SCIENCE DAY 22
Built and Lived Environment –
Towards a Sustainable and Livable Urban and Regional Future

Urban Health Solutions
Carbon Sink Solutions & Materials
Built-as-Resource Solutions
Climate Change Adaptation
Agile Infrastructure Solutions

Book of Abstracts
SCIENCE DAY 22

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Towards a Sustainable and Livable Urban and Regional Future
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INTRODUCTION

The Science Day 2022 for the growth area ‘Built and Lived Environment’ aims to foster inter- und transdisciplinary exchange in relation to urgently needed solutions for a livable future of cities and human settlements. In times of multiple and accelerating trends that are aggravated by drivers such as climate change, individualization, digitalization as well as energy or mobility transitions, the built and lived environment must adapt, reorient and profoundly restructure to enhance sustainability and resilience. The current ‘full world’ of existing settlements and infrastructures such as in Western Europe requires transition processes for which solutions are context-specific, ‘error-friendly’ or even self-repairing. Simultaneously, these solutions need to be sensitive to the shifts as well as interrelations of different spatial scales – from the component to the construction site, and up to the district, city, or regional scales.

Meanwhile, the scarcity of material resources as well as habitable and productive land are, to some extent, driving innovation. More specifically, this scarcity inspires and stimulates close interplay between spatial, technological, and social innovation. The potential and interwoven innovation can generate possible solutions that cannot be envisaged as one-time responses. Rather, these solutions are better conceived as a set of interventions intended to carefully anticipate change that is specific and systemic. Setting forth in developing these solutions is both an opportunity and challenge in identifying and improving factors that build and enhance capacities to be ‘mutual adaptive’. In other words, these are solutions with which users might interact; these are solutions that might reflexively (re)act with each other over time, too. Whether these solutions are oriented towards urban health, carbon neutrality, climate resiliency, resource efficiency and value, permeating flexibility, BLE is a moment for us to come together and frame how we solve.
BLE focuses on five ‘mutual adaptive solutions’: Urban Health Solutions, Carbon Sink Solutions & Materials, Built-as-Resource Solutions, Climate Change Adaptation and Agile Infrastructure Solutions.

BLE invites researchers from a broad range of disciplines within RWTH Aachen University as well as collaborators from different institutions and fields of action to share their knowledge and to further discuss research perspectives in each of the five solutions. In particular, BLE addresses young researchers, Doctoral and Post-Doc candidates, to join the diverse solutions and research groups through insightful and short presentations on original work!

The event will be an occasion to experience the unique atmosphere of the BBSR Pop-up Campus – an excellent demonstrator for a ‘built-as-resource’ solution in the city of Aachen and a place to share R&D outputs as well as outcomes regarding sustainable building with colleagues from all over Germany.

The Science Day event is open to interested public in the city and region of Aachen. From 4 pm on the event will focus on inter- and transdisciplinary dialogue and hence actively involve external partners in the scientific debate. A public lecture will conclude the event before guests are invited to informally mingle at the rooftop bar.

Agnes Förster & Frank Lohrberg
URBAN HEALTH SOLUTIONS
Organizers: Marcel Schweiker, Agnes Förster, Daniel Münderlein, Helena Schulte

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Urban spaces and buildings are one of the most important contributors to greenhouse gas emissions. Much of the building sector's contribution to global warming is due to providing healthy and comfortable thermal, visual, olfactory, and acoustic conditions of indoor spaces, where we humans spend 90% or more of our time. At the same time, people living indoors and in urban spaces are also among those most affected by climate change (e.g., greater number and severity of heat waves or floods). More than half of the world's population lives in cities, which exacerbates the negative impacts of climate change (e.g., synergistic interactions between heat waves and urban heat island effects). Research suggests that energy-intensive solutions not only accelerate climate change (and further degrade outdoor environmental quality), but also harm human health and reduce human resilience. Urban Health Solutions (UHS) therefore address the core of BLE: the interactions between space and people – between the ‘built’ and the ‘lived’ environment. Due to the complex interactions between people and space, solutions to increase the resilience of urban spaces, indoor environments and their inhabitants require multi-disciplinary and multi-scalar approaches. UHS stakeholders present their work related to one or more of the following four scales: (1) component & interior, (2) house & ensemble, (3) site & neighbourhood, and (4) city & region. All together, these contributions consider: (I) multiple modalities, (II) interactions between environment and user, and (III) quality and value. Multimodality includes consideration of multiple sensory modes (e.g., thermal, acoustic), as well as disciplinary backgrounds and targets (e.g., architecture and medicine; aesthetics and health). Interaction and role of the user considers people in the urban context as active designers: indoors through their interactions to ensure comfortable environmental conditions and in the urban context for the co-design of transformation processes towards health-promoting urban districts. Quality and value represent the objectives of research and action defined on different scales and differentiated according to the disciplines. Exemplary research questions include the effect of physical stimuli on human behaviour and health and the relation to energy use and sustainability. Methodologies reflect the diversity of approaches and include among others (a) new/mixed methods within laboratory environments, real buildings, and the urban context including thoughts on understanding health inline of the salutogenic model and, (b) theoretical approaches to healthy cities & regions.
How can nature-based solutions promote health and well-being in cities? This question is being addressed by a broad transdisciplinary team in the Horizon 2020 EU funded research project GoGreenRoutes. The Nature-Based Solutions (NBS) interventions which will be established within the project hopefully will increase the acceptance of NBS interventions in many areas of urban design.

In GoGreenRoutes work package 3 (Cultivating: Re-/Co-Design, Co-Creation, and Co-Ownership), RWTH Aachen University is leading a pivotal role within the projects that serve as so-called seedbed interventions.

These temporary interventions will be carried out in the cities of Burgas, Lahti, Limerick, Tallinn, Umea and Versailles, before implementing long-term NBS interventions (see Fig. 1). They are meant to foster awareness and promote understanding of NBS in cities. The seedbed interventions will be carried out in public spaces in each city in the summer of 2022. As a ‘seedbed’, they should provide a stimulus to propose, explore and debate ways in which to improve each urban space. During the seedbed intervention local residents, visitors and passers-by will be involved in questionnaires that focus on issues related to urban health and well-being, can join walking interviews or will be able to share their opinion by means of various options.

The location of the seedbed interventions serves as the base for new urban well-being labs (UWL) in the cities. These spaces are understood as spaces for experimentation which are both physical, geographically bound locations in each city and are frameworks for engagement and collaboration with local stakeholders.
During the course of the seedbed interventions mixed methods will be applied. Co-creation and diversity are guiding principles of the projects, therefore different methods are used to capture as many experiences and voices as possible:

- Participatory on-site meetings/actions (e.g., planting plants together etc.)
- Workshops
- Questionnaires
- Participant observation
- Walking interviews
- Guided interviews
- Expert interviews
- Analysis of secondary data (including statistical data)

WP3 (Consortium partner connect the dots) will provide guidance (through a workshop or presentation) on the best methods of ensuring diversity in the engagement of citizens throughout the seedbed interventions process. This could allow for the capturing of many perspectives, for example, young people could submit drawings rather than questionnaires.

In the context of the documentation of the seedbed interventions, a photo- as well as a film-documentation will presumably take place on site in each city. The interventions may also be documented via creative methods such as a live graphic illustrator.

We see the possibility to expand the benefits of NBS to include health and well-being in the urban environment. By developing and testing seedbed interventions as pre-NBS interventions we hope to establish an innovative format based on co-creation and engagement, to ensure locally appropriate interventions.
Subjective Evaluations of Urban Sound- and Landscape Using Virtual Reality

Josep Llorca-Bofí, Jonas Heck, Christian Dreier, Philipp Schäfer, Michael Vorländer

To evaluate the urban environments under reproducible conditions is not an easy task using traditional techniques based on questionnaires and in situ assessments. However, urban planners and architects are interested in the effects the environment they design has on the inhabitants. This is valid for different scales of our built environments: especially ranging from the components and interior interactions to the neighborhood scale, where the pedestrian’s interaction with the architecture is constant. For this reason, we present a framework, which incorporates physically-based simulations of both visual and acoustic aspects of the urban environments, to be used in Virtual Reality.

The tool runs on Unreal Engine (UE), commonly used in the game industry, together with the open source Virtual Acoustics (VA) software, to be used for scientific purposes in the field of subjective evaluations of urban areas. From the acoustics side, VA includes the main effects of propagation, reflection, absorption and diffraction of sound in urban environments. From the visuals side, the UE includes physically-based-rendered materials, direct and indirect illumination and weather effects. The synchronization of both acoustic and visual cues is done in real time under certain constraints. In addition, the modular nature of the tool allows for the control of the different variables present in the urban environment. This includes the combination of simulated and recorded data to reach higher plausibility.

One of the applications of the tool is the ecologically valid representation of urban areas, such as parks, were the different variables can be parametrically varied according to weather conditions. In the demonstrator presented, three weather conditions have been represented varying acoustic parameters such as atmospheric absorption and wind-related ambient sound, together with light variations and velocity of leaves in the vegetation.

The tool can be used in a range of applications where different urban scenarios are evaluated, especially if the subjective responses to those environments are in the focus of the studies. In studies where the client’s or future user’s plays an important role in the design process (from individual architecture houses to citizen’s participation), the tool might help to reveal the individual or group preferences in a controlled manner.
Put Human Well-Being on the Map
Daniel Münderlein

Motivation and objectives
Making human emotions tangible is a vexing scientific problem. Grand Challenges such as climate change or even pandemics increasingly highlight the spatial dimension of health and well-being while underlining the demand for a better and more fine-grained understanding in order to deal with urban health issues. Medical research and environmental psychology have developed a wide range of scientific methods for this purpose in the past. These include, for example, mood scales or measurement of vital functions. However, corresponding studies are usually carried out stationary and in a controlled environment. In order to adapt these methods in spatial planning, it is necessary to collect data in a real world setting and to process and present results cartographically. For this reason, a dichotomy between place-based and person-based research methods can be observed. Innovative research needs integrative approaches, which evaluate human and spatial characteristics and put both into context.

The main methods
This study presents a multimethod research design, including qualitative and quantitative research modules, which is applied and illustrated in an urban park. It includes innovative and mobile methods like go-along interviews and photo-based research, which can be considered as natural parts of recreational practice and are derived from classical urban studies like the dérive or the mental maps approach. These explorative methods are combined with well-established evaluation strategies like questionnaires for self-reported emotions. Mood scales were developed and applied as pre- and post-measure in order to determine differences and emotional changes of park visitors. The collected data is being analyzed by using self-developed evaluation strategies, spatially projected by using a GIS System and synthesized by incorporating a theory driven framework as well as presented according to effective components.

The main outcomes
The results of the study indicate, that navigating in between the built and natural environment affects human emotions and well-being. Park areas are part of the natural environment and are supposed to provide restorative qualities. Spending time in these restorative environments results in a change of psychological and psychologic
well-being, which can be measured on site. The presented empirical results underline, that people felt more mentally and physically balanced after leaving the urban park than on arrival. Furthermore, restorative effects differed between several park areas and significant differences could be determined for different sites. The statical data also indicates, that effects need to be considered in regards to the use and activities within the park area, because physical movement influenced the measured effects.

In addition to quantitative outcomes, explorative methods were used to explain findings by using verbal and visual content. The qualitative findings indicate, that people are perceiving and experiencing restorative environments in sequences and as spatial choreographies. Open vistas, contact to water or atmospheric spaces were regarded as highlights and contributed to the overall positive experience, while other parts of park we used for transit only without deeper restorative qualities. Transitions in these spatial choreographies can feel ‘hard and abrupt’ or ‘soft and fluid’, which also shapes and affects the according restorative experience.

Important ‘take-home’ message
The presented research illustrates, that spatial planning heavily relies on methods from medical research and environmental psychology in order to put human emotions and especially well-being on the map. Addressing human health and well-being in urban design and landscape planning, requires a deeper understanding of the underlying mechanics, while results need to be visualized in established formats like plans and maps. Perception and well-being-based mapping approaches result in new and uncommon visual styles, which are based on hotspots and fragments instead of exhaustive area coverage. Developing new ways of visually communicating health issues in spatial planning, will hopefully foster the integrative approaches for combining person- and place-based research.
Strategies and Techniques for Urban Space Adaptation to Extreme Climatic Phenomena

Daniele Santucci

Counteracting extreme microclimatic conditions in cities is the foremost urgency in climate change adaptation. As already demonstrated, extreme heat is the first cause of summertime mortality and has specific impacts on communities with pre-existing health conditions and the elderly. As heat extremes in urban areas are reoccurring, extending their duration and becoming more intense due to increasing greenhouse gas emissions and surface sealing, deaths and illnesses are expected to increase.

Due to the intrinsically artificial nature of urban climate and the consequent archipelago of microclimates, mitigation strategies to prevent heat stress at the human scale are crucial to reducing fatalities and achieving public health.

