Architecture and the Built Environment

Self-Evaluation Report on Research Departments 2016-2021
Summaries and Case Studies

Contents

ARCHITECTURE

SUMMARY ARCHITECTURE

The connective tissue that binds all research taking place in the Department of Architecture together is its focus on design. The Department has a healthy stream of income to support the research activities of its staff, who perform well in publishing peer-reviewed articles in respected journals and contribute to architectural discourse (beyond academia) through the production of books, contributions to professional magazines, conferences (that cater to a variety of audiences) and exhibitions, such as the Venice Biennial.

The Architecture department is one of four in the Faculty of Architecture and the Built Environment. Kees Kaan heads the department, and its research programme is led by Janina Gosseye, who works in close collaboration with the Department's two research committees. Anno 2021, the Department of Architecture employed 118 persons as research staff – resulting in 20.3 FTE research time – who contribute to the Department's ten agendas for research.

The research agendas are:

1. Architectural Pedagogies;
2. Architecture and the City;
3. Architecture, Culture and Modernity;
4. Borders & Territories;
5. Design Research;
6. Digital Culture;
7. Ecologies of Architecture;
8. Global Housing;
9. History;
10. Situated Architecture.

Each of these agendas is pursued by an eponymous research group within the department.

The Architecture department has an extensive research network, both within the Netherlands and beyond. In the Netherlands, we maintain close ties with other institutes for higher education, such as the Erasmus University Rotterdam, and with funding bodies, such as the Dutch Research Council (NWO). The department is also actively involved in several centres and programmes that have been set up as part of the Leiden-Delft-Erasmus (LDE) strategic alliance, including the Centre for Governance of Migration and Diversity, the Centre for Global Heritage and Development, and the PortCityFutures programme. Many staff members maintain close ties with practice. Some are practitioners themselves, while others collaborate with practitioners, as well as professional architecture organisations, such as the Branchevereniging Nederlandse Architectenbureau (BNA) and the Atelier Rijksbouwmeester. The department's researchers are also actively involved in national heritage, design and history organisations, such as Het Nieuwe Instituut (HNI), the Koninklijke Nederlandse Oudheidkundige Bond (KNOB) and the Cultural Heritage Agency.

Internationally, the TU Delft Department of Architecture is actively involved in BauHow5, a European alliance between five leading research-intensive European universities in Architecture and the Built Environment that seek to push the boundaries of current practices in architectural pedagogies, research, and practice. Many of the department's researchers are members (sometimes even board members or presidents) of prestigious international academic societies and associations, such as the European Architectural History Network (EAHN), the European Association for Urban History (EAUH), the European Association for Architectural Education (EAAE), the Society of Architectural Historians (SAH), the Society of Architectural Historians of Great Britain (SAHGB), the Society of Architectural Historians of Australia and New Zealand (SAHANZ), the Architectural Research Network (ARENA), the Global Urban History Project (GUHP), and the International Planning History Society (IPHS). Several staff members also collaborate closely with intergovernmental agencies, such as UN-Habitat, philanthropic organisations, such as the Aga Khan Development Network, and international cultural associations, such as the International Confederation of Architectural Museums (ICAM).

EAAE, annual conference, 2016 / Image credit: Mick Morssink

Case Studies

Included in this first appendix (appendix 1) are four case studies. These introduce the three new research lines that were established following the 2019 mid-term assessment – (1) Architectural Pedagogies, (2) Digital Culture, and (3) Design Research – as well as the department's overall research programme, called 'X Agendas for Architecture'.

Apart from enunciating the overall approach and aims of the research line, each of the first three case studies reveals the work that has been done within the research line in the past few years, with particular emphasis on the interaction between research activities, non-academic partners, and societal aims. Each of these case studies also includes pathways to impact, which sets out the research line's strategy for the next six years.

ARCHITECTURE | 1.1

Architectural Pedagogies

The Research Line Architectural Pedagogies at the Department of Architecture, initiated in 2020, focuses on the connection and interactions between research and education. The Department of Architecture has a large task in architectural education. Most of our staff members are working in research and education, and in many cases, a mutual influence exists between research and education. As a Department of Architecture, we have the responsibility to train future professionals. To properly address the urgent themes of our built environment, a reflection on the way we educate is crucial. Which are the methodological and epistemological frames of reference for our pedagogical efforts? How does the diversity of positions within our department offer an invitation for students to develop their own position as future responsible architectural thinkers and practitioners? How can we teach students to operate simultaneously in sustainable, functional, affordable, artistic, and meaningful ways? And what is specific about design teaching? How can we guide the critical moment of design invention in our teaching, for instance, the crucial stage of moving from analysis to design in the graduation studio?

The research line engages in discussion with the different chairs and studios in the department to bring forward architectural pedagogy as a field of knowledge. Rather than a delineated research group with internal PhDs and projects, this research line aims to transverse the different groups in the department to collaborate with research (studio) mentors across the department and to stimulate a reflection on our education.

The group will collect ongoing reflections to contribute to the value of architectural pedagogy as a field of knowledge. It will take the findings to the stage of critical discussion, engaging in debates among the various groups at the departmental level and interrelating with the faculty as well as outside educational research developments. The group aims to (1) gather ongoing reflections on architectural pedagogies within the department, (2) represent the department in faculty-wide investigations in pedagogy, claiming a key role for design education and architectural thinking and (3) bring the pedagogical position(s) of the department in relation to those of architectural schools abroad.

Research and Projects

Since 2020, we have initiated several activities at the level of the Department of Architecture to connect research and education more explicitly at the master's level. We have organized regular discussions/ presentations reflecting on links between research and education and exploring pedagogical approaches. The Architectural pedagogy group organized dedicated sessions on the department research days (Oct 30, 2020, Apr 9, 2021, Jan 11, 2022) with all department staff and invited guests. Further, we used the opportunity of our Theory fellow programme (2019-2022) to get feedback from peers, such as Prof. Eeva Liisa Pelkonen from Yale, who responded to research mentors from various studios sharing their research approaches in Fall 2021.

Also, through our educational activities, we have made steps to make the links between research and education more explicit. For instance, a new course, 'Research Plan', has been offered since Sept 2020 to all diploma studios at the Department of Architecture. The course is developed and taught by the chairs of Methods, Theory and History in collaboration with the research mentors of the studios, providing the opportunity for closer collaboration between studios and for presentation and discussion of the distinct research approaches of the graduation studios. The course offers lectures on research in the graduation trajectory, helps students to write a research plan and organizes a joint meeting each semester in which all diploma studios discuss their research approaches.

Starting in Fall 2022, the pilot course, 'The Space of Words', will be developed based on a Comenius grant obtained by Angeliki Sioli. The Space of Words is a pedagogical project targeting an important pedagogical problem in the beginning stages of master- level education. It will address the significant difficulties for productive and creative collaboration among first-year students caused by their notably diverse educational and cultural backgrounds. Based on recent findings in neuroscience – proving that language and imagination work collaboratively in the brain (Mallgrave, 2017) – The Space of Words innovates in engaging language for a new purpose: that of imagining spatial atmospheres. Also, based on a Comenius grant, Nelson Mota recently started the research project 'Housing as Healthcare: Mapping the correlation between housing design, micro biodiversity and health in The Hague'. This research will explore a trans- disciplinary pedagogical approach to stimulate co-creation between different academic fields and actors from

society, investigating the potential correlations between housing design and health. Working in collaboration with students, teachers and researchers of Leiden University Medical Centre and Hogeschool Leiden, the project will be developed in the MSc2 elective course 'Architectural Ethnography', where architecture and (bio-) medicine students will map how spatial configuration and social practices influence and are influenced by the interactions between humans, non-humans and the diversity of environmental microbiota.

At the faculty level, we actively participate in Studio Pedagogies, a faculty-wide project financed by the 4TU/CEE. It will be about analysing and comparing studio pedagogies faculty-wide, running in parallel at the TU Delft Faculty of Industrial Design Engineering. This will also be an opportunity to learn from each other's best practices. (PIs: Roberto Cavallo and Willemijn Wilms Floet)

At an international level, we actively participate in the EAAE (European Association for Architectural Education), which offers the opportunity to share experience with colleagues abroad and set the agenda for architectural pedagogies internationally. Further, we are active in EU-funded projects that link research and education, such as the Marie Curie ITN network TACK (Communities of Tacit Knowledge) and CA^{2}RE+. CA2RE+ / Collective Evaluation of Design Driven Doctoral Training (PI: Roberto Cavallo). CA^{2}RE+ is an EU-financed project that started in 2019. This project is about Doctoral Education of Design Driven PhD research to build up common understanding, knowledge and strategy regarding this way of pursuing a PhD. The Erasmus+ Strategic Partnership CA2RE+ develops a collective learning environment through the Evaluation of Design Driven Doctoral Training. Design Driven Doctoral research (DDDr) is taken as a multi- disciplinary example of an experiential learning-through-evaluation model, appropriate for identifying and promoting the relevance of research singularity, its transparency and recognition, to award excellence in doctoral training for creative and culturally rooted solutions of contemporary design-driven developments.

CA^{2}RE+ advances the doctoral training from being a support measure to an experimental collective evaluation training environment for DDDr. It critically transfers the traditional design studio learning model from the master's to the doctoral level: learners at different stages of their process learn collectively with evaluators. The project objectives are achieved iteratively by means of a conference series following the main project steps from observation and sharing, comparison and reflection to reformulation and recommendation. PhD candidates and supervisors actively participate in the CA^{2}RE+ series of conferences that started in October 2019 and will continue up to 2022. After this period, the partners intend to continue the activities through the half- yearly CA^{2}RE+ Conferences on Artistic and Architectural Research.

TACK, Communities of Tacit Knowledge: Architecture and its Ways of Knowing, Marie Curie ITM network (PIs: Klaske Havik, Janina Gosseye). This Innovative Training Network, part of the Marie Sklodowska-Curie Actions within the European Framework Program Horizon 2020, trains young researchers to understand the specific knowledge that architects use when designing buildings and cities. In TACK, ten major academic institutions, three leading cultural/architectural institutions as well as nine distinguished architecture design offices collaborate to offer an innovative PhD training programme on the nature of tacit knowledge in architecture, resulting in ten parallel PhD projects.

Pathways to impact

PEDAGOGICAL SETTINGS
The Department of Architecture has a large task in architectural education. Especially in master's education, there is a mutual influence between research and education – ideally, they feed into each other. Graduation studios serve as laboratories for research and design, as forerunners and prototypes exploring and testing upcoming agendas. In addition, the studio setting helps in conveying and transferring knowledge. Graduation studios, in particular, serve as laboratories for research and design. Our staff members publish some of the studio work we do with the students. In many of these studios, the research outreach goes through the student's work, often the optimal vehicle to test research input or findings. The knowledge of the studios is developed by making, by doing, by performing and transferred via drawings, images, objects, etc. In other words, the studio setting allows us to speak of the tacit and/or embodied knowledge, knowledge components we all know, proper of the field of architecture. In addition, seminars and studios link research and education, in some cases also reaching out to the professional world, while the lecture series invites research staff and external experts to bring to the fore research topics of interest. The History and theory thesis offers students the opportunity to do archival research or a literature review, and work may be developed to the stage of a proper research paper. In the coming years, we intend to further study the productive relationships between research and education, reflecting on current educational formats and possibly experimenting with new types of pedagogical settings.

PEDAGOGICAL PATHWAYS
This research strand investigates the methodological underpinning of our pedagogical efforts. While methods with a long pedigree in research at the department, such as mapping, plan analysis and model making have a strong impact on teaching, we also see increasing use of ethnographic and narrative methods in several studios. Additionally, there is a growing interest in pathways of inquiry and tools deriving from other disciplines. It is worth discussing how particular research methods influence architectural pedagogies and design projects' outcomes. In the upcoming period, we hope to identify some of these ongoing and emerging pedagogical pathways, which will harvest from interdisciplinary collaborations and bring new insights from other disciplines such as pedagogy, anthropology and neuroscience into the realm of architectural education.

PEDAGOGICAL FIELDS
To critically position the Department of Architecture in the field of architectural pedagogy, it is necessary to be aware and further study international pedagogical experiences in architecture. Part of this endeavour is an active membership in the EAAE (European Association for Architectural Education), which offers the opportunity to share experiences with colleagues abroad but also set the agenda for architectural pedagogies internationally and actively participate in international projects that link research and education, such as the Marie Curie ITN network TACK (Communities of Tacit Knowledge) and CA2RE+. Also, the topic of architectural pedagogies should be accommodated in our (PhD) research. Oscar Andrade's recently finished PhD project (2021) about the pedagogical position of the Ciudad Abierta initiative at the school of architecture PUCV in Valparaiso, Chile, is one example.

Digital Culture

For some time now, we have been experiencing new cultural forms of recoding, trans- coding and converting spaces, objects, forms, surfaces, materials and even the human body. The research agenda examines what it means to design for a data-driven society that is seeking a balance between an ecological sense of resources and Artificial Intelligence.

The UN has published a series of reports describing the possible uses of data technologies for public and civil community projects. The publications are part of the Global Pulse initiative launched by the UN Secretary-General a few years ago and are based on two remarkable basic assumptions: first, that data will be 'harnessed safely and responsibly as a public good' in the future, and second, 'that digital data offers the opportunity to gain a better understanding of changes in human well-being [...].' In contrast to the current situation, mainly private companies that capitalise on big data technologies, this approach emphasises the enormous potential and use of data as a freely available resource for culture and the common good, including architecture. Therefore, this vision is about nothing less than the idea of developing a new open structure for our future data-driven society – a new technological situation for the 21st century. And thus, the UN's central question is 'How can citizens be involved in collecting community-level data and mapping their own living environments, and how can they then use this information in planning for the future?' Which new emancipatory possibilities would such a new approach bring forth for architecture? What would a world look like in which all the data about our environment and our cities and buildings was not a private economic resource but was, instead, freely available? And what would such a step mean for society — on a cultural, scientific, social, and political level?

The computerisation of the world makes us realise what it means to be part of a globally operating industrial complex, which is especially true for architectural production. Materials, objects and capital circulate in an infrastructural matrix whose scale and impact we are only gradually beginning to understand. Thanks to more precise simulation models of material and substance cycles, we can increasingly document and research the consequences of an environment that has been completely transformed by humans. Digital mappings are now emerging that will lead to new insights and simultaneously question traditional supply and production systems. We are only beginning to grasp, for example, that the way buildings are manufactured and constructed around the world is a process that no longer takes place only on Earth's surface but also leaves traces deep inside Earth. Sandstone, iron, copper, and lithium are mined with elaborate methods and then processed for the global construction industry. How can construction, raw materials and digitalisation be brought together? And what is the actual geological footprint of future data-based digital architectural production? These are tricky but important questions that are not only about innovation but also about responsibility. In the coming decades, they will undoubtedly impact construction more than we may have expected. The 21st century will require us to develop concepts for thinking about design in a data-based ecological way. This Department of Architecture research line takes up these critical questions, positioning them at the very centre of future projects linking design to open science and the vision of an open data society.

