supported by several advisory members and a secretary. The dean is chair of the department board and reports directly to the university's Rector Magnificus.
The current dean and vice-dean have been appointed in their positions since June 2019, halfway of the assessment period. From June 2011 until June 2019, prof.ir. Elphi Nelissen and prof.dr.ir. Bauke de Vries were dean and vice-dean, respectively. The managing director during the entire assessment period was Suzanne Udo MSc.
Since January 2022, the Board of the Department of the Built Environment consists of:

- prof.dr.ir. Theo Salet, dean, portfolio education;
- prof.dr.ir. Maarten Hornikx, vice-dean, portfolio research;
- Merle Rodenburg Msc, managing director.

The Board is assisted by:

- dr. Jacob Voorthuis, director BSc program Architecture, Urbanism and Building Sciences (advisor);
- prof.ir. Bert Snijder, director of graduate program Architecture Building and Planning (advisor);
- Floor de Jonge (student advisor);
- Petrie Daams (secretary).

1.2.2. UNITS AND RESEARCH PROGRAMS

The department is organized in four units. Each unit has a research program (See 1.3 The research programs).

Figure 1: Overview of units and related research programs (and used abbreviations)

	SED	USRE / DDSS	AUDE / LC	BPS
Units	Structural Engineering and Design	Urban Systems and Real Estate	Architectural and Urban Design and Engineering	Building Physics and Services
Research programs	Structural Engineering and Design	Design and Decision Support Systems	Living Cities	Building Physics and Services

The four research programs are discipline-specific and have been developed over the past decades. The programs are organized in diverse ways, with different flavours following the varying research philosophies and discipline-specific methodologies. With respect to education, the units each are responsible for a master's track within the main master program of the department *Architecture, Building and Planning*. Each unit has a unit chair for overall management, who reports to the dean and who is supervisor of all full professors in the unit. In addition, each unit has separate program coordinators for both education and research.

1.2.3. GOVERNANCE AND RESEARCH INFRASTRUCTURE

The governance and organizational structure of the department are depicted in Appendix 1.
The unit chairs meet with the department board in the **departmental Consultative Council (DCC)** regarding general management issues. The **departmental Council** is the representative participatory body. The departmental council has the task of critically monitoring the general affairs of the department and can make suggestions to the board and express points of view. An **Advisory Board** with external stakeholders provides requested and unrequested advice to the department board, aimed at aligning the contents of the educational programs with the requirements of the professional field.
The department has multiple committees that mostly have purposes with respect to education or research. As regards the governance on research, the **Management Team Research** (MTR) is an important tactic and strategic body. The MTR consists of the research coordinators of the four research programs. The position of chair and vice-chair of the MTR is filled by one of the research coordinators. Advisors to the MTR are the departmental board member holding the portfolio for research (in this case the vice-dean) and the research policy and project development officers of the department. The main duty of the MTR is to develop the research programs of the respective units in line with the department's vision and policy. To achieve this, the MTR is responsible for stimulating the acquisition of new research by the staff and for the quality assessment procedures of their doctoral research. The MTR is supported by a pool of assessors, who contribute by evaluating the PhD candidates of the department in their first year.

The research in the department is supported by research policy and project development officers, who provide support both in the pre- and post-grant award phase as well as on monitoring processes regarding the progress of PhD students.
The department has a range of experimental facilities: a structures laboratory, a building physics and services laboratory, an atmospheric boundary layer wind tunnel, facilities for testing innovative solar energy systems, a VR lab, as well as access to TU/e wide research facilities including computational facilities.

Table 1: Headcount of staff in the Department of the Built Environment in 2021, per unit. (Source: TU/e BI-Portal)

Headcount	SED	BPS	USRE	AUDE
Full professor	5	6	3	7
Associate professor	3	2	5	1
Assistant professor	9	13	9	10
Total Scientific staff	**17**	**21**	**17**	**18**
Postdoc	2	8	2	3
PhD candidates	29	71	50	37
EngD trainees	9	16	8	2

1.3. THE RESEARCH PROGRAMS

An overview of the research programs and the related research groups can be found in Appendix 1, a brief description is included below.

1.3.1. STRUCTURAL ENGINEERING AND DESIGN (SED)

The chairs groups that contribute to the research program SED are Innovative Structural Design, Applied Mechanics, Steel and Aluminium Structures, and Concrete and Masonry Structures.
The chair of Innovative Structural Design currently focusses on research on bio-based, sustainable and reusable, lightweight structures, designed and constructed with support of Artificial Intelligence (AI) and robotics. An example is the Living Lab project, in which structural biobased building materials and load-bearing structures are developed and tested. The chair of Applied Mechanics has a strong international reputation in the modelling of failure (plasticity, fracture, damage, phase transformations) and deformation of advanced engineering materials. The coupled modelling of the mechanical behaviour of materials with other physical processes finds relevant applications, as e.g., the chemical degradation of concrete sewer systems. The research in the chairs Steel and Aluminium Structures encompasses the structural behaviour and fatigue of building elements and structures (buildings and bridges) made from steel and aluminium. Structural applications of high-strength steel and 3D printed steel are subject of research. In the chair of Concrete and Masonry Structures, one of the highlights is the advanced research in 3D-printing of concrete structures, further elaborated in the case study (Chapter 5), besides research on sustainable concrete and masonry structures. An important goal of the program is the valorisation of its research results towards relevant engineering applications, thereby contributing to the practical understanding of structures, structural design processes, and building materials.

1.3.2. DESIGN AND DECISION SUPPORT SYSTEMS (DDSS)

Recognizing that the structures and functions constituting the city interact with each other and with the users, integrated and human-centred solutions to urban and transport planning as well as real estate management are needed. Using a system's approach, the objective of the DDSS research program is to conduct innovative and ground-breaking research, to develop and apply models and systems that allow planners and managers often in co-creation with users to address the major challenges cities are facing to create healthy living environments for users and attain sustainability objectives.

The three chairs that participate in the research program include Urban Planning and Transportation, Real Estate Management and Development, and Information Systems in the Built Environment. The focus of the research program is to:

- develop models that help to better understand how users of the built environment respond to changes in the environment (new plans, policies, and technological advances) and to analyse their impacts on health and well-being of individuals and sustainability of cities;
- develop city and building information modelling techniques and applications for digital twinning of urban processes and systems;
- develop decision support tools integrating the behaviour models and real time state of supplies, enabled by city and building information models, in the form of digital twins for improving decision making and citizen participation in built environment planning and management.

1.3.3. BUILDING PHYSICS AND SERVICES (BPS)

Designing and operating buildings and built environments that preserve energy and materials, limit the environmental impact while providing a healthy and comfortable indoor and outdoor environment are challenges that form the basis of the Building Physics & Services (BPS) research program. An integrated approach is deemed necessary to tackle the complexity of these large societal challenges at hand. This is also reflected in the research domains of the six BPS research chair groups: Building Acoustics, Building Lighting, Building Materials, Building Performance, Building Physics and Building Services.

Examples of current research topics at BPS related to societal challenges are the energy transition (e.g., reduction of energy use by smart sensing), reducing our ecological footprint, e.g., development of sustainable and smart use of circular materials, without compromising the user's needs but supporting healthy indoor and outdoor climate options (e.g., light for circadian alignment, reduction of pollutants and pathogens).

The contributions of the unit BPS to the societal challenges have different appearances, for example:

- development of novel building materials with a reduced ecological impact;
- methodologies and tools to support designers (e.g., design methodology, evaluation methods, creativity, generation of alternatives, etc.);
- experimental facilities to validate models and test solutions on reduced or full scale.

1.3.4. LIVING CITIES (LC)

Architecture and the city are increasingly becoming central to leading academic studies from the fields of social sciences, economy, technology, ecology, governance, and history. However, studies are often conducted from the perspective of a single discipline. The Living Cities program specifically focuses on how these aspects work together and materialize in the spatial development of the city and its architecture, interpreted as an evolutionary and integrated process of construction and urbanization driven by socio-historical processes. The program brings together research from

the chairs of Architectural History and Theory (AHT), Architectural Design and Engineering (ADE), Rational Architecture (RA), Smart Architectural Technologies (SAT), Transformational Architecture (TA), and Urbanism and Urban Architecture (UUA).
In line with the departments' strategic research agenda Vision 2030, the program focuses on exploring and understanding the response of architecture and the development of the city for reuse, adaptation, and new interventions in response to the shifting societal challenges, with focus on three systemic cross-over themes: energy, sustainability, and inclusiveness in relation to the built environment. Aspects of history and theory, geography, technological systems, urban form, and architectural typologies influence each other reciprocally and dynamically in such a cultural ecosystem. Living Cities research

- is cross-scalar (from the single architectural element scale to that of the city or region);
- is multi-disciplinary (combining architectural and urban scholarship, theory and practice, policy and technology, construction, and planning);
- within a temporal perspective of historical evolution (retrospective and prognostic);
- combines qualitative and quantitative research methods from social and historical science with those of design research from spatial sciences (geography, urbanism, and architecture).

1.4. FACTS AND FIGURES

Research in the department is initiated and coordinated by permanent scientific staff members (assistant, associate, and full professors). At the time of writing (2022), the department employs 76 scientific staff members who supervise about 350 temporary staff members (EngD and PhD candidates, post-doctoral researchers, and university researchers). In total, there are about 1,450 students studying in the bachelor and master programs offered by the Department of the Built Environment. More detailed information regarding staff development can be found in the tables below and in Appendix 1.

Table 2: Number of staff (headcount) years 2016-2021 (source: TU/e BI-Portal, status EOY)

Headcount (#)	2016	2017	2018	2019	2020	2021
Full professor	18	18	18	18	22	21
Associate professor	13	13	10	11	12	11
Assistant professor	40	39	40	36	39	41
Total Scientific staff (#)	**71**	**70**	**68**	**65**	**73**	**73**
Postdoc/researcher	14	14	14	18	24	17
PhD candidates	139	160	176	185	186	187
EngD trainees	14	17	22	18	29	35
subtotal	**238**	**261**	**280**	**286**	**312**	**312**
Teaching staff (lecturer)	24	26	23	25	25	40
Support staff (technician)	9	11	11	11	11	10
Support staff (other)	78	66	60	66	73	64
Total staff (#)	**349**	**364**	**374**	**388**	**421**	**426**

Table 3: Overview of the department's educational programs

Educational programs	Enrolled students (2021/2022)	Diplomas (2020/2021)
Bachelor: Architecture, Urbanism and Building Sciences (3 year program)	778	156
Master: Architecture, Building and Planning (2 year program)	543	162
Master: Construction Management and Engineering (2 year program)	74	22
EngD: Smart Buildings and Cities	35 (2021)	9 (2021)

2. Mission and strategic aims of the past six years

The directions and choices of the department in the period 2016-2021 have been guided by the departmental strategy 2014-2020 written down in the Building the Future document (Appendix 2), and by the succeeding Built Environment Strategic Plan 2020-2030 (Appendix 3), which is fully aligned with the TU/e Strategy 2030 (Appendix 4).
Also, valuable feedback and recommendations from the previous research assessment (held in 2016) and the mid-term assessment (held in 2019) have supported the department in its development (see 2.2). Apart from these strategic plans and recommendations, the department is influenced by multiple contextual factors at departmental, university, national and international level, which are described in the final paragraph of this chapter (see 2.3).

2.1. DEPARTMENTAL STRATEGY 2016-2021

In 2016, the department was in the middle of financial crisis. One of the reasons for this situation was that the department was vulnerable to the economic cycle, both in terms of obtaining government funding (which is based on student numbers that can fluctuate highly from year to year) and in terms of external funding (at that time mostly from companies in the architecture, engineering and construction sector, which are highly sensitive to economic crises). To strengthen its academic position and to improve continuity for the long-term, the department decided strengthening the research profile of the department, so it would be less dependent on fluctuating student numbers and so it would be able to access more stable 2nd and 3rd tier sources of funding[1] .