To address the need for an urgent response, research has primarily focused on biometeorological simulation models for predicting local microclimate in new climatic regimes. Indeed, the implementation of mitigation strategies, which must be shared and addressed by public bodies, administrators, citizens, and local organizations, requires evidence for formulating practicable measures. Since the microclimatic manipulation is hardly implementable on a vast urban scale, microclimatic mapping of urban systems generates a differentiation to define and prioritize interventions, detecting the most exposed places that become fatal for specific population groups.

In this context, the ongoing research develops microclimatic sensing methods with a portable georeferenced device and implements it through a participatory process that puts the human dimension at its core. Due to its cumulative and dynamic nature, the experiments called Climatewalks allow a spatiotemporal mapping of microclimates that puts into evidence variations and thermal intensities as humans perceive them, including the subjective physiological and psychological components. Climatewalks are inspired by the science of strollogy, a traditional method in cultural studies created by Lucius Burckhardt, as well as experimental practices like the walks of Alison and Peter Smithson and Lawrence Halprin. During the Climatewalks experiments, participants express their thermal preferences, contributing to depicting the quality of urban space. The resulting mapping represents microclimatic conditions...
on the walked trajectories detecting variations with a high spatiotemporal resolution: mapping can also highlight hotspots as well as the cooling effect of certain features like trees and green infrastructure. The values generate microclimatic knowledge, combined with the subjective response, that becomes the base for formulating site-specific mitigation strategies that include e.g., densifying green infrastructure, replacing heat-trapping materials, unsealing surfaces, extending shading, and evaporation, etc.

Climatewalks also allow understanding people’s behavior without using large dataset analysis, creating a fast and effective method to generate a common understanding of human response to microclimatic conditions.

Addressing and realizing the ambitious target of adaptation to extreme climatic conditions in urban space requires a variety of stakeholders to facilitate cohesion and effectiveness. The participatory character of Climatewalks generates additional and unexplored potentials for unveiling evidence and creating a common understanding of microclimatic domains. This evidence can be used to shape and facilitate human-powered mobility for achieving climate neutrality in the built environment, and for increasing public health.

Figure: Microclimatic Mapping in Berlin. Source: Climateflux

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Health in Growing Districts – Neighborhood as a Prospect for Well-Being

Helena Schultea, Agnes Förster

Structural, natural, and social environmental conditions have a direct impact on everyday life and human health. Insufficient living environments can, among other things, cause physical and psychological stress, trigger illnesses and provoke domestic accidents. Especially in urban, densely populated areas, extreme situations can have devastating health effects on residents. Densification processes, environmental stress and the increase in social inequalities lead to fast-paced development dynamics in cities and urban regions. The constant urbanization (densification, conversion, replacement etc.) provides the opportunity for a sustainable transformation of the tension between health-promoting and health-damaging factors (psychological, physical, environmental, socio-economical, individual ae). When it comes to well-being in the growing city, holistic measures in terms of environmental justice, mental and physical health as well as eco and urban health solutions for the local population are needed. By getting a better understanding of health challenges and judiciously combining health resources, one can turn new districts on the outskirts into test fields for social, spatial and ecological innovations and investments.

However, the pursuit of these innovations and investments demands integrative methods and planning approaches for urban redevelopment, that dynamically illustrate processes of health and well-being while also accounting for them in the multidimensionality of planning factors of living environment. The lack of health as an architectural, urban, social quality is difficult to identify and operationalize. In particular, its immaterial, dynamic condition is not easy to integrate into urban development processes. Previous work, relegates or reflects health as a relation to the built and lived environment through one-sided and sectoral planning methods. To embrace the different angles of well-being, it is valuable to link different scales (from the interior space to larger city building blocks) and temporal dynamics (short, medium, long-term) as well as inter- and transdisciplinarity. The consideration of health as a process requires, indeed, a multilayered scale, observation and development model. It also implies the permanent entanglement of the built, social, and natural dimensions of living environment as well as the dualism of a person-based perspective (human sensory, individual and collective sensing of well-being according to user groups, user-specific requirement ae) and a place-based perspec-
tive (spatial access to health in form of room types/characteristics and design principles). The development of mixed planning methods and modules establishes a dynamic, learning planning process that intends to strengthen growing neighborhoods. This contribution responds to this developmental need by proposing a (learning) toolbox for ‘healthy living spaces’ as a multilayered planning approach and helps to give impetus to the (usual) master planning processes of large districts.

With a specific focus on the concept of the neighborhood (as a triad of interaction, motion, perception) depicts an interesting lever of health promotion in new housing areas. Everyday space and routines, as well as new forms of social alliances in the neighborhood play a crucial role in the well-being of residents and users. When community is initiated, strengthened, and nurtured, an adaptable urban society grows together. The ‘living’, ‘moving’ and ‘sensing’ spheres of neighborhood can initiate health promoting impulses and involve people actively in the process of the growing city. In a process-based, learning approach, individuals and neighborhoods have an active role in discovering, exploring, and appropriating space and also giving feedback. That is when users can become from consumer to prosumer. Generating actionable knowledge through a participatory, action-orientated research process pursue the concern to nudge a transformative planning procedure of well-being in the growing city.

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Housing Consumption in Germany – No Significant Reduction in Per Capita Living Space in Sight

Simon Hein\textsuperscript{a}, Tobias Kuhnimhof\textsuperscript{b}

Germany’s per capita living space has increased significantly in recent decades. At an average of 47.4 sqm/pers., it reached a new high in 2020 (destatis 2021). High levels of per capita living space go hand in hand with high consumption of resources hindering the achievement of sustainability goals, especially with regard to climate change mitigation. In this context, estimates of sustainable or sufficient per capita living space provide different benchmarks. While Grubler et al. (2018) assume that in the global North, avoiding a further increase in per capita living space is sufficient to achieve climate change mitigation goals, Cohen (2021) highlights the need for a drastic reduction in per capita living space. Such a reduction would have implications for urban health solutions and healthy built and lived environments, in part because of existing correlations between size of living space and the subjective well-being of residents (see Foye 2017). Even though some forms of housing with reduced floor space designs such as so-called micro-apartments for students or young professionals appear in European major cities (for controversial discussions see Harris and Nowicki 2020; Hein 2021; Uyttebroeck et al. 2020), we wonder how likely a significant decrease in per capita living space in Germany is. Thus, we derive the following research questions:

- Which factors and trends have a significant impact on housing consumption on the individual and household level?
- Which influencing factors could become more relevant in the future?
- How will housing consumption develop in the future?

In order to answer these questions, we first analyse data from the German Socio-Economic Panel (SOEP) in a descriptive manner. Subsequently, we use econometric analysis procedures and methods of panel data analysis (fixed-effect regression) to better understand housing consumption at the individual and household level. For descriptive analyses and the estimation of econometric models, we use the software ‘R’, which provides a tool for the analysis of panel data via the package ‘plm’ (see Croissant and Millo 2008).
As a main finding, our descriptive analyses of the SOEP data show significant differences in housing consumption between birth cohorts. Whereas 50-year-olds born between 1930 and 1939 consumed an average of 35 sqm/pers. of living space, 50-year-olds born between 1960 and 1969 occupied an average of 45 sqm/pers. (see Figure). Younger birth cohorts thus seem to consume more living space than older ones. In addition, older people consume significantly more residential living space than younger people. While 19- to 30-year-olds in Germany live on an average of 39 sqm/pers., the corresponding figure for people aged 80 or older is 70 sqm/pers. in 2018. Furthermore, spatial differences between rural communities and major cities exist. While per capita living space in cities with more than 100,000 inhabitants has stabilised at 46 sqm/pers. for several years, it has increased in smaller communities (with less than 5,000 inhabitants) to 57 sqm/pers.

Our multivariate analyses allow for a differentiated insight. The main factors influencing the consumption of living space are the household structure, the age of the household head, and the size of the municipality or city in which the household’s dwelling is located. The results are in line with Weber (2020), according to which remanence effects and a growing share of small households are the main drivers of housing consumption, whereas housing affordability problems in many German major cities slow down any further increase in per capita living space. Other relevant factors are household income and whether household members work from home. In contrast to Deschermeier und Henger (2015), we cannot clearly identify a strong cohort effect that has or will have an influence on housing consumption beyond changing household structures. Demographic developments (remanence effects and singularised household structures) will therefore remain a main driver of future housing consumption. The further spread of work-from-home and rent developments will also influence housing consumption. Despite rising rents in the major cities, we do not expect a significant reduction in per capita living space in Germany in the near or medium future.

References
HYDE – Hybrid Tools of Thought. At the Interface of Material Experience and Digital Abstraction

Christina Klug, Sina Hensel, Hannah Groninger

Motivation and Objectives
With the teaching and research project HYDE–Hybrid Tools of Thought, Department of Visual Arts, Prof. Thomas H. Schmitz, funded by Curriculum 4.0.NRW in the time frame of 03/20–02/23, architect Christina Klug, visual artist Sina Hensel and scenographer Hannah Groninger address in three case studies the continued interrelation of humans to technology and their surrounding – between lived and built environment. The aim is to develop new strategies for creative and design processes in order to actively and reflexively investigate complex environments at the interface of material experience and digital abstraction. We define thinking tools, similarly to the concept of ‘solutions’ mentioned in the Call for Papers, as open-ended interactions that within the engagement with natural materials (clay, living colours, facial expressions, and gestures):

- explore new technologies and additive processes,
- investigate time-based aspects,
- take into account complex human-media-technology relations,
- include questions of sustainability and anthropocentrism as a reaction to a changed environment caused by ecological crises.

Based on the results of HYDE, explorative hybrid design processes will be presented in order to bring emotional, spatial and physical aspects of influences and perception into a shared context and to confront the increasing complexity of the built and lived environment.

Main methods and Outcomes
In the case study ‘Additive Structures in Ceramics’ by Christina Klug, one of the oldest and most natural building materials in the history of humankind is explored through the additive process of ‘Liquid Deposition Modelling’ (LDM). Here, the question of design, as well as constructive and aesthetic approaches are investigated through prototype elements. The liquid behaviour of the material can neither be precisely calculated during digital modelling nor during subsequent digitally controlled production. Hence, the final shape can only be vaguely planned, and the material properties generate an additional quality of information that influences the outcome. The aim is to develop new design strategies by understand-
ing on one hand the material's inherent characteristics and on the other hand parametric process developments. The extent to which the material as a building or construction material can hold new qualities or health-promoting measures remains open at this point.

Starting from traditional dyeing techniques, the case study ‘Living Colour’ by Sina Hensel (with Anja Neufeld, RWTH Aachen University) addresses the sustainable and ecological production of material and its application. New, hitherto unnoticed resources such as microalgae and cyanobacteria are considered to generate dyes using new technologies (e.g. freeze drying). They become ‘smart materials’ which react to changes in environmental conditions and adapt to them. Since the material is active, the question of lightfastness and durability arises, and its practical application presupposes the acceptance of transformation as well as the loss of control. This case study serves as a basis to discuss topics such as fragility, dynamics, and decay as well as the interrelationship of humans as planners and designers and their role as users in a changing environment, both ecological and social.

The third case study focuses - in contrast to the other two - on an immaterial, fleeting and barely visible material. Especially when objects of the imagination, e.g. rooms and built environments, are communicated and described in their location, proportions and positional relationships to each other, bodily-spatial gestures are increasingly used - in sync with the spoken language. We draw, shape, represent and model in communication with others to place objects visually in space. By means of recording methods such as ‘Motion Capturing' and additive processes, this case study ‘Mimic and Gesture' by Hannah Groninger renders visible how creatively and spatially gestures act. Considering the findings of ‘embodiment theory' and the application of multimodal forms of communication, the aim is to visualise the interrelationship of the lived and built environment in the transition between mental and physical-material spaces.

Approach
Based on these three case studies, the objective is to discuss the question of aesthetics and empathy in the many ways and adaptations through which we nowadays deal and communicate with lived and built environment. Here, the perception and consideration of unconventional materials and processes are explored which consider the principles of New Materialism as well as interdisciplinary collaboration (in this case with engineers, biotechnologists and social scientists) a source for innovation. Through data visualisation and exploratory translation processes which interact between the digital, haptic, and mental realm, we also hope to gain new insights for our research during the Science Day.

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City Factories as Means for Mixed Use and Densification in Outskirts

Carolin Möllers

Urban production as a rediscovered concept in architecture and urban planning aims to increase the economic resilience of the city, to rise the mix of uses within urban neighborhoods and to create synergies. In this context, a great potential lies in the transformation of the outskirts, especially the commercial and industrial areas, because of their need for change and the available space. Under the premise of functionality, these areas are currently mostly monofunctional and rather separated from the city, with a below-average quality in architecture and open space as well as a low building density. The study examines the question of how the various architectural and urban planning requirements for a city factory in the outskirts can be translated into typological overall solutions in the form of buildings, and asks for tangible and transferable solution approaches that can be derived from this. The aim is to develop a new urban typology for large commercial uses with a focus on production. This typology pursues the intention to generate urban qualities through mix use, density and design quality and thus contributes to strategic urban and neighborhood development. Thereby, production and industry become the subject of architecture and building culture and promote the necessary dialogue for the transformation between the stakeholders. At the same time, the study serves to support the design process of the typology by structuring tools and making them operable.