An open society is considered one of the most significant civil society projects handed down to us from our architectural ancestors. The way landscapes, cities and buildings look and are organized, how they touch us emotionally and become part of communication and collective memory and how they can perform elements of the transformations we need all shape our ideas of 'self' and 'society'. For the future, the significance of this heritage lies in our collective responsibility to question and renegotiate the concept of 'openness' constantly and critically. However, the notion of it changes depending on the context in which we speak of an open society. It makes a difference, for example, whether the political basis of a democracy, the economic principle of a market economy or the handling of personal data is the topic of discussion. This is also indicated by the UN study mentioned at the beginning. The UN study might be mentioned in the same breath as Buckminster Fuller's World Game simulation of 1961, even if such juxtapositions always seem a little awkward given the rapid technologization of the world. Both Fuller's World Game and the UN study are two mental experiments that use an agenda of enlightenment – therefore giving them a certain social relevance – and indicate the direction architecture might take. Dreaming of an open-data society as a project is one side of the coin. The other side of the story is the question of what it means to design in such a data-driven society or even how we can produce meaning from the vast amounts of environmental data. In the future, we will not be able to avoid new tools in architecture, such as machine learning, because human intuition will eventually reach its natural limits when faced with so much data. We are collecting and sharing more and more data about materials, the environment and the climate, but the faster this data is collected and shared, the more likely we are to be confronted with the limitations of our own ability to make judgements. At stake is the interpretive prerogative we have regarding both the built and natural environment. We will have to admit that we will neither be able to evaluate nor judge the complex structure of an open-data society without automated analytical capabilities. Therefore, one of the key questions for architects at the beginning of the 21st century is: what does it mean to design in a society that seeks balance between Artificial Intelligence and the datafication of all areas of life and urgent environmental issues?

Architects curate, organize, communicate and explain data in a digital world, facing new ecological, cultural, aesthetic, social, and political challenges and paradigms of the built environment. To deal with the growing complexity of architectural data, designers need to consider social, material-related and environmental impacts. Artificial Intelligence, in particular, augments new decision-making processes that are increasingly characterized by multiple stakeholder influences: from ecological and human data to customised building standards and performance-based life cycles. This facilitates a transition in research towards a data-driven design of more versatile and sustainable buildings.

Research and Projects
The research line 'Digital' interacts with the following five groups and labs:

FUTURE OF HISTORY
The History of Architecture and Urban Planning group led by Carola Hein explores new and innovative forms of the historiography of architecture and the built environment using cutting-edge Digital Humanities research methods and concepts. Examples of this are

the completed projects 'ArchiMediaL' and 'Time Machine' and the ongoing participation in the 'Time Machine Organization', aiming to combine Europe's rich past with up-to-date digital technologies and infrastructures, creating a collective digital information system mapping the European economic, social, cultural and geographical evolution across times. In the proposed approach, digitization is only the first step of a long series of extraction processes, including document segmentation and understanding enhanced by Augmented/Virtual Reality (AR/VR) applications, leading to simulations of hypothetical spatiotemporal 4D reconstructions.

FUTURE OF ARTIFICIAL INTELLIGENCE IN DESIGN
As part of a TU Delft-wide AI initiative, the Faculty of Architecture and the Built Environment has established the Artificial Intelligence for Design, Analysis and Optimization in Architecture & the Built Environment (AiDAPT) Lab in 2021. Led by Seyran Khademi, this lab brings together data-driven intelligence and model-based engineering to support long-term, adaptive, evidence-based abstraction and synthesis of structural and architectural choices toward a more sustainable and resilient built environment. Big data from the built environment are ubiquitous in the form of images, videos, and sensory measurements of structural health. Moreover, the computing power for data processing is growing. Harnessing these opportunities, Artificial Intelligence provides us with unprecedented capabilities to analyse, optimise and automate the different phases of decision-making in the built environment. Therefore, the AiDAPT Lab (together with four new PhD students) studies and develops state-of- the-art machine-learning and deep-learning methods from automatic recognition of visual architectural elements for dynamic feature extraction, inference, optimisation and autonomous decision-making under uncertainty.

FUTURE OF DESIGN
The Complex Projects group, led by Professor Kees Kaan, targets all scales of architectural thinking, from detail and buildings to cities and regions. It aims to expand the knowledge about design and dense urban area development and broaden future architects' minds and thinking. Here, digitalisation plays a significant role, forming the group's research focus, 'Datapolis', and aiming to explore physical and spatial aspects of data: from automated landscapes of factories and distribution centres to non-human architecture of datacentres.

FUTURE OF ARCHIVES
The Jaap Bakema Study Centre, led by Dirk van der Heuvel, is a collaborative project of Het Nieuwe Instituut and the ABE Faculty. It initiates and undertakes research projects that result in exhibitions, publications and public events, often in collaboration with third parties and within international networks. The National Collection for Dutch Architecture and Urban Planning collections form the basis for a research programme situated at the intersection of advanced historical and theoretical research and urgent social issues. The activities are divided into several long-term projects addressing digital archives and future data-driven concepts of architecture collections linking Artificial Intelligence and archival research, for example, 'MVRDV Living Archives' or 'Building Data: Architecture, Memory, and New Imaginaries'.

FUTURE OF DESIGN AND SOCIETY
The Theory of Architecture and Digital Culture group, led by Professor Georg Vrachliotis, was founded in 2020. It critically explores the technological conditions under which architecture in the age of global digital infrastructures emerges, from small to large scale and from everyday practice to the very big picture. Datafication is nothing new in architecture, and there is a long tradition of design by statistics or empirical research. But computer vision and machine learning have fundamentally changed the cultural techniques of observing, measuring, calculating, writing, modelling, drawing, and the meaning of data. (Open) data has operationalised our knowledge about space and time, people, materials, buildings, cities and landscapes and has, in a sense, become a medium of integration, converging models, media and methods from different disciplines and scales. This raises new questions for research at the intersection of design and society. The group leads 'The New Open', the flagship project of the Faculty of Architecture and the Built Environment initiated in 2021 and is a partner for the EU Horizon project 'Digital Ecosystem for the New European Bauhaus (digiNEB)', initiated in summer 2022.

Pathways to impact
In the coming years, this research line will pursue three projects that seek to (1) integrate AI into architectural design, (2) create a cross-departmental research platform for the students and members of the ABE Faculty, and (3) close the gap between academia, architectural practice and the public at large through the 'The New Open' flagship project.

ARTIFICIAL INTELLIGENCE FOR ARCHITECTURAL DESIGN
We will continue to study and develop state-of-the-art machine-learning and deep- learning methods, from automatic recognition of visual architectural elements to dynamic feature extraction, inference, optimisation and autonomous decision-ma- king under uncertainty. Today, architects are well equipped in their creative process with computer modelling tools and software. Nevertheless, support for interpreting architectural design is yet to be explored in the age of Artificial Intelligence. Recent developments in Artificial Intelligence offer new opportunities for supporting this complex optimisation process in architectural design and engineering. Big data from the built environment are ubiquitous in the form of images, videos, and sensory measurements of structural health. Moreover, the computing power for data processing is growing. Harnessing these opportunities, Artificial Intelligence provides us with unprecedented capabilities to analyse, optimise and automate the different phases of decision-making in the built environment. For this, we propose curating and collecting a worldwide first open-source benchmark machine learning dataset to benchmark the performance of state-of-the-art machine vision models for automatic parsing and recognition of architectural elements in floor plans, leading our expectations and inspiration toward a more reliable AI application in research and practice. The outcome of the dataset is twofold: first, benchmarking the existing computer vision model for automatic recognition of architectural elements. Second, training and developing advanced computer vision models by deep-learning methods to achieve superior models that can label building elements. An essential aspect of this project is its reusability for the broader research community. We will promote the benchmark dataset in world-class conferences and platforms, such as Kaggle, to get other researchers to improve the state of visual recognition for architectural design data. A potential application is an integration of trained intelligent models into Building Information Modelling (BIM), a standard for universal and effortless information flow for collaborative architectural design on different scales. The Faculty of Architecture and the Built Environment at TU Delft is a well-

known research institution that could offer the first comprehensive open floor plan dataset for AI research worldwide. An openly accessible architecture dataset is essential in developing competent AI models for perceiving build and design forms. This is as relevant as the advancement of the computer vision models in image recognition owed to the creators of the Stanford University-based ImageNet dataset. Particularly important for architectural design data are floor plan images, in which the information is sparse in the pixel space compared to the natural photo imagery.

DESIGN, DATA, AND SOCIETY (DDS) PLATFORM
We will continue to develop the Design, Data and Society (DDS) platform, the new cross-departmental infrastructure for communication, education and research, aiming to share and reuse open data, allow the reproducibility and reliability of data-driven research in architecture and the built environment, and to create new forms of scientific interaction by the principles of findable, accessible, interoperable and reusable data (FAIR Data). For research, the goal is leading cross-departmental design research also referring to the TU Delft Open Science Program, creating new forms of scientific inter- action through the principles of findable, accessible, interoperable and reusable data (FAIR Data) and exploring further key questions such as: What does it mean to design when architects can train machines to assist? How could we re-think fundamental cultural concepts and human design skills, such as intuition, evaluation, and cooperation in an open data society? For education, the goal is to enhance Open Educational Resources (OER) for digital design education, share studio projects and course materials, strengthen the transferability of design knowledge, and train architects in designing and re-designing for society by connecting open data to social questions of environment, energy, and health. For communication, the goal is to exchange between academia and society, link architecture to the data management discourse, and foster social innovation with sustainable design standards and public values.

The New Open

We will continue to develop The New Open, a flagship project of the Department of Architecture, initiated 2021 led by the Theory of Architecture and Digital Culture group to explore the role of open data for design and social change. Architects Jaap Bakema, Frei Otto and Fritz Haller; the Club of Rome and Bouwcentrum Rotterdam laid the philosophical groundwork for an open data society where democratic design informed public spaces. These innovators of the open data society also experimented with 'participatory design' to better involve citizens in the design decisions of their cities, which transformed the architect's role from sole decision maker to moderator and curator of communication processes. The New Open builds on these historical references to inspire today's visions for a future open data society. We aim to address todays and tomorrow's most pressing concerns, from sustainable building materials and better design to data literacy and data democracy, to curating the cohesive fabric of highly functioning, ecologically savvy smart societies. Themes like inclusivity and social justice were at the core of the project. In a world drowning in data and pixelating in data fog, 'The New Open' aims to increase data optimism through data literacy and new ways of seeing, processing, interpreting and sharing (open) data in collaboration with artificial intelligence. The New Open explores openness by overcoming data sharing anxiety and scepticism. We aim to democratise data to make our collective data cloud more visible and useful for all and to foster a co-creative mindset in designing our living environments. By unlocking a new data culture, we cultivate architectural trans- formation by demonstrating the potential of open data for radically new design, and as a resource to advise, inspire, and inform architectural practice, business decisions and planning. As a dynamic platform with ongoing critical contributions from global thought leaders in architecture, design, climate, data science, art, culture, economics and politics, 'The New Open' rethinks the future foundations of design and its impact on our societies. Through a vibrant mix of digital and analogue experiences, ever-evolving critical topics in the cultural, political and social arenas will be addressed to bring open data futures to life and support tomorrow's creators in their critical work. These will include a podcast and a book series, live and digital talks, workshops, exhibitions, social media happenings and a fellowship programme featuring special projects with creative visionaries.

Design Research

Following the recommendation of the last research assessment, the Department of Architecture has established a new research agenda focusing on 'design research'. The department takes the position that there is a profound urgency to evaluate the relationship between design and research within the context of the faculty in general and the department in particular. While there have been numerous attempts over the years to formulate how design can better fit within established university understandings of research – think, for example, 'research informed design', 'research for design', 'research into design', 'research about design' and, most notably, 'research by design' – the department seeks to finally clarify the false dichotomy between design and research and to acknowledge and embrace this tautology, eliminating the need for prepositions or verbs.

The elision 'design research', the intertwining of subject and object, envisions the possibility that designers might research while researchers might design, offering a reconsideration of what is 'design' and what is 'research' within the department's activities. Design research is inherently linked to the practice of architecture and can apply knowledge from professional practice into academia while at the same time offering knowledge gained from professional practice to academia. Therefore, the engagement of the department's professors of practice (Dick van Gameren, Kees Kaan, Winy Maas, Daniel Rosbottom, Paul Vermeulen, Nathalie de Vries) is central to the future development of this research agenda. The professors of practice represent the importance and qualities of architectural excellence, i.e. excellent design practice, excellent design education and excellent design knowledge. The qualities of this excellence need to be reclaimed as the main currency of 'research output' within the department.

Pathways to impact

Design practitioners and educators need a platform to share their research through other means than traditional scientific terms that are presently dictated by established university norms and protocols. To better achieve this ambition, the department is working on the following four initiatives:

Perspectives from Practice
A working group including the professors of practice and led by a (newly appointed) director enterprise could provide input on future research priorities and topics from the realities of professional practice. This would enhance the department's already strong history and theory expertise with knowledge of the spatial and design implications of contemporary societal changes.

Design Research Dossiers
A new publication series will be created with the aim of featuring the output, from realized buildings and unpremiated competitions to exhibitions and books by the department's academic staff from practice.

Forms of Architectural Inquiry
New coursework will be created focused on how established and emerging design tools, techniques, and mediums may be used to develop innovative means of architectural inquiry and investigation. While, at the same time, continuing to explore how established and traditional research methods can be used to speculate and question established design means and tools.

The Architecture of _____
The synergy between the post-master's degree, which is provided by the Berlage Centre for Advanced Studies in Architecture and Urban Design, and PhD research will be initiated, following the NVAO's recommendation. Building on the knowledge gained from its participation in CA2RE, the department will commence a design research PhD path. Within the framework of the Berlage, as has been advised by past research assessment committees and previously mentioned by the department, the new thematic PhD programme, entitled 'The Architecture of _____', will be launched at the end of 2022. It will examine the design of building types that emerged in the Enlightenment, started proliferating at the end of the nineteenth century, saw their collapse in the late twentieth century, and are being reconfigured today. If the Enlightenment shaped and formed new types of institutions and spaces, the aim now will be to examine what new physical forms will represent revised globalism. The underscore of the title – to be filled in by either a noun or a verb – will have a distinct relationship to a building type or spatial characteristic. For example, 'The Architecture of Fitness' could investigate the emergence of physical culture, sports clubs, and gymnasiums as uniquely designed collective spaces in the nineteenth and early twentieth centuries and how they are rede- signed today to fit into market-driven real estate development. Or the 'The Architecture of the Post Office', which could examine the postal spaces and infrastructures that were once public buildings central to urban life but have now been transformed into service points within other spaces or into big boxes placed at the periphery. The methodological approach will consist of historical research and design documentation, interpretive reconstruction, discourse analysis, and projective speculation.

X Agendas for Research

At present, the Department of Architecture has ten agendas for research, each pursued by one designated research group. The research programme of the department focuses on architecture as an expanded field of expertise that links making and thinking, design and research, history and theory, typology and morphology and culture and context. From this understanding, we address architectural production as a concrete spatial and material configuration of cultural, social, functional, philosophical, economic, and ecological factors. Each agenda relates to architecture's contemporary situation – often addressing real-world challenges, such as climate crisis, energy transition, societal diversity, geopolitical conflict, etc. – through its position, research themes and methodologies. As a cultural field of action and reflection that is strongly related to other disciplines, architecture addresses both societal and scientific questions.