The department's first aim therefore was to make the transition from a mainly education-oriented department to a department where research and education were more in balance. To do so, the department recruited staff with especially strong research profiles. The internal systems supported the focus on research excellence. Also, the department maximized the opportunities to strengthen research groups with funding from the university (by actively taking strong roles in the institutes EAISI[2] and EIRES[3]) and from the government (by *Sectorplan Engineering I*[4]).

Second, the department aimed for a clearer profile, both within the university and beyond, to be recognized for its scientific excellence and to be considered a valuable partner for research (scientific impact) and innovation (societal impact). For this purpose, themes were formulated already in 2014 and the Smart Cities Program was introduced to facilitate and organize collaboration within and between research groups. These have proven useful in the sense that they supported the departmental profile and they have facilitated bottom-up initiatives by researchers, e.g., joint project applications and a content-driven *Think Tank* by young researchers.

1 Funding of Dutch universities: https://www.universiteitenvannederland.nl/en_GB/funding-of-universities.html
2 https://www.tue.nl/en/research/institutes/eindhoven-artificial-intelligence-systems-institute/
3 https://www.tue.nl/en/research/institutes/eindhoven-institute-for-renewable-energy-systems/
4 https://www.nwo.nl/en/news/sector-plans-work-more-permanent-and-temporary-appointments

Currently, the department is in the phase to define its focus within themes related to *energy*, *sustainability* and *inclusiveness*.

In addition, with the growing awareness of the department's role in society and its responsibility towards the great societal challenges related to the liveability of our planet, the department invested in building networks with societal partners. Benefiting from the proximity of partners in the region, the department co-founded the Urban Development Initiative (UDI)[5] together with Brainport Development, the municipalities of Eindhoven and Helmond, and the Fraunhofer institute. Via the UDI, the department can interact with societal partners, bridging the academic and the real world in a quadruple helix setting. Societal challenges are translated into joint research agendas (UDI program lines), and funding is jointly applied for.
Also, the department invested in strengthening the EngD program Smart Buildings and Cities[6]. The trainees in the 2-year program are trained as design engineers, bridging the research in the department with design assignments and societal partners.

Roughly halfway of the evaluation period, the department achieved a more stable situation with a brighter prospect in terms of stability and finances. The strong focus on research excellence has clearly proven successful as evidenced by indicators such as scientific output and impact, increase in funding and ongoing research projects (see Chapter 4). The department has a strong scientific profile. It is acknowledged for its expertise by academic peers and has a strong position in academic networks.

From this strong disciplinary basis, with expertise covering so many aspects related to the built environment, the department is equipped to address the societal challenges integrally and collaboratively. The challenge for the department in the coming years is how to connect the various disciplines effectively, and how to organize a collaborative and socially safe community, where there is room for everyone's talent and where researchers are enabled to have maximum (scientific and societal) impact.

Summarizing the above, two major objectives related to research were set out in 2014:
- An accelerated transition from a mainly education-oriented department to a department where education and research are better balanced (including the ambition to be internationally recognized for high quality research);
- Research in the department should be directed along themes to improve collaboration and societal impact.

Adding to that, in the course of the evaluation period a third major objective was added:
- The department should be a open, inclusive, safe and collaborative community with room for everyone's talent.

The ambitions and achievements related to Open Science, PhD Policy, Academic Culture and Human Resources Policy will be addressed in Chapter 3.

5 https://brainporteindhoven.com/udi/en/
6 https://www.tue.nl/studeren/graduate-school/engd-smart-buildings-cities/

2.2. RECOMMENDATIONS PREVIOUS ASSESSMENT

Following the recommendations from the external peer review committee of the 2010-2015 assessment for the department (see Appendix 5), the Board has increased the focus on *Smart Cities*[7] research and strengthened its central position in this field within the university as well as within the region, by appointing a dedicated director and by actively seeking cooperation with local stakeholders and taking initiative in setting up the Brainport Urban Development Institute (UDI). UDI intends to be a quadruple helix platform to initiate living labs in the Brainport region[8], to solve the grand societal challenges in urban development and building. Also, various researchers in our department have been closely involved and played an instrumental role in the development of 'Brainport Smart District'[9] in the city of Helmond, which was initiated by our department, and which is currently being realized in cooperation with local public partners and industry.
The recommendation, to recruit young (international) promising researchers, could not be followed up in the first years after the assessment, because of severe cost reductions at the department as described in the introduction of this chapter. Fortunately, the financial circumstances have improved over the past years and from 2019 we have been able to appoint talented and promising researchers on key topics to ensure long-term viability. Reflections by the research programs on the program specific recommendations from the committee are included in Appendix 5.

2.3. RELEVANT CONTEXTUAL DEVELOPMENTS

2.3.1. DEPARTMENT LEVEL

The following major developments on department level have taken place in the evaluation period: As described before, the aftermath of the impact of the financial crisis on the department lasted well until halfway through the evaluation period. This resulted in less contract research and a decline in student numbers (numbers on contract research can be found in Chapter 4), which forced the department to increase its management focus on obtaining additional funding. At times this has led to preference for short-term priorities above long-term strategic goals. As a result, for instance, some key positions were not filled after the retirement of (senior) staff, and room for strategic investments was scarce in the first years of the evaluation period.

As a result of persistent lobbying, the department was acknowledged as one of the academic Civil Engineering disciplines in the Netherlands. Because of this, in 2019 the department was given financial support by the government to strengthen scientific fundaments in two nationally aligned focus research areas 'sustainable materials for civil engineering structures' and 'wind loading on civil engineering structures. This gave the department the opportunity to recruit 6 assistant professors in the civil engineering-oriented groups (SED and BPS). Because the positions were added to the civil engineering groups only, it did, however, not give relief to the other (more education-intensive) disciplines in the department.

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7 The Smart City Program was launched in 2016 by the Department of the Built Environment. It aimed for the development of an impact innovation program across disciplines and addressing in a holistic way all the systemic challenges urban society was facing. It brought together staff from different departments of the Eindhoven University, and the different units within the Department of the Built Environment. The program targeted, research, valorization and education.

8 Brainport Region Eindhoven is a partnership between municipalities in Metropolitan Eindhoven, companies and knowledge institutions operating in the Southeast Brabant region (Metropolitan Eindhoven and surrounding areas). The region is characterized by its high-tech and manufacturing industry (source: wikipedia)

9 https://brainportsmartdistrict.nl/en/

The composition of the department board changed in 2019; both the dean and vice-dean were succeeded. With the start of the new board, the new vision and strategy towards 2030 were developed, building on the earlier strategy, influenced by contextual developments and with new accents. While the new strategy is explained in more detail in Chapter 6, the main components are:

- Focus on taking the lead and being impactful on societal challenges related to the built environment;
- Creating a departmental community: attention for the internal culture to be an inclusive and safe working environment, and to create an open academic collaborative environment;
- Development of research teams, consisting of individuals with room for diverse academic profiles, targeting strategic personnel planning;
- Embracing modern academic practices by aiming to be impactful in science by quality, promoting leadership for inspiring and safe working conditions and stimulating open science.

2.3.2. UNIVERSITY LEVEL

The following major developments at university level have taken place in the evaluation period that have affected the department's strategy:

- In 2019, the university launched the Irène Curie Fellowship[10]. This program is aimed at talented women who pursue an academic career. The program is dedicated to obtaining at least 30% female researchers among TU/e's permanent academic staff by 2024 and it contributes to the societal goal of promoting equal opportunities and a society. As part of the program, Irène Curie fellows receive a substantial start-up package (100k€) and have access to a dedicated mentoring scheme. For all regular vacancies (i.e., not part of the Irène Curie Fellowship program), the choice for the preferred candidate must be made on the basis of the assessment of equal suitability. This means that in addition to 1 male candidate also 1 female candidate must be assessed by a selection committee. In case of equal performance, the position will be offered to the female candidate. The department maximized its opportunities in the program and was able to appoint 5 Irène Curie fellows.
- The university encourages departments to implement the principal investigator (PI) model, which implies that as a PI, also scientific staff members who are not full professor may get a high level of responsibility for their own work, projects and employees, and are expected to take responsibility for the department at the same time. The department embraces the PI-model and sees it as an opportunity to encourage researchers to develop their individual profiles.
  The department is currently working on a local translation of the model and does this together with the unit chairs and the staff. To prepare the young new assistant professors for the PI-role, the department initiated a Talent Program (see 3.6).
- The university established new institutes at university level, especially the Eindhoven Institute for Renewable Energy Systems (EIRES, since 2020) and Eindhoven Artificial Intelligence Systems Institute (EAISI, since 2019). The institutes receive funding from the university to facilitate community building, network events, start-up packages and to provide funding opportunities for joint research projects. The department has made a strategic choice to actively participate in these institutes and encourages researchers to collaborate with their peers from other TU/e departments on shared topics (see also Chapter 5 for further elaboration).
- The university Executive Board actively supports the department in its ambitions to take a leading role in a regional context related to the energy transition in the built environment and sustainable urban development, more explicitly in the context of the Brainport Smart District (BSD) and the Urban Development Initiative (UDI).

[10] https://www.tue.nl/en/working-at-tue/scientific-staff/irene-curie-fellowship/

- In 2019, the university established the Ethics Review Board (ERB). All research projects involving human participants and/or identifiable research data now must get approval from the ERB prior to the data collection. A local departmental subcommittee was established in line with this. To meet the additional demand for support related to ethics and privacy, a data steward was embedded in the department's research support team.

2.3.3. EXTERNAL LEVEL

Of course, also national and international developments have affected the department's strategy, of which the following are especially noteworthy:

- In 2017, the 'ius promovendi' (the right to act as 1st promotor for PhD candidates) was extended to associate professors. Together with the upcoming PI-model as mentioned before, this shifted the academic system to a system where responsibility for projects and PhD students is distributed over the wider scientific staff.
- The Open Science developments have had significant impact on the practice of science, not only with regards to Open Access publications and associated fees, but also with regards to research data management and open-source software. Professional support is increasingly required to help researchers understand and meet the requirements. The department therefore invested in the availability of nearby research support in the department (see also paragraph 3.3).
- A national shift is ongoing regarding different ways of rewarding and recognizing scientists. The main ingredients that are promoted in the shift are: diversity in career paths and profiles for academics, team science and balance between the individuals and the collective, focus on quality (rather than quantity), stimulating open science, stimulating academic leadership. These ingredients fully align with the vision and ambition of the department, and are reflected in the new departmental strategy towards 2030 (see Strategic Plan 2020-2030, Appendix 3).
- Funding agencies increasingly have mission-oriented programs with a focus on societal challenges that are also high on political agendas, such as the energy transition and a circular economy. The department's themes *energy*, *sustainability* and *inclusiveness* are aligned with these developments.
- Naturally, covid-19 also greatly affected the department in the final years of the evaluation period. Lockdown measures have for instance impacted the department by the restricted options to carry out research, in particular human-related research. Also, the labs faced decreased capacity to comply with 1.5m-distance measures, but the department was able to facilitate the lab research and minimize delays thanks to strict but clear working policies which were well monitored. The department applied for university funding for the temporary staff who were affected by covid-19 and extended such contracts where possible.


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3. Strategic actions to accomplish the ambitions

This Chapter describes which further actions the department took in order to achieve its strategic aims as laid out in Chapter 2. The department board has taken various actions to implement its strategy and to empower the department to work in line with the strategic plans. Below the most noteworthy actions, distinguishing between *contribution to science*, *contribution to society* and the four aspects *Open Science*, *PhD policy*, *Academic Culture* and *Human Resources policy*.

3.1. CONTRIBUTION TO SCIENCE

- Recruitment of 24 international excellent scientists, mostly assistant professors thus bringing renewal to the staff population. The ambitions of the department to strengthen its research profile were reflected in the profiles of the new hires: academics with a very strong disciplinary background. This has successfully led to increased scientific quality and output.
- The establishment of a new largescale research facilities, especially the atmospheric boundary layer wind tunnel and the 3D concrete printing facilities, and the SolarBEAT lab for testing innovative solar energy systems.
- Due to the financial situation of the department in the first part of the evaluation period, the departmental board actively encouraged its scientific staff members to acquire research grants and PhD students[11] in order to obtain more research funding for the department.
- Opportunities to participate in collaborative research projects have been supported, with success in a big national program on energy transition (IEBB program) in the built environment and collaborative research projects from the four Universities of Technology in the Netherlands (4TU).
- Strategic connections have been established and participation in networks strengthened, in particular by being member of the two TU/e institutes EAISI (AI institute) and EIRES (energy institute); by being represented in the national 4.TU Built Environment team; and in the alliance between the universities of Wageningen and Utrecht.
- A research support team has been established in the department to organize professional nearby support for the researchers. Three hires have taken place on top of the two positions that already were filled.