As part of a master's student design project, a research-by-design approach was used in combination with case study analysis to develop appropriate design solutions for the typology of a city factory using nine test designs and to answer the research questions mentioned above. The study is based on preliminary work of the researchers in this research field.

The main outcomes of the study comprise design parameters for architects and urban planners supporting the design and transformation process of city factories and the outskirts in the form of a requirements catalog for the typology, a morphological box with diverse design approaches, a collection of best practices as well as nine complex test designs. The latter exemplify the shape and quality of the possible typologies.
The study allows some general conclusions about the idea of urban production as a contribution towards sustainability:

- The city factory is a dense multistorey building accommodating multiple users and an operator.
- The users share parts of the infrastructure and premises, whereby the individually available area is larger and can reach higher standards while investment costs (construction costs, facilities, infrastructure) can be distributed.
- Beyond the actual production-use, people from the direct neighborhood and the city are invited into the building via additional use offers, e.g. in the field of education or sports, as well as via sales and service points of the companies or gastronomy uses.
- Next to functionality, the aim of flexibility of space and the interplay between the building and its neighborhood (e.g. through the mix of uses, openness of the building, attractive facade) determine design solutions for the typology. It is intended that the city factory will generate a variety of added values beyond the upgrading of the neighborhood. In contrast to existing commercial typologies, the appearance of the building and the open space becomes more important.

In terms of the transformation of the outskirts the following challenges can be noted:

- While appearing attractive in theoretical concepts the realization of the mix of uses, especially production, in a neighborhood is strongly limited by planning law, more tangible by the zoning plan and the respective requirements regarding building density, noise emissions and more.
- The idea of multi-story, mixed-use city factories requires the open-mindedness and support by investors and operators in order to get the transformation started.

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tegrieren. Ein Forschungsbericht im Rahmen des Verbundprojektes MIA – Made in
Method for a Holistic Measurement of Indoor Air Quality and Resulting Comfort

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Motivation
The physical conditions of rooms in buildings are important for user satisfaction, well-being, health and performance. These are underlined by the fact that citizens in industrialised countries are spending 90\% of their times indoors. In order to ensure good indoor conditions and at the same time guarantee energy efficiency, the current status of the physical room conditions must first be measured. Based on this, necessary measures considering building management, indoor furnishing and user behaviour can be derived.

Main methods
To record the multifactorial room conditions a method is introduced to measure objective physical parameters and compare them with the subjective perception of building occupants. The set of parameters are chosen according to the building element of which the effect should be tested. The method could for example be used to compare different types of ventilation or even different buildings.

Physical parameters to be measured include temperature, humidity, CO\textsubscript{2}-concentration, molecular analysis of volatile organic compounds, air velocity, number of fungal spores and bacteria, sound pressure and illuminance.

The subjective perception can be evaluated using an questionnaire for example the INKA questionnaire including current state of health, general statements according to workplace and field of work, aspects at the workplace as acoustic conditions/noise level, spatial conditions, lighting conditions, indoor climate, health conditions, furnishing/design, importance and need for change of comfort areas, saving energy, furthermore, general questions about the building and its surroundings, personal information, comments. The questionnaire is designed in a way that it covers all measured physical parameters to insure the comparability of objective and subjective parameters at the workplace.

The holistic method including two different parameter combinations is used to evaluate two different effects in buildings (i) the effect of natural elements in an office environment and (ii) a comparison between old and new building through the relocation of an archive. The measurements are executed in two different buildings (i) an
office building, where measurements are already finished, and (ii) an old and new archive, where the new archive still needs to be evaluated next year.

**Main Outcomes**

(i) The evaluations of the natural elements showed an increase of humidity by introducing water and plant walls into the office rooms and no effect on CO₂, fungal spores or bacteria. Analysis of CO₂ concentration while the rooms were occupied, was used to enhance the energy efficiency of the mechanical ventilation.

(ii) Measurements of the archive are still ongoing. The measurements should test the change of indoor conditions achieved by moving the archive. Physical and subjective measures are included and will be compared.

**Take-Home Message**

Measuring physical room conditions and their subjective implications can contribute to healthy and comfortable indoor conditions while maintaining low energy costs.

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Working from Home: Non-Energetic Effects and Rebounds of Changing Workplace Environments

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With increasing availability of information communication technology, there has been an ongoing trend towards working from home. Additionally, the COVID-19-pandemic has led to an unprecedented uptick of this trend. This shift has ensued changes regarding the use of energy, heating, and mobility. Our understanding of the interaction between the alterations in the workplace environment and their users is currently still limited. Therefore, there is an increasing need to investigate any potential rebound effects caused by this development. The current study is part of a larger project aiming to holistically assess the energetic and non-energetic rebound effects of this change. The non-energetic part of the project presented here, aims to identify potential effects on psychosocial factors such as stress-levels, well-being, job satisfaction and job performance.

One part of this study includes a field study. In this field study, a stratified sample will include participants in different workplace arrangements, namely exclusively working in an office, exclusively working from home, and working both, in an office and from home (hybrid). Participants' well-being, health, job performance, and job satisfaction will be assessed using questionnaires. Additionally, heart rate variability (HRV) will be assessed using wearables. Covariates affecting HRV will be taken into consideration. Measurements will be taken on two occasions, once in the warm season and once in the cold season. Participants will receive the questionnaires and measurement devices along with instructions for correct utilization of the wearables. Questionnaires will be filled out before, during and after the HRV measurement period of 48 hours to assess several constructs. Alongside the previously listed variables, questionnaires will be used to assess personality traits, experience of positive and negative affect, psychological detachment from work, and spillover from one domain to the other, such as work-home conflict and vice versa. Additionally, participants will be asked to briefly fill in a diary during each measurement day, documenting perceived stressors experienced during the day.

We expect that working from home will lead to both positive and negative effects. Some of the positive effects of working from home might be increased ratings of well-being, health and job satisfaction and reductions in general...
stress-levels (i.e. higher HRV). While some negative effects might be presented, such as working more hours and a decrease in the ability to detach from work when work is over, or an adverse impact on health due to a decrease in physical activity resulting from the ceasing need to commute. We expect to find different effects of workplace environment on the aforementioned outcome measures depending on personality factors and personal living conditions affecting the workplace environments at home, such as living alone or with a partner, having a young child at home, having a designated working area, or social connectedness outside of work.

Identifying the effect of work environment on different psychosocial aspects depending on personality characteristics and personal characteristics will enable the development of a model which can be used for guiding decision-making processes in the implementation of working from home, while showcasing possible pitfalls. Results of this study will be aiding the development of novel workplace arrangements while accounting for psychosocial factors, promoting successful implementation and acceptance by employees and companies alike.

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The Effects of Remote Working on our Behavioral Patterns and Energy Consumption

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In the course of the Covid-19–pandemic, the practice of remote working evolved into an indispensable part of work-life in many sectors, as most of us experienced ourselves. Working from home seems to have shaped our society now and will likely do so beyond the pandemic. Therefore, a deeper understanding of its advantages and disadvantages is necessary to evaluate remote working and implications for energy consumption and greenhouse gas emissions.

HOffEn is a BMWK funded, interdisciplinary project pursuing the goal to identify chances and boundaries of remote working. The participants are the Institute for Energy Efficient Buildings and Indoor Climate – E.ON Energy Research Center (EBC), the Institute for Occupational, Social and Environmental Medicine – Teaching and Research Area Healthy Living Spaces (HLS), the Institute for Ecological Economy Research (IÖW) and the Institute of Energy Efficiency and Sustainable Building (E3D) as well as the associated companies. The E3D focusses on the effects concerning energy transition. Further project information is accessible online (see www.e3d.rwth-aachen.de/go/id/stfmc and www.enargus.de/detail/?id=8101048). One of the main questions is how the external circumstances at home influence our behavior and our habits: Is it possible to reduce our energy consumption or do we even have to expect rebound effects leading to higher expenses of energy when working from home? Which recommendation can be given for companies or employees based on specific personal circumstances?

The initial approach schedules the implementation of up to 50 partially structured, qualitative interviews with functionaries and leaders of the associated companies. Representatives of the companies are interviewed in their specific functions. The substantive focus corresponding their remits is supposed to allow a preliminary but reliable assessment of the main observable effects of remote working. Based on the companies experience and literature research an online survey for about 500 participants from various organizations will be designed and conducted to provide the necessary database for the following evaluations. These consider, among other criteria, the use of digital infrastructure, the use of area, mobility and rebound effects. The multidisciplinary approach of the HOffEn project allows the establishment of a wide-ranging database and offers a repertoire of evaluation methods. Thus, the interdependences between remote working and en-
ergy consumption are intended to be edited from an overall perspective.

By the time of the science day in June 2022 the first interviews are expected to have been conducted so that the evaluation and preparation of the online survey can be started. Summarizing findings from the literature, the interviews, and the online survey, we develop a tool assisting companies, individuals, and policy makers with the decision whether remote working is from an energetic perspective worthwhile or not. Therefore, quantitative analyses are planned for the evaluation of individual framework conditions. An understanding of the following aspects and questions could be useful to give adequate guidance: Which factors of living or working environment provoke energy wasting or saving? Might it be useful to take measures on a small individual scale regarding a person's workspace or is it necessary to carry out fundamental structure changes on a company scale to reduce energy expenses? Do the suggested modifications concern the built setting, the equipment or the employee's well-being?

Climate change poses one of the greatest challenges of our time. Thus, a critical assessment of our energy consumption is essential. With remote working becoming an important part of the working landscape, this opens new opportunities. Hopefully, this deeper insight into the interdependences between our environment and our way of acting will at least improve our awareness for energy consumption and provide a new accessible tool to criticize oneself.
Effects of Cool and Warm Conditions on Physiological and Psychological Responses

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Thermal conditions experienced during daytime can be different from those experienced during after-working-hours outdoors or at home. Since most dwellings in Central and Western Europe (temperate climate zone) are naturally ventilated, while public spaces and offices are often air-conditioned, a substantial gap between daytime and evening thermal exposure can occur. This thermal gap likely influences physiological and psychological responses towards the thermal environment during daytime and in the evening at home. Next to a lack of knowledge on thermophysiological responses towards the transition between work and home, there is a particular lack of understanding how thermal conditions affect psychosocial aspects of our lives, such as how connected or disconnected we feel from other people, or how empathetic we are towards people around us. Therefore, the present study aimed to assess the impact of staying in cool vs. warm environments on thermophysiological and psychological responses, as well as subjective perception of the thermal environment, during working hours and in the evening at home. The project was funded within the ERS project Attract-HC 'Attracting human capital for the Rhenisch mining area through comfortable, healthy, and productivity-enhancing indoor environmental spaces'.

In this hybrid laboratory and field study, 31 participants (41±17 years, BMI: 24±3 kg/m\textsuperscript{2}) were exposed to a simulated workday (between 9 am and 5 pm) in either 21˚C (cool) or 28˚C (warm) at two separate occasions (Figure 1). Mean skin temperature (based on four body sites), thermal sensation and thermal preference were measured at eight timepoints throughout the day (lab) and evening (home) until the following morning. Additionally, participants were asked to complete a series of questionnaires investigating their levels of empathy and social disconnection before and after the lab part of both testing days. Statistical analysis was performed using the free software R. Wilcoxon signed rank tests were applied to statistically compare results of the cool and the warm condition.

Preliminary results suggest that daytime thermal conditions affected participants' thermophysiology and thermal perception after working hours at home, such that people were feeling significantly warmer at home after the cool condition compared with the warm condition. The effect was most pronounced shortly after arriving at home and...
decreased over time. Regarding psychological responses, a significant effect was observed for levels of empathy between pre- and post-measurements of the cool and warm condition. Here, individuals exposed to the cool condition reported lower levels of empathy, while participants exposed to the warm condition exhibited higher empathy levels after thermal exposure. For social disconnection, no significant effects were found. Our results raise the question whether conditioning of work places solely based on onsite productivity and comfort, but without considering the influence on psychological factors as well as the impact on comfort and well-being during leisure and recovery time at home, is the way to go in the future. Further research is needed to support our findings and to extend and translate the findings to other thermal environments.

Figure 1: Flow chart hybrid study design. Blue diamonds = Timings of mean skin temperature measurements and subjective perception questionnaires. Yellow diamonds = timings of empathy and social (dis-)connectedness questionnaires.
Noise and its multifarious effects on productivity, well-being, and health within the built environment are general knowledge. In certain areas such as open-plan offices, noise is typically one of the (if not the) biggest contributing factors towards occupants' dissatisfaction within the compass of indoor environmental quality (IEQ) factors. One of the primary issues in characterizing the effects of noise on humans includes the diversity of noise sources and their interaction with human activities. Herein, noise may comprise of a dynamic and complex mix of various transient (e.g., a loud crash) and longer/continuous (e.g., drilling, air-conditioning) sounds, some more disruptive than others depending on the context. The old adage – one person's noise is another person's music – could not be more relevant in expressing the difficulties in studying noise effects on humans.