Architecture and the City approaches the city as a collective artefact shaped by public processes and considers the notion of the public realm as a lens to look at the (trans)formation of built forms. In doing so, this research group explicitly includes the changing socio-cultural dynamics of public institutions along with the development and transformation of physical public infrastructures over time. The **Borders & Territories** research group focuses on the critical relationship between architectural theory, socio-spatial analysis, and architectural design. The group studies architectural constructs as a precursor of a 'now' discourse, addressing other possibilities of architecture by speculating on the relevance of the appropriation, implementation and application of methods and instruments that have been progressively externalized to the disciplinary core (cartography, literature, art, philosophy) and the constructs and objects that the discipline historically has not considered as architectural material as such. The research group **Situated Architecture** recognises that the experience of architecture is bound to situations that architecture both articulates and produces. The consideration of these situations includes material cultures, languages, representation and a multitude of framings and mediations. The issue of situated architecture demands inquiry into the complex nature of the conditions of its appearances and its experience. This research group takes the notion of situated experience as a common ground between academia and practice as a topic to explore both conceptually and through material and building practice. The **Architecture, Culture and Modernity** research group focuses on the multiple ways architecture absorbed and responded to the conditions of modernity, in particular the emergence of mass society and related urbanisation processes, new forms of (democratic) government systems and concomitant issues of subject-formation, emancipation and citizens' empowerment. Departing from the observation that the rate of urbanisation will increase dramatically in the coming decades in low- and middle-income countries and that this process will create many opportunities but also challenging problems regarding the access to adequate housing for low-income groups and special groups, such as elderly, disabled, students or starters, the aim of the **Global Housing** research group is to promote more inclusive, sustainable and resilient urban communities through projects that analyse, evaluate, and develop knowledge on housing design combining situated approaches with a global perspective. **Ecologies of Architecture** is a neo-materialist research group whose axiology stems from the mutual determination of technicity (reciprocity of subjects and their built surroundings) and affect (response-ability) driven by a discerning attitude to hylomorphism. This group champions the ecologisation of architecture: a cross-scale relationality, non-entailment and agential realism, i.e. a different – non-linear and non-local – conception of causality (including both the efficient causes and neo-finalist causes). The **History of Architecture and Urban Planning** research group explores architectural and urban forms, functions and meanings from long-term, multi-scalar, and multidisciplinary perspectives. It combines diverse methods of historical and historiographical analysis (archival investigation, literature studies, interviews, site visits, statistics

and mapping and big data explorations) to understand the construction of the past and its role in the formation of the present. Believing that substantial historical knowledge can only benefit prospective designers, our research aims to anticipate fundamental issues that will impact our immediate and distant futures.

Complementing the aforementioned seven (established) research groups, three new research groups have been set up since the 2019 mid-term assessment seeking to advance research within the department on pedagogies, digital culture, and design research. The **Architectural Pedagogies** research group builds upon the knowledge produced in the department's education to make a plea – both within the faculty and beyond – for the importance of architectural thinking and making in education. The group collects ongoing reflections and publications about the various studios and engages in discussion with the different chairs to bring forward architectural pedagogy as a field of knowledge. The research group **Theory of Architecture and Digital Culture** critically explores the technological conditions under which architecture in the age of global digital infrastructures emerges, from small to large scale and from everyday practice to the very big picture. It questions what it means to design in a society that seeks its balance between Artificial Intelligence and the datafication of all areas of life, increasingly rapid global migration and urgent environmental issues. Finally, the **Design Research** envisions the possibility that designers might research while researchers might design, offering a reconsideration of what is 'design' and what is 'research' within the department's activities.

Research and Projects

The research carried out by the Department of Architecture is broad in scope. Included below are brief descriptions of some of the research projects pursued by the department's (seven) established research groups. Projects pursued by the three newly established agendas are discussed in the other case studies (above) in appendix 1.

As one of the largest research groups in the department, *History of Architecture and Urban Planning* can boast a wide array of projects. Water is one important theme that is central to several projects, including **PortCityFutures** (PI: Carola Hein), which examines the evolving spatial use and design of port city regions over time, with a special focus on port and city activities occurring in the same places that might conflict. Several projects focus on the digital/digitization, including **ArchiMediaL** (PI: Carola Hein), which investigates the automatic recognition of architectural and urban forms that are available digitally or on the web to examine how computers perceive urban scenarios and which spatial features enable them to distinguish between cities and buildings.

Digitization and Teaching with Collections (PI: Charlotte van Wijk), another 'digital' project, seeks to improve the presence and impact of the ABE Faculty's large collections of architectural models and chairs beyond the faculty (through online digital means) and to actively use these collections in object-based learning. Another project that can be categorized under 'digital' is **Time Machine** (PI: Carola Hein). This project aims to develop big data of the past – a vast distributed digital information system mapping Europe's social, cultural, and geographical evolution across times – to turn Europe's long history into a living social and economic resource. Apart from such larger themes, the History group also pursues other (more singular) projects related to topical issues, such as **Is Oil Dying? Long Live Its Heritage!** (PIs: Stephan Hauser, Carola Hein), which examines the spatial traces of oil transportation, storage and refining over time, taking into account the numerous environmental and health challenges as well as the local, national and European regulations that have come into effect since industrial oil drilling began in the 1860s. Another such topical project is **Identity and the Built Environment** (PI: Gabriel Schwake), which focuses on the architecture and urban planning of Israel and Palestine to examine the efforts made toward creating a local identity amidst tensions between the ideas of east and west, as well as global and local.

Key projects pursued by the *Global Housing group* are the **Addis Ababa Living Lab** (PI: Frederique van Andel), which develops a new co-creation model that uses multidisciplinary tools and methods for affordable housing development in Addis Ababa and **Collective Housing and the City** (PI: Nelson Mota), which compares housing projects developed in The Netherlands and in Brazil since the early 1990s (after the neoliberal turn) to examine how social and economic policies affect design-decisions and how design-decisions can affect policies.

Among the projects pursued by the *Ecologies of Architecture* group are **Architectures of Life and Death** (PIs: Andrej Radman, Stavros Kousoulas, Robert Gorny), which starts from the assertion that life extends beyond its merely biological aspects through the non-living artefacts that support it and, at times, oppose it. As such, this project examines how the built environment and its technicities produce a style for living and dying that may be said to take place simultaneously. Another key project of the Ecologies group is **Critical and Clinical Cartographies** (PI: Andrej Radman), which seeks to address questions such as: What is the impact of the digital turn on contemporary medical and architectural education and/or practice? How does the posthuman turn influence the possible convergence of medical and architectural education and/or practice? How has the biopolitical concept of care mutated under the proliferation of digital technology? How could medical research contribute to architectural design, and how could design, in turn, contribute to improving health care?

Situated Architecture is another of the department's larger research groups, which has a good critical mass and counts several professors of practice (such as Daniel Rosbottom and Paul Vermeulen) among its members. As a result, the group pursues research that is strongly related to (even intertwined with) architectural practice. **Communities of Tacit Knowledge: Architecture and its Ways of Knowing** (PIs Klaske Havik and Janina Gosseye) is a good example. This project examines the role that tacit knowledge, which is a type of practical or implicit knowledge, plays in the architectural design process and how it is embodied in the specific media and instruments that architects work with, from treatises and drawings to models and buildings. The group also pursues research projects that examine the perception of place and the role of narrative and the space of words in architecture. A good example is **Writing Urban Places: New Narratives of the European City** (PI: Klaske Havik), which focuses on the potential of narrative methods for urban development in medium-sized European cities.

The research pursued by the *Architecture, Culture, Modernity* research group is quite varied in scope. One of its key projects is **Her Office** (PI: Amy Thomas), which examines the correlation between workplace design and workplace inequality. This project aims to

show how women's well-being, health, status, and career progression have been disproportionately disadvantaged through space management and design, furniture and product design and the client-designer relationship. Another important project the group pursues is **The Critical Visitor** (PI: Dirk van den Heuvel), which focuses on developing intersectional approaches for rethinking and retooling accessibility and inclusivity in heritage spaces. Put differently; this project seeks to discover pathways for heritage institutions to achieve greater inclusivity and accessibility for outsider groups and marginalized voices. **Constructing the Commons** (PI: Jorge Mejia) probes into the figure and project of the commons – a concept that is today widely and extensively discussed within economic, social, and political theory, as well as within the creative industries – to reflect upon the multiple challenges that the commons pose today to the fields of architecture and urbanism.

An important research project pursued by the ***Borders and Territories*** group is **Securing Democratic Society: State Policies, Technological Surveillance and Spatial (Cross-) Boundary Practices** (PIs Marc Schoonderbeek, Grazia Tona and John Hanna), which examines the effects of the current heightened state of security alert of public space to formulate policy recommendations that help to secure the democratic nature of public space. **Idiosyncratic Infrastructures** (PI Filip Geerts) examines the customized solutions developed to reconcile the highly regulated and normative nature of infrastructure design with the complex pre-existing realities (produced by contradictory desires and often influenced by conflicting agencies) that need to be addressed. Another important project of Borders and Territories is the **Topological Atlas** (PIs: Nishat Awan, Asim Rafique and Ishita Sharma), which seeks to develop a transdisciplinary research programme for mapping, analysing and intervening in border areas in the form of a digital atlas, examining how such a topographical representation par excellence might be reimagined differently.

Like the Situated Architecture group, the ***Architecture and the City*** research group also succeeds in bringing together professors of practice (Kees Kaan and Nathalie De Vries) and academic researchers pur sang. Apart from projects that focus on the city at large and that seek to develop integrated design approaches to transform inner-city areas into future-proof urban environments – e.g. **City of the Future** (PI: Hans de Boer) – several projects pursued within this group focus on particular architectural types or elements that make up (or contribute to) the urban environment. Such projects include **Stations as Nodes** (PI: Manuela Triggianese) which examines the role and function of the station of the future, considering the growing number of users, sustainability challenges, urban integration, heritage and spaces for culture, etc. Another example is **The Next Public Library** (PI: Olindo Caso), a project that examines the changing identity, programming and architectural character of the public library as a key node of this infrastructure.

ARCHITECTURAL ENGINEERING AND TECHNOLOGY

SUMMARY

The Department of Architectural Engineering and Technology (AE+T) must, by design, perform a balancing act between engineering specialists addressing technical aspects of material science, heat transfer, mechanics and indoor health and design generalists combining the architectural design of new or reused (historic) structures and façades with the possibility of advancing the engineering field.

What unites our specialists and generalists is that all societal challenges in the built environment have a substantial technological component.

We must educate and persuade generalist architects and specialist building technologists to collaborate in resolving these challenges. Therefore, shaping such collaboration and interaction is foremost on our minds. However, while recognizing that human and societal aspects are critical and reaching out to involve scientists with the required expertise, we remain true to our focus on engineering and technology.

Our mission is to advance technology to enable the design of a better-built environment considering our planet's finite resources and with added value for people and nature. To achieve this goal, we aimed at developing excellent research content and output through interdisciplinary collaborations that address the complexity of the built environment; while maximising our impact through valorisation and external visibility to reach different societal actors and building industry stakeholders.

During the current review period, 2016-2021, we worked on a strategy based on a collaborative academic culture that allows for individual development. Different research programmes were merged into one overall research unit at the department level to create an improved organisational research structure and facilitate closer collabo- ration. The people in our department are the ones that materialise our mission, and we take great care to attract the right experts and provide them with possibilities for academic growth. In alignment with our strategic plan to strengthen certain disciplines, we have appointed several full professors, professors of practice and assistant professors in tenure tracks who ensure the department's future. In addition, we worked on a more effective policy for the PhD candidate's selection and training.

Our output supports the transition towards a better-built environment if the knowledge is adopted not only by academics but also by key actors. Such actors are the policymakers, the planners and designers, the building industry and the users and residents of the built environment. To this end, it is crucial to develop design methodologies, demonstrate real-world implementation and collaborate with stakeholders to influence their practices. Our commitment to open access not only regarding scientific publications but also regarding data and education, such as the development of open online courses, supports this goal.

Internationally, our department is a recognisable and authoritative unit with expertise in building engineering and design and a desired partner in international consortia and committees. This recognition materialises in our research staff members being part of numerous international research and academic networks. We continuously seek to enlarge those networks and create strong links between industry and academia. The collaboration goes beyond dissemination activities and often includes setting up joint research projects and networks.

AE+T's investment in the topics of energy transition, climate adaptation, health and comfort, circularly, digitisation and heritage is a vital contribution to the sustainability of the built environment and, ultimately, life on earth. Operating within those broad topics are a variety of specialisms at regional to façade to interior and component scale. Specialisms that are confidently growing toward greater societal engagement through dissemination approaches that form a bridge of trust, knowledge and aspiration between specialists, industry, and citizens.

Case studies

Circularity in the Built Environment Hub

The Circular Built Environment Hub is bringing together about 70 researchers and lecturers from the four departments of the Faculty of Architecture and the Built Environment with the aim to foster synergies between the different disciplines and develop and promote knowledge toward a circular built environment. It was founded in 2017 to address the faculty's many ongoing activities that needed alignment. Understanding that circularity in the built environment is manifested on different scales and with different approaches, methodologies and stakeholders and seeing the broad spectrum of the faculty provided a unique opportunity to formulate a first holistic view of the topic.

The Hub relies on the individual activities of its members and the dynamics of their collaboration. Therefore, the CBE Hub functions as a facilitating platform, stimulating all members to contribute to present their research and other activities such as networking around the topic of circularity. In return, they create new knowledge and gain visibility and connections. Working in a multidisciplinary team challenges preconceptions and opens new ways of creating and testing the limits of current practices.

An important achievement of the CBE Hub is a methodological framework defining the circular built environment. This framework, developed and published in articles and conference contributions[1], acts as the basis for a coherent understanding of the still emerging topic and linking research results to practice applications.

Furthermore, we have developed a vision for circular education and a life-long learning strategy. The Hub has established a set of new learning objectives for the BSc, MSc and PhD programmes, a number of specific courses and course-supporting materials. It also aids educators through the Circularity for Educators and the Educators for Circularity platforms. Life-long learning projects, on the other hand, include the creation of diverse formats for adult education: a MOOC, two ProfEd courses, a series of Planned Collaboration Programmes and, as of late, a webinar series made available on the TUD online learning platform.

The CBE Hub supports the team through communication activities, research story writing, content dissemination, events and monthly meetings. In collaboration with the TU Delft Innovation & Impact Centre, funding opportunities are highlighted. The Hub channels the involvement of its members in policy-making organisations such as CB23 or BTIC. Numerous conference participations of the members are shared.

The members of the Hub together maintain a large national and international network. In 26 research projects, they worked with about 100 industrial partners, more than 80 research institutions and 15 governmental institutions and municipalities. Projects are key elements impacting the practice world and policymakers.

The Hub is leading a TU Delft-wide action to foster the collaboration of all faculties, called Delft Circularity Impact (DCI). It supports the TUD Campus Real Estate department in developing a circularity strategy for their building portfolio, including several living lab projects on campus. A website contains all Hub activities for internal and external communication. These activities have made TU Delft the number one university on the international academic map.

1. Ioannou, O., Geldermans, B., Klein, T. & Wandl A., 2022. Planning for Change: A Methodological Framework for Integrating Circularity at TU Delft's Faculty of Architecture and the Built Environment's curricula. In Serbian Journal of Architecture 12(3), 234-269. DOI: 10.5937/saj2003234I

Position and added value of the CBE Hub

The faculty has defined the depletion of resources as one of the main societal challenges and circularity as a means for human development within the planetary boundaries. The concept of circularity has evolved from the 1970s when the limits of growth due to human development became obvious. Its theoretical foundation is influenced by several concepts such as Regenerative Design, Cradle to Cradle, Biomimicry and Blue Economy. In 2013, the Ellen McArthur foundation brought renewed attention to the concept framing it as an "industrial economy by intention and design"[2].