[11] In the Dutch system, universities are financially rewarded for each educational certificate, including PhD degrees, which implies that increasing the number of PhD students has financial benefits

3.2. CONTRIBUTION TO SOCIETY

- Already in 2014, the department launched research themes, with the idea that they would give the department a clearer profile (see Building the Future, appendix 2). These themes were closely connected to the TU/e strategic areas. Embedding in the department was limited, although the governance was efficient: each theme had one theme leader, who was member of the Departmental Consultative Council. In recent years, the department has slightly shifted its focus and aims to address societal challenges related to *energy*, *sustainability* and *inclusiveness*. These align with the UN Sustainable Development Goals, and as such with political and funding agencies' agendas. However, the department is in an ongoing search how to embed these in the department in the best way.
- The Smart Cities Program was launched to boost the collaboration with industry and society, by amongst others setting up a system of research lines with 'thought leaders' and connecting its name to the EngD program Smart Buildings and Cities.
- Evolving from the Smart Cities Program, de department co-founded the Urban Development Initiative (UDI), together with Brainport Development and the municipalities of Eindhoven and Helmond and the Fraunhofer institute.
- At national level, the department took a leading role in the 4.TU Built Environment, which unites all built environment disciplines at the four universities of technology in the Netherlands. Through this, the department also took the opportunity to participate in the national Top Consortium for Knowledge and Innovation (TKI Bouw en Techniek). It brings together knowledge partners and industry and addresses building design, construction and technology aimed at a CO_2-free and future-proof built environment.
- To improve dissemination of research results to society, the department positioned an employee dedicated to addressing the external communication of the department. Also, the university has targeted to increase its media listings, and media training was provided. The department's research is regularly featured in university press coverage.

3.3. OPEN SCIENCE

Supporting the developments towards open science, the department wants to encourage open science practices regarding transparency and dissemination of scientific results to society, and as such also the FAIR of research data. The following actions have been taken:

- To support the researchers, since 2019 the department has employed a professional data steward (0.4 fte) from the TU/e Data Management and Library.
- To increase awareness and to encourage good practices on research data management and FAIR principles, trainings have been organized regularly (2-4 times per year).
- Expertise regarding Open Access and the available university deals with publishers is also available to the researchers via the TU/e Data Management and Library.
- The department's annual internal research award criteria have been updated by the Management Team Research to include open science aspects (see appendix 7 and paragraph 5.4.1).

3.4. PHD POLICY AND TRAINING

In the department, the Management Team Research (MTR) plays a pivotal role in the evaluation of PhD candidates. The most noteworthy actions in the evaluation period have been:

- In 2018, the departmental PhD monitoring and progress evaluation procedure, which had been in place since early this millennium, was redesigned by initiative of the MTR. Supervisors, research program coordinators and PhD candidates were actively consulted and their input was the base for a new procedure. It maintained the 3-step design of the previous PhD evaluation procedure (entry PhD plan upon start, go/no-go, and annual evaluations), but optimized each step according to the new situation, with the aims to 1) improve the quality of the evaluations by making them more to the point and by involving the PhD candidate and the supervisors more in this process and 2) to make the procedure more efficient (Appendix 6 Monitoring milestones PhD candidates Built Environment).
- Additionally, in 2020, the university's Graduate School introduced Hora Finita, an administrative software system to facilitate the uniform registration, monitoring and graduation of PhD candidates at TU/e. The department was one of the first in the university to have had successfully merged its local administration into Hora Finita.
- Together with the PhD candidates and with relevant stakeholders, the department has identified points of attention related to the relatively large growth in the number of PhD candidates. These are written down in a position paper which identifies a number of actions (see Appendix 11, and also paragraph 5.4.2).

3.5. ACADEMIC CULTURE

Aiming for an open, inclusive, safe and collaborative working environment, the most noteworthy actions in the evaluation period have been:

- The criteria for the internal annual research awards (see Appendix 7) were updated during the evaluation period. While initially the criteria were based on scientific excellence in terms of output and scientific impact to reflect the department's ambitions related to disciplinary excellence, the new criteria (see Appendix 7) reflect the department's new desired academic culture, which is one of mutual support, team science and a feeling of a joint community. This is also made explicit in the names of the different awards, which do not carry the label of 'best' any longer, but rather 'exemplary' and 'outstanding.' Also, the criteria are more comprehensive and now include aspects related to societal impact and open science.
- Started during the first covid-19 lockdown, the department board has increased attention for internal communication and to promote the sense of one community, by organising quarterly meetings for the entire department, by sending regular newsletters and by starting an internal science café series where research topics are discussed in an informal setting.
- Last but not least, a Talent Program has been launched in 2021, which has greatly contributed to the development of an internal community, see also next paragraph 3.6.1.

3.6. HUMAN RESOURCES POLICY

The department wants to create the most optimal environment for everyone to excel, and for everyone's talents to develop. The most noteworthy actions are described below.

3.6.1. EMPOWERING STAFF

- To encourage employees to develop and pursue their academic ambitions, the department launched a Talent Program[12] focused on early career researchers (assistant professors), organized for the first time in 2021. The program entails individual coaching by a senior staff member, workshops, and intervision-style sessions connecting the new researchers to each other in an informal setting. The main objectives of the program are (self)reflection and personal development, development of research profiles, as well as building a strong community feeling across the department. The program has attracted the attention of other departments at the university, which are now starting similar programs.
- Employees receive support at TU/e for personal grants by providing training and application support by specialized Personal Grants team at university level, and by the department by temporarily relieving them of (a part of) their tasks to focus on writing a successful application.
- Also, by actively offering both scientific and support staff opportunities for training of leadership and supervision skills, the department works towards further professionalization of the working environment.

3.6.2. DIVERSITY AND SHARED IMPACT

The department board believes that inclusiveness and shared impact are instrumental in reaching all diversity targets. Together with the university (central HR department and diversity office) the department actively works on creating the right conditions to foster diversity and to encourage upwards career paths regardless of gender or background and regularly monitors the balance. The composition of all recruitment and assessment committees evaluating the performance of staff must comply with university diversity regulations. The guidelines and procedures include a minimum number of female members and Inter Faculty Committee members (from other departments). Also, the departmental operational and management committees are expected to have a healthy balance, although this is currently not (yet) actively steered or monitored. Trainings for supervisors are organized by the university about dealing with cultural awareness and recognizing implicit biases.

[12] https://www.cursor.tue.nl/en/news/2022/december/week-1/talent-program-for-assistant-professors-at-built-environment/


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4. Evidence

4.1. INDICATORS OF EVIDENCE

The results of research activities in the Department of the Built Environment are presented in this Chapter. Indicators have been chosen to quantify these results and serve as evidence on the performance of the department. In selecting the indicators, its definitions and registration methods, the department adhered to the internal agreements within the university (and within the research field). The results are displayed for the department as a whole. A complete report per research program (see Chapter 1.3 for a description of these programs) can be found in the appendix (Appendices 9a-9d). The report is based on the data in the university research information system Pure[13] (by Elsevier). Table 4 shows the Table from the Strategic Evaluation Protocol 2021-2027 that organizes the indicators along the dimensions assessment and quality domains. For each of the six boxes we have selected indicators.

Table 4: SEP Table E1 indicators of evidence

		Quality domains	
		Research quality	**Relevance to society**
Assessment dimensions	**Demonstrable products**	1. Research products for peers	1. Research products for societal target groups
	Demonstrable use of products	2. Use of research products by peers	2. Use of research products by societal target groups
	Demonstrable marks of recognition	3. Marks of recognition from peers	3. Marks of recognition by societal target groups

4.2. INDICATORS FOR RESEARCH QUALITY

For the indicators for research quality, the selection has been made following the departmental strategy. For the design oriented disciplines, the categories 1.b books and 1.c designs have been added. Finally, there are two indicators for which the department has ambitions in the next evaluation period following open science practice, but which were not targeted for the current evaluation period: 1.d datasets and software, and 2.a use of data sets and facilities. These indicators are marked with an #.

[13] For multiple table entries, information has been extracted from the TU/e Pure system. The reliability of this data depends on the diligence of the researchers to manually register these activities in Pure, it is possible and expected that the data is incomplete. In the past, the department (or groups within the department) used a financial model where many scientific achievements as entered in Pure, like peer-reviews, publications, articles in professional journals etc. were translated into monetary values. The diligence of departmental members to enter these numbers in Pure may have declined after this system changed in 2013.

Table 5: Indicators of evidence for research quality with numbering according to SEP 2021-2027)

1	Research products for peers	**1.a**	**Journal articles**
		1.b	**Books, source publications and exhibition catalogues**
		1.c	**Designs**
		1.d	**Datasets and software#**
2	Use of research products by peers	**2.a**	**Use of data sets and facilities#**
		2.b	**Citations of articles, books and other products**
3	Marks of recognition from peers	**3.a**	**Research grants awarded to individuals**
		3.b	**Grants awarded to major collaborative research projects**
		3.c	**Other research grants**

 # Indicator that will be of higher relevance in next 6 year period

4.2.1. RESEARCH PRODUCTS FOR PEERS

Table 6: Indicators on research products for peers

SEP output type	2016	2017	2018	2019	2020	2021
1.a (Open access) Journal articles and reviews (refereed/non-refereed) (Source: Pure d.d. 12-07-2022)						
Publications in refereed journals	156	203	204	237	280	229
Average number of publications in refereed journals per PhD student*	1,1	1,3	1,2	1,3	1,5	1,2
Publications in non-refereed journals	1	3	2	0	3	2
Open Access refereed journal publications (%)**	56	64	72	73	75	84
1.b (Open access) Books, source publications and exhibition catalogues (refereed/non-refereed) (Source: Pure d.d. 12-07-2022)						
Books and monographs	2	1	4	2	4	2
Book Chapters	24	31	17	17	11	17
PhD theses	12	13	19	28	23	26
Percentage of PhD graduations compared to total number of enrolled PhD candidates in that year	9%	8%	11%	15%	12%	14%

SEP output type	2016	2017	2018	2019	2020	2021
1.c Designs (Source: Pure d.d. 12-07-2022)						
PDEng (EngD) theses	9	8	1	13	10	7
Percentage of PDEng graduations compared to total number of enrolled PDeng candidates in that year (%)	64	47	5	72	34	20
1.d Datasets and software# (Source: data steward/Elsevier Data Monitor/Github)						
Published datasets (4TU.Researchdata, Zenodo, Mendely a.o.) as found by Elsevier Data Monitor	3	0	2	0	1	2
Software repositories (Github, TUe Gitlab) as found via the systems' search engines	1	5	2	6	10	8

* Number of Publications in refereed journals divided by the number of registered PhD students in that year.
** Sum of gold, green and hybrid open access publications (Source: TU/e Data Management and Library)
# Indicators for which the department has ambitions in the next evaluation period following open science practice

1.a (Open access) Journal articles and reviews (refereed/non-refereed)

The most classical indicator, the number of scientific journal articles and reviews, is listed in Table 6 (above). These numbers show that nearly all publications are peer-reviewed and show a tendency for an increasing number of publications in the department, except for the year 2021. It is not clear whether 2021 is an exception, or that the high number of 2020 is rather an outlier. Since most publications are (co-)authored by PhD students, the average number of publications per PhD student is an interesting number to look at. That number, which is a bit over 1, shows that the 2020 result was indeed a very productive year in this respect. In absolute numbers, the departmental strategy from 2014 targeted to reach a number of publications in high-impact journals and books of 70 yearly. It is obvious that this number has been reached clearly, and even the publications in top 10% journals is higher than this number (see Table 7 Indicators on the use of research products by peers, produced by researchers affiliated with the department.). Table 6 also lists the percentage of publications that have been published as open access papers. This number has increased to over 80% in 2021, which is a very good step forward in good open science practice.