Within the continuum of ecological validity, transferring the 'in the wild' noise scenarios to laboratory conditions offers a tremendous degree of control that is generally offset by the accompanying lack of 'realness' of laboratory simulations. At our institute (IHTA) we have been pushing the boundaries of what is possible in laboratory conditions, in terms of representing the complexities of human interactions with noise in certain contexts. The two contexts highlighted here include classrooms for children and open-plan offices for adults. The research aims include characterizing the effect of noise and other IEQ factors on cognitive development and mental health of children in classroom conditions in Germany and characterizing auditory distraction and speech communication for office employees, both within audiovisual simulations of the respective contexts. The audio stimuli used are created per context based on combining insitu measurements, sound design, auditory scene analysis, inhouse room acoustics simulation software, etc. The audio reproduction includes the use of advanced methods such as customized head-related transfer functions for adults and children (for accurate acoustics simulation), high-order loudspeaker systems, etc. The visual stimuli are created per context using video rendering software, which are reproduced using head-mounted displays. The cognitive and subjective tests used in these audiovisual settings are representative of certain activities per context, e.g., speech comprehension in multi-talker scenarios, attention switching during competing cues in classrooms, etc. These tests,
some established and some exploratory, are continually informed through various collaborations with researchers in applied psychology, e.g., child developmental psychologist for classroom contexts. Overall, these methods allow a high level of immersion in an audiovisual environment for the participants performing a certain task, with ever-increasing blurring of the lines between laboratory and real-world experience. Multimodal immersion with variable control of other IEQ factors remains a future goal.

The broad outcomes of this ongoing research include an untangling of the effects of context-specific noise in classrooms and offices and informing the methodology of future research that aims to bring the laboratory and real-world experience closer. Taken together, these broad outcomes represent a merging of the best features of the field and laboratory research methodologies (as understood traditionally) with the expectation that the laboratory findings will be more readily applicable to real-world settings than ever before. More specific outcomes include design and policy guidelines for better and healthier learning environments for children, especially in relation to the complex and multisource noise environments in classrooms; and reducing the ill-effects of noise-based productivity decline in open-plan offices. Besides the current focus on classrooms and offices, the methods outlined above are adaptable to inform research directions in other areas in the built environment that involve a human-noise interaction, such as hospital and nursing units, residential units including proliferation of work-from-home settings, etc.
CARBON SINK SOLUTIONS & MATERIALS

Organizers: Thomas Matschei, Anya Vollpracht

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New Solutions to Close the Gap
The construction sector is currently responsible for ~40% of the global CO₂ emissions out of which ~11% can be directly attributed to the manufacturing of building materials e.g. cement, steel, etc. The growing world population and increasing global demand for comfortable living space magnify the problem still further. In order to fulfil the current demand for housing and infrastructural development, more than 40 billion tons are annually mined. These consist of mainly primary materials. On the other side ~33 billion tons of wastes are generated every year out of which the majority is lost due to landfilling, incineration, amongst other reasons.

There must be smarter ways to close these circularity and carbon gaps. We must search for material solutions that utilise CO₂ instead of emitting even more. Improved design principles enable material minimised structures. Alternative material streams, novel co-processing pathways and new construction technologies may pave the way towards net-zero or even climate-positive construction strategies. In any case, individual silo approaches are not an option for the future. Only a collective synthesis of integrated interdisciplinary view-points will provide a way to more circularity, less materiality and novel carbon sink solutions.

In this session we therefore have a variety of impulses focussing on the following sub-topics:

1. New materials as enablers for a decreased resource and carbon footprint in construction
2. Circularity in construction (less primary, more secondary materials)
3. Novel design principles and manufacturing technologies for material minimised structures
4. New approaches to assess sustainability and materiality of construction
5. Treatment and utilisation of wastes e.g. from dumps and landfills
Biobased, High-Performance Geotextiles with Defined Degradability

Gholamhosein Tavakoli Mehrjardi\textsuperscript{a}, Raul Fuentes\textsuperscript{b}, Jan Derksen\textsuperscript{c}, Magdalena Kimm\textsuperscript{d}, Thomas Gries\textsuperscript{e}

The use of geosynthetics, as one of the most important constructing materials in civil engineering, generally shows advantages in the consideration of the entire life cycle (energy balance, CO\textsubscript{2} emissions, etc.) compared to constructions without mechanical improvement, since less earth and rock material and lower transport efforts are required. Today, geosynthetics are mostly made of petro-based polypropylene (PP) or polyethylene terephthalate (PET). The dependence on petroleum as a raw material is controversial from social, political and ecological points of view. On the other side, geosynthetics remain in place for decades, forming plastic fragments and microplastics, causing serious biological repercussions on organisms living in the nature. From geotechnical point of view, there are temporary earthworks, being constructed over a short period of several months to a few years and require a geosynthetic function during this time. In effect, temporary geosynthetics reinforcements are integrated into earthworks in order, for example, to prevent critical fracture mechanisms in embankments or supporting structures, to compensate for deformations below load application areas such as foundations, storage and construction sites, to reduce the development of ruts in construction roads, to increase the loadbearing capacity of earthworks or to enable construction on soft ground. Moreover, in some permanent earthwork structures such as traffic routes, shorelines and especially on slopes to be recultivated in opencast mines, the geotextile function in the earthwork is temporary because that function will be taken over by another element at a later time. For example, newly constructed, unvegetated slopes and embankments are protected against erosion due to wind and precipitation. The use of geotextiles increases the shear and flow resistance of the mostly uncompacted upper soil layer against surface erosion. This ensures the initial erosion protection until this function is taken over by natural vegetation after two to three vegetation periods.

According to Figure 1, through the running project titled ‘DegraTex’, the functionality of these novel bio-based, biodegradable geosynthetics with the application of reinforcement, erosion control and vegetation protection is verified in standardized tests, small-scale demonstrators and practical pre-competitive large-scale demonstrators. Typically, the textiles should be firstly installed and then retrieved in the field for durability assessments.
For small-scale demonstrators, the soil and the textiles should be stored under specific environmental conditions and then, the degraded textiles are tested for several degradation stages in different kind of index and performance tests, including pull-out tests, plate load tests and erosion tests. To validate the findings obtained in the small-scale demonstrators under controllable and reproducible conditions, large-scale demonstrators will be implemented in a practical environment. For large-scale demonstrators, the applicability of the bio-based products in the context of large-scale slopes as well as unbound road is examined. The mechanical properties of the bio-based textile structures will be tested in isolation and comparatively evaluated against petrol-based products. Since the ongoing project is a multidisciplinary subject, different parties consisting of Institut für Textiltechnik (ITA), Huesker Synthetic GmbH, Essedea GmbH & Co., Institut für Angewandte Mikrobiologie (iAMB), Fraunhofer Institut für Umwelt-, Sicherheits- und Energietechnik (UMSICHT), Wurzelbau cooperate to conduct the work.

The project deals with different aspects including development of a methodology to investigate the time-dependent interaction mechanisms of the geotextile in contact with soil, air and organisms due to its degradability, development of installation methods through testing in laboratory and field environments, and creation of an evaluation framework for degradable geotextiles. It is expected that this study will about the required design factors that is crucial to have in prudent engineering practice. Furthermore, from environmental point of view, this research besides the other aspects will fully investigate the applicability of biodegradable geosynthetics. Moreover, the observations after the period of textiles incubation in soil can potentially help the producers to improve their products by implementation of different strategies such as polymer processing, changing the admixture, coating and etc.
Biomass Ashes as Supplementary Cementitious Materials

Steffen Overmann\textsuperscript{a}, Anya Vollpracht\textsuperscript{a}

Due to the significant environmental impact of the cement industry caused by the high CO\textsubscript{2} emissions and consumption of energy and natural resources during Portland cement production, supplementary cementitious materials (SCM) like industrial by-products are used to substitute, to a certain extent, Portland cement. However, for environmental reasons, attempts are being made to further reduce the proportion of Portland cement clinker in the cements, while at the same time the availability of the most commonly used SCM, coal fly ash and blast furnace slag, is decreasing in Germany. Therefore alternative SCM are required.

The reactivity of pozzolanic SCM is mainly based on a metastable Si (and Al) rich amorphous structure which can release significant amounts of Si (and Al) in a cementitious environment to form C-(A)-S-H, similar to the Portland cement hydration products. Therefore, other Si and Al rich ashes from biomass combustion can potentially be used as SCM. In comparison to fossil fuels, energy generation from biomass combustion is considered as ‘CO\textsubscript{2}-neutral’ because only in relation to how much carbon is released as the plants previously absorbed. However, further material parameters like the specific surface area and the content of unburned carbon/organic matter, phosphate and sulfate can strongly influence the performance as SCM. Furthermore, from an economic perspective, the local availability of the raw material is important. For example, rice husk ash is a very good SCM, but not relevant for Germany because rice is not grown here.

In a current study, 5 different wood ashes (2 without additive, 1 with gypsum additive, 1 with halloysite additive, 1 wood pellet ash) and one hemp pellet ash were evaluated for the use as an SCM and compared with four rice husk ashes (all bottom ashes). The ashes were characterized with respect to fineness, particle size distribution and chemical and mineralogical composition. Their performance in the cement system was evaluated on mortar scale. Furthermore, the reactivity was determined according to a new reactivity test for SCMs (ASTM C1897-20).

It was found that the rice husk ashes have an extremely high specific surface areas (>300 000 cm\textsuperscript{2}/g) even without grinding so that the substitution level had to be reduced from 25 wt.-% to 10 wt.-% in order to achieve sufficient
workability. The amorphous contents were >90 wt.-% and the 28 d relative compressive strengths (compared to pure cement mortar) were around 100% (96-104%). The isothermal calorimetry according to ASTM C1897-20 showed a reaction heat comparable to that for coal fly ashes. The data approved the usability of rice husk ashes as SCM.

The other ashes were ground to a fineness of about 5000 cm²/g (Blaine) to gain comparable results. However, the BET surfaces were more than three times higher caused by a nanoporous structure of the ash particles. For the hemp and wood pellet ash only 59% and 48% 28 d relative compressive strengths were achieved which could be attributed to the high P₂O₅ content of about 31.5 wt.-% of the hemp pellet ash (about ten times higher than for the other ashes) and the high unburned carbon content evident from the high loss on ignition of about 44 wt.-% of the wood pellet ash.

The other wood ashes had 28 d relative compressive strengths in the range of 71-83% and showed a cumulative heat release after 7 d according to ASTM C1897-20 in the range of 66-144 J/g ash. The results of both tests touch the lower range of coal fly ashes.

It has been shown that the use of locally available biomass fuel ash, such as wood ash, as SCM is possible. However, the burning process should be adjusted to obtain a low carbon residue and a high content of glassy phases. When choosing the fuel, it should be considered that the resulting ash require a low phosphate content and a high content of SiO₂ in the glassy phase. In addition, soluble Al₂O₃ and CaO can contribute to strength development.

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Stabilised Earth Binders for Low Strength Applications

Selina Vaculik, Thomas Matschei

Due to the increasing consumption of raw materials, especially in emerging countries such as China, India and Brazil, and the high proportion of increasing CO₂ emissions, which is to a non-trivial extent associated with the cement industry, the motivation to find alternatives for the building industry is significant. There are several approaches that can be pursued. One is the development of new resource-saving materials through material minimization and/or improvement.

Probably one of the most promising approaches towards climate-neutral construction is the use of clay as a tried and tested building material. Clay is currently mainly used in the restoration of historical buildings and as an interior plaster. It is known for its pleasant indoor climate regulating properties and its easy workability [1]. Challenges with general earthen construction are the strong shrinkage during drying and the required protection against water and frost. Fresh clay properties are less known, and strengths are generally inadequate. Durability is also a major problem for general residential construction [2]. One of the successful approaches is to stabilize the clay with mineral additives to improve the overall mechanical properties. The use of cement-reinforced earth in low-strength components is one of them [3,4].

Within this paper, we share how first tests were carried out that pursued this approach and achieved some results. Initial tests show that a minimal addition of Portland cement as binder improved the compressive strength of the cement-stabilised clay concrete by at least 10 MPa. Thus, an increase in strength by 550% could be obtained with the use of 10% cement as binder. The shrinkage behavior could also be minimized, and the water resistance increased at the same time. In further studies, the influence of an optimized particle size distribution and the combination with other mineral additives will be investigated and analyzed in more detail.

This interaction shows a viable alternative to normal concrete in the low strength sector. In addition, clay is a natural product and degradable. It also does not produce overstrength that could lead to tensile strain.

Since the water content in these compounds must be kept as low as possible, this compound is also suitable for...
some additive manufacturing processes. Additional compaction during the extrusion process could further improve the strength properties. [5,6]

With the use of clay in general construction, an alternative to traditional construction can be found. The use of mineral additives shows improvements in mechanical properties compared to untreated raw clay. Further research is needed in the near future to further improve certain properties.