Today, Circular Economy has been embedded into policy documents such as the Circular Economy Promotion Law of the People's Republic of China[3], the EU 2015 Circular Economy Strategy[4] and A Circular Economy in the Netherlands by 2050[5].

Circular Economy is still an emerging framework and, therefore, still indeterminate. Material resources come from global supply chains to create building products. These are assembled in buildings. All geared toward an urban metabolism in which supply and waste streams are channelled and where social aspects come into play. The CBE Hub is a cross-departmental activity touching all scales, from material to regional scale. With a research portfolio by its members of more than 26 projects representing a budget of more than 8 million Euros in the past five years, the Hub has allowed aligning research and dissemination activities. Reaching out to stakeholders from the building industry, architects and engineers, users, inhabitants, investors, government and policymakers requires a holistic way of communication that represents all the different research approaches.

The Hub is open to all faculty staff members involved or about to get involved in aspects of circularity in research and education. The Hub supports its members to excel and deliver high-quality output and impact. In this sense, it has mainly a facilitating role, but it also provides a holistic communication strategy, publishes research output in appealing stories and develops and creates new knowledge. The Hub offers joint efforts in finding research funding and project calls.

Fig. 5 **The Scales to Aspect Model of the Circular Built Environment hub**

2.   Ellen MacArthur Foundation (EMF), 2013. Towards the Circular Economy, vol.2. Isle of Wight.

3.   Su, B., Heshmati, A., Geng, Y., Yu, X., 2013. A review of the circular economy in China: moving from rhetoric to implementation. J. Clean. Prod. 42, 215–227.

4.   European Commission, 2015. Closing the loop - An EU action plan for the Circular Economy, Com (2015) 614 communication from the commission to the European parliament. the council, the European economic and social committee and the committee of the regions. European Commission, Brussels.

5.   The Ministry of Infrastructure and the Environment and the Ministry of Economic Affairs, 2016. A Circular Economy in the Netherlands by 2050.

Fig. 6 **BK Talks session about Scales to Aspects: Scale Matters. In transition to a Circular Built Environment'**
(November 2021)

The expertise of the faculty has allowed the CBE Hub to develop a theoretical framework and definitions. The Scales to Aspect Model is a conceptual framework to structure the complex theme and align research activities. It explains how different building scales relate to involved stakeholders, applied technologies, processes and economic aspects. At the same time, it offers a framework for bringing circularity into the faculty's lifelong learning strategy with the development of on-campus training and online courses and webinar series for professionals. For that reason, a set of learning objectives has been developed that guides the development of the course contents.

This framework was the subject of a BK Talks session in November 2021, 'Scale Matters. In transition to a Circular Built Environment'. (https://www.youtube. com/watch?v=R639-kWDu7E.)

Monthly CBE Hub meetings inform members about funding opportunities, conference participation, and new publications and help to develop the new action plan. External guests from other research institutes and practice are invited to participate and present their institutes and knowledge during these meetings. A news feed on the Hub website informs members and externals about actual content and events.

The CBE Hub supports the faculty's group of 10 PhD students related to the theme by giving them a voice in the meetings and helping them disseminate their output. Also, the Hub is currently leading in establishing a TUD-wide Delft Circularity Impact (DCI) team with the involvement of all university faculties.

Fig. 7 **Delft Circularity Impact team (DCI)**
The DCI is developing a transdisciplinary group with the involvement of all faculties and the Campus Real Estate Department. The wider TU Delft community on circularity counts about 150 people.

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THE CONTRIBUTION OF THE CBE HUB TOWARD THE TRANSITION TO A CIRCULAR ECONOMY

The Hub seeks to **change design practice, politics, society, and the way students think** – at home and abroad. We aim to provide the next generation with a circular research and design approach, providing new research findings. For that reason, we keep developing our large national and international network and reaching out to the industry, research institutes and government organisations.

Together, the Hub members create and maintain a growing network, connecting to more than 80 universities and institutions worldwide. We maintain close contacts with over 100 companies, design and engineering practices. One example of network activities is the feedback the CBE Hub provided in an online webinar on the Denmark Technical University in Copenhagen sector development plan on circular construction.

Furthermore, members of the Hub hold position in think tanks and commissions on the topic of the circular transition. It is a member of Platform31, a knowledge and network organisation for urban and regional development supported by the Ministry of Internal affairs. This opened up options for promotion and direct dissemination to governments and industry. Other relevant organisations we contribute to are the Dutch Environmental Agency (PBL) to explore the spatial consequences of and requirements for the circular economy transition, the 'Circular design working group' of Platform CB'23, whose Prof. Hans Wamelink was the chairman in 2020-2021 and Transition Team Circular Building Economy, which was installed in 2018 by the Dutch government and currently chaired by Prof. Vincent Gruis.

The CBE Hub offers expertise, consultation and research to Campus Real Estate on themes like total costs of ownership and circularity and involves Hub members when needed. Numerous projects have been realized in collaboration with TU Delft's Campus Real Estate (CRE), such as 2600 m2 of façades at the Faculty of Civil Engineering in the form of a Circular Lease Façade. The CBE Hub also supported CRE in developing a Circular Campus strategy. This includes ongoing renovation activities and the circular development of the South Campus (Kluyvergebied) with the definition of targets and circularity indicators.

EDUCATION

Circularity is geared into the faculty's teaching agenda through several activities. The CBE Hub has developed a set of learning objectives for the BSc, MSc and PhD educational programmes. The Hub also acts as a platform to unite circa ten PhD students on the topic of circularity at the faculty while supporting educators to learn about and integrate circularity into their teaching. The BSc programme is supported by several curricular and ex-curricular activities, such as lectures, workshops and events. Part of the resources is the Circular Design Atlas (CiDeA) website which provides relevant practice case studies for students and teachers. The open-access programme 'Circularity for Educators' has been online since the end of September 2022, providing faculty teachers with relevant teaching aids.

Finally, a successful contribution to education is the developed online teaching portfolio of a MOOC, two ProfEd courses and an expert webinar. The MOOC 'Circular Economy for a Sustainable Built Environment' was created in collaboration with all faculty departments and, until today, has reached more than 15.000 learners from 110 countries. (https://www.tudelft.nl/en/architecture-and-the-built-environment/ research/research-themes/circular-built-environment/lifelong-learning)

Fig. 8 **CBE Hub Summer School**
Participants and staff of the first CBE Hub Summer School, summer 2022, here on an excursion at Binckhorst in The Hague. The Summer School on Circular Built Environment was organised with 40 participants (PhD students and practitioners) from all over the world.

THE CIRCULAR BUILT ENVIRONMENT HUB IN NUMBERS:

Since the start of the CBE Hub in 2017 until mid-2022, the Hub members jointly published about 60 scientific papers (https://www.tudelft.nl/bk/onderzoek/onderzoeksthemas/circular-built-environment/publications). Books such as 'Circulariteit: Op weg naar 2050?' and the 'Nieuw Handboek circulair renoveren woningcorporaties' have been published.

The Hub has published 15 research stories about projects, translating research results into engaging content for externals. (https://www.tudelft.nl/en/architectu- re-and-the-built-environment/research/research-themes/circular-built-environment/ stories).

'Energies' special issue on 'Circular Built Environment': Open-access journals publisher MDPI is preparing an 'Energies' special issue entitled 'Circular Built Environment' and invites Hub members to contribute. Hub participant Peter Luscuere is guest editing this 2022 publication.

A paper about the philosophy behind circularity in the built environment was published in an international journal: A methodological framework for integrating circularity into TU Delft's Faculty of Architecture and the Built Environment's Curricula (Ioannou et. al, 2022).

Week van de Circulaire Economie 2021 and 2022: 160 events, including TU Delft contributions. Week van de circulaire economie (Circular Economy week): Online symposium 'The architect's roles in the Circular Economy and Circular Society'. Offices invited:

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Space & Matter, Superuse Studios, Thomas Rau and CityFoerster. HUB participants Piero Medici, Tillmann Klein, Roberto Cavallo and David Peck provide the intro- duction and participate at a round table.

At the Ecocity World Summit 2021, CBE Hub members had a special slot available. Workshop on socio-spatial consequences of transitioning to a circular built environment: towards new research agendas.

Regions in Recovery Global E-Festival 2021 (Regional Sciences Association (RSA): The online Regions in Recovery Festival in June 2021 attracted many participants (1250). TU Delft turned out to be a forerunner in putting circularity on the RSA agenda. TU Delft, Erasmus and UCL (University College London) (London) cooperated, and about 20 papers were delivered.

ProfEd in Extension school spotlight: An article about the ProfEd 'Spatial Circularity Strategies for Sustainable Regional Development' can be found on the Extension school website.

CBE Hub story in TU Delft top 10 in 2021: The CBE Hub story 'Zooming in on and out of a circular region' on how students of the Spatial Strategies for the Global Metropolis studio learn to look at spatial functions and processes on various scales, reached the top 10 of best-read TU Delft stories in 2021.

The Hub organises the yearly Circular Built Environment Graduation Award for students of the faculty to stimulate them to integrate circularity in their future work. An average of about 40 projects are handed in each year.

Outreach outside the faculty through Guest presenters at CBE Lunch meetings.

OUTLOOK: WHERE WILL WE BE IN 2-3 YEARS, AND HOW DO WE EXPECT TO GET THERE? WHAT IS NEEDED?

So far, the Hub has succeeded in creating an interdepartmental team of teachers and researchers ready to answer the societal challenge of resource scarcity. The active involvement of faculty members shows that the efforts are appreciated and provide value to individual ambitions. We receive a lot of positive feedback from our peer universities that also start to focus on the topic of the circular built environment. But besides maintaining the momentum, a lot of work still needs to be done.

Circularity is still an emerging framework, and methods need to be developed to help implementation in the practice world.

We are currently discussing the potential of creating a TUD-wide DCI Circularity Initiative and are exploring possible collaboration topics and organisational frame- works that will promote collaboration.

After having developed a strategy for circular education, we will need to ensure it is optimally implemented in the curriculum. The dissemination of our teaching material to academic partners is our goal. The platform "Circularity for Educators" is one of the promising tools that we will test.

Our ambition is to maintain our world-leading role as the number one academic institute on a Circular Built Environment through excellent research, education, publication and events we plan to host in the near future.

BK LABS BY AE+T

The AE+T laboratories, part of BK-Labs, have the common aim to support research and education in answering the questions posed by a rapidly changing society. The expertise and work of AE+T staff are diverse, thereby supporting interdisciplinary research and education and creating a fertile ground for collaboration among different disciplines. An overview of the AE+T labs is given below, in Table 1.19.

In the last six years, the situation of the laboratories at AE+T has evolved considerably: new laboratories were set up (Sustainable structures lab, Glass lab, Heritage & Technology lab, Genesis lab), some have moved to AE+T (SenseLab, Geo-Database Management Center lab), while others have further broadened and developed (Laboratory for Additive Manufacturing in Architecture, Virtual Reality lab and Robotic Building Lab).

At the faculty level, actions were recently taken to facilitate the organisation and collaboration between the laboratories. The AE+T Laboratories have become a ground to share knowledge and fertilise ideas across several disciplinary fields.

SUMMARY OF IMPACT

The overall impact of the laboratories on the research and education carried out at the AE+T department is considerable. The laboratories have:

Promoted collaboration within and outside the department and favoured transdisciplinary research to answer questions posed by industry and society.

Made students familiar with experimental research.

Next to scientific and societal impact, the labs have contributed significantly to increasing the amount and size of acquired projects at AE+T in the past six years. The following sections describe some selected examples of research carried out thanks to the AE+T laboratories, including collaborations and scientifically, technologically and socially relevant output, results and impact. Considering that many of the AE+ labs have been set up only in the past few years, the relevance of their output, results and impact is considerable and expected to grow significantly in the coming years.

RESEARCH AT AE+T LABS

The AE+T laboratories have contributed to answering the needs posed by a changing society, by stimulating collaboration between research groups within and outside the department and the faculty and by working on common research themes, which align with societal challenges, perspectives and strategies identified as most relevant by the faculty and the AE+T department. Moreover, the presence of laboratories has stimulated and enhanced the collaboration with industries, SMEs' and public parties (such as municipalities, provinces and national entities) in co-financed research projects. In the coming sections, the relevance of the work of the AE+T labs is presented through some representative projects clustered according to some main themes.

Research at AE+T labs

The AE+T laboratories have contributed to answering the needs posed by a changing society, by stimulating collaboration between research groups within and outside the department and the faculty and by working on common research themes, which align with societal challenges, perspectives and strategies identified as most relevant by the faculty and the AE+T department. Moreover, the presence of laboratories has stimulated and enhanced the collaboration with industries, SMEs' and public parties (such as municipalities, provinces and national entities) in co-financed research projects. In the coming sections, the relevance of the work of the AE+T labs is presented through some representative projects clustered according to some main themes.

Glass Lab	Sustainable architectural materials and structures	Development and assessment of sustainable applications of glass components and solutions for structural and architectural application
Heritage & Technology Laboratory	Heritage & Architecture	Development and assessment of materials and solutions for intervention in the built environment, with a focus on heritage conservation
Laboratory for Additive Manufacturing in Architecture – LAMA	Architectural & Geo-informatics	Optimisation and rationalisation of design techniques and methods with the additive manufacturing process for appli- cations in architecture
VR Lab	Architectural & Geo-informatics (& Urbanism dept.)	Applications of VR in architecture, ranging from testing façades and visualising buildings in a virtual 1:1 environ- ment to the use of biometrics
Building Physics Lab, including the Light-van	Climate, Energy and Circularity & Health and Comfort	Thermal, acoustic, visual and indoor air quality equipment to be used for research and/or education on Building Physics. The light-van is a mobile lab for studying the impact of daylight through façades on people.
Geo-Database Management Center - GDMC	Architectural & Geo-informatics	Research and development centre for all activities related to the modelling, storage, retrieval, analysis, presentation and distribution of geo-information
SenseLab	Health & Comfort	Testing and experiencing single and combinations of indoor environmental conditions: indoor air, thermal, lighting and acoustic quality
Genesis Lab Laboratory of Generative Systems and Sciences in Architecture and Built Environment	Architectural & Geo-informatics	Development of open-source scientific computing methods & tools for topological and com-binatory design, mathematical design optimisation, form-finding and spatial decision-support
Product Development Test Lab (PD Lab)	Architectural façades and products	Testing of product innovations in the fields of digital construction, circular economy, energy saving, acoustics and integrated installations design
Mobile BuckyLab	Architectural façades and products	Collection of equipment and tools for developing and constructing prototypes

Table 19 BK Labs operated by AE+T

HEALTHY AND COMFORTABLE INDOOR ENVIRONMENTS

The importance of a healthy and comfortable indoor environment is universally recog- nised, but the attention towards this theme got a boost in early 2020 with the start of the COVID-19 pandemic.

At AE+T, research on indoor environment quality is carried out using an integrated approach, which considers the effects of the four indoor environmental qualities (air, thermal, lighting and acoustic quality) on the building user. Thanks to the Senselab, including an experience room and four test chambers, it is possible to study the effects of different combinations of environmental conditions (thermal, sound, lighting and air) on the users when changing the architectural design and choice of materials and systems. This makes the SenseLab one of its kind among the labs around the world.