1.b (Open access) Books, source publications and exhibition catalogues (refereed/non-refereed)

The number of books and book Chapters (co-)authored by members of the department does not show the same increase as seen in the publications. The number of book Chapters has even lowered over the years. About 50% of the contributions to this category come from the Living Cities research program. This contrasts with the contribution of this program to the publications in refereed journals, which is only around 10% for the evaluation period. The number of graduated PhD students has increased over the years, which correlates with the increasing number of registered PhD students over the years. Looking at the percentage of registered PhD students that graduate per year, we see a number that (apart from the most severe covid-19 year) slightly increased. The target of the department was 20 PhD graduations per year in 2020. That number has been reached. Still, for an average duration of the PhD period of 4,5 years (as targeted at TU/e level), this percentage should be 22,5% if the number of PhD students is constant over the years. We are quite far below that number. Another ambition of the department was to attract very good PhD students and postdocs. The number of cum laude PhDs 2016-2021 from PhD graduates in the

department is 9, which is 11% of the total number of cum laude degrees awarded by the university in this period. Given that cum laude degrees are awarded to the top 5% of PhD candidates, this number is high.

1.c Designs

For the design category, a low number of entries can be retrieved in our Pure system. Only 2 academic design entries over the 6-year period are reported. Anecdotally, the actual number of designs is much higher, but due to ambiguity as to how designs in the Pure system should be registered, these have not been recorded. At the same time, the department is responsible for the designer EngD (PDEng) program[14] (from September 2022 this certificate name has changed from PDEng to EngD), in which trainees are working on a design assignment with an industrial or societal party, and in parallel receive courses as part of their training. The theses of the PDEng graduates over the 2016-2021 period have also been listed as design outputs. The percentage of PDEng graduates should strictly be 50% if all trainees finalize within the 2-year program duration. The percentage is heavily fluctuating but close to the target number.

1.d Datasets and software#

The department has written in its new strategy document to follow the open science principles, and that is why it is valuable to report on what happened in the past period. Although funders and publishers increasingly require the publication of underlying data of research results, the number of published data sets remained very limited in the past years. However, many projects that have been awarded funding in the past year will soon have to prove compliance with the publication requirement. Therefore, these numbers are expected to take a steep rise in the upcoming years. With regards to the open source sharing of software, researchers are clearly active (e.g., on Github) but the discoverability is an issue. Estimations by the data steward indicate a few hundred repositories published between 2016 and 2021, but lack of good metadata make it nearly impossible to get a clear picture. With the advent of platforms like the research software directory[15], a listing of shared software belonging to researchers from our department would be easier to monitor.

4.2.2. USE OF RESEARCH PRODUCTS BY PEERS

2.a Use of data sets, software and facilities#

While tracing the existence of datasets and shared research software already is a hard job, collecting information on the usage of datasets and software is even more difficult. A reason for this is that even when a shared dataset or research software is connected to a journal paper, the usage of the paper and citations to it are easily tracible, but that does not hold equally for the data and software. Developments in open science will make this easier in the future, as cff files[16] and doi-identifiers help to provide citation metadata that enables to cite software or datasets. Training is needed within the department to make researchers aware of this recent option.

14 https://www.tue.nl/studeren/graduate-school/engd-smart-buildings-cities/
15 https://research-software-directory.org/
16 https://the-turing-way.netlify.app/communication/citable/citable-cff.html

2.b Citations of articles, books and other products

A comprehensive analysis from SciVal[17] for year range 2012-2021 can be found in Appendix 10 (department level) and Appendices 10a-10d (per research program). Please note that both ranges 2017-2021 and 2012-2021 are used for Table 7. Due to selections limitations of the SciVal tool, the latter is used for the comprehensive analyses in the appendices. Looking at the numbers in Table 7, we see that the number of output has increased: 915 in the past 5 years compared to 619 in the 5 years before. The FWCI (field-weighted citation impact) and FWVI (field-weighted view impact) numbers are above the average number of the whole university (as these numbers are 1.47 and 17.2 respectively). Compared to the 10-year period, these numbers are stable for our department, which holds for the top 10% publications and publications in top 10% journals as well, while the share amongst the most viewed publications worldwide is increasing. Some remarkable outcomes from the tables that can be found in the appendix are that over the 5-year interval international collaboration leads to a higher impact in terms of citation output (FWCI 1.88) than national collaboration papers only (FWCI 1.65). Note that until now, the department did not have a central publication strategy on department level. Developing one will be one of the assignments for the Management Team Research (MTR).

Table 7: Indicators on the use of research products by peers

2.b Citations of articles, books and other products
(Source: SciVal d.d. 23-11-2022)

	2017-2021	*2012-2021*
Total number of scholarly output	915	*1,534*
Total citation count	16,097	*32,137*
Average number of citations per publication	17.6	*20.9*
Field-weighted citation impact (FWCI)	1.69	*1.69*
Share of publications that are among the top 10% most cited publications worldwide (field-weighted) (%)	19.9	*20.1*
Publications in top 10% (most cited) journals (%)	52.5	*50.0*
Field-weighted views impact (FWVI)	1.85	*1.83*
Share of publications that are amongst the most viewed publications worldwide (field-weighted) (%)	32.5	*29.3*
Percentage of scholarly output co-authored with researchers from outside the institution (national and international) (%)	74.3	*67.1*

[17] https://www.scival.com/

4.2.3. MARKS OF RECOGNITION FROM PEERS

Table 8: Indicators related to the marks of recognition from peers

	2016	2017	2018	2019	2020	2021
3.a Research grants awarded to individuals						
NWO Veni		1		1		
Contract value in k€		243		250		
3.b Grants awarded to major collaborative research projects (Source: TU/e BI-portal/BE-Finance)						
Number of projects #	1	6	5	4	10	5
Total contract value (k€)/	30	2,732	524	1,933	1,439	2,297
Average contract value per project (k€)	30	455	105	483	144	459
3.c Other research grants (Source: TU/e BI-portal/BE-Finance)						
Number of projects #	16	10	13	16	43	14
Total contract value (k€)	2,500	1,641	1,806	2,849	7,718	3,313
Average contract value per project (k€)	156	164	139	178	179	237

3.a Research grants awarded to individuals

In the past years, two researchers of the department have received a personal grant from the Dutch Research Council (NWO) . Given the number of scientific staff members (fluctuating around 70 for the evaluation period), this is a low number. The department has written down in its 2014 strategy document to aim for scientists that win high-profile prizes and grants, and researchers have indeed been supported and encouraged to write individual grant proposals during this period. The view in the current strategy is that there are differences between researchers and for some pursuing an individual grant is a good opportunity, but this may not apply to others. The current view on research in the department is that it should be impactful, which does not necessary require researchers to apply for or be dependent on individual grants.

3.b Research grants awarded to major collaborative research projects

The funds that have been awarded to research projects under the EU's Horizon 2020 program, in which researchers affiliated with the department act as principal applicant/investigator or as lead partner, are listed in Table 8. Following the department's ambition to get a strong position in international networks and collaboration with internationally renowned groups, this category of major collaborative grants is an important indicator. The number of projects and funding clearly fluctuates over the years.

3.c Other research grants

These indicators include all external research funding for which the department act as principal applicant/investigator or (lead) partner, which is not listed in indicator 3.a or 3.b, or is not contract research (for contract research, see Table 11). Clearly, the share of these projects towards the total research funding is bigger than for the other two categories. The research budget has increased over the years, (see also 4.4.1 SEP Table E3 Funding). In the years 2020 and 2021, the department has been very successful in obtaining research grants. The spike in 2020 is largely due to the

department's success in the national RVO MOOI call (RVO is the Netherlands Enterprise Agency), by which various public-private consortia with multiple projects in the field of energy and sustainability were awarded grants.
An interesting result is that the average contract value per project for this indicator is, apart from the year 2021, below 200k€. Most of the research in the department is carried out by PhD students, and the total budget needed to employ a PhD student (as salary and research costs) exceeds 200k€. This means that there are many PhD students in the department that are not funded by only one project. The department set the aim to obtain 8M€ research funding annually by 2020, and the SEP Table E3 (see 4.4.1) indeed shows that this number has been reached in 2020 and 2021.

4.3. INDICATORS FOR SOCIETAL RELEVANCE

Indicators for societal relevance should be connected to the departmental ambition to have societal impact. The selected indicators were not explicitly identified in the strategy documents but provide the best fit to the department.

Table 9: Indicators of evidence for societal relevance with numbering according to SEP 2021-2027

	SEP Table E1		
4	Research products for societal target groups	**4.a**	**Books, source publications, guidelines, and catalogues for a professional readership**
		4.b	**Websites for professional visitors**
		4.c	**Lectures, masterclasses and conferences for a general audience**
5	Use of research products by societal groups	**5.a**	**Projects in cooperation with societal parties**
		5.b	**Contract research**
6	Marks of recognition by societal groups	**6.a**	**Media attention**

4.3.1. RESEARCH PRODUCTS FOR SOCIETAL TARGET GROUPS

Table 10: Indicators of evidence for research products for societal target groups (Source: Pure d.d. 12-07-2022)

	2016	2017	2018	2019	2020	2021
4.a Books, source publications, guidelines, and catalogues for a professional readership						
Professional publications	90	85	79	43	49	52
4.b Websites for professional visitors						
Web publication/site for professional audience	1	3		1	1	1
4.c Lectures, masterclasses and conferences for a general audience						
Presenting at conferences aimed at general public	4	4	8	2	6	3
Organizing an event for general public	2		1			
Inaugural lecture	2	1	1			1

4.a Books, source publications, guidelines, and catalogues for a professional readership
This category displays the activity of members of the department towards informing and training the professional field related to the Built Environment about recent research activities and results, see above Table 10 Indicators of evidence for research products for societal target groups . The key observations are that the numbers decline over the years. Comparing these numbers with the scientific publications of the unit (see Table 6 Indicators on research products for peers), we see that the latter numbers have an increasing trend. Assuming that the diligence of researchers to register professional output stayed the same, it means that the department is in proportion less active on conveying information via publications in professional media and instead focuses on a scientific audience.

4.b Websites for professional visitors
The number of websites for professional visitors that have been registered in Pure is low.

4.c Lectures, masterclasses and conferences for a general audience
Three categories have been chosen for this indicator. Again, assuming the diligence to register did not decrease, for all categories the number of performances is low, and a tendency for a decline in presentations at events with a general audience is visible.
So, all in all, we observe a decline in communication to a general audience as regards to publications and lectures, in contrast to the increased scientific activities. An indicator that is not listed in the SEP protocol is media appearances (newspapers, online news channels, radio, tv etc.). These greatly increased in the evaluation period. Media appearances are evaluated in paragraph 4.3.3 and in Chapter 5.

4.3.2. USE OF RESEARCH PRODUCTS BY SOCIETAL GROUPS

5.a Projects in cooperation with societal parties
The number of projects in cooperation with societal partners is high. The reason is that for the majority of projects funded by NWO and EU societal parties are part of the consortium, as well as projects directly funded by industry and EngD projects. It is not possible to get reliable numbers out of the management system, but the department's financial controller estimates that in 70% of the research projects, a societal party is involved. Cooperation of research with societal parties can also be seen in the journal publications with co-authors from non-academic institutes. For the time frame 2017-2021, around 7% of the peer-reviewed journal papers were co-authored with partners from society. This is similar to the value of the whole country, but significantly lower than the TU/e wide 13%.

5.b Contract research
The number of research projects funded directly by societal partners fluctuates between 10 and 22 yearly (see below Table 11, and the contract value is increasing over the evaluation period, with an exception for 2020. On top of that, every year a couple of EngD projects are funded by industry. The total contract research amounts to approximately 25% of the total research funding for the department. Also, the trend goes towards more funding of EngD projects by grant organizations instead of societal partners (e.g., companies). This is considered a positive development in terms of financial reliability and project coverage. Also, use of the experimental facilities in the departmental laboratories by construction or engineering agencies is considered a form of contract research.