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Mycelium-Based Composites with Minimal CO₂ Footprint for the Building Industry

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Construction is an industry with huge material consumption that generates large quantities of waste, from which only a small part can be recycled [EEA, 2018]. Novel organic, bioengineered materials would contribute to the transition to a more environmentally friendly construction industry by saving CO₂, reducing entropy, and considering dismantling by the end of their utilization cycle, thus conserving resources and protecting the environment. One approach that can positively contribute to solving this problem is the so-called mycelium-based composites as matrix materials that combine fungal mycelium with a lignocellulosic substrate, e.g., wood, as a nutrient. It is necessary to improve these materials’ mechanical properties, particularly their strength in compression, shear, and bending/tensile stresses, to expand the range of their applications significantly.

Mycelium-based composites exhibit mechanical properties similar to soft plastics or plastic foams in their untreated form. Combined with solid materials, they can also be used as a matrix material on the building scale. The construction industry, particularly in the case of Germany, has high regulations and standards to accomplish. Also, there is high economic competition with conventional building materials. Both high standards and economic competition represent significant challenges in developing and establishing materials of organic origin. The most critical areas of influence and the control parameters that affect the strength and stiffness of the matrix material include the selection of the mycelium-substrate combination, the targeted influencing of the growth of the mycelial filaments (hyphae), and the combination with various aggregates to form a composite material. The influencing parameters make a top-down approach to material design and the development of controllable and predictable properties of mycelial materials based on certain material forms, such as conglomerates or laminates, as well as material structure models.

Three prototype construction systems were developed based on the material design: first, a masonry block system with a hole (based on limestone blocks); second, a masonry system in a brick format that can be processed without joints; and third, a sandwich construction system for wall and ceiling elements based on wood panel construction. The unique property of the mycelium material to take on any
shape using a formwork also allows the production of complex components with single or even double curvature, from which further structural advantages can be exploited [Saez et al. 2022]. In addition to developing different prototypes, the optimization of their mechanical properties was intensively investigated, aiming to present an alternative to traditional construction products. Consequently, various material tests were carried out to determine the compressive, flexural, and shear capacity. Developing a different test setup would have been necessary to determine the pure tensile strength of the matrix material, and for this reason, no pure tensile strength tests have been conducted until now. Nonetheless, the bending tensile test series could draw conclusions on the tensile strength. All test setups and procedures were based on the specifications of standards for insulating materials in the building industry [DIN EN 826, DIN EN 12089, and DIN EN 12090]. It is also worth of mentioning that all tests were conducted with mycelium composites as two-component materials: pure mycelium-substrate combinations without additives. The fungus Ganoderma lucidum combined with chipped beech wood as substrate showed considerable fast growth in comparison to other basidiomycetes; for that reason, it was the selected mixture for the test specimens manufacturing.

Among the benefits of mycelium and wood-based materials, we can mention that they can be wholly integrated into the natural material cycle and allow the production of entropy-reducing building elements. With the application of material structure models, conglomerate and laminate materials can be developed in many shapes offering an alternative to traditional materials. Numerous production-relevant conditions for the construction industry could be obtained through targeted investigations. In this context, various strength-improving measures were also developed; for example, the compressive strength was increased by 200% within an iterative material improvement workflow—however, other parameters need further investigation, such as mycelium-substrate combinations concerning optimal mechanical properties. Nevertheless, mycelium composites present themselves as an alternative material that can be composted after their utilization cycle, reducing construction waste in longterm landfilling.

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Recycling Strategies to Exploit the CO₂ Savings Potential of Textile Reinforced Concretes

Lia Weiler*, Anya Vollpracht*

In search of innovative and sustainable construction materials the building industry started research on textile reinforced concrete (TRC) some 25 years ago. By using non corrosive glass- or carbon reinforcement (GRC and CRC), instead of the established steel bars, the concrete cover of reinforced components can be significantly reduced. This allows for the reduction of materials consumed and, currently expected, more durable structures. Depending on the application scenario, raw material cutbacks are quantified at up to 80% [1] and CO₂ emissions are lowered by 6% [1] to 70% [2] in comparison to established building solutions. On average, Life Cycle Analyses (LCA) of CRC revealed, partially only slight, improvements in Global Warming Potential (GWP) [1,3–8] but higher [1,8] to uniform [4,7] energy consumption (PE). For GRC some studies calculate advantages for GWP [2–4,9] and PE [2], while others result in higher CO₂ emissions [4,6,9] and energy demand [4]. Furthermore, varying impacts in favour of either steel or textile reinforcement in the other LCA categories such as ozone depletion, acidification, or also social impact are reported. Comparing among TRC, GRC mostly performs environmentally friendlier than CRC. Yet, all LCA results strongly depend on the respective chosen reference values and system boundaries. A difficulty that, e.g., is also highlighted for the declared units (weight vs. tensile strength) of CRC by Stoiber et al. [9] and for the system boundaries (cradle-to-gate vs. cradle-to-grave) of GRC/CRC bridges by Cadenazzi et al. [7].

While the ecological advantages of TRC in comparison to steel reinforced concretes in production and service life remain unclear or rather dependant on the application scenario, most researchers conclude that functional recycling processes as a key driver of environmental impacts are crucial to exploit the potential environmental advantages of TRC [3,5,9,10]. Investigations on the recycling process of carbon concrete by the TU Dresden University and the RWTH Aachen University already demonstrated the possible separability of CRC [11–13]. However, a holistic solution that includes the recycling options of the recycled fractions generated in this way, as well as concepts for the recycling of GRC components, are not yet available.

A difficulty in finding recovery solutions for TRC is the currently inevitable destruction of the textile during the separation process and therefore a downcycling of long to short fibres, especially for GRC [13]. In addition,
Laiblová et al. pointed out, that the next best solution according to the current state of the art, demolition and pyrolysis of the short carbon fibres for a reuse in fibre fleece, are ecologically less beneficial than the use of steel [3].

The ‘FaBer’ project therefore aims to develop a high-quality, health-sensitive, and environmentally beneficial utilization of the mineral and fibre fractions of carbon and glass textile-reinforced concrete components to be recycled for reuse in the production of high-performance mineral materials. For this, the developed recycling process should consider to not separate fibres at the expense of concrete recycling so that all fractions generated in the treatment process can be reused. The recovery scenarios are developed in three case studies by the project partners RWTH Aachen University, Holcim (Germany) GmbH and Mitsubishi Chemical Advanced Materials GmbH. Accompanying this, occupational health and safety will be considered and a life cycle assessment will be carried out to verify (or disprove) the advantage of the recycling paths.

The project results will not only serve from a technical point of view, but are also of high importance for future LCA studies, that will be able to apply more distinct estimations, reduce uncertainties, and improve generality and therefore credibility.
Waldlabor Köln: Introducing Additive Manufacturing into Landscape Architecture in a Cross-Discipline Approach

Elisabeth Heuermann\textsuperscript{a}, Federico Garrido\textsuperscript{b}, Joost Meyer\textsuperscript{c}

The effects of climate change are extensive and complex. This requires rethinking in all areas of our society. Examples for this are the energy transition in Germany and the reorientation of the worldwide construction industry. The New European Bauhaus and the European Green Deal, declared by the President of the European Commission Ursula von der Leyen, illustrate the need for interdisciplinary collaboration to not only mitigate the impacts of climate change, but to actively counteract them. This research presents the idea and practical approach on how collaboration between landscape architectural design and additive manufacturing (AM) techniques can contribute to tackling the climate crisis. This is done by a concept on how to use regional regrowing resources in urban forestry for recreational public needs as well as sustainable additive manufacturing procedures for building industries and architectural needs.

Nowadays, landscape architecture faces the task of meeting the sociological and economic challenges of the 21\textsuperscript{st} century. Urban forests must increasingly withstand extreme weather events such as heavy rain, droughts and storms. They should improve air quality, mitigate periods of heat and serve as recreational space. The call for a New European Bauhaus by the President of the European Commission, Ursula Von der Leyen, and the European Green Deal further expand the requirements and strengthen the call for interdisciplinary cooperation. One example of this is the Waldlabor Köln. It was created as part of the Regionale 2010 Cologne/Bonn and is part of the open space corridors that link Cologne’s green belt with the surrounding countryside. The aim of the Waldlabor is to protect regional open spaces and to vividly convey their value. (Lohrberg/Matros 2017) The total area of 25 hectares is divided into four areas: The climate forest, the transition forest (Wandelwald), the wilderness forest and the energy forest. In the climate forest, stress-resistant tree species are experimented with, the transition forest deals with varieties of aesthetic forest images and the wilderness forest examines natural succession. On the areas of the Energy Forest, the Institute of Landscape Architecture was looking sofar for answers to the questions of the energy transition and for sustainable, regenerative energy production. A short-rotation plantation (Kurzumtriebsplantage) covers 6.3 hectares and is planted with fast-growing tree species such as poplar and willow. The wood is harvested every two to
five years. The woodchips are then fed into the thermal utilisation process. The operation of this short-rotation plantation requires virtually no fertilisation, which significantly reduces the emission of greenhouse gases compared to the cultivation of corn or wheat, for example. (www.koeln-waldlabor.de) This use for energy supply is now extended as our research proposes: to implement a regional opportunity to use wooden resources for additive manufacturing in an (landscape-) architectural context.

Subtractive manufacturing processes are an established method for creating wood components. This contrasts with additive manufacturing processes, where the use of wood is still a novelty. Common materials are plastics, metal, or ceramic materials such as clay and concrete. So far, there are only a few examples of the use of wood in AM, where the focus is mainly on the wood-like structure and not on sustainability or biodegradability. (3D printing and wood 2015) 3D printing offers the advantage of allowing free shaping based on digital models. By building up in layers, the material used is used highly efficient, resulting in little to no material waste. In addition, the flexible manufacturing process ensures a cost-reduction for complex components that are produced in small quantities compared to traditional manufacturing techniques. (3D printing and wood 2015) The prospective use of wood as an essential component of the printing material also increases sustainability by using local resources directly on site. Large-scale 3D printing in wood is new and follows the public demand for a sustainable, resource-saving, and appealing co-creation of our environment. Through the 3D printing process, easily regrowing tree species in urban forestry can also serve as raw material for biodegradable architectures and, once their use has ended, they can either be thermally recycled or returned to nature’s metabolic cycle through composting. This form of multiple use of the resource wood by humans is referred to as cascade use. To achieve this multifunctionality of forest areas as aesthetic recreational space, raw material supplier and producer of regenerative energy, it is our task to further investigate on this: an approach to combine and interact urban forestry, landscape architecture and 3D-printing and design methods in a cross-discipline strategy.
**Spatial Concrete Extrusion for Material-Minimized Concrete Structures**

Thomas Adams\textsuperscript{a}, Anya Vollpracht\textsuperscript{b}, Sigrid Brell-Cokcan\textsuperscript{a}

**Motivation and objectives**

Worldwide, the building and construction sector accounted for over 36% of final energy use and 39% of energy and process-related CO\textsubscript{2} emissions. The production of cement alone is responsible for 11% of greenhouse gas emission due to combustion and chemical reaction of its raw materials. The fabrication of concrete, mainly done by casting, requires additional material and labor for formwork manufacturing. Especially complex structures come up with additional material effort and labor intense formwork fabrication, especially at low quantities. The design and fabrication of individual and material-minimized concrete structures is limited in construction practice. Therefore, robotic fabrication methods became more and more relevant in research and development over the last decade. In particular, additive manufacturing (AM) technologies such as 3D concrete printing and contour crafting became popular for individual designs because of their potentials for formwork-free and CAD-driven concrete fabrication. Nevertheless, current AM approaches are characterized by limited overhangs restricting the design of complex structures. Therefore, spatial concrete extrusion in support material is promising to improve the design flexibility and AM of material-minimized concrete structures.

**The main methods**

3D concrete printing and spatial concrete extrusion are both extrusion-based AM technologies and were investigated by fabrication of scaled concrete element examples. 3D concrete printing describes the successive build-up of concrete elements layer by layer. Fresh concrete is continuously pumped and extruded through a nozzle moved by a three axis robot system. The fresh concrete stability is achieved either by viscosity modifying agents, which are added in-situ to the concrete mixture, or by rapid setting accelerators, which are added at the nozzle during extrusion. Spatial concrete extrusion describes the three-dimensional concrete strand extrusion in a support suspension. The robot extrudes the concrete in three-dimensional space frames. During extrusion and curing, the suspension stabilizes the fresh concrete through its buoyancy and yield strength. After curing, the hardened concrete structure can be taken out and post treated. As support material bentonite clay was used due to its pseudoplastic behavior and inert material property.
The main outcomes
Examples of 3D concrete printed, and spatial concrete extruded elements can be differentiated as follows: 3D concrete printing is suitable for building elements with single and double curved contours. The design possibilities depend on the build-up orientation during fabrication. Hollow structures can only be fabricated vertically to the layer build-up. Horizontal curves can be unlimitedly realized, whereas vertical curvature and overhangs are limited by yield strength and setting time of the fresh concrete. Spatial concrete extrusion extends the design possibilities since the concrete can be placed arbitrary in space. It allows for unlimited overhangs and enables hollow sections in vertical and horizontal orientation. Instead of fresh concrete properties, the design is depending on the container size, path collisions between robot and concrete and the yield strength and density of the support suspension. The structural behavior depends on layer bond, which can be impaired by support material depositions between layers.