The research on the transmission of SARS-COV-2 and the role of ventilation had a big impact. Since the outbreak of the coronavirus, the Senselab, in collaboration with other groups at TU Delft, NLR/DNW, Erasmus Medical Centre, Utrecht Medical Centre and the University of Utrecht in the ZonMW project Schools and COVID-19 and with research groups from all over the world convincing the

WHO about the role of airborne trans- mission, has focussed on investigating the spread of indoor aerosols and the measures that can be taken to minimise this. The researchers concluded, among other things, that small respiratory droplets in the air can play a role in the spread of the coronavirus and that, therefore, 'proper' ventilation of indoor spaces is vital. Those findings have gained a lot of attention, informing the public and policymakers on how to tackle the pandemic. In Nieuwsuur, a nationwide television news outlet, Prof. Bluyssen, initiator and head of the Senselab, discussed the letter to the Dutch Prime minister requesting to pay attention to ventilation; this resulted in the new icon "opening windows" in the national COVID-19 guidelines. With an international group of scientists, the work resulted in a Science publication (see Annex Table 1.2).

The other line of research in the SenseLab is focused on an integrated approach towards IEQ, with which occupants of different scenarios can be profiled using their prefe- rences and needs, and risk factors for both negative and positive effects can be deter- mined. The SenseLab, a unique playground for the senses, plays an important part in the detailing of this approach. Prof. Bluyssen has been invited for diverse keynotes and lectures all over the world to talk about it. Since 2019, Prof. Bluyssen has been visiting professor at the Feng Chia University in Taichung, Taiwan, with the specific assignment to assist them in building a SenseLab of their own.

SAFER, HEALTHIER AND MORE COMFORTABLE CITIES

A theme highlighted in the faculty multi-year plan and addressed by research at AE+T laboratories is sustainable urbanisation; based on an integrated approach including CO2-reduction, climate adaptation, inclusivity, liveability, health and heritage protec- tion. Research carried out at the AE+T labs tackles this theme's different technical and social aspects.

For example, the EU-funded Green Quays and the follow-up KIEM Wall Garden projects (cumulative TU Delft budget about 400k), developed at the **Heritage &Technology laboratory** and set up in collaboration between the "Architectural Façades and Products" and "Heritage & Architecture" research groups together with companies and municipalities, focus on developing bio-receptive quay walls. The results of the projects informed the choices for the new quay walls to be built in the city of Breda, contributing to a greener and healthier city. Besides, two prototypes of green and fully circular quay walls were built, now exposed nearby the Delft train station (Figure A 11), thanks to co-financing by the municipality of Delft and the support of the inhabitants.

Where previous projects addressed mainly the "technological" aspects, the project Equicity, developed at the **Genesis lab** in collaboration between the "Architectural and Geo-informatics" and "Heritage and Architecture" research groups, addresses the social aspects of sustainable urbanisation. This research creates a platform for urban and spatial simulation to facilitate research on multi-dimensional, multi-criteria, and multi-actor aspects of the built environment. A serious digital gaming approach is adopted for creating a 'smart polder mol' to support transparent and inclusive decisi- on-making processes in urban planning and management.

SUSTAINABLE AND CIRCULAR BUILT ENVIRONMENT

The **scarcity of resources**, together with the huge impact of the building sector on CO2 emissions, has sped up the search for environmentally friendly and sustainable solutions, including circular and bio-based building materials and systems. Within this scope, the KIEM "Wood Without Trees" project was set up as pilot research to answer the needs of the construction industry, looking for circular, sustainable bio-materials. Developed at the **LAMA lab** in collaboration with companies, the project explores the potential of cellulose and lignin from waste sources, combined with 3D printing, for application in buildings. To reach this objective, the three research groups "Architectural and Geo-informatics", "Architectural Façades and Products" and "Sustainable Architectural Materials and Structures" provided their expertise in the fields of digital fabrication, building product requirements and material science, respectively.

Another example of collaboration for the development of sustainable applications are the 4TU. Bouw Lighthouse granted projects on glass engineering. These regard circular building systems (4TU.Bouw 2017 Lighthouse project "R3 Glass", 50 K grant) and the reversible and discreet application of cast glass as a potential answer to the materiality debate in heritage conservation (3TU.Bouw 2016 Lighthouse project "Restoration of historic structures by glass"). The projects were developed at the **Glass lab** in colla- boration with glass manufacturers and recycling facilities. Re3 Glass, a New Material Award (2018) and S+T+ARTS Prize (2020) nominee, focused on the development of recyclable and reusable structural cast glass components, achieving circularity at the material and construction level, yielding cast block prototypes from several glass waste sources. This has been exhibited at several international exhibitions, including the Venice Design 2018, Dutch Design Week 2018 and Milan Design Week 2019. Currently, the project is exhibited at the topic's media station of the EU Parlamentarium, representing the topic of "Climate Change". The findings from this novel research and the group's unparalleled knowledge on the glass casting process and the resulting physical and chemical characteristics have led to follow-on R&D collaborations on the novel use of cast glass bricks in renowned international building projects, namely the GlassVault (2020, UK), led by Princeton University and SOM, a nominee for the 2021 Structural Award in the Structural Artistry category by the Institution of Structural Engineers, the Qaammat Pavilion (2021, GL) for a Unesco World Heritage in Greenland, the 2021 Public Choice Winner at the Architizer A+Awards in the pavilion category and two industry-funded R&D projects, the Mirage Project at Apple's HQ in Cupertino (USA), which further builds on the knowledge of the group on glass casting incorporating contamination through the investigation and mechanical validation of cast glass made by using sand from 58 different deserts; and a large feasibility study involving several glass casting experiments to explore the recyclability of glass display screens used by one of the largest global consumer electronics companies.

New sustainable solutions are sought for also in the field of heritage and renovation. For example, the OTP TTW MORISAL project (total budget 670keuro), carried out at the **Heritage &Technology laboratory**, in collaboration with other faculties and universi- ties, mortar producers, building contractors and public parties, focuses on developing renovation mortars with improved durability

with respect to salt crystallisation decay. By increasing the service life of renovation mortars, the project is expected to have a significant impact on the sustainability of renovation interventions.
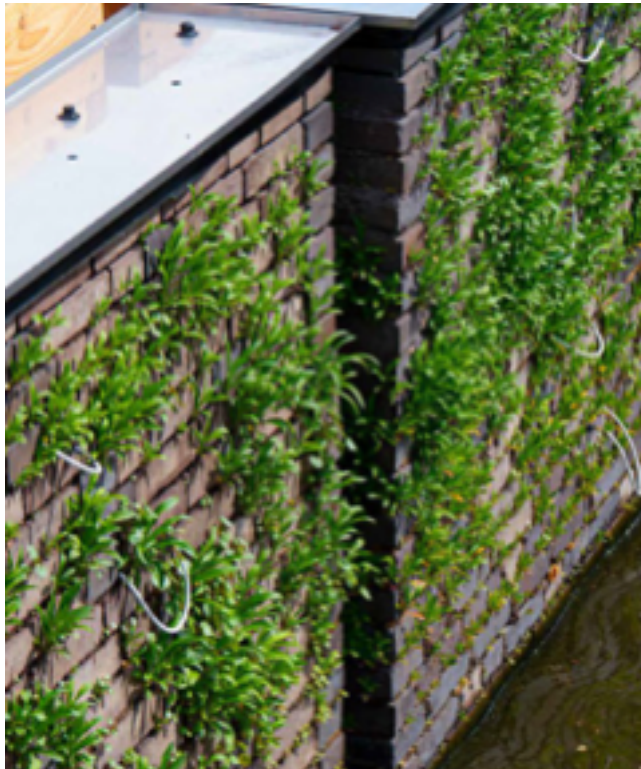

Fig. 9 **Prototypes of green quay walls in the city of Delft**

Fig. 10 **Prototypes of recyclable, reducible and reusable cast glass components, developed at the Glass Lab for the R3 Glass project**

DIGITALISATION AND ARTIFICIAL INTELLIGENCE

As mentioned in the faculty's multiyear plan, one of the questions architects of the 21st century need to deal with is their role in a changing society in which Artificial Intelligence (AI) and datafication in the different life domains are acquiring an incre- asing role. In the field of architecture and the built environment, digitalisation can be a strategy to address and solve design and societal questions in a still unexplored way.

Digitalisation opens new ways of designing based on computational performance optimization and exploration of design options. This includes, for instance, the design of building components, computationally optimized and digitally produced to meet specific requirements and individual preferences. Examples of such inno- vative approaches related to energy saving and thermal comfort are the 4TU Bouw- DoubleFace and the follow-up NWO DoubleFace2.0 projects, developed thanks to the support of **LAMA** and up in collaboration between the "Climate, Energy and Circularity" and "Architectural and Geo-informatics" research groups and with companies. These projects developed a design and prototype for an adjustable, lightweight, translucent Trombe wall (a passive system to mitigate indoor temperature peaks) by combining expertise in 3D modelling, robotic 3D printing and simulation-based optimisation. The prototype was exposed at several exhibitions, including the Venice Biennale 2018. In a similar approach, but focusing on acoustics, the NWO-OTP project ADAM developed a building component for optimizing acoustic absorption based on 3D printing, facilita- ting performance optimization and design customization. All these projects show how digitalisation, with the support of Additive Manufacturing (AM), can open new possi- bilities for producing complex geometries and going beyond the limits of traditional industrial repetition.

Another facet of digitalisation in the design process is given by Virtual Reality (VR). VR can support the immersive visual exploration of design options and allow both the design teams and future users to experience 3D spaces before construction. It also enables to recreate different environments to survey and better understand users' preferences. Employing biometrics, using sensors added in headsets or sensors attached to the body, one can measure the impact of certain design decisions (Virtual Prototyping). Research in this field is running at the VR Lab, such as the projects in which an efficient signage concept is designed for the Internationale School Utrecht and "Bio-mirror", using VR to test the effect of the design of interior products for the work environment on the emotions of users to favour stress reduction.

Moreover, digitalisation opens new ways of interacting with buildings and building components. It enables the integration and optimisation of performance require- ments in active building components and, thereby, allows for dynamic customisation during use, based on specific preferences and needs of users. This is shown in the project Face2Face, developed at the GlassLab, in collaboration between "Sustainable Architectural Materials and Structures", "Architectural Façade and Products", and "Climate, Energy and Circularity" research groups. This research addresses the inter- actions between occupants and smart glazing technologies: a dynamic glazing system is developed that is controlled by real-time occupant facial action units and environ- mental measurements, using advances in affective computing.

Digitalisation does not only contribute to addressing social challenges with new, high-performing and more interactive design but also through the integration of big data. An integrated approach to large datasets is sought in the project nD-PointCloud (total budget 479k Euros), developed at the **GDMC Lab**, in which data management solutions for massive data sets, integrating space, time and scale, are developed. The first proof of principle of the developed solution focuses on water management in colla- boration with Deltares. When successful, this method could be applied to several fields, from transport and mobility to cultural heritage or vegetation monitoring. Another project in which large datasets are generated and analysed is the Brains4Buildings project (total budget 504k Euros). Here, digitization and AI techniques are applied to fault diagnostics in Building Energy Management systems and increase the energy flexibility of buildings. The project intends to develop methods (for non-residential buildings) to harness big data from smart meters, building management systems and IoT devices to develop AI-based models and algorithms, including data communica- tion and user behaviour models. The project aims to reduce energy waste in buildings while saving on installation and maintenance costs, increase comfort, respond flexibly to user behaviour, and adapt better to local renewable energy supply and demand.

EDUCATION AT AE+T LABS

AE+T laboratories strongly support the integration between research and education. Laboratory facilities are not only made available to PhD and PostDoc researchers but also to BSc and MSc students. Many of the MSc theses completed at AE+T would not have been possible without the significant support of the labs. Next to traditional acti- vities supporting education, further steps have been recently made at AE+T labs. For example, special education-oriented experimental facilities have been developed to facilitate students' access to experimental research. For example, in the SURF Project HANDzone (total budget 200K) recently set up by the **VR Lab** and **LAMA,** a hybrid workspace will be developed for blended and hands-on learning activities. Virtual Reality and Human-Robot Interaction technologies are integrated into the existing robotic fabrication setup to enable remote access to the robotic fabrication lab at the faculty through an immersive VR environment. This way, practice-learning activities become more flexible, inclusive and resource-efficient, even when access to the faculty is limited, as happened in 2020 and 2021 due to the COVID pandemic.

Next to facilitating blended learning, research at the lab supports teaching and engaging students and the general public. For example, the "Product Development Test Lab" group, in collaboration with the "Sustainable Architectural Material and Structures" group, developed the mobile test frame MaTe-frame, which can be used for demonstra- ting the mechanical response of materials and testing simple structural components. MaTe-frame is used for live and online demonstrations of the theoretical principles for supporting teaching and engaging with the general public.

SYNERGIES BETWEEN EDUCATION AND RESEARCH

CONNECTING EDUCATION TO RESEARCH

Regarding education, the department of Architectural Engineering and Technology contributes to the Bachelor's education of the Faculty of Architecture and the Built Environment, the track Architecture of the MSc degree programme Architecture, Urbanism and Building Sciences and the track Building Technology in the same MSc degree programme, as well as the MSc Geomatics. This allows for ample opportunity to connect research to education and create synergies between research and education by teaching the latest innovations to our students, coaching them in a research mindset and by involving them in ongoing research projects. It also increases our impact on society because many of our students become leaders in their fields. Only a few examples of such combinations are the graduation projects of our students, the KaDEr Gelderland project and the Solar Decathlon Europe competition.

GRADUATION PROJECTS OF THE BT-STUDIO

The Building Technology Graduation Studio, as the final project in the Building Technology master's track, continues to build up knowledge and skills as part of the student's learning process. The studio intends to be in solid coherence with themes from the department's research programme so students can benefit from and contribute to the research activities by our staff. On the one hand, the structure of the graduation studio embeds our students in a research environment where they can learn the latest insights from the research community, which they can later also bring into practice, and, on the other hand, it gives the research projects additional research capacity and fresh ideas that help advance the research. In the graduation studio, students work on their individual graduation projects, comprising a technical-scientific study and a design. We promote interdisciplinarity and collaboration in the graduation projects; students are therefore supervised by two tutors with different (research) backgrounds and academic fields. The approximately 60 students per year also have the option to graduate in cooperation with a company, which we stimulate. The topics students graduate on are clustered around the themes: Façade & Products; Energy & Climate; Transparent structures / Glass Design; Computational Design; Circular Building Design; Nature-Inclusive Design; Sustainable Structures, topics which are highly connected to the AE+T research portfolio. Finally, this approach fosters collaboration between staff members, who can get better acquainted with each other's expertise while developing new research output in collaboration with the students.

Fig. 11 **Impression of students working in the studio**

KADER GELDERLAND

In 2017, the KaDEr research project was initiated by the Province of Gelderland. The aim of the collaboration between the Delft University of Technology and the Province of Gelderland was to define an adjusted framework for the policy of a more sustainable approach to the conservation of monumental heritage. The classic, object-oriented restoration mission will have to make place for sustainable and, therefore, future-proof management, in which the following sustainability themes will be leading: energy effi-ciency, financial viability, functional use and knowledge safeguarding in the long term. In this process, everything is brought into balance with monumental values and sustai- nability is placed in a broad perspective.