Table 11: Indicators of evidence for use of research products by societal groups (Source: TU/e BI-portal/BE-Finance)

5.b Contract research	2016	2017	2018	2019	2020	2021
Number of projects # (excl EngD)	14	10	14	22	16	13
Total contract value k€ (excl EngD)	784	1,060	1,352	2,179	1,149	2,365
Number of EngD projects funded by societal partners #	3	5	5	6	3	2
Total value of EngD projects funded by societal partners k€	121	221	245	378	253	149
Average k€ per EngD funded by societal partner	40.3	44.1	49.1	63.0	84.3	74.5
Total contract research k€ (incl EngD)	905	1,281	1,598	2,557	1,402	2,514

4.3.3. MARKS OF RECOGNITION BY SOCIETAL GROUPS

6.a Media attention

Coverage by media is a form of recognition by society. The central TU/e communication strategy in the past decade was strongly focused on media attention, and the share of media coverage is considered as measure of impact. The TU/e Communication Expertise Center (CEC) kept an overview of media presence per department for the years 2016-2019, and analysed the coverage of Built Environment research and researchers by (inter)national and regional television and newspapers as compared to the other departments in the university (see Table 12). Structured data of recent years is not available, but experts of the CEC state that the department has continued to be one of the most visible departments of the university.

Table 12: Relative media mentions by BE researchers at TU/e, in parenthesis the position compared to all TU/e departments.

	2016	2017	2018	2019
% Built Environment research or researcher mentioned in media, compared to total TU/e	7% (2nd)	18% (1st)	16% (1st)	21% (2nd)
% Built Environment research or researcher as main topic covered by media, compared to total TU/e	7% (1st)	24% (1st)	23% (1st)	24% (1st)

It shows that the Built Environment belongs to one of the most visible departments in the media and contributes positively to the presence of the TU/e as a whole in the media.

4.4. RESEARCH STAFF, FUNDING AND PHD STUDENTS

Staff development tables are included in Appendix 1. This chapter contains the SEP tables E3 and E4, regarding funding (research related funding only) and regarding the success rates of PhD candidates respectively.

4.4.1. TABLE SEP E3: FUNDING

Table 13 below, shows the funding and expenditures directly related to research as prescribed by the SEP protocol. General 1st tier funding for permanent staff is excluded. Personnel costs include the cover for wages of scientific staff obtained by 1st, 2nd or 3rd tier funding. Further explanation of the table can be found in Appendix 8.
Looking at the development of the staff of the department, we mostly see a remarkable increase of PhD students (35%), which is related to the increased research funding as shown in this table. Also, the number of PDEng/EngD trainees shows an increasing trend (150%). This contrasts with the rather stable number of scientific and support staff. Only the teaching staff (lecturers) has increased significantly from around 25 in 2016-2020 to 40 in 2021, which can be related to additional capacity organized to cope with increased educational load due to covid-19 measures. The increase of 1st tier funding in 2021 is additional government funding that was awarded to the department from the *Sectorplan Engineering I*.
In addition to the comments already made in paragraphs 4.2 and 4.3, it is remarkable that the funding made available by the university for research projects is much less than the funding obtained from projects and partners outside the university, which advocates for the viability of research activities in the department.

Table 13: SEP Table E3 Research Fundings & Expenditures (K€) (Source: TU/e Financial Controller)

SEP Table E3 Research Fundings & Expenditures (K€)*		2016	2017	2018	2019	2020	2021
Built Environment	Funding 1st tier	821	883	690	544	961	1,579
	Funding 2nd tier	1,359	1,558	1,498	2,001	1,734	1,854
	Funding 3rd tier	3,363	2,648	2,927	3,972	5,343	5,941
	Other	313	81	113	156	185	240
	Total Research Funding	**5,856**	**5,170**	**5,228**	**6,673**	**8,223**	**9,614**
	Personnel costs	5,205	4,321	4,206	5,613	6,804	7,982
	Other costs	651	849	1,022	1,060	1,419	1,632
	Total Research Expenditure	**5,856**	**5,170**	**5,228**	**6,673**	**8,223**	**9,614**

4.4.2. TABLE SEP E4: PHD CANDIDATES ENROLMENT AND SUCCESS RATES

Table 14 SEP E4 gives an overview of the influx and cumulative success rates of all PhD candidates as prescribed by the SEP protocol. All PhD candidates are considered that are conducting research with the aim/obligation of graduating at TU/e Built Environment (≥0.8 fte at start of appointment). This includes PhD candidates with employee status and contract PhD candidates without employee status, with external funding or a university scholarship, who are conducting research under the authority of the department with the primary aim of graduating.

The percentage of PhD candidates without employee status has dropped from over 60% to 55% in 2022 (see Appendix 1). As written in the PhD position paper (Appendix 11), for multiple reasons we aim to reduce this number to 33%.

Table 14: SEP E4 PhD candidates (Source: TU/e Graduate School annual report 2021 / PhD administration Built Environment). Shaded area legend: Blue <25%, Orange: >25% <50%, Yellow >50% <75%, Green > 75%

Enrollment				Success rates (cumulative)													
Starting year	Female	Male	Total (M=F)	Graduated in 4 years or less		Graduated in 5 years or less		Graduated in 6 years or less		Graduated in 7 years or less		Total finished 31-12-2021		Not yet finished 31-12-2021		Dis-continued	
	#	#	#	#	%	#	%	#	%	#	%	#	%	#	%	#	%
2013	8	22	30	9	30%	15	50%	18	60%	19	63%	19	63%	9	30%	2	7%
2014	12	6	18	2	11%	8	44%	10	56%	10	56%	12	76%	4	22%	2	11%
2015	11	17	28	10	36%	18	64%	19	68%	20	71%	20	71%	5	18%	3	11%
2016	9	20	29	11	38%	17	59%	17	59%	17	59%	17	59%	9	31%	3	10%
2017	17	17	34	9	26%	9	26%	9	26%	9	26%	9	26%	20	59%	5	15%
2018	16	15	32	2	6%	2	6%	2	6%	2	6%	0	0%	27	84%	3	9%
2019	10	22	33														
2020	10	18	28														
2021	21	26	47														

Candidates who enrolled and graduated between 2013 and 2021 (with an appointment of 0.8 fte or more) graduated on average in 4.5 years. Note that this is the average of the defended PhD theses, the PhD projects that have not been finalized yet are not included in this number, see discussion in Chapter 4.2.1.

In 2019 and 2022 the Built Environment MT Research made an overview of the status of all PhD trajectories that had been open for more than five years (about 18% of trajectories) and discussed the underlying reasons with the responsible supervisors (on an individual basis). Although this does not directly lead to changes, it does create continued attention with the supervisors for the duration of trajectories.

Most PhD students and EngD trainees have an assistant professor as daily supervisor. With the increasing number of these students and trainees, we observe that the number of these students/ trainees that an assistant professor is supervising on average has risen from 3.8 to 5.8 in 6 years' time. The department still has a number of senior assistant professors without a PhD degree (as that was not needed at the time of their recruitment) who are not supervising PhD students. This implies that the supervision load of assistant professors that do supervise PhD students in the department is rather high.

See Appendix 11 for the department's position paper which describes various action points related to the departmental PhD program.

5. Accomplishments during the past six years – research quality and societal relevance

The research efforts as carried out by the department in 2016-2021 are summarized in Chapter 4, mostly translated into indicators and our reflection on them. In this Chapter we start with looking at the contributions to science and society with regards to the ambitions and strategy of the department. To frame and explain these contributions, an overview of strategic collaborations will be presented first. To give a better picture of the typical research activities carried out in the department, five case studies have been included in this Chapter. While the full stories of these studies can be found in the appendix, their major outcomes are reported here. Finally, the Chapter will also describe unit-wide accomplishments in terms of the four SEP ingredients[18].

The department has invested in building strategic collaborations, especially on board level. This is visible in a strong network that has been successfully built and expanded in the past years. An overview of strengthened strategic collaborations in the period 2016-2021 (department level, external partners) can be found in Figure 2, where we distinguish between societal and academic collaborations, and the regional, national, and international level. While these various institutes and networks are listed in Appendix 12 (Table 3), the accomplishments reached with the collaborations are subject of paragraphs 5.1 and 5.2.

Figure 2: Matrix of strategic networks on department level

	Regional	National	International
Academic	EIRES EAISI	EWUU 4TU.BE	EuroTech
Societal	UDI BSD	BTIC/TKI BE	ECTP NEB

[18] Open Science, PhD policy and training, Human resources policy and Academic culture

5.1. CONTRIBUTION TO SCIENCE

The departmental strategy as summarized in Chapter 2 has ambitions related to research quality, for which the accomplishments are here addressed.

HIGH-QUALITY RESEARCH

This aim was made concrete in the Building the Future strategy document (see Appendix 2) by four targets. Most targets have been met:

1. *Research funding. Aim: Increase with 100% by 2020 (from 3.5 M€ to 8 M€ yearly)*
   -> Achieved result 2020: 10.4M€
2. *PhD students. Aim: Increase with 100% by 2020 (from 10 to 20 PhD degrees yearly)*
   -> Achieved result 2020: 23 PhD degrees
3. *Publications in high-impact (ISI) journals and books. Aim: Increase with 50% by 2020 (from 45 up to 70 yearly)* -> Achieved result in 2020: 101 publications that fall within the top 10% journals by CiteScore
4. Visitation score. Aim: Steady at or above the TU/e average (2012: 4.5)
   -> Due to changes in the system, no scores are given any longer

Together with the scores on the indicators of Chapter 4, we can say that the department has managed to achieve its ambitions. Naturally, the output and impact of research is not equally distributed across a department. We have listed the main research indicators per research program in Table 15 below, to provide a general understanding of the distribution. All programs have a Field Weighted Citation Impact (FWCI) which is higher than the world average (1.00) and the TU/e average (1.34). A full table with research output and impact per research program can be found in appendices 9 and 10.

Table 15: Distribution of research output across the four research programs of the department, and their FWCI scores. Shaded colors: Green > 35%, Yellow >15% <35%, Orange < 15%. Shaded colors: Green > 35%, Yellow >15% <35%, Orange < 15%.

	Refereed publications (%)	Books (%)	PhD thesis (%)	FWCI
BPS	45	13	51	1.73
DDSS	31	7	30	1.33
LC	9	60	10	1.42
SED	15	20	10	1.55

The colored cells indicate the percentage of the respective indicator against the total of the whole department. We can see that BPS has the highest number of PhD theses defended and the highest publication output, followed by DDSS and SED. The LC program has a lower number of publications and PhD theses, while these numbers are close to the SED numbers. Finally, LC clearly has most books and book Chapters published, which is in line with the expected type of research output by that program.

To get insight in the high research quality of the department in terms of the top research carried out, the work behind the most impactful scientific publications (as estimated by the Scopus citations and FWCI) was analysed, considering the publications with first authors from the TU/e Built Environment. The following was derived from that analysis:

- The publications with the highest number of citations and the highest FWCI (three out of the top-4, six out of the top-20) come from research related to 3D concrete printing (3DCP), an emerging research field in the department. The 3DCP research group, and partly also the Applied Mechanics group, is clearly a frontrunner in this field (see case study in paragraph 5.3.4 and Appendix 17). The success is a direct result of the investment in the largescale 3D concrete printing facilities, which was possible thanks to contributions from societal partners.
- Another research area that appears (five out of top-20) is related to the performance of vertical axis wind turbines, where computational fluid dynamics analysis is the underlying methodology. The expertise on fluid dynamics modelling and experiments in the built environment by the Building Physics group is a topic on which the department has had a leading expertise for around 15 years. The investment in the atmospheric boundary layer wind tunnel has proven successful.
- Researchers of the department are active in writing scientific review papers. When impactful, these publications indicate authority of the main author(s). Five out of the top-20 papers are review papers, written by researchers from the groups Building Physics, Building Performance, and Building Services.
- The last category are publications that report on covid-19 related topics. Three of these publications have high FWCI scores. However, only one of them has a researcher from our department as lead author.