Important ‘take-home’ messages
In conclusion, 3D concrete printing is suitable for individual and hollow concrete elements with straight closed contours. Cavities can only be applied in a single direction with layer build-up and overhangs are impaired by fresh state properties of concrete. Instead, spatial concrete extrusion increases design flexibility through the support suspension. Unlimited overhangs and filigree structures that haven’t been possible with conventional technologies can be realized. Therefore, it opens up novel design opportunities for material-minimized and greenhouse gas saving construction. E.g. It excels for ultra-lightweight space frame structures by free floating concrete strands saving up to 50% of material and greenhouse gas compared to 3D concrete printing. Since the filigree concrete design is more susceptible to buckling and brittle failure, its structural application requires for high tensile and ductile concrete compositions that need to be investigated and applied in future research.
An Innovative 3D-Printing Process for Reinforced Concrete Structures

Sisi Zhanga, Matthias Kalusb, Martin Claßen\textsuperscript{c}

The building and construction industry is one of the largest contributors to global CO\textsubscript{2} emissions, which is responsible for 10\% of the total emissions. In order to achieve the global goal of net zero CO\textsubscript{2} emission by 2050, structurally more efficient buildings consuming less materials also need to be addressed by structure engineers besides the efforts made by the material sciences to decrease the carbon footprint of cement and concrete. In the conventional construction, optimized tailored structural elements with curved geometries is highly challenging due to high cost and waste of non-standard formwork shapes, while additive manufacture (AM), also known as 3D-printing, has the advantages of producing individually structures using less material with little extra cost because of its higher geometric flexibility. Although 3D-printing of plain concrete has been pushed forward by growing research community in recent years, a practical automated method for integrating reinforcements in 3D-printed concrete structure is lacking to meet the most important requirements such as load-bearing capacity, ductility, robustness, etc.

In this paper, a novel 3D printing process for reinforced concrete structures called Additive Manufacturing of Reinforced Concrete (AMoRC) is proposed. The process consists of a continuous concrete extrusion process and an intermittent stud welding process, both carried out by a robotic arm respectively. The welding robot runs ahead of the concrete extrusion robot and produces the spatial reinforcement mesh from prefabricated reinforcing bar segments. A novel fork-shaped print head with four adjustable nozzles allows for concrete extrusion around the reinforcement with different diameters. By joining segmented rebars of limited length to a reinforcement mesh in the AMoRC process, the consumption of energy and time can drastically be reduced compared to shape welding. The length of the joined rebars can be adapted to the component geometry and the extrusion speed. The bar segments to be joined are kept ready in a magazine belonging to the print head, which enables the feeding of bars with different diameters to arrange a load-efficient and economical reinforcement mesh.

The preliminary testing of the additively fabricated reinforced concrete components is also implemented to characterize the structural behaviour of those 3D-printed composite specimens. In the initial phase, the reinforce-
ment installation was performed manually until the second robot will be added to the process in the course of this year. The pull-out test is used to investigate the bonding behavior between reinforcements and printed concrete. The four-point bending test is also utilized to study the mechanical behavior of the printed reinforced concrete specimen in a larger scale. Since the printed concrete structure has an anisotropic character due to its inhomogeneity caused by the layer-by-layer printing, the reinforcement layout orientations (in x-, y, and z-directions) are considered in the pull-out test. The printing direction is denoted as x-direction, the other direction perpendicular to the x-direction in the same horizontal plane is the y-direction, whereas the vertical direction is referred to z-direction. On the other hand, only the reinforcement in x-direction is considered in the 4-point test in the first step. In the pull-out tests, three kinds of failure modes could occur: (1) split crack failure; (2) shear fracture failure; and (3) weld joint failure. The average bond strength in x-direction is 8.89 N/mm², 11.74 N/mm² in y-direction and 12.9 N/mm² in z-direction, whereas the casted specimens have an average bond strength of 10.67 N/mm². Nevertheless, the measured bond strength values were largely scattered and high bond stresses were measured in each reinforcement direction. Thus, no clear statement could be made as to which reinforcement orientation exhibited the best bond. In the 4-point tests, the average load-bearing capacity of printed specimens is about 85% of that of the conventional casted specimens. It was also noted that the layering of the printed test specimens had no influence on the crack pattern and the cracks developed independently from the printed filaments, which indicated a very good bond between the printed concrete layers.

![Figure: Process design and preliminary tests of the 3D-printed reinforced concrete structure:](image)

\[\text{Figure: Process design and preliminary tests of the 3D-printed reinforced concrete structure: (2) innovative AMoRC method for an additive manufacture process of concrete extrusion and simultaneously stud-welding reinforcement; (b) pull-out test for characterizing the bond between reinforcement and printed concrete; (c) testing results of 4-point bending test for printed reinforced concrete beams.}\]
New Design Possibilities and their CO₂ Footprint – An Outlook to the Future

Jana Gerta Backes, Marzia Traverso

Motivation

How to build in more environmentally sustainable manner? This issue is increasingly coming to the fore in construction sector, which is responsible for a relevant share of resource depletion, solid waste and Greenhouse Gas (GHG) emissions. Materials like fibre-reinforced concrete, as e.g. carbon reinforced concrete (CRC), with its potential of material saving are important to improve the sustainability performance of buildings – but does it make CRC more environmentally sustainable than steel reinforced concrete (SRC)? This research aims to assess and compare the environmental impact of material and production scenarios of a CRC with a respective SRC double wall.

Methodology

With growing global awareness and importance of sustainability, there is increasing interest in the development of methods that contribute to a better understanding of the different impacts a building has in its life cycle. In this study, the focus is only on the environmental dimensions of a Life Cycle Sustainability Assessment (LCSA): the Life Cycle Assessment (LCA) of reinforced concrete. LCA identifies, analyses, and evaluates all impacts that a product, service – or building – has on the environment during its life cycle, starting from resource extraction up to the end of life (EoL). The assessment (LCA) is standardized according to ISO 14040 and ISO 14044, and in the building sector additionally by ISO 15686-5 and DIN EN 15804. The structure of LCA, as stated in the standards (ISO norms), in general and in this research in particular comprises four phases, named as: Goal and Scope, Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA), and Interpretation. The LCA is considered the best methodology for evaluating the environmental impacts caused by a product during its life cycle in the construction sector.

The used and assessed cradle-to-gate (=resource extraction, transport, production, up to building component) LCAs are based on primary and secondary data. The functional unit is a double wall and the reference flows are 1 m³ for concrete and 1 kg for fiber. CML-Methodology is used for Life Cycle Impact Assessment (LCIA) in the software GaBi® ts 10.0. A sensitivity analysis focuses on electricity grid-mixes, concrete mixes and steel production scenarios.
Results
The Global Warming Potential (GWP) – also known as CO₂-footprint, which is only one small specific aspect of a full LCA – ranges between 453 kg CO₂e and 754 kg CO₂e per CRC double wall. A comparable SRC double wall results in GWP emissions of 611 - 1,239 kg CO₂e. Even though less raw material is needed for CRC, it does not represent a clear advantage over SRC in terms of Global Warming Potential (GWP) (as 'best' SRC GWP: 611 kg CO₂e/double wall < ‘worst’ CRC GWP: 754 kg CO₂e/double wall) – focusing only cradle-to-gate and not considering possible different life times (e.g. steel reinforced concrete: 50 years, carbon reinforced concrete: 100 years). In a comparison, the production of steel (conventional vs. Electric Arc Furnace vs. recycled steel) and the choice of cement type are of decisive relevance. For concrete mixes, a mixture of Portland Cement and blast furnace slag (CEM III) is beneficial to pure Portland Cement (CEM I). For fiber production, the production itself mainly raises the GWP-emissions (>90% of fiber GWP); Styrene Butadiene Rubber (SBR) has an advantage over Epoxy Resin (EP) impregnation and the use of renewable energy could reduce emissions of fiber production up to 60%.

Conclusion: CRC requires less material (concrete cover) than SRC, however, exhibits comparable CO₂e to SRC – depending on the production process of steel. In the future, new construction concepts and raw fiber production and impregnation should be studied in detail. Since in terms of GWP emissions neither wall (CRC vs. SRC) clearly performs better, further indicators for a full LCA as well as the two other pillars of sustainability (economic and social, resulting in LCSA) must be focused on.
Thinking the Future – End-of-Life Life Cycle Assessment of Fibre Reinforced Concrete


The construction industry is an energy- and resource-intensive economic sector responsible for a great part of the global CO2-emissions, resource consumption, primary energy use and waste production. In this regard, fiber-reinforced concrete plays an important role in the improvement of the sustainability performance of construction works. Indeed, this material is an innovative alternative in the construction sector due to the significant material savings that can be achieved since no corrosion protection is required in comparison to conventional steel-reinforced concrete (SRC). To optimize the environmental performance of fiber-reinforced concrete, the definition of suitable End-of-Life (EoL) scenarios is key to minimizing environmental impacts and maximizing the implemented resources. Therefore, this work aims to identify the current, possible methods for recycling carbon- (CRC) and glass-fiber-reinforced concrete (GFRC) to enable environmental assessments of different EoL scenarios for comparison with the current practices for the EoL of traditional SRC.

Life Cycle Assessment (LCA) according to the ISO 14040/44 is an established method that allows the quantification of the environmental impacts occurring throughout the life cycle of products. Due to its life cycle and modular approaches, with LCA it is possible to determine the impacts caused on individual life cycle stages, such as the EoL and the recycling process. In particular, in the case of promising high-performance materials like CRC and GFRC that are expensive and often energy-intensive, the definition and assessment of possible EoL scenarios are of utmost importance to optimize the environmental performance of the materials. Following the LCA method and using secondary data from literature, all relevant energy and material inputs and outputs related to the EoL and recycling processes of CRC, GFRC and SRC are considered in our study.

Our study found that, for all types of fiber-reinforced concrete, the main driver of the impact category Global Warming Potential (GWP) is the energy consumption, which could improve through the implementation of renewable energy. Furthermore, for CRC, the transport to the stationary processing plant is a hotspot for GWP, highlighting the need for processing plants near the demolition sites to reduce transport distances. It is emphasized that although mechanical recycling of CRC shows a lower GWP
value, the inferior quality of the recycled carbon fibers and the resulting lower range of recycling options for new products are clear disadvantages compared to pyrolysis. Therefore, the importance of the closed material loop and the associated processing of the recycled carbon fibers into carbon reinforcement to maximize material savings is highlighted in this work. This relevance stems from the high energy input and the dependence on petroleum, a non-renewable raw material needed to produce carbon fibers from primary raw materials. Moreover, the fraction of concrete separated from the steel and the fibers can be successfully used as recycled concrete.

In the study, we show detailed comparisons between GFRC and SRC. The explicit consideration of the EoL of reinforced concrete is highly relevant, allowing an early determination of the environmental impact of the recycling processes and the definition of the most suitable EoL scenarios from an environmental perspective. Furthermore, the question of whether fiber-reinforced concrete has the potential to play a decisive role in improving the environmental performance of the built environment is addressed.
Preserving the natural environment puts a growing pressure on the built environment, transforming the linear economy into a circular economy (CE) appears to be a promising opportunity to reduce environmental impact and resource depletion. As the construction industry is the most resource intensive industry with millions of tons of raw material and waste produced each year, CE offers alternative strategies to the current linear economy. However, the transition towards a CE requires more knowledge and information especially about mineral material, their waste and energy streams as they have the highest shares of consumed resources. Since a building is a conglomerate of building products where all resource streams come together, the entire life span of each product needs to be considered. In this regard, building planners have a strategic position in implementing circularity aspects and managing information flow within the design process of a building. While selecting recycled or reused products and designing demountable connections, planners have a substantial impact on the future material flow. On the one hand, planners are confronted with an increasing amount of information about products and how they should be constructed, on the other to a lack of experience and knowledge while implementing circularity into practice. Besides, essential information about products gets lost during a life cycle of a building. Especially during design and construction phase, information errors or their absence cause misleading communication between stakeholders. Consequently, a lack of data leads to a higher workload and lower quality of material flows. Therefore, the description of essential qualitative and quantitative requirements of information during the entire design process and predefined exchange points of information are essential for closing material flow circles. Only if all relevant information about products is defined, documented and exchanged, material streams can be managed transparently, efficiently and circular. Especially during design phase physical properties, judicial and organizational information regarding circularity aspects become important as they influence the product selection and construction process of planners. For example, by knowing the key information about a products circularity potential planners have the possibility to make the right decision during product selection. By delivering the right information about a product or design method at a certain time, planners’ decision can be influenced and the design process therefore steered according to circularity. An in-
tegral information delivery model can distribute all relevant information about for example building products and construction methods to planners and their collaborators. This model has potential to document and deliver information, hence to guarantee a successful work-, information and material flow.