The KaDEr project consisted of four parts: Framework, Living Labs, Education and Safeguarding of Knowledge. The general policy was analysed by theoretical and histo- rical data research. In addition, four Living Labs were initiated: XL-Cities, L-Estates, M-Churches, S-Reuversweerd. The KaDEr project is strongly tied to our educational system, one of the conditions for the project. So, all living labs included design projects from Heritage & Architecture, Landscape Architecture and Building Technology. They provided design case studies like Zutphen, Winterswijk, Reuversweerd, Churches in Tiel and Arnhem and the energy transition in Elburg. Four years of graduation studios were organised around the project. Moreover, it connected to a MSc1 design project, a MSc2 design project and a MSc3 SWAT studio with students of the MSc track Building Technology participating in roadshows in which sustainable urban interventions were designed onsite. Also, Urbanism / Landscape Architecture organised a graduation studio linked to the living lab L-Estates.

The involvement of students in the research enlarged the scientific design output of the project. It brought in new, fresh ideas that benefited the Province of Gelderland and the different municipalities involved. The design-oriented research approach of master students was very helpful in several interactive sessions with diverse groups of stakeholders. Students brought themes to the table that would not have been addressed without their involvement.

Fig. 12 **Redevelopment Baudartius College, Zutphen Jacqueline van Dam, 2018.**

SOLAR DECATHLON (EUROPE)

Created in 2002 by the U.S. Department of Energy, the Solar Decathlon (SD) is an international competition open to universities and institutions of higher education worldwide, allowing them to compete in meeting a challenge: "Design and build a solar house that is energy independent". The SD competition is not simply creating a building concept; it involves a wide range of aspects, including engineering, construc- tion, innovation, social awareness, etc., marked as ten sub-contests of the competition. The competition ends with a final exhibition, requiring a workable house prototype as a result of the entries.

During the development of the concepts, the student teams lead all aspects such as design, execution, financing and logistics. Faculty advisor Andy van den Dobbelsteen states that the Solar Decathlon delivers the best architects, engineers and building managers: students who can develop a concept, design it, engineer it, fund it, get it organized, construct it and make it perform. The SDE designs are frequently used to teach younger students and the market about sustainable design. The prototypes accommodate tests of new equipment and user appliances. And innovative building and energy concepts are developed and tested under real-life conditions on a regular basis. Participation in the Solar Decathlon team is embedded in the department's curriculum.

The students can gain credits for electives by participating and use the time invested in their graduation to research, evaluate and validate innovation and concepts to be applied in the competition.

TU Delft student teams supported by staff members participated in three competitions: the Prêt-à-Loger team during the Solar Decathlon Europe 2014 (SDE14) in Versailles (France), the MOR (Modular Office Renovation) team during the SDE19 in Szentendre (Hungary) and Team SUM (Symbiotic Urban Movement) during SDE21/22, in Wuppertal (Germany). Prêt-à-Loger ended 3rd in the competition; MOR won a world record of awards and should have won but ended 2nd; Team SUM also finished 3rd. Only SDE19 and SDE21/22 took place within the timeframe of this research assessment. Both the Prêt-à-Loger and MOR prototypes can now be found on The Green Village at the TU Delft Campus.

The MOR team tackled two crucial current challenges in the Netherlands: a large number of underperforming and often vacant office buildings and a lack of housing, especially affordable housing. By redesigning an office tower in the city of Rotterdam, the Lee Tower, the team showed how existing office buildings could be transformed into housing units that achieve net positivity for energy, water, materials, air and biomass (food). The team won a world record of nine awards: 1st place: Communication & Social Awareness, Innovation & Viability, Energy Efficiency; 2nd place: Circularity & Sustainability, Neighbourhood Integration & Impact, Engineering & Construction, House Functioning; 3rd place: Comfort Conditions. The contest's overall position was 2nd. More importantly, the MOR team gained a lot of attention in the media and was even invited for coffee with the Prime Minister.

Team SUM developed a renovation and densification strategy for the 847,000 under- performing tenement flats in the Netherlands, tackling social, economic and environ- mental challenges. Existing housing units inside the flats are improved, and additional units are added on top of the roof structure, becoming the energy plant for the old buildings. The entire concept is based on circularity and prefabrication, focused on preserving the neighbourhood and improving it for the residents. There are several innovations applied in the prototype of the building, including the newest printed vertical PV panels and lightweight biobased top-up modules. The plan was a prominent feature on the national popular-scientific tv programme Atlas.

The team won 4 competition awards: 1st place: Affordability & Viability; 2nd place: Energy Performance; 3rd place: Urban Mobility, Sustainability. Overall, the team ended 3rd. Furthermore, the team also won several out-of-competition awards: the German Sustainable Housing Award (3rd place), Green BIM Award (1st place), Timber Construction Award (2nd place) and Building for Future Award (1st place).

Fig. 13 **Team SUM's entry to the Solar Decathlon Europe 2022 competition in Wuppertal.**

MANAGEMENT IN THE BUILT ENVIRONMENT

SUMMARY

Management – the process of governing, organising and managing – is an essential part of the continuing cycle of use, (re)design and (re)develop, maintain and upgrade of our buildings, portfolios, urban areas and regions. The research of the Management in the Built Environment (MBE) department is concerned with developing and applying theories, methods and tools for managing the built environment. Herein, the department interacts closely with practitioners.

Based on the recommendations of the 2016 MBE research assessment and in line with the faculty strategy, MBE formulated four strategic research aims:

— Better integrate research aims of separated research programmes into one larger, department-wide research programme and search for coherence, collaboration and integration, both in content and organisation;

— Improve scholarly rigour in further developing sound, theoretically and methodo- logically substantiated research;

— Attract more PhD candidates and develop better procedures in supervision and progress monitoring;

— Become more aware of and steer on developing our academic culture to foster safety, diversity, inclusiveness and research integrity.

Part of the result of the 1st action was one overall MBE research mission: to theoretically understand governing, organising and managing in the built environment to design interventions for societal challenges and transitions, translated into the following objectives:

— Develop novel perspectives and translate these into designing innovative strategies, solutions, methods and tools;

— Improve governing, organising and managing that can impact future designs in the built environment;

— Engage with societal stakeholders and users within and across different functions and scales (buildings, portfolios and urban areas) and different project phases and lifecycle stages (from initiation, design and construction to use, management, maintenance, and redevelopment);

— Develop knowledge for next-generation leaders in management in the built environment.

Together, the strategic research aims have contributed to a single and more coherent MBE research programme, which helped the programme participants to raise more longer-term research funding. This increased the research capacity of contracted PhDs and PostDocs, allowing for more scholarly rigour in developing and applying novel theoretical insights and increased academic output in terms of journal articles and impact. The coherence of these research projects also enabled MBE to have a more agenda-setting position in the field, academically and societally.

Even though we have shown progress in all four strategic research aims, they will need continued attention in the 2022-2027 period. The visit to KTH in Stockholm, in preparation for our MBE Research strategy 2022-2027, helped us to reflect on our research in the previous period and to learn from our peers for the next period. The visit inspired us to formulate actions to address the following: Substantiation of the MBE Research programme, Strategic personnel plans, Funding strategy, Societal impact, visibility and identity, Open Science, Academic culture and PhD policy. Based on our SWOT in paragraph 6, we believe that MBE research is in a better situation than six years ago and that our strategy will allow for further development.

CASE STUDY

MBE has contributed to understanding and designing responses to many societal challenges. In this paragraph, we present our case study in the form of a narrative based on our research accomplishments following the three main themes as introduced in paragraph 3. These have been relevant throughout the whole assessment period:

- – Energy transition related to the built environment;
- – Organisation of construction and management of real estate in the light of circularity;
- – Issue of equity and the built environment.

Besides these three main themes, digitalisation is discussed as an emerging theme in MBE research activities. Finally, we will present some accomplishments of the MBE approach toward longer-lasting interactions with communities of design and practice.

ENERGY TRANSITION

A key challenge is the energy transition and the need to make buildings more energy-efficient. The focus of MBE is not primarily on how certain innovations work in laboratory conditions but rather on how they work in a real life-context, i.e., how actual energy savings can be achieved by people living in their homes (Van den Brom et al., 2019).

Studies facilitated by AEDES (the umbrella organisation for housing associations in the Netherlands) created a huge database (SHAERE) with key characteristics of the millions of dwellings held by its members. This database is used for various PhD theses: on energy in dwellings (Van den Brom, 2020), longitudinal analysis of energy performance (Filippidou, 2018), predicting energy consumption and energy savings (Majcen, 2016), thermal comfort and energy-related behaviour (Ioannou, 2018), quality failures in energy savings projects (Qi, 2021), using transaction cost theory to analyse energy retrofits (Jia, 2021), urban renewal decision making in China (Zhuang, 2020), futu- re-proof renovations (Brinksma, 2017), the complexities of the energy transition (Stutvoet, 2018), sustainable values-based strategic decision-making in a Dutch housing association (Hoomans, 2019) and policy instruments to improve energy performance (Murphy, 2016). The adaptive capacity of the built environment relating to new climatological conditions is the topic of the PhD by Keenan (2016).

Through the TU Delft Urban Energy Institute, hosted by MBE, the knowledge gathered in all research is shared among experts. The contribution toward the societal challenges is based on research, such as papers by Van den Brom et al. (2017) on performance gaps in energy consumption and by Mlecnik et al. (2020) on policy challenges for the development of energy flexibility services. Another field of growing concern is the climate governance strategy for the Dutch delta. A consortium led by MBE has been created for a transdisciplinary research agenda (an Interdisciplinary NWA Research Programme) focusing on developing integrated real estate and infrastructure climate risk strategies. Next to academic partners, practice partners and SKG (Fig 5.3) are involved. A bid submitted in 2021 was funded by NWO.

CIRCULAR BUILT ENVIRONMENT

Making more efficient use of materials resulting in a shift towards a circular built environment is a challenge in which MBE has developed expertise. One example is an Interreg project with the AMS Institute, housing association Ymere, construc- tion company Dura Vermeer and students from the Rotterdam University of Applied Sciences to design a Circular Skin for energy retrofitting. Another example is the circular kitchen (Figure 5.3), designed in an EIT Climate-KIC consortium with research organisations, housing associations, private landlords and the construction sector, with a prototype placed in a selection of rental dwellings.

The transformation towards circularity demands a shift beyond the scale of individual buildings, impacting the whole production, use and reproduction chain of buildings. Our expertise is represented in important industry-wide forums such as Platform CB'23, where our research resulted in the formulation of a framework and lexicon for a circular built environment and guidance on circular procurement and design.

Thus, MBE has been active in many discussions on circular building, circular cities and regions, circular area development, the circular economy, the position of buyer groups in circular housing, and on circular collaboration (theme of the NWO Behaviour and Transitions awarded TransCiBo).

The challenge of circularity relates to insights and research on how construction processes are managed. PhD theses defended include Strang (2018) on supervision and coordination in the building process, Venselaar (2017) on supply chain partne- ring in the Dutch housing sector, Papadonikolaki (2016) on the alignment of partne- ring with construction IT and Wu (2021) on the challenges of prefabricated housing. Relationships between public and private agents is an important topic highlighted by the PhD of Leclercq (2018) on the privatisation of the production of public space and the PhD by Kuitert (2021) on how public construction clients safeguard public values in a changing construction industry. These also fit in a wider programme on public values, organisational structures and collaboration with market parties financed by the Forum of Public Commissioners in the Built Environment[6].

In cooperation with the LDE Centre for Sustainability and Wageningen University & Research, a project on circular area development in The Hague (Binckhorst area) was also financed by the knowledge and innovation programme ACCEZ of the province and industrial partners. The results of the project provide input for the provincial 'accele- rators' and have led to a follow-up project with

partners from government and industry 'Samen Versnellen', in which an assessment of frontrunner projects in circular building will result in a joint framework to be used by clients and commissioners. The results of these projects are also shared in the UCL-based Circular Cities Hub and the Circular Built Environment hub at our faculty.

Figure 5.3 The circular kitchen
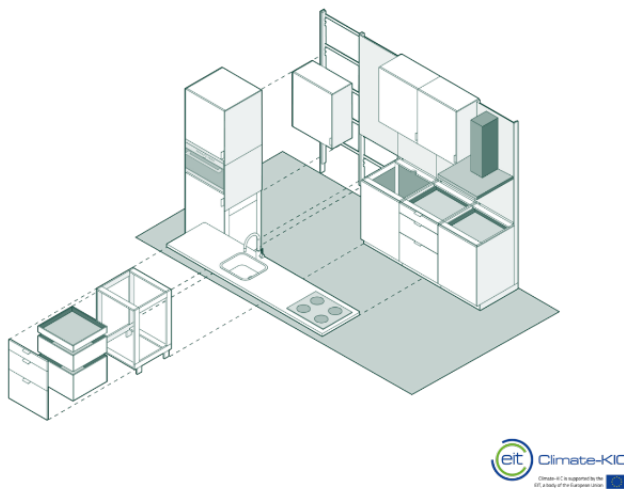
Source: Climate-KIC

EQUITY IN THE BUILT ENVIRONMENT

Societal inequalities are reproduced through the built environment. Issues of equity and justice play a role in a lot of our activities, including issues on housing affordability, access to adequate housing and the housing systems that cater for this accessibility. Intergenerational inequality and understanding the issues confronting younger people in getting access to the property market are addressed in several Horizon 2020 Research and Innovation actions:

- The UPLIFT project examines vulnerable youth from an educational, housing and employment perspective. In this project, there are interactions between research orga- nisations, institutions from practice (such as the housing association Lieven De Key) and the youth themselves. This is essential as the project aims to put young people's voices at the centre of Youth Policy.
- In RURALIZATION, coordinated by MBE, generational renewal is key. Here the focus is on rural areas and the issue of access to land for new generations. The RURALIZATION consortium (18 partners) is a mix of research organisations and practice partners, such as Terre de Liens, that work together in the Access to Land network.
- RE-DWELL, a European Training Network in which 15 early-stage researchers get the opportunity to develop capacity in design, planning and building, community partici- pation, policy and financing to generate innovative solutions for the ousing problem in the EU.

In the course of these projects, many interactions with societal actors take place, such as presentations on the research progress for youth workers, policymakers, neighbour- hood groups and governmental institutions.

Issues of inequality may also relate to opportunities for young people in the housing market (as is the topic of the PhD of Deng, 2018), management of social condominiums (the PhD of Vergara d'Alençon, 2018), affordable condominium housing (the PhD of Donoso-Gomez, 2018) and management of self-organisation initiatives (the PhD of Tempels Moreno Pessoa, 2019).

Vergara d'Alençon and Tempels Moreno Pessoa have jointly initiated the MOOC 'Rethink the City' (Tempels Moreno Pessoa et al., 2019), in which PhD candidates and staff from the faculty addressed issues of spatial justice, urban resilience, and housing from a global perspective. For this MOOC, they have been awarded the Excellence in Teaching prize of the Association of European Schools of Planning (AESOP).

Additionally, global housing issues are addressed by a living lab in Addis Ababa financed by an NWO WOTRO grant in which both the department of Architecture and MBE participate. Affordability can also be aligned with economic processes, as is done in the PhD of Bin Mohd Noor (2016), presenting a new business model for affordable housing in Malaysia. Issues of inequality and diversity are also addressed in the PhD of Ahmadi (2017) on living with diversity in Toronto. Understanding the role of housing associations is addressed by the PhD of Van Bortel (2016).

DIGITALISATION

MBE is also growing capability in digitalisation and the built environment, which is an emergent research field. One example is the work on Industry 4.0, which includes a Chinese fellowship, advice (Chan et al., 2021), a briefing note (Chan, 2020), a special issue (Ejohwomu et al., 2021) and talks to industry practitioners.