STRATEGIC COLLABORATIONS

Another indicator of being recognized for high quality research are the strategic collaborations that have been established with academic partners.

- At TU/e level, two institutes were inaugurated in 2019 and 2020, the Eindhoven Artificial Intelligence Systems Institute (EAISI) and the Eindhoven Institute for Renewable Energy Systems (EIRES) which the department considers valuable vehicles for collaboration.
- For EAISI, our department has defined four AI research themes which align both with the department strategy and the institute's application areas. The department has representatives in the EAISI advisory board (dean prof. Theo Salet), and in the scientific board (dr. Pieter Pauwels). The involvement of members of the department ranges from active attendance of EAISI meetups to joint PhD projects (3 in 2022) with other departments (e.g. Mathematics & Computer Science). Also, two assistant professor positions of the DDSS research program have been partly funded by EAISI, as well as several start-up packages for newly appointed assistant professors.
- Our department is also actively involved in EIRES for research related to the energy transition in the built environment. Dean prof. Theo Salet is member of the advisory Board and assistant professor dr. Lisanne Havinga is Principal Scientist for the focus area System Integration which relates to the impact of the energy transition on the built environment, transport and industry on a systems level. The department leads this topic together with the department of Electrical Engineering. Via EIRES, researchers of our department collaborate with peers from other departments (e.g. Electrical Engineering, Mechanical Engineering, Chemical Engineering).
- In terms of research collaboration with other departments at TU/e, most collaborations in terms of join research output (> 25 joint research output over the evaluation period) have taken place with the department of Applied Physics, Mechanical Engineering and Industrial Engineering & Innovation Sciences.

- At a national level, the department is part of the center 4TU.Built Environment[19]. This is one of the centers of the national 4TU.Federation, where the universities of technology of the Netherlands (TU/e, TU Delft and University Twente) and Wageningen University and Research are united. An exemplary development in 4TU.Built Environment are the self-established teams that collaborate on the world's current and future societal challenges by means of Domain Acceleration Teams (DATs) on energy transition, circularity and sustainability, digitization, infrastructure and mobility and climate adaptation and mitigation. These teams were initiated under the supervision of prof. Hornikx, who was scientific director of 4TU.Built Environment in 2020 and 2021. The department is particularly active on the first three DATs.
- In 2019, the EWUU alliance between Eindhoven University of Technology, Wageningen University & Research, Utrecht University and University Medical Centre Utrecht was established as these institutes are complementary in knowledge and talent on a national level. Within the collaboration topics of EWUU, our department has a leading role in the Circular Society topic. Prof. Salet has taken a leading role in the working group for this topic. The EWUU alliance provides researchers opportunities for collaborations with the other universities, and a number of researchers have received seed funding from EWUU for collaboration projects.
- In terms of research collaboration with other universities, most collaborations have taken place with the Delft University of Technology and KU Leuven (both > 100), and > 20 joint research output with Utrecht University, Aalborg University, Ghent University, University of Liege, Technical University of Denmark, Wuhan University of Technology, and Nanjing University of Aeronautics and Astronautics. The list of universities with 15-20 joint research output contains: University of Leiden, University of Amsterdam, EPFL, University of Cambridge, Harbin Institute of Technology, Southeast University and Beijing Jiaotong University.
- Two of the universities from this research collaboration list are member of the EuroTech alliance, which is a strategic partnership of leading European universities of science and technology joining forces "*to build a strong, sustainable, sovereign, and resilient Europe*". TU/e is member of this alliance. The alliance has several instruments to support collaboration, exchange and grant writing. Also, it has financially supported post-doc fellowship program and since 2022 also a PhD program. Our department has been active in this alliance, by hosting four EuroTech post-doctoral fellows, by utilizing the instruments to collaborate in grant writing and by participating in the visiting researcher schemes. The department has not strategically acted in the alliance, other than actively communicating about funding and collaboration opportunities.
- Obviously, there are nearby universities with high reputation that the department frequently collaborates with, but remarkable also some Chinese universities. There are a number of research groups that have good connections with Chinese universities, also evidenced by a significant number of PhD candidates funded by a Chinese scholarship.

BALANCE RESEARCH AND EDUCATION

Research funding has increased over the past years, and as a result also the number of PhD candidates. Also, the department has hired 18 new assistant professors, 2 associate professors and 2 full professors from outside. The requirement to possess a PhD to start a career as a scientific staff member only is in place since about a decade, and we indeed observe a reducing number of scientific staff members in the department not holding a PhD. Since all new staff members have been trained as a researcher during their PhD period, this all has led to a better balance in research and education, although this is different per research program. In line with the distribution of research output in Table 15 the emphasis in the BPS program is on research activities more than

[19] https://www.4tu.nl/bouw/

education, while this is the opposite for the LC program. The DDSS and SED program are in that sense more in balance. This relates to differences in both local culture and the scientific practices in the discipline.

Another aspect of this objective is related to the teaching-research nexus: teaching should be driven by research. We have not used or developed an indicator for this nexus, although this would be valuable to get a good picture of it. Still, there are some signals that give direction:

- All new scientific staff members have been trained as a researcher, and they all must obtain their University Teaching Qualification (UTQ) to get tenured. In the process of getting this certificate they need to (re-)design and reflect on the performance of a course they are involved in or are responsible for. It therefore is likely that these (re-)designed courses will be inspired by the research activities of these staff members.
- The thesis work of MSc students is regularly co-supervised by PhD students. In such cases, especially when the thesis work relates to the PhD project, the connection with current research is made.
- The overview in Appendix 13 shows the relation between courses and research. This overview was made in 2018 as part of the Self-Evaluation for the department's educational programs (BSc program AUBS and MSc program ABP).

THEMES TO IMPROVE COLLABORATION AND SOCIETAL IMPACT

A way to analyse the accomplishments on the thematic ambitions of the department is to evaluate the collaborations between research groups in terms of joint research output 2016-2021[20]. This is relevant as for addressing the themes, a multidisciplinary approach across research programs is an important indicator (see Table 4 in Appendix 12). In the boxes, the collaboration within program can be found (abbreviations of groups can be found in figure 2 of Appendix 1), where green means >15 collaborations and yellow means >10 collaborations. At program level, the Living Cities program has published over 25 research output items together with the Design and Decision Support Systems program, and the same goes for the Building Physics and Services and Structural Engineering and Design programs. Given the total amount of research output over this period (>900 journal publications), these numbers show modest collaboration between research programs. When looking at collaboration at group level, we see that the collaboration between groups in the DDSS program are strongest, followed by BPS, LC and SED. Across the program, only two collaborations can be identified.

It is visible that the research themes that were formulated in 2014 did not continue to resonate within the department. Exception to this is the Quality of Life / Health theme, which shows the strongest evidence of a departmental community, with active engagement and support by the Health in the Built Environment team (HitBE), chaired by prof. Helianthe Kort. This team has been organizing meetings on a structural basis with internal and external participants, in which collaboration opportunities and research projects are actively explored.

Since 2020, with revived encouragement from the department board, similar departmental communities related to AI/Digitalization, energy and sustainability/circularity have been gradually starting to develop, although they have not yet matured due to delays related to covid-19 lockdown

[20] Note that we here assume that thematic research on societal challenges needs attention from multiple disciplines and collaboration within the department on these themes should be hidden in joint publications, yet those joint publications could also cover work that is not related to such themes.

measures and capacity constraints. The department wants to give the maturity of the themes more attention in the upcoming years, because of its ambition to take a leading role in complex societal challenges related to transitions in the field of *energy*, *inclusiveness* and *sustainability,* which are currently the overarching themes of the department. These themes and the technology to address them (*digitalization*), are also visible in the academic collaborations, see Table 3 in Appendix 12.

5.2. CONTRIBUTION TO SOCIETY

STRATEGIC COLLABORATIONS

An indicator for societal impact are the collaborations that have been set up by the department with societal partners. At a strategic level, the collaborations are listed in Table 3 in Appendix 12.

Regionally, our department has since 2016 participated in Brainport Smart District (BSD), a new housing district of Helmond and Eindhoven, where 500-1500 new dwellings would arise. In this district all new smart technologies would be fully integrated, implemented at large scale and evaluated in real-life. The department intended to take a leading role in it via its Smart Cities Program (SCP). The collaboration in BSD comprised of local government and industrial stakeholders. The ultimate goal with SCP was finally not reached. After a very inspiring phase of visioning and program setting, it slowly ran into inertia of the teams on the respective innovation lines, due to the lack of concrete cases, partners, and funding to roll out the program (see more about this in the case study in Appendix 14).

From 2018 onwards, with the learned lessons the department joined the initiative taken by the Municipalities of Eindhoven and Helmond, the regional economic board Brainport Development and the Fraunhofer Institute to found the Urban Development Initiative (UDI), making it possible to build on a programmatic approach towards research and innovation. To accommodate for concrete cases, municipalities defined and set urban living labs, most notably Knoop XL in Eindhoven and Brainport Smart District in Helmond. UDI is one of the departmental case studies, see Chapter 5.3.1.

At the national level, the department is participating via 4TU.BE in BTIC which has merged into TKI *Bouw en Techniek* (Built Environment), which was already mentioned in Chapter 5.1. The participation has led to joint funded programs (one of them, the IEBB program is a case study in this Chapter, see Chapter 5.3.3) with many societal partners involved. The TKI *Bouw en Techniek*, part of the topsector Energy, is part of the nine top sectors of the Netherlands that have been established as the sectors where Dutch industry and research centers excel worldwide.

At international level, the department is participating in the ECTP[21] – European Construction, built environment and energy efficient building Technology Platform. ECTP has more than 140 member organizations from across the sectors. It is one of the 38 European Technology Platforms (ETPs) acknowledged by the EC, and it targets to mobilizes stakeholders to deliver on agreed priorities and share information across the EU. prof. Kort and prof. Mohammadi are chairing the Built for Life committee within ECTP.

Also, the department is an official partner of NEB (Neu European Bauhaus), which connects the European Green Deal to our living spaces and experiences.

[21] https://www.ectp.org/

THEMES TO IMPROVE COLLABORATION AND SOCIETAL IMPACT

The main idea behind the departmental themes is that they are related to societal challenges which are complex by nature, and therefore require an integral approach from multiple perspectives and, as such, require collaboration between multiple disciplines. The main vehicle to connect the internal research themes with societal partners was first the Smart Cities Program and currently the Urban Development Initiative (UDI). The themes in UDI ('*digital city*', '*energy transition*' and '*futureproof building and living*') were defined in collaboration with the department and match with the new departmental thematic directions on transitions in *energy, sustainability* and *inclusiveness* and include digitalization as the instrument to enable the transitions.

The departmental themes align with the European Horizon missions '*Adaptation to Climate Change*' and '*Climate-Neutral and Smart Cities*'.

ENGD TRAINEES, SPIN-OFFS AND STUDENT TEAMS

Two other ways to measure societal impact are by the success of our two-year post-master technological designer program (EngD) Smart Buildings and Cities, and by the success on initiating spin-offs. On the former, in Chapter 4 an increase on EngD students over the evaluation period has been seen (from 14 in 2016 to 35 in 2021). All EngD trainees perform a design assignment for an industrial or societal partner, which often also is the funder of the traineeship. Clearly, the growing number of EngD trainees indicates the increase of collaboration between societal partners and our department.

The department has not actively encouraged, nor discouraged, students and staff to pursue entrepreneurship in the form of spin-offs related to their research at the university. However, during the assessment period, there has been at least one spin-off which is a direct result of the research of the involved PhD candidate (Zahvy BV, R&D and consultancy regarding 3D concrete printing for construction industry) with (non-financial) support from the department. Also, two student teams (CASA and VirTUe) received in-kind support from the department while preparing for the international Solar Decathlon.