First, relevant information that influence a circular material flow, this research aims to provide essential product properties, judicial and organizational information that effect a circular material flow of mineral building products based on literature review need to be defined. Then, information exchange points are defined based on case study research and literature review. Based on this, information is captured and tasks for the following circular design scenarios are defined:

1 building with reused products,
2 building with recycling products,
3 design for disassembly.

Finally, all relevant information and design tasks according to circularity principles are implement in a model that was selected due to its applicability into digital tools.

This dissertation aims to link information about mineral building products regarding circular material flows to the design process of buildings in a coherent information flow model. The goal is to reliably deliver guidelines and standards for the use of mineral building products which decrease the use of natural resources, reduce emissions during production and close material flows. The model developed in this research offers a basic for future implementation into BIM as a holistic and collaborative working method that enables a circular design process.

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The main source of CO₂ emissions in cement production accounts for about 9% of all global CO₂ emissions. Replacing clinker in cement with industrial by-products as supplementary cementitious materials (SCM) is used to reduce CO₂ emissions. Conventional SCMs can be fly ashes or steel slags, for example, combustion residues generated by various different industrial processes. Frequently used as SCM are for example fly ashes of combustion of stone coal and ground granulated blast furnace slag. Both will be less available in the future, so new SCMs are needed. These could potentially be lignite fly ashes (LFA) or steel slags (StSl). In the EU about 10 million tons of carbon steel slags and in Germany, up to 5-10 Mt/y of LFA are produced yearly. In the past, both StSl and LFA have rarely been used as SCMs because of the phases of CaO and MgO and heavy metals. CaO and MgO in concrete can react with water to hydroxids which could cause a massive enhancement in the volume and could finally result in cracks in the concrete. Hazardous heavy metals could also be leached out of the binder containing the SCMs and infiltrate into the groundwater. A main objective of the CO₂TREAT project is to make StSl and LFA nonetheless usable as SCM.

For this purpose, the LFA and StSl will be beneficiated with CO₂ to achieve mineral carbonation. Such a reaction with CO₂ inhibits the reaction of free CaO and MgO with water to hydroxids by formation of calcium carbonates and reactive silica and alumina gel, respectively. The CO₂ beneficiation process reduces the high pH value of concrete which could result in the immobilization of hazardous substances of concern and, importantly, enables to sequester CO₂ in solid, stable mineral products [1].

Some StSl slow down the hardening process of the binder, reduce early age strength development and impact dimensional stability if left untreated. The abovementioned properties are of utmost importance for the usability of the cements. Recent research shows that those StSl properties could be improved by CO₂ treatment (CO₂ uptake levels 50-200 kg CO₂/t steel slag) [2].

A limited fraction of LFA can be used as SCM for common cements. The carbonation of lignite fly ashes for beneficiation purposes and their subsequent utilization as binder has not been in the focus of research at present, therefore only few publications about carbonation for
other purposes are available. Reported CO₂ uptake levels for calcareous fly ash up to 90 kg CO₂/t of fly ash, depending on the ash composition and the CO₂ treatment process conditions [3].

For the carbonation of the LFA and StSl a carbonation process shall be developed. Important parameters influencing carbonation kinetics and efficiency are the reaction temperature and CO₂ (partial) pressure. Higher temperatures generally increase mineral dissolution and conversion rates, yet lower the CO₂ solubility in water [4]. The CO₂TREAT project will initially test carbonation in the climatic chamber at controlled temperatures, relative humidities and CO₂ concentrations (semi-wet process). Increasing CO₂ pressure on the other hand enables to increase the amount of dissolved CO₂ gas and can be used to counteract the effect of temperature [5]. Also the liquid to solid ratio and the use of leaching agents (e.g. NaOH) are additional process parameters affecting carbonation efficiency [6]. Therefore, to further increase the carbonation efficiency, a pressure reactor (example in figure 1) is also to be built in which the StSl and LFA are carbonated in liquid water (wet process) under pressures up to 20 bar and 100 vol% CO₂. This process will also be optimized to achieve the highest possible CO₂ uptake levels.

The CO₂TREAT project is investigating new and innovative ways of reducing CO₂ emissions from the cement industry. In addition, possibilities are being developed and optimized to increase the environmental compatibility of secondary raw materials, so that overall a significant contribution is made to the sustainable development of the cement industry.

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Activated Bauxite Residues – Secondary Cementitious Materials for the Future

Michael Wenzel, Thomas Matschei

The development of sustainable concrete is necessary for fulfilling the SDGs and reducing the construction sector’s ecological footprint. The biggest contributor to a concrete’s environmental impact is the production of the contained cement. Usually Portland cement clinker, which is manufactured by the decomposition of >80 wt.% Limestone and roughly 20 wt.% shale or clay, contributes more than 50 wt.% to common cements. Therefore, the substitution of clinker with secondary cementitious materials (SCMs), like Blast furnace slags and Fly ashes, is one of the most effective tools to develop sustainable cements. However, the currently used SCMs will become scarce due to emergence of sustainable power generation and circular economy, which makes the utilization of new SCMs very important. In the last decades residues from various metallurgical and incineration processes have been systematically researched in regards to their suitability as SCM.

Bauxite residue is the inorganic, alkaline waste of the primary aluminum production and has been researched as a potential SCM for years. The ReActiv consortium plans to develop new cements containing at least 30 wt.% of Bauxite residues, which can be used for structural applications. Bayer residues are comparably inert in a cementitious system, mainly accelerating the first 48h of hydration reaction through their strong filler effect and high alkali content. Their composition contains 10-20 wt.% Al2O3, 2-10 wt.% SiO2 and 1-8 wt.% CaO, which is a foundation for the synthesis of a reactive material. The inherent problem of Bayer process residues is their high amount of stable crystal phases, i.e. Hematite Algoethite Gibbsite or Boehmite, which leads to a very low initial reactivity. To enhance the solubility of Al, Si and Ca species in the alkaline milieu of a cement paste several thermal treatments have been developed, to modify the BRs phase assemblage. In the ReActiv project co-calcined, clay containing BRs, vitrified BRs and amorphous slags are manufactured and analyzed. It could be proven that thermal activation, especially with the addition of clays and or other CaO/SiO2 sources, leads to reactive SCMs with more than 80 wt.% BR content.

The high alkali (up to 5 wt.% of the BR) and high iron contents lead to strong differences between BRs and other pozzolanic SCMs. This causes a differing durability performance, which needs to be investigated systematically,
since deteriorating reactions with e.g. CO₂ or chloride are usually limiting a building's lifetime. Most durability issues show a very slow progression, where the chemical deterioration process progresses unnoticed until the macroscopic damage i.e. spalling or cracking becomes visible. Due to their differing mineralogy Bauxite residues have to be investigated on a fundamental level to understand their influence on a cement's phase assembly, pore solution composition and pore network development.

RWTH Aachen University determines the long-term phase development and the changes inflicted by selected exposure scenarios, that lead to reaction driven deterioration mechanisms like Cl ingress, carbonation and sulfate attack. To complete the durability assessment long term strength development and Alkali-Silica-Reaction will be monitored to confirm the applicability of the researched systems. While the binder's phase composition is analyzed via QXRD/TGA, SEM-EDX the pore solution composition is determined using IC and ICP-OES. Finally, the porosity of the binders is described using 1H-NMR and Hg-porosimetry. This is done on ripe microstructures before and after exposure to the damaging reagents. The obtained results are compared with the results of thermodynamic modelling for the specific exposure scenarios. Diffusion experiments of chloride ions and CO₂ are carried out on paste samples to determine diffusion coefficients describing the transport properties of the binders. Finally, the determined microstructure related parameters will be compared to application related durability parameters, i.e. carbonation depth or sulfate driven expansion. These mortar and concrete scaled experiments will be carried out on selected representative systems. The research of RWTH Aachen University evaluates the durability performance of the binders developed by the ReActiv consortium and describes the effect Bauxite residues have on the microstructural development and deterioration of cements.

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The Built Urban as Potential and Challenge for Sustainability

The exorbitant amounts of energy invested in existing buildings and the bound socio-cultural values on the one hand, and the high consumption of materials and energies in new buildings on the other, render existing building stock into the most precious resource. It is therefore important to focus on built-as-resource solutions and to establish and profile them as an interdisciplinary field of research and practice. Planning and construction solutions must be developed to protect, redevelop and/or adapt existing buildings to significantly promote the socio-ecological transformation in our cities and regions. These solutions must be linked to historical, cultural, social and design practices, which enable and condition new forms of careful use, as well as taking engineering, economic and environmental science issues into account.

The confrontation with the existing settlements and urban fabrics is central here, as these require causally integrated, i.e. inter- and transdisciplinary approaches. Current debates point at the built and lived neighborhoods as the key arena, where measures for shaping sustainability and resilience transitions are assumed particularly effective. Built and lived neighborhoods comprise also multiple forms of cultural heritage, which constitute a valuable, yet often sidelined resource in resilience and sustainability debates. At the same time, however, the consideration of built and lived districts as urban heritage still poses manifold and important conceptual, methodological as well as practical (instrumental and procedural) challenges, how integrated transitions towards sustainability and resilience could be informed, initiated, and steered.

The session 'The Built Urban as Potential and Challenge for Sustainability' steps in here and proposes two foci for in-depth discussions in this broader field. In a first part, presenters and discussants will focus on the nexus of disaster resilience and urban heritage. Guiding this part is the question: how could conceptually capture and practically operationalize this nexus on the ground? The second part of the session will be dedicated to the challenge of resource management in built-up and lived farbrics. Guiding this final part of the session is the question: how do energetic and material resource link up to, or conflict with cultural and historic resources embodied in heritage?
Resilience and Cultural Heritage - Challenges for Local Governments and Interdisciplinary Experts

Christoph Klanten

The Cultural Heritage of European cities is threatened in its existence by various hazards. These include anthropogenic hazards such as fires, wars, as well as hazards originating from or intertwined with climate change (such as heavy rainfalls, droughts, or storms). At the same time, heritage constitutes a potential for resilience, e.g. through identity-building and socio-cultural bonding or as archive of historic knowledge. In consequence, there is the urgent need and benefit of taking-action towards risk management, which considers cultural heritage as protection good and resource. So far, however, integrated risk management at the interface of heritage management and disaster management are broadly missing in practice. Knowledge is missing at which points and phases of risk management key stakeholders and actors would need to (better) cooperate and how approaches of integrated risk management would look like in detail. Here the research project ‘Resilience and Cultural Heritage’ steps in: Its overall aim are guiding principles of integrated risk management which considers cultural heritage.

Conceptually, the research project draws on theories of risk management and governance. It builds on the so-called risk management cycle, differentiating the four management phases of prevention, preparation, response and recovery. In each phase, the understanding and evaluation of risks is essential in order to take informed actions. This conceptual approach is developed further by our research, which elaborates on the methodological bases of the three essentials steps that are understanding, evaluation and managing risks. Empirically, the research builds on the extensive analysis of relevant handbooks, projects and publications on hand. Moreover, European experts from the fields of heritage management and risk management were interviewed. An European expert workshop was held, focusing on the interdisciplinary discussions of challenges and risk management principles. In a further step, experts from German municipalities were interviewed and a planning simulation was conducted in order to test the guiding principles in a local context.

Against this background, the proposed presentation is going to outline the key challenges of heritage-sensitive risk management in more detail and to propose possible approaches for solution. In particular, the paper is highlighting three aspects:
- the challenge of and need for heritage-sensitive risk assessment methods. Here different approaches to risk assessment need to be understood and used by local actors. Different local data bases call for digitalization and integration, requiring (complete) digital exchange formats and human resources for the collection and interpretation of data. With regard to cultural heritage, novel approaches of vulnerability assessments need to be tested locally.

- the challenge of and needed awareness for the normative and thus political nature of risk management. Evaluation is an integral part of risk management, yet there is still fundamental need for sectoral/disciplinary as well as integrating/interdisciplinary exchange about goals, procedures and standards of judging and decision-making in risk management. The definition of rules for prioritization constitutes one of the key challenges in the heritage field.

- the challenge and need for communication management. In all four phases of risk management, communication is of particular importance for a proper risk management. Standardized procedures for action and communication as well as clearly distributed responsibilities are essential here, yet still widely missing so far. Here the involvement of local communities is an important issue that challenges also local heritage experts.