We also address other topics concerning digitalisation, such as smart city technologies (Ersoy, 2019), the digital dimension of circularity (Çetin et al., 2021), using artificial intelligence to predict building age (Garbasevschi et al., 2021) and, of course, Building Information Management (Papadonikolaki et al., 2016; Koutamanis, 2020).

MBE will also host an AI Lab aimed at activating intelligence in buildings' lasting and liveable environments. There are close links with the work streams of adopting artifi- cial intelligence and stimulating user and citizen acceptance of such technologies in the NL-AI Coalition.

MBE APPROACH: INTERACTION WITH DESIGN AND PRACTICE

In all themes, many interactions take place with professionals. Specifically, our position within the Faculty of Architecture and the Built Environment provides an excellent context to impact the design community. This allows a connection between research insights into societal impact through design. Examples of this connection are a master- class on circularity for the BNA (the professional organisation of architects) and an open-access tutorial, developed in cooperation with the Faculty of Industrial Design, to support creative professionals in treating value conflicts (Lousberg et al., 2019).

Also, the architectural practice itself is studied, such as in a project for the ArchiScienza Foundation on architecture analysed from the sociological theory of professionali- sation and by the PhD of Bos-de Vos (2018) on project-specific value capture strate- gies of architectural firms. In this domain, it is worth mentioning the steps taken to innovate Real Estate Education through the application of Virtual Reality (VR) tech- nologies (also an NWO Behaviour and Transitions grant 'VR-Renovate' led by the department) and a Summer School Sustainable Housing and Environment from an international perspective.

The nexus between research and education is not only based on the educati- onal programmes in the faculty where MBE has its own independent track in the MSc Architecture, Urbanism and Building Sciences. But also, in other educational programmes such as the MSc Metropolitan Analysis, Design and Engineering (MADE) (at the Amsterdam Institute for Advanced Metropolitan Solutions with Wageningen University), the MSc Construction Management and Engineering (CME) (with other TU Delft Faculties) and the Master City Developer (MCD) (with Erasmus University; see also below).

COALITIONS WITH PRACTICE
Besides studying spaces for interaction between public and private stakeholders, including citizens, in the forms of living labs and processes of co-production and co-cre- ation, MBE also actively builds and maintains connections with professionals. Based on the policy of long-term coalitions, there are more structural interactions with practice. A very important one is in the field of urban area development. Here, there is a founda- tion with many participants (Fig.5.2) financing research, including PhD projects. Their website (gebiedsontwikkeling.nu) has about 25 thousand unique visitors per month, publishing regular contributions based on research of the staff.

In cooperation with Erasmus University, the Master City Developer is developed for professionals in the field. With the National Renovation Platform (NRP), we deliver, at the NRP Academy, courses to professionals on property renovation and transformation. How professionals learn and collaborate across disciplinary boundaries in addressing sustainability transitions in urban transformations is the theme of the Behaviour and Transitions Grant 'Stepping Out' led by MBE and in collaboration with the University of Amsterdam. All these efforts make MBE an established player in the professional field.

PROFESSIONAL INSTITUTIONS
In related fields of public commissioning, building law, public real estate and housing- market analysis, there are close links with professional institutions. PhD theses include studies on public rental housing governance in China (Yan, 2021), on public housing management in Ghana (Aziabah Akanvose, 2018) and on technology campuses and cities (Curvelo Magdaniel, 2016). University campuses are also the topic of the PhD of Alghamdi (2018) and Valks (2021). The analysis and briefing of school building designs,

especially from the perspective of teenagers with autism, is the topic of an NWO grant received by the BOLD Cities consortium (a cooperation of MBE with Leiden University and Interpsy Groningen).

The alignment of an organisation's real estate to its corporate strategy is the topic of the PhD of Arkesteijn (2019). Our expertise in the use of smart tools and the alignment of real estate and organisational strategy has led to a four-year cooperation agreement with the Dutch police force.

HOUSING MARKETS
Housing markets have been analysed in the PhDs by Teye (2018) in collaboration with Statistics Netherlands, by Gong (2017) considering the spatial dimension of house prices and by Dol (2020) studying the West European home ownership sectors and the Global Financial Crisis. External PhD candidates with professional experience can also forge connections. Verburg (2021) has studied the effects of municipal investments on welfare using house prices as a proxy for welfare effects.

Researchers from the department, invited by the regional and national authorities, have reported on the housing market consequences of earthquakes caused by gas exploita- tion in the province of Groningen. This is a very sensitive issue with many desperate people, political and legal conflicts relating to the allocation of gas exploitation costs and benefits (Boelhouwer and van der Heijden, 2018). Housing market developments in the Netherlands are monitored in quarterly reports based on cooperation with profes- sional real estate organisations and authorities. Insights flow not only in scientific and professional debate (including an often repeated 4-day course on new developments in housing for professionals) but also to the public at large through numerous[7] interviews and contributions to newspapers, radio and television, for which good relationships with journalists have been built.

So, the MBE approach to achieving the societal impact of our research is based on building long-term relationships with potential users of knowledge so that we know what kind of scientific questions are relevant to society and that we can bring our insights to good societal use.

Professor Marja Elsinga presenting during a Master class at the European Real Estate Society (ERES) annual conference, 2017.

URBANISM

Summary

Sustainable urbanisation, climate adaptation, circularity and digitisation are among the core themes the faculty embraced as relevant societal themes for research and education. The Department of Urbanism adopts them as the foundation for developing excellent scholarship and research. We see Urbanism as an interdisciplinary planning and design activity that focuses on the (re) creation of sustainable urban landscapes aimed toward climate adaptability, circularity, social equity, and ecologically inclusive urbanisation at all scales.

This is reflected by our mission: to advance, share and apply knowledge on how to adapt the built environment to societal and environmental changes; and to apply contextual design, planning and engineering strategies and interventions with impact for a better society. The Urbanism research programme is shaped by our understanding that the quality of the urban environment is crucial for societies' social, economic and environ- mental performance and for a more sustainable and fairer urban environment.

The Department of Urbanism received the highest score for excellence in the 2016 research assessment. Urbanism has an international reputation for academic research, scholarship and education built on the Delft Approach to Urbanism. This approach is knowledge-based, design-oriented, and multiscale, in which landscape architec- ture, urban design and planning closely collaborate with engineers, data scientists, sociologists, geographers, and ecologists. Urbanism is committed to socially relevant research, exemplified by our involvement in design projects and policy development, the development and implementation of practical tools and methods and our leader- ship and participation in (inter)national networks. A high level of scientific output in the form of journal articles, books and datasets and their use, but also the high number of prestigious ERC grants and awarded NWO and Horizon2020 funding testify to our premium research.

Our research is organised around four cross-cutting themes, which involve staff from across Urbanism: Delta Urbanism, Inclusive Urbanism, Green Urbanism and Data- supported Urbanism. These four themes are closely aligned with the research themes of the faculty. We are dedicated to open science, disseminating research through publications and datasets in open formats. Strengthening a safe and productive academic culture, in which research integrity and inclusivity are key elements, is part of our ongoing effort to enhance the conditions for a thriving urbanism community and a strong PhD culture. Through our HR policy, we are continuously working on the talent management of existing staff, developing leadership, increasing cultural diversity, and improving female representation among senior staff.

In the future, the department will consolidate the research programme to remain world- leading in design-related scholarship and socially relevant and impactful research for the understanding, planning and developing of sustainable urban landscapes. We will strengthen the Delft Approach to Urbanism, which is socially and ecologically inclusive, with a strong link between spatial research and design across all scales, based on inter- and transdisciplinary working, and employing state-of-the-art digital technology. To foster disciplinary breadth, depth and innovation, we nourish a fair, diverse and inclusive academic culture where everyone can excel and talent is rewarded, with a strong connection between research and education. We will strengthen our PhD culture to stimulate a more efficient Urbanism PhD programme. We will actively participate and lead academic and societal networks and engage with NGOs and governmental and other societal partners. We will continue stimulating open and collaborative research practices to make publications, data, software and other types of academic output available to the world.

Four urbanism research themes illustrated through case studies

The research programme of the Department of Urbanism is organised in four themes: **Delta Urbanism, Data-supported Urbanism, Green Urbanism** and **Inclusive Urbanism**. We illustrate the quality and impact of the research themes through **four case studies** of the research and projects conducted by the department. The cases also show proof of the viability of our research as the four themes represent the ways how we address societal challenges such as sustainable urbanisation, climate adap- tation, circularity and equity. The case studies stretch across the sections and are not strictly connected to one section or research group (Fig. 5.2). In each of the case studies, we could only highlight a selection of our research outputs, use and recognition, as mentioned in paragraph 4. See Appendix 2 for more detailed narratives of the four case studies and an overview of the research and projects involved.
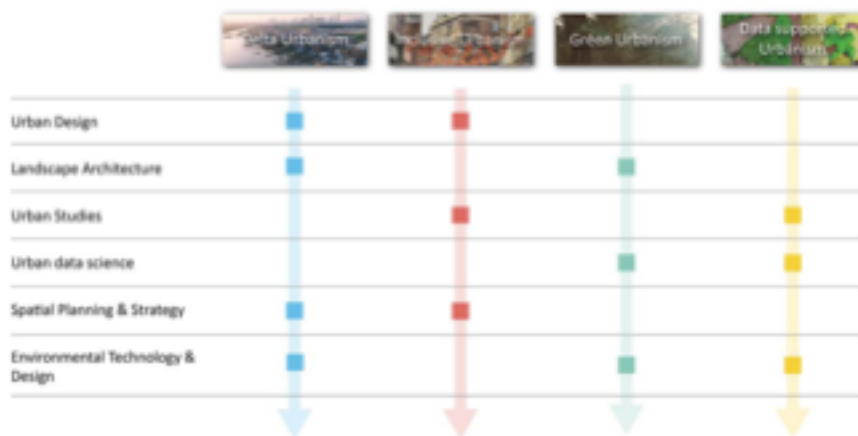

Fig. 5.2

Four themes to explain the research results of the department as a whole
(distribution of the research is only illustrative)

Delta Urbanism

Sustainable urbanisation, loss of biodiversity and **climate change** are key challenges for **deltas around the world**. These highly dynamic geographies are characterised by fragility, criticality and risk: transitional landscapes between land and water, altered by the effects of urbanisation, industrialisation and extractivism. The department's research on Delta Urbanism covers the most important scales of the **relationship between land and water, focussing specifically on the development and application of design-oriented, systemic, and inter- and transdisciplinary approaches sensitive to social-cultural and ecological conditions on-site.** Adaptive multiscale design stra- tegies, nature-based solutions for coastal and riverine flood protection, water-sensitive urban design and vernacular water practices are some of the themes that are elabo- rated on in research and teaching.

Several **major international collaborations** exemplify the quality of our research and societal impact with partners from academia, the private sector, governmental bodies and local NGOs, building a transdisciplinary framework at the intersection of spatial design and planning, governance, social sciences, water science and engi- neering. One example is the DST-NWO Water4Change project, a collaboration of the Dutch and Indian governments in which the department takes the lead. This project started in 2020 with a research grant of **€ 3.5 million**, enabling **13 PhDs** (4 NL, 9 India) and **3 Postdocs** (1 NL, 2 India). It addresses the complex challenges to urban water systems faced by fast-growing secondary cities in India and the sustainability tran- sitions needed for short- and long-term mitigation of, adaptation to, and coping with urgencies and uncertainties (Fig. 5.3). By co-creating a Water Sensitive City Framework and a Fit-for-Purpose Guideline, this research enables water-sensitive development, accounting for site specificities, knowledge and practices, presenting innovative inter- ventions, practices and design, and policy guidelines.

Fig. 5.3
Water4Change The Water4Change project regards India as a perfect 'testing ground' to reflect on the inter- plays and co-dependencies between society and nature; three case-study cities (Credits image: Water4Change)

Another example is the NSFC-NWO- EPSRC Adaptive Urban Transformation project, a collaboration of the Chinese, Dutch and British governments in the Sustainable Deltas Programme. The project started in 2018 with a research grant of **€ 1.1 million**, focusing on urban landscape dynamics, regional design and territorial governance in the Pearl River Delta in China, the fastest urbanising delta in the world. This joint research project with academic and societal partners addresses sustainable urban transformation and, in parti- cular, adaptive socio-ecological inclusive design strategies and principles that employ natural and urban dynamics to address increasing flood risk and loss of biodiversity in fast urbanising deltas. This has led to **17 refereed journal articles, 3 PhD theses** and **5 invited keynote addresses** at major conferences such as the prestigious Annual National Planning Conference China with **10.000+ visitors and 15.000+ streamings.** Also, online/ offline media coverage displays the societal interest in the research, exemplified by an article in Les Echos Week-End, a weekly magazine by France's largest business newspaper and a Television interview at the 5:00 pm Wink News in South Florida. Next to policy guidelines and adaptive design principles, the project also led to practical applications and implementation through design projects in which we led the design team responsible for urban development plans in, for example, Guangzhou and Shantou (Fig. 5.4).

Fig. 5.4 **Landscape-based design for a new urban extension for the Municipality of Shantou** Employing water-sensitive and socio-eco- logical principles (Credits image: OKRA Landscape Architects with Steffen Nijhuis, TU Delft)

Transdisciplinary working with scholars, designers, students, and societal partners is fundamental to Delta Urbanism. Collaborations with the Departments of Architecture and Management of the Built Environment and the Faculties of Technology, Policy and Management, and Civil engineering ensures its interdisciplinary focus. Besides research, there are also **strong links with education** through research-by-design graduation labs dedicated to Delta Urbanism. Especially the Delta Interventions Lab and Transitional Territories Lab, related to Urbanism and Architecture MSc tracks, and the Circular Water Stories Lab and Resilient Coastal Landscapes Lab from the Landscape Architecture MSc track are examples of teaching related to Delta Urbanism across the departments and sections. We play a leading role in the cross-faculty Delta Futures Lab, uniting master students, researchers and professionals in multidisciplinary projects in the framework of DIMI Delft Deltas, Infrastructure and Mobility Initiative. The organisation of several international symposia, conferences, PhD seminars, workshops, and exhibitions, such as the constructed pavilion 'The Port and the Fall of Icarus' at the Venice 16th International Architecture Exhibition 2018, further connected and expanded our network in academia and practice and helped to disseminate our work to the public nationally and internationally (Fig. 5.5).

Fig. 5.5 **Constructed pavilion 'The Port and the Fall of Icarus'**
Venice 16th International Architecture Exhibition 2018 (Image credit: Taneha Bacchin, TU Delft)

Inclusive Urbanism

Growing urban **inequality** is an **increasingly urgent concern** for citizens, urban practitioners and policymakers around the world. Inequality is not only unacceptable from an ethical and normative standpoint; it also generates high costs for society, hampering the performance of cities, with impacts on the health, social cohesion and living standards of cities, where people and economy can flourish. The department's research on Inclusive urbanism addresses those urgent challenges from an **integrated and cross-disciplinary perspective**, emphasising **the spatial dimension of inequality** and how spatial planning and urban design can be mobilised to make cities more just and inclusive. What makes our approach to researching those topics unique is how we combine insights and methods from the disciplines of urban design, spatial planning, urban geography and urban sociology. At the same time, in our research on and for inclusive urbanism, we seek to **engage a diversity of stakeholders** and, in particular, representatives of vulnerable and marginalised groups in the co-design of and co-decision on sustainable urban futures.