MEDIA ATTENTION

The analysis in paragraph 4.3.3. shows that the Built Environment belongs to one of the most visible departments in the media and contributes positively to the presence of the TU/e as a whole in the media. It is remarkable that almost 1 out of 4 main topic media items concerned Built Environment research. Although for recent years no structured data is available, according to the experts from the CEC the department continued to be one of the most visible departments of the university. The presence in the media relates to a relatively small group of researchers, who have become widely known for their expertise and are therefore regularly consulted by the media: prof. Wijte on failures in structures, prof. Salet on 3D concrete printing and prof. Blocken on cycling aerodynamics and aerosol dispersion. Worth mentioning is that the *Milestone*[22] project is considered a success in terms of media coverage; the 3D concrete printed house in Eindhoven got attention from global media from over 50 countries, among which BBC, CNN, the Guardian, El Pais, Washington Post.

[22] https://www.3dprintedhouse.nl/en/project-info/

5.3. CASE STUDIES: REPRESENTATIVE RESEARCH ACTIVITIES (APPENDICES 14-18)

Five case studies have been chosen to give a representative way on research activities within the department: each research program was asked to provide a case study, and an overall departmental case study about the UDI program is presented. The key outcomes of the case studies are described here, the full texts can be found in the appendices (Appendices 14-18).

5.3.1. UDI: FROM SMART CITY PROGRAM TO URBAN DEVELOPMENT INITIATIVE (APPENDIX 14)

The Urban Development Initiative (UDI) case study comprises the departmental efforts on collaborating with industry and other stakeholders in field labs on societal themes. The initiatives range from the Spark project in 2013 to the Smart Cities Program (SCP) in 2016 and the current UDI initiative[23]. These initiatives are exemplary for how the department is taking a leading role on collaboration on societal themes. The lessons learned in the first phase (Smart Cities Program) is that a programmatic approach is favoured over a project approach. However, it remains challenging to set up a successful programmatic platform in which all sectors in the Built Environment are engaged and involved. The cross-disciplinarity needed to address societal challenges needs attention within our department.

5.3.2. PV OPMAAT PROJECT (APPENDIX 15)

This is an example of a project on a thematic topic (energy transition) involving both academic and industrial partners. In the project, a unique facility was used which has become a key facility for the department since then (SolarBEAT lab[24]). A strong collaboration with the applied research institute TNO was shown within the project, and excellence was demonstrated by publications and recognition of individual researchers. The success of project was evidenced by a follow-up project of the consortium. The project serves as a good example within the department for open science: software resulting from the project was published on GitLab.

5.3.3. THE IEBB PROJECT (INTEGRAL ENERGY TRANSITION EXISTING BUILDING STOCK) (APPENDIX 16)

The IEBB project comprises a large (>13M€) national intersectoral project[25] on a thematic topic (energy transition). The project addresses disciplinary research (mainly via PhD projects) but also collaboration with industrial partners at higher TRL levels. It takes an interdisciplinary approach, involving several research programs of the department. The alignment between fundamental research and EngD projects was not optimal, although still considered valuable. Open access publications resulted from the (still running) project.

5.3.4. 3D CONCRETE PRINTING (APPENDIX 17)

The 3D concrete printing research line is using *key enabling technologies* (robotics and AI) to advance the manufacturing of concrete building structures. The results from the research line evidences disciplinary excellence, in terms of output, impact and organisation of a conference. This research involves most sub-disciplines of the research program SED, with an outlook for more collaboration. The research line is a good example of the newest departmental strategy in taking

[23] https://brainporteindhoven.com/udi/en/
[24] https://www.tue.nl/en/research/research-labs/solarbeat/
[25] https://tki-bouwentechniek.nl/samenwerkingen/iebb-consortium/ (Dutch only)

the lead in transitions, in this case a transition in technology. A challenge is the pathway to the industrial uptake of the 3D concrete printing technology, which is slow. Also within this project, open software has been published.

5.3.5. SMARTNESS CONFERENCE (APPENDIX 18)

The smartness conference, organized by members of the LC program, aimed to develop and foster an open discussion on smart systems in architecture and urbanism. It is an example of an event, to which multiple disciplines contributed. The initiative to organize the conference is an example of taking initiative and gaining international authority and reputation by organizing a conference. However, the connection to Brainport stakeholders was limited.

5.4. FOUR ASPECTS IN CONDUCTING RESEARCH

While accomplishments on the four SEP aspects regarding the conduction of research are implicitly also addressed in the previous paragraphs, notable achievements are listed below.

5.4.1. OPEN SCIENCE

The 2020 winner of the departmental research awards in the category 'Outstanding PhD Candidate' was dr.ir. Sjonnie Boonstra, who was celebrated explicitly for his efforts to make the software resulting from his PhD research open source according to FAIR standards. Similarly, in 2019, assistant professor dr.ir. Roel Loonen was acknowledged in the category of 'exemplary research' for his efforts to make his software open source. These awards are an example of the emphasize within the department on open science.

Vice-dean prof. Maarten Hornikx plays an exemplary role with various projects, including his eScience center fellowship, in which he is training his research group on sustainable open software practices as well as targeting a culture shift towards open research software.

5.4.2. PHD POLICY AND TRAINING

The MTR has changed the evaluation system of PhD candidates (see Appendix 6). These changes enable the monitoring of the candidates, in particular in their first year as it includes an evaluation at three and at nine months. With the arrival of the TU/e wide Hora Finita PhD monitoring platform, a step towards professionalizing the PhD training has been made. The wide variety on courses at TU/e (PROOF program[26]) does help candidates in managing their project, both content wise as well as with all relevant soft and mental skills involved. However, the growing number of PhD candidates has given the department challenges: e.g. the average duration of PhD students is rather long, and in some cases they did not always receive a sufficiently equal treatment in terms of e.g. opportunities for conference attendance and supervision time. For this reason, a position paper (Appendix 11) and a PhD Guide (Appendix 19) have been written that describe guidelines, duties and rights of PhD students. These documents should also serve as a starting point for a dialogue with the professors on a common ground for working with PhD students and expectations from them.

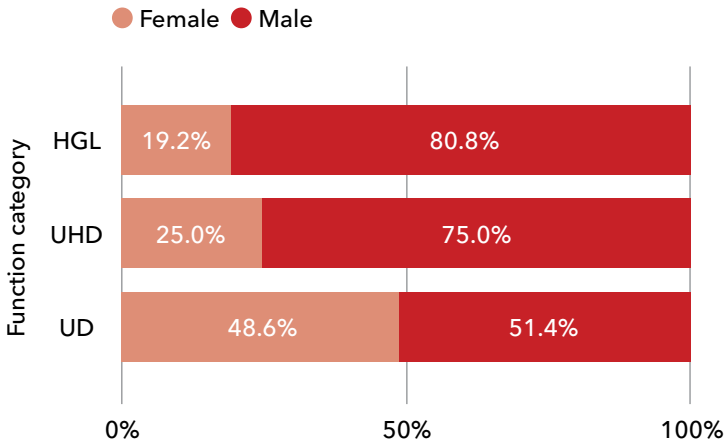
[26] https://www.tue.nl/en/storage/careers/development-and-career/scientific-personnel/phd-and-postdoc/providing-opportunities-for-phd-students-4tu/

5.4.3. HUMAN RESOURCES POLICY

TU/e has set gender targets for female staff members until 2025, as these not only influence the hiring of female scientists, but they also address the retention. These targets are 35% assistant professors, 30% associate professors, 25% full professors. The percentage is higher for the assistant professors as this group is the breeding ground for development to higher ranks. The numbers of the department are shown in Figure 3.

These numbers show that gender is well-balanced for Assistant Professors (UD). For the higher functions, full professors and associate professors, these targets are not yet met. The board actively steers on this aspect with the recruitment of new staff. The Irène Curie fellowship program[27] as mentioned before is helpful in this regard.

Figure 3: Gender distribution (headcount) per function category in the department of the BE (Source: BI-portal d.d. 24-10-22)



In order to be an inclusive employer and reach out to a diverse population of candidates, it is important that job descriptions reflect TU/e's inclusive values. For this purpose, TU/e uses an augmented writing tool to stimulate gender neutral wording in job descriptions.

5.4.4. ACADEMIC CULTURE

One of the strategic objectives formulated is to be a department with an open, inclusive, safe and collaborative community, and which gives room to everyone's talent to develop. This translates to a culture of openness, mutual support and social safety. Stressing these aspects aligns with the TU/e and national policy on rewards and recognition, and calls for team science and open science (see Appendix 12). The first results of this desired culture are already visible: the science café series in which research topics alternate with live discussions among researchers; and the bottom up think tank group of young academics where all topics related to (executing) research are discussed. Also, all staff were invited to the theatre play MindLab[28], which is a play about the academic world and addressed themes such as scientific integrity, social safety and leadership.

[27] https://www.tue.nl/en/working-at-tue/scientific-staff/irene-curie-fellowship/
[28] Trailer: https://youtu.be/Pd8DKB3-18g

5. Accomplishments during the past six years – research quality and societal relevance

6. Strategy for the next 6 years

6.1. STRATEGIC PRIORITIES 2020-2030

The vision statement and strategic priorities (*Built Environment Strategic Plan 2020-2030*, appendix 3) will guide the department in the upcoming decade. It builds upon the previous strategy (*Building the Future*, appendix 2) and, even more than before, it shows the department's awareness of its role in society. Building on strong disciplinary bases within the teams and units, cross-disciplinary collaboration is encouraged by actively building networks and reaching out to academic and societal partners in sustainable partnerships. Good examples are the department's leading role in the TU/e institute EIRES (Eindhoven Institute for Renewable Energy Systems), and its pivotal role together with the regional public partners and industry in the Urban Development Initiative (UDI). To empower the department to realize its ambitions externally, the strategic priorities have a strong internal focus as well, creating the right conditions for everyone in the department to excel in their own way. Allowing room for everyone's talents to develop and building a cohesive community with a culture of openness, shared responsibility and social safety, and by removing administrative and organizational barriers to encourage collaboration. The strategic priorities 2020-2030 are summarized in Figure 4 (also see Appendix 3, page 9).

Figure 4: Strategic priorities as formulated in the Built Environment Strategic Plan 2020-2030

STRATEGIC PRIORITIES

Related to the three strategic choices of TU/e, the department has the following vision:

TALENT. The department strives for scientific excellence in education and research in its disciplines of technology and engineering, human behavior and design in the domain of the built environment. We stimulate our talent to explicitly work together in teams to achieve our departmental ambitions. Team science requires room for differentiation. We want to bring talents together with a different focus regarding research, teaching, impact and leadership, and to benefit from synergy. All members of the scientific staff are both active on research and in education, be it that the balance may be different for each individual. To enhance our educational programs, including talented scientists in the development and execution thereof is essential. The same applies to defining and carrying out plans to strengthen our research and increase our societal impact. This requires leadership that excels in providing space for the talents of each individual, simultaneously looking at the best interests of the team, and taking into account differences between disciplines, cultures and backgrounds.

COOPERATION. The department aims to take a leading role in addressing the complex societal challenges which profoundly affect our built environment. These challenges in the field of energy, inclusiveness and sustainability are characterized by the strong interconnection of many factors. In order to play the leading role, we will work together with partners on these societal challenges in research and education through thematic programs over a number of years.

Teamwork and cooperation are therefore the key to success. To encourage collaboration, we build, maintain and strengthen internal networks, and we incorporate societal challenges in research and project education. Our staff is encouraged to actively engage with the TU/e institutes EAISI and EIRES, with the universities in the alliance of Utrecht University, Wageningen University and Eindhoven University, with the 4TU federation partners and with the public partners and industry in the Urban Development Initiative (UDI). Finally, we build stronger connections with our alumni. This calls for leadership that connects through communication and is highly visible.

RESILIENCE. The development of talent, and the ambition to have true impact on our built environment by cooperating on societal issues, requires a highly professional and resilient community. This also calls for well-organized education and research management teams, and professional support for both research and education. In terms of leadership, both the ability to build communities and the flexibility to rethink the way we use our Vertigo building and our experimental facilities are indispensable.

6.2. SWOT ANALYSIS

An analysis of strengths and weaknesses (internal factors) and opportunities and threats (external factors) was made in a joint workshop, with the dean and vice-dean representing the departmental board and the members of the Management Team Research representing the departmental research programs. A summary of the SWOT analysis can be found below.

Table 16: Main results from the internal SWOT workshop held 01-06-2022.

Strengths	Opportunities
Multi-scope; broad spectrum of built environment disciplines (social, technical, spatial) on all scale levels (from materials to cities).	Societal challenges; often have impact on or relate to the built environment, this naturally enables us to take a leading role. Because of their complexity, these challenges must be addressed with input from multiple disciplines. As a result, this opens opportunities both for collaboration and for obtaining funding.
Human capital; excellent staff and a large and diverse group of new talent.	Collaboration; within the university in the TU/e institutes EIRES and EAISI, with other Dutch universities in 4T.BE and EWUU alliance, and via the UDI with societal partners in the Brainport region.
Reputation and networks; strong international academic reputation of individuals and groups, and good representation in networks, also on board level.	Design methodologies; to realize true impact on societal challenges, design methodologies are key enablers.
Facilities; excellent experimental facilities, some of which unique in its scale, and access to both local and national high performance computing facilities. Professional research support staff.	Collaboration with Industrial Design; positioning in TU/e will give more opportunities to connect.
	Building on ability to connect disciplines to develop a distinguishing profile; urban level, multi-scale.
Weaknesses	**Threats**
Quantity vs quality; focus on individual performance along classic and quantifiable criteria (#publications, #citations, #proposals, #PhDs), leading to high workload.	Funding; shift from fundamental research towards funding for large consortia and higher TRLs. Long-term funding from industry is limited and subject to fluctuations in economic cycles.
Organisation and leadership; lack of incentives for collaboration, limited feeling of shared responsibility for the department as a whole.	Societal partners are not ready to team up in long-term collaborations for research and innovation.
Disbalance in funding sources of PhD positions; difficult for some groups to access funding programs, causing reliance on scholarship/self-funded PhDs.	Difficult to attract talent; both because of (international) labour market conditions and because of the reputation of the academic working environment (highly competitive, highly hierarchic, high workload).
Visibility; limited capacity to support external communication about research and impact.	Academic system, nationally and globally; highly competitive and individually driven.
Disbalance research-education; high teaching load in some groups, lack of students in other groups.	

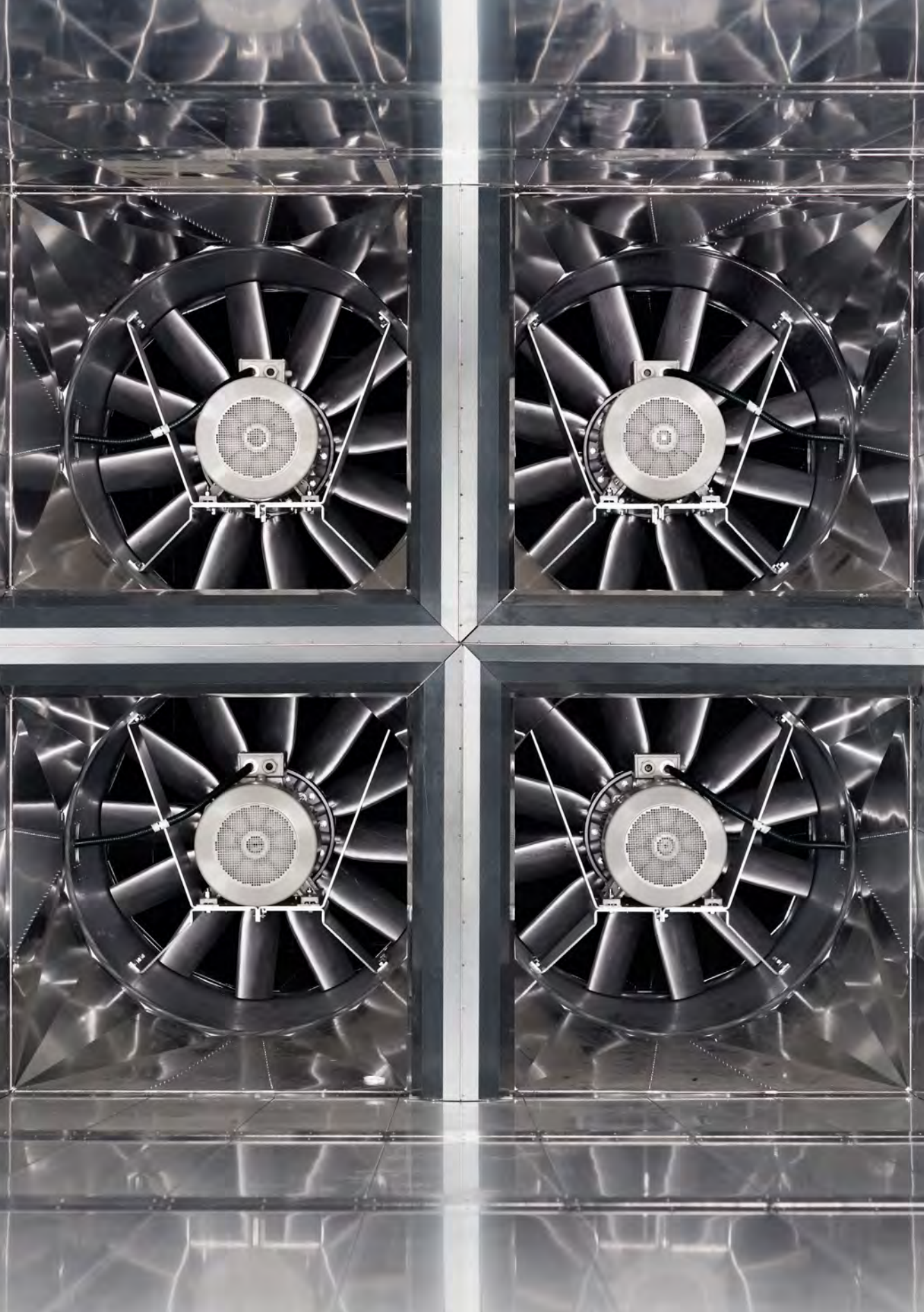
6.2.1. REFLECTION IN RELATION TO THE DEPARTMENTAL STRATEGY 2020-2030

Reflecting on the outcome of the SWOT analysis against the vision 2020-2030, these are the main observations.

- The previous departmental strategy and following actions have resulted in an increased number of publications (reputation), outstanding experimental facilities and professional research support staff, a rejuvenation of scientific staff because of the recruitment of many new talents and the fostering of individual excellence, especially in terms of research performance. All of these observed strengths are in line with the results and accomplishments that have been summarized in Chapters 4 and 5.
- At the same time this has resulted in an increased focus on quantity, and individual performance indicators. This focus is following the academic system at the start of the evaluation period, where quantity indicators prevail, and incentives on team science are generally not (widely) present.
- The societal challenges in the built environment offer opportunities for the department to take a leading role in connecting disciplines and collaborating with (societal and academic) partners. The department has built and participates in strong networks, both on the level of the individual researcher as well as on the level of the board, both within the university and on national level. This will help in obtaining funding, both from (inter)national funding programs and from societal partners. Establishing the right internal governance and corresponding stimuli are challenging.

In summary, the main challenges for the department in its 2020-2030 strategy are:

- Contextual developments on institution level and on national level related to recognition and rewards are expected to have a positive effect towards a more collaborative, less competitive, environment. How to translate the department's core values and strategic aims into the recognition and reward criteria set by the university is a challenging process. It requires both different and strong leadership, and a matching organizational structure. Both topics are addressed integrally as part of the departmental Strategy 2030.
- The transitions in the department are taking place on multiple levels and layers, and are highly interdependent. There is a common sense of urgency, but reality shows that it is challenging to allocate sufficient time and resources to manage the process and keep the pace.
- The department has a distinguishing profile, yet so far lacks the capacity to structurally and strategically build its external visibility with consistent and frequent communication about its research and impact.
- The relatively large group of young staff naturally breathe the culture shift towards impact, collaboration, openness and shared responsibility, but struggle with the potential impact on their career perspectives. They still have to find their position in the existing environment, in which they are highly dependent on their supervisors and on meeting the classic performance criteria for promotion set by the university.



7. Conclusions

The department is always evolving, following a strategy set by the departmental board, and influenced by external factors at university, national and international levels. The Department of the Built Environment, for the period 2016-2021, is evaluated against the departmental strategy as set out for the period 2014-2020 but also ingredients from the new strategy towards 2030 were already visible in the strategic choices made in the evaluation period.
Overall, two major objectives related to research were set out in 2014:

- An accelerated transition from a mainly education-oriented department to a department where education and research are better balanced (including the ambition to be internationally recognized for high quality research);
- Research in the department should be directed along themes to improve collaboration and societal impact.

Adding to that, in the course of the evaluation period a third major objective was added:

- The department should be an open, inclusive, safe and collaborative community with room for everyone's talent.

Looking at the indicators as described in this self-evaluation report, the department well achieved its first objective. The department is internationally recognized for its high quality, having reached its targeted research funding of 8M€, awarding annually over 20 PhD degrees, and publishing over 100 publications in top 10% journals. The research and educational activities are more in balance at department level, but there are large differences when distinguishing the four research programs. Also, the department is recognized for its high quality research, evidenced by all its (strategic) sectorial and inter-sectorial collaborations at local, national and international scale, and by its visibility in national and international media. Especially the 3D Concrete Printing group and the Building Physics group have had high societal impact. All these achievements are a result of the strategy to attract scientific staff members with an excellent track record on research, and by promoting the acquisition of research funding, PhD candidates, publishing scientific work and by fostering strategic collaborations.

Looking at the introduction and the adoption of the research themes over the years, efforts have been made to address societal topics in a collaborative and programmatic manner. It turns out to be a long stretch and the department still has a way to go. Over the evaluation period we have not fully reached what we targeted for, evidenced by the relatively low collaborations between the various disciplines within the department, and the external strategic partnerships that take much time to develop and to mature (BSD, UDI). The reasons for this are both internal, as the governing academic system focuses on and rewards individual excellence, and external, with the layered complexity of setting up long-term collaborations with industry and governmental bodies in largescale consortia.

Whereas the focus in the first years was on promoting, recruiting and rewarding staff members who excel in disciplinary research, with the new strategy the department shifts to a focus on societal impact through both research and education. For this, a balanced mix of staff members with a variety of backgrounds and profiles is needed. It enables the department to take care of its primary

processes, of which research is one: staff who excel in team science, in collaborating with societal partners, in individual research, in science communication, and in leadership. In the department of the Built Environment, researchers are given the agreed-upon space to develop their talents. This shift is very much in line with the national developments related to rewards and recognition. In line with these developments, team science, PhD policy, human resources policy, and open science are high on the strategic agenda of the departmental board.

The challenges the department currently faces and that will need attention in the coming years are related to: finding the most suitable internal structure to encourage both collaboration and shared responsibility (*PI-model*); the balance and connections between disciplines; organizing impact on the societal challenges; accommodating the increasing number of PhD students and reducing the average PhD graduation time; increasing awareness, training and support for open science; developing a strategic personnel plan to maintain a balanced staff fleet; boosting the departmental community feeling towards a collaborative and open community; building research teams that can produce high quality and impactful work; and creating a safe and healthy work environment for everyone.


STUDENT TEAMS
IN

8. Overview of appendices, tables and figures

8.1. APPENDICES

All appendices are available in digital format via:
https://surfdrive.surf.nl/files/index.php/s/wuqDDKmej9tAJc1

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Appendix 5:	Summary recommendations and follow-up actions previous assessment (2016) and mid-term (2019)
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Appendix 7:	Procedure and selection criteria Annual BE Research Awards
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Appendix 14:	Case Study UDI: From Smart City Program to Urban Development Initiative
Appendix 15:	Case Study PV OpMaat (BPS)
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Appendix 19:	BE PhD Guide for candidates

8.2. TABLES

8.3. FIGURES

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