Next to major international collaborations, the research quality and impacts are illus- trated by several **research grants awarded to individuals**, such as three prestigious ERC grants and a NWO-VIDI. An example is the 5-year DEPRIVEDHOODS research project funded by the European Research Council with a **€ 2 million ERC Consolidator Grant** awarded to a researcher from Urbanism. The project started in 2014 with ten researchers from Sweden, the United Kingdom, Estonia and The Netherlands. The objective was to better understand the relationship between socio-economic inequa- lity, poverty and neighbourhoods (Fig. 5.6). The project resulted in **55 refereed journal articles, 4 books, 3 PhD theses** and more. The output is widely used, as exemplified by **378 citations** of a refereed article (2016) and **232.000 downloads** in the period 2021- 2022 of a refereed open-access book. The research also had wide media coverage in international newspapers such as the Financial Times, Washington Post and The Guardian, and on radio and television. The research fundamentally advanced under- standings of the ways in which individual outcomes interact with the neighbourhood, which will ultimately lead to more targeted and effective policy measures.

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Fig. 5.6 **Better understanding of the relationship between socio-economic inequality, poverty and neighbourhoods**
(Image credit: Maarten van Ham, TU Delft)

An example of a **major international collaboration** is COHESIFY. Against stiff compe- tition from 28 other consortia across Europe, this winning EPRC-led consortium comprised eight universities and two SMEs from ten EU Member States with complementary disciplinary backgrounds and applied creative expertise in communication, branding and citizen engagement. This two-year research started in 2016 with a total budget of **€ 2.4 million** in the framework of the **EU Horizon 2020: Inclusive, Innovative and Reflective Societies.** The project focussed on citizen engagement in spatial policies and the ways in which policy decisions affect citizens' lives. We explored the ways in which European policies to improve territorial, economic and social cohesion in cities and regions affect the identities and attitudes of the citizens, providing policy recommendations and **14 research papers** with insights for **bringing the European Union's Cohesion Policy closer to citizens** (Fig. 5.7).

Fig. 5.7 **How European identity and perceptions of the EU and Cohesion policy vary at national, regional and local levels**
(Image credit: Cohesify)

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The department is a **centre for responsible urbanists' research and education**, relying on inclusion, diversity and social justice. Next to our research, this is also reflected by our **outreach** activities involving partners in the **Global South**, for instance, through partnerships via the Delft Global platform, promoting the adoption of **co-creation** and **participation of vulnerable stakeholders** in social inclusive planning and design of public spaces and facilities. For example, via WHO Téchne, we participated in a World Health Organization network of architects, engineers, designers and public health practitioners that responds to acute public health events with urgent and customised support. In the context of the COVID-19 pandemic, we produced advice and design guidance for health authorities and other local organisations, helping to rapidly redesign and adapt existing facilities to accommodate the demands created by the pandemic. In Inclusive Urbanism, we also **integrate our research work with educational activities**, for instance, by co-creating a Manifesto for the just city with scholars and students or offering courses geared towards broad international audiences, including **MOOCs** on spatial justice and inequality as well as physical and online summer schools and workshops.

Green Urbanism

This theme aggregates, on the one hand, the department's research that deals with the urgent and intertwined societal challenges of climate change, energy transition, environmental degradation, biodiversity loss and food and material security, and, on the other hand, the more explorative and conceptual research that reframes the contemporary urban territory as landscape metropolis. The focus is on **advancing human and ecological well-being** through understanding and employing **nature, space** and **place conditions** for **socio-ecologically inclusive design** from the building to the regional scale. But also, the development of **design-oriented landscape approaches** that base spatial development on the natural system along with exploring and employing the cultural, spatial and perceptive characteristics of landscapes in planning and design. Research on **urban climate and energy, regional landscape approaches, urban biodiversity** and **regenerative and circular urban landscapes** are connected to systemic design, adaptive design principles and regenerative strategies that lead to **healthy and inclusive green-blue cities**. The development of metropolitan landscape and nature networks, heat stress mitigation concerning urban morphology and incre- asing the sponge capacity and biodiversity in the urban context through greening cities are important topics for research and applications, along with circular approaches to address improvement or restoration, renewal or revitalisation of energy and materials sources in the built environment.

Fig. 5.8 **Urban Climate Arboretum at the Floriade in Almere**
(Image credit: Fotolinie)

One example is the involvement of the department in the design and construction of the Van Leeuwenhoekpark in Delft, an example of the **use of academic results in contexts of practice in collaboration with societal partners.** Here, researchers were involved in formulating the project brief, the tendering process, advising the Municipality of Delft and the design team on microclimate design measures, and numerically simu- lating and (forthcoming) monitoring the microclimate in and around the park with custom-developed weather stations. The park is currently under construction, and our involvement in the project led to significant alterations in the park's design. In another practice context, we collaborated with the **Municipalities of Rotterdam, The Hague** and **Amsterdam** to better understand the relationship between urban heat, urban morphology and its effect on health. The research was funded by the municipalities, the **Climate Proof Cities programme** by the Dutch Government and **4TU.BOUW**. The results were published in open-access publications Amsterwarm (2020), Haagse hitte (2018) and Hotterdam (2017). They indicated that urban heat islands pose serious health issues, and that short-term social and behavioural measures must be accom- panied by long-term action to regenerate the urban tissue. The research also resulted in policy advice that proposes a mix of solutions where residents, homeowners and the municipality each have a role to play in adapting to an environment that will be hotter more often and for longer periods in the future. The recently awarded, **prestigious personal NWO VENI grant** for research entitled 'The Garden Complex' is a significant acknowledgement from peers and showcases our excellence in research on metropolitan landscapes. Generous financial support by societal partners such as Birdlife Netherlands and the National Association for Greenspace Professionals in the Netherlands (VHG) enables research fellows to work towards the establishment of a centre of excellence in urban ecology and urban forestry, respectively. The Urban Climate Arboreta in Delft, Almere, Barendrecht and Dordrecht are examples of inno- vative experimental sites that generate knowledge on the cooling effects of trees in the urban environment.
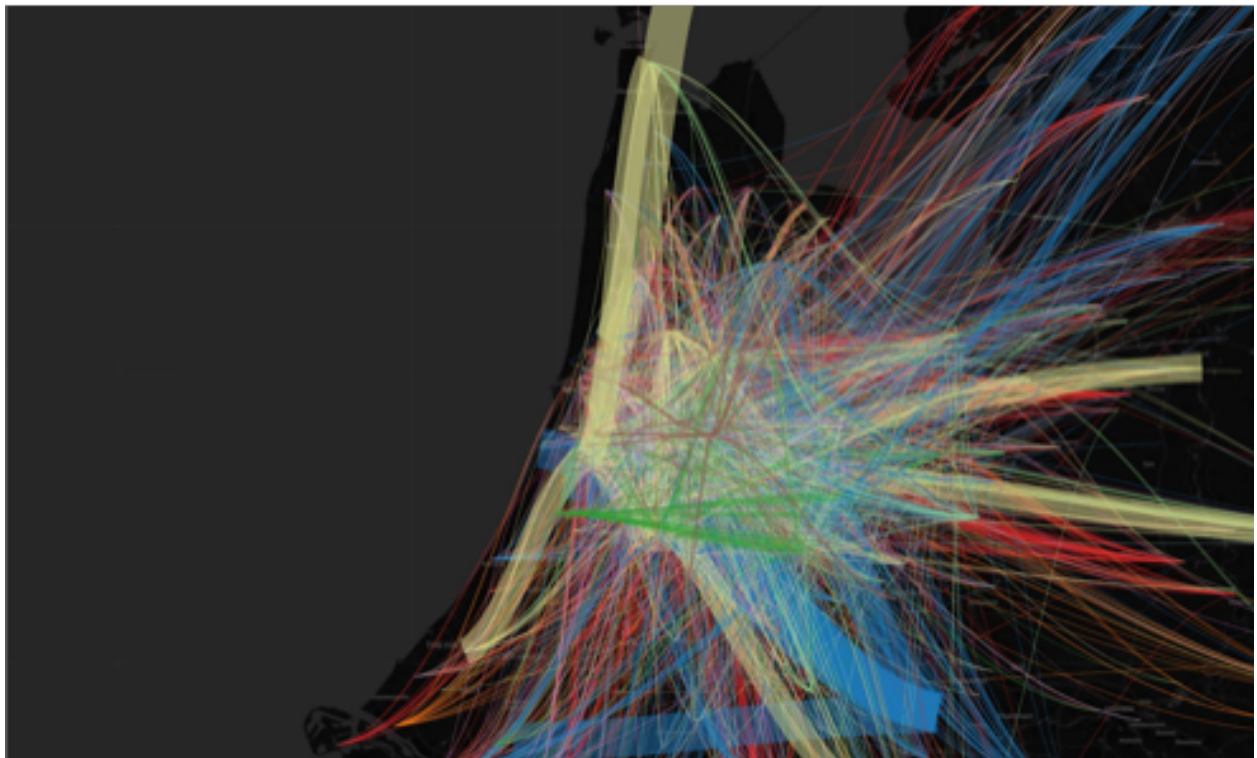

Fig. 5.9 **Analysis of material flows in the western part of the Netherlands**
(Image credit: REPAiR)

The **EU H2020 Project** REsource Management in Peri-urban Areas (REPAiR) is an example of a **major international collaboration** with a total funding of **€ 5 million** in which we take the lead in a 4-year project started in 2016. The core objective was to provide local and regional authorities with an **innovative transdisciplinary open- source geodesign decision support environment (GDSE)** developed and imple- mented in **living labs in six European metropolitan areas.** The GDSE allows creating integrated, place-based, eco-innovative spatial development strategies aiming at a quantitative reduction of waste flows in the strategic interface of peri-urban areas (Fig. 5.9). These strategies will promote the use of waste as a resource, thus supporting the ongoing societal initiatives to establish a strong circular economy. The research resulted in more than **40 refereed open-access papers, project reports, virtual exhibitions, an online knowledge transfer handbook** and an Online geodesign decision support environment (GDSE)-tool.

As exemplified by the research outreach, capacity building and stakeholder engagement are fundamental to the way we work. This also becomes clear in major conferences that we hosted and organised, such as the 14th Ecocity World Summit Rotterdam 2021, with more than **500 participants, 400 abstracts and 200 research papers.** But also, **MOOCs** such as Sustainable Urban Development, Nature

Based Metropolitan Solutions and Spatial Circularity Strategies for Sustainable Regional Development display our efforts in making a difference in society. Four theme issues in the refereed open-access journal Spool helped to increase our visibility around the theme of Landscape Metropolis.

Data-supported Urbanism

In the field of data-supported urbanism, the department's impacts are manifold, covering the whole lifespan of data (i.e., generation and reconstruction, standardisa- tion, management, usage) as well as the different possibilities that modern open/ big-data approaches offer to urban landscape planning and design in the context of Digital Twinning. The department is strongly committed to generating and using **innovative, sustainable and open data ecosystems** where researchers and practitio- ners can interact in different ways: by retrieving and using the data, adding new data, and delivering improved data and new insights back into the ecosystem. The impact encompasses both theory development as well as implementation. It focuses on how **buildings, cities and landscapes** can be **automatically** and **semantically modelled in 3D/4D** to be used for urban planning and design, which new legal, economic, societal and ethical **challenges and opportunities that new big/open urban data** brings to urbanism and how data-supported approaches foster the development of **new methodologies** and products that support all stages of **co-creative urban planning and design** with a particular focus on sustainability, circularity and inclusiveness challenges.

The prestigious project Urban Modelling in Higher Dimensions serves as an example of the research quality and societal impact of our work in this theme. This **€ 1.7 million** project funded by the **European Research Council** and **Amsterdam Institute for Advanced Metropolitan Solutions (AMS)** started in 2016. It enabled a team of **7 researchers (incl. 2 PhDs and 2 Postdocs)** to design, develop, and implement user- driven solutions to model cities, buildings and landscapes in 3D for environmental modelling, urban planning and design. The project contributed to generating a coun- trywide open 3D dataset called 3D BAG, a register of addresses and buildings of the Netherlands, including building height information and related quality metrics. The open dataset is very popular with **~900 downloads a day** and **~168.000 downloads in the period Jan-Mar 2022.** It is used on **municipal platforms** such as 3D.Amsterdam.nl and 3D.Utrecht.nl (Fig. 5.10). Next to this (and other) open data, open software is also developed for applications in urban planning such as noise simulation, computa- tional fluid dynamics (e.g., for wind and air pollutants), characterisation of the energy performance of the building stock, etc. Given the growing role of Digital Twins in the immediate future, particular attention has been paid to the issues related to **inter-operability between different data formats and standards**, with a specific focus on integrating BIM and GIS data in the project EuroSDR GeoBIM. At the same time, the definition and release of the CityJSON as an OCG community standard have contri- buted to the standardisation effort regarding data for 3D city models.

Fig. 5.10 **The Municipality of Amsterdam is building a digital copy of the city: 3D Amsterdam.**
It consists of a 3D model of the city, various functionalities and an interactive web viewer (Credits image: 3D.Amsterdam.nl)

Another aspect of Data-supported Urbanism is the governance of open data, its societal, economic and ethical impact, and the legal conditions for implementing and utilising open data policies. In that regard, the department also takes the lead in open science via programmes like ODECO: towards a sustainable Open Data ECOsystem, a 4-year **Horizon 2020 Marie Skłodowska-Curie Innovative Training Network initiative.** The central aim is to train the next generation of creative and innovative early-stage open-data researchers to unlock their creative and innovative potential to address current and future challenges in creating a user-driven, circular, inclusive open-data ecosystem. The programme runs between October 2021 and September 2025 and will deliver 15 PhD degrees in joint supervision and training between the public and private sectors.

The department also extends its role as a knowledge hub for Data-supported Urbanism with the recently launched 3D Urban Understanding Laboratory (3DUU) within the TU Delft AI Labs programme (Fig. 5.11). Combining data from different sources and using AI will allow computers to learn and work with them so that large amounts of urban data can be automatically processed and

interpreted. The department will continue to be proactively sought and further developed, both with other academic/research institutions and with public/private companies, to maximise the dissemination of knowledge, best practices and applications.
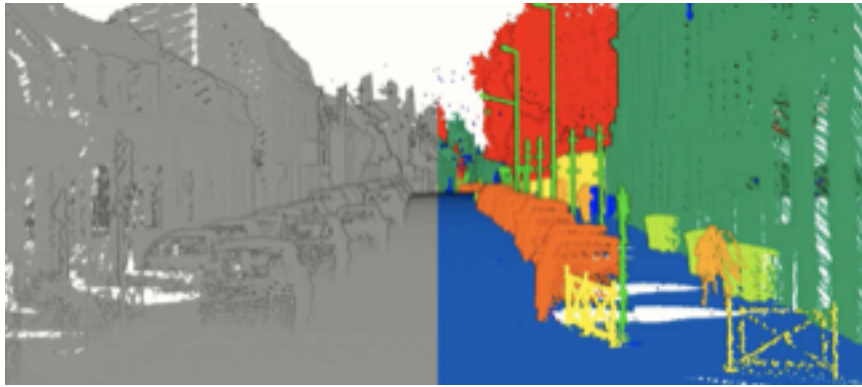

Fig. 5.11 **The 3DUU Lab** Developing new methods and techniques that automatically recognise and model objects in real-world scenes in 3D by combining data from various sources, such as aerial photos and laser scanners on vehicles (iCredits mage: 3DUU).