References
2 One of the 14 partnerships within the Urban Agenda of the EU deals with the topic of cultural heritage. Within the individual actions within the partnership, the research project ‘Resilience and Cultural Heritage’ presented here was initiated, which deals with integrated approaches in the field of Cultural Heritage and Risk Management
3 The Risk Management Cycle was established in the SHELTER research project and modified in the context of the current research project ‘Resilience and Cultural Heritage’. Cf.: https://shelter-project.com
4 SHELTER, ARCH, ProCultHer, ATLAS
5 The findings for experts at the European level will be summarised in the so-called Guidance Paper, which is to be published in the summer of 2022

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The disastrous and catastrophic flooding of parts of Western and Central Europe in 2021 has led to a profound transformation of Rhineland-Palatinate's Ahr valley, the survey, analysis, and assessment of which requires decisive action from various disciplines. In addition to a river landscape that has changed regarding its constituting elements and an infrastructure that has largely collapsed (and so far, only has been rebuilt provisionally), the towns and villages of the valley, often the embodiment of cultural traditions going back over many centuries and characterized by the immediate connection between local identity, street layout and formal relationship of its buildings to the river, have also suffered serious architectural losses. Against this background, a sustainable redesign of the cultural landscape of the Ahr valley can only succeed if it is grounded in a comprehensive study of its identity-forming features and in an assessment of their applicability within future interventions at the level of both landscape design and architecture. Research on these aspects therefore forms the central aim of the project Futur[AHR] at RWTH Aachen University's Chair of Architectural History.

Methodologically, the main tenet of the project lies in its practice-based approach, which is characterized by the involvement of students via taught research courses and by a constant exchange with the responsible authorities within the Ahr valley itself. In addition, a division into several interlinked project stages allows a step-by-step approximation both to the interventions into the landscape and to their consequences for future developments. An initial phase of the project, which began directly after the flood, in the autumn of 2021, was devoted to a survey of the changes to the local landscapes of the region Mittelahr: from Kreuzberg and Altenahr, to Dernau and Bad Neuenahr-Ahrweiler, we collected facts and personal impressions regarding the erosion of soil, the destruction of or damage to the building stock, and the consequences of the flood on local centres. The observations on site were then followed by a comprehensive study of the architectural history of the villages and towns, which revealed a tradition of settlements in the river valley that goes back over many centuries. Thus, the first phase resulted in a solid overview of the identity-defining features and characteristics of the villages.
On this basis, a second and still ongoing project phase, which is not only deepening and substantiating the research on the various local identities, but also providing design stimuli for the villages of Altenahr, Mayschoß, Rech and Dernau, has begun in the spring of 2022. Preliminary design concepts, which will later be elaborated on both an urbanist and an architectural level, provide far-reaching insights into the cultural, historical as well as the social structures of the villages. These insights will, in August 2022, be presented to the public in form of an exhibition.

The results so far illustrate the importance of an approach to the flooded areas that is grounded in architectural history and hold out the prospect of highly promising insights in the future. In general, the evidence of the flood’s aftermath in the region Mittelahr shows that the challenge of flood prevention can only be met by way of supraregional planning, which provides for sufficient retention basins along the upper course of the river. In the villages themselves, a parallel task lies in the development of settlement structures and construction methods that can cope resiliently with high-water events in the future.

In addressing these complex challenges, a careful observation and analysis of the architectural tradition of the specific sites can serve as a valuable design resource: this became apparent during the study of historical planning documents showing how medieval village centres – with their marketplaces and churches – were always situated either in considerable physical distance from the river or on the hillside and thus placed in flood-proof locations. This suggests the existence of historic and urbanist traditions adapted to floods and an awareness for flood-risk that have been undervalued in the recent past. The development of the village layouts clearly shows that in the Ahr valley the construction of buildings in proximity to the rivers and the sealing of their formerly wide beds only occurred in the last century and reflects an underestimation and an illusion of controllability with regard to flood events.

In addition to the perspective of urban history, the historic building stock also offers architectural solutions that could serve as a model for resilient building practices and thus enable sustainable growth in the Ahr valley. First among these is the so-called Gesindehaus (servants’ house) in Kreuzberg, located below Kreuzberg Castle in what is essentially dangerous proximity to the river, but in which a massive ground floor in the form of a vaulted cellar not only allowed the building to withstand the ‘floods of the century’ in 1804, 1910 and 2022, but also served to protect the valuable living quarters on the upper floors. Another such example can be found in the Etzhardgasse in Mayschoß, where a half-timbered house was again built on a massive stone base and was thus also able to protect the elevated floors from the masses of water.

Ultimately, the reconstruction and redesign of the Ahr valley thus represents a multilayered challenge that requires cooperation on a transregional political level and interdisciplinary communication aimed at achieving concrete results. In this context, cultural heritage and architectural legacy on site with its longstanding and identity-defining features represent a valuable source of knowledge for the rediscovery of resilient building practices and for future growth that is sustainable both culturally and ecologically.
With the enactment of the European Green Deal as a central component of European climate policy, the European Commission has set itself the goal of zero net emissions of greenhouse gases by 2050. The need to renovate the building stock for more resource and energy efficiency in building operation was recognized and a strategy for a renovation wave was published. (European Commission, 2021) Nevertheless, the energy bound in the building fabric is often regarded as being of lesser importance. Therefore, legislative regulation systems should be complemented by the inclusion of embodied energy. The taxonomy as part of the European Green Deal is intended to guide future financial flows towards sustainable investments by setting science-based thresholds in relation to the sustainability performance of buildings. It classifies the building sector into two relevant categories: new construction and refurbishment. The latter is to be examined more closely in the research. Whether buildings qualify as sustainable investments will be decided with the Sustainable Finance Disclosure Regulation (SFDR), which makes data transparency on environmentally relevant data mandatory. Financial market participants should thus receive information on the environmental performance of an asset to be able to better assess investment risks. However, since publication of the taxonomy in 2020 the dynamic state of the regulations has led to uncertainty among many stakeholders in the construction and real estate industries, making broad implementation difficult. Additionally, with environmentally relevant data becoming a basis for assessments, decision-making processes and interfaces between the stakeholders are changing. Therefore, it requires research that models and analyzes ideal processes. Against this background, to achieve the climate neutrality targeted by the EU by 2050, it is becoming increasingly important to modify legislative regulatory systems to include ecological considerations in the demolition of existing buildings.

At present, the interdependencies between the political framework, the current funding landscape and the insufficient data on the building stock lead to greater hurdles for renovations than for new constructions. With the implementation of the current EU taxonomy, this could lead to a competitive advantage for new construction projects, as the sustainability performance of the latter is easier to prove under the SFDR. The latter is associated with the loss of embodied energy and increased energy consumption.
in the production of new buildings. Consequently, the prevention of stranded assets and the greatest possible preservation of the building fabric should be in the focus. Although regulatory systems in the EU taxonomy are aimed at managing financial flows and thus primarily affect financial companies, they also have a direct impact on the construction industry due to the close ties between the financial sector and the real estate industry. The research therefore intends to develop basic knowledge on the interdependencies of the real estate industry and planners in the context of legislative regulatory systems for climate protection measures. Incorporating the German building law as well as the funding landscape, the research project shall contribute to a better implementation of the EU taxonomy, in accordance with the sustainability goals of the EU. The knowledge gained will be used for a holistic evaluation of sustainable investments in the building sector and is thus relevant for both the construction industry and the real estate sector.

The aim of the research is to develop a hypothetical process model that shows approaches for qualifying the ecological added value for the preservation of existing buildings in the framework of the EU taxonomy.

The model will be the basis for a decision matrix that incorporates and prioritizes the embodied energy of the building stock. Such a matrix aims to rank beforehand defined criteria and ideally shows a spectrum of alternative actions that can be preferred to demolition. After the development of the process model, an application of the decision matrix is intended with the aim of validation by different stakeholder groups. Through a subsequent evaluation of the statements, an ideal process of a decision-making process is to be described. The intended decision matrix could then serve planners as an instrument for planning taxonomy-compliant projects and financial market participants by showing a spectrum of possible measures for maintaining the value of existing buildings while taking embodied energy into account, thus reducing the risk of stranded assets.
Superlocal Circular Building Project
Marc Maurer, Nicole Maurer

SUPERLOCAL is an innovative project, in which four apartment blocks and their surroundings were transformed in a circular way – resulting into a new healthy and sustainable living environment. The project was initiated by social housing fund HEEMwonen and the municipality of Kerkrade. The project owners formulated the joint goal of building 125 social housing units with the exceptional ambition to use only material harvested from the demolition of 400 apartments on location.

The 400 dwellings were developed in 1967. Kerkrade and Bleijerheide flourished during this time. This went well for 25 years. After that, several social changes took place. Families shrank, single parenting increased, and unemployment gained due to the closing of the local mining industry. In addition, the architectural condition of the flats deteriorated considerably. Demolition was a responsible choice, partly because there was no population growth at all in Kerkrade. For the first time there was a serious demographic shrinkage and therefore homes had to be withdrawn from the market.

However, the social housing fund had developed the ambition to recycle as many existing onsite values as possible (not only the materials). Maurer United Architects developed the place branding name SUPERLOCAL along with the circular process triangle for the project. Based on a multiannual phasing, the initiative was set in 2014 and the completion in 2022. Instead of the usual ‘fast-more-global’, a ‘slow-less-local’ philosophy was introduced in this project. A thorough inventory of all the values in the area was made. The former – and the at that time partly remaining residents – were interviewed. This made an evaluation of the archetype Dutch ‘gallerij-flat’ and its functioning over the period of the past 50 years possible. But many other indexations were also made, such as the construction, materials, landscape, floor plans and more. All these findings had a substantial influence in the developing of the new plans.

Circular demolition and construction are becoming increasingly important. In the long run, it will become impossible to keep extracting new raw materials from the planet. The SUPERLOCAL process was set up to conduct experiments in the field of circular building. For example, concrete elements from the existing flat were sawn and relocated.
to investigate whether they could be reused. As an experiment and self-explaining statement, a complete pavilion was built from only onsite harvested materials. In addition, the contractor managed to regrind concrete that was released from the demolition. It was mixed onsite and used for the construction of new infrastructure and homes.

All the knowledge gained from the SUPERLOCAL project was used to realize a new social housing block on site. Different types of housing and amenities were integrated, making a mix of resident target groups possible within the apartment block. Different types of circular building techniques were applied. Half of the block was not demolished but stripped to its concrete structure. This concrete was reused as constructional structure for 50 dwellings. Secondly, concrete from the demolished flats was reused according to the principle of regrinding. And thirdly, when applying new materials, the architectural details were constructed in such a way that they would be reversible in the future. A fine example is the dry brick façade at the ground floor of the block. In this part of the building, social functions were realized for community activities.

Today, the 114 apartments are in use. Residents were screened on their personal interest in sustainability concepts. A new SUPERLOCAL community has risen, mainly as a result of the communication campaign that was incorporated in the ‘slow-less-local’ approach during the years.

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Living Lab for the Energy Transition in the Building Sector

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In Germany, the building sector is responsible for nearly 34.4% of the annual primary energy demand, which translates to 25.9% of overall CO2 emissions in the country. To achieve the Paris climate agreement goals, the consumption of fossil fuels needs to be strictly reduced. In addition to the energy refurbishment of the building stock, the reduction of fossil fuel consumption in the building sector can be realized by using renewable energy sources and an intelligent interlinking of energy producers, energy storage devices and consumers. The project SmartQuart - a living lab of the energy transition - was launched to study the potential of climate-neutral energy supply. The project brings together stakeholders of city districts, like building design companies, residents, and energy providers, with technology and concept developers from industry and academia. Through the facilitated collaboration, the interconnectivity between districts should be leveraged for energy savings and reducing greenhouse gas emissions.

A key step toward achieving the climate goals is the holistic consideration of the power, heating, and mobility sectors. Specifically, linking each sector over district borders utilizes synergy and complementary effects on an urban level. Within SmartQuart, this linkage is demonstrated in a living lab to show that interacting districts are already technologically and economically viable today. The municipalities participating in the living lab are located in the cities of Essen and Bedburg in North Rhine-Westphalia and Kaisersesch in Rhineland-Palatinate. Essen represents an urban district with a high building density. In highly populated urban areas, usually, the energy demand exceeds the local production. Therefore, the district's energy supply by photovoltaics is supplemented by electrical energy generated in the other districts. The urban area consists of existing buildings that were modeled and integrated into a digital urban district. To assist the transferability of the project results, the selected buildings in the Essen district reflect the typical mix of facilities and building usages of other German cities.

The district in Bedburg is a residential area. The energy-optimized housing estate is currently being built on a former surface mine. As a resource protection community, all buildings are planned to reduce resource and energy demand as well as CO2 emissions over the whole life cycle.
of the buildings. Provided with emission-free power from the adjacent wind turbine park and communal photovoltaics, the area with provincial building density can be the energy source for the other two districts in times of low internal energy usage. Furthermore, an innovative multilayered heating solution is implemented, which incorporates a low-exergy district heating network with both central and decentral heat pumps as well as thermal and electrical energy storages.

Kaisersesch demonstrates how rural living and industry areas realize hydrogen technologies and sector coupling. Industry increases the energy demand of the rural area up to the order of a small town.

Renewable sources are supposed to cover the energy demand. Additionally, green power will feed a power-to-gas plant to produce green hydrogen. Distributed by a local hydrogen grid, this energy resource is used for public transport or heating buildings. Therefore, the buildings are fitted with modern hydrogen fuel cell technology installed alongside the existing heat pumps.

The three described districts are chosen for their complementary aspects and represent the district structure in Germany. The energy consumption is determined on a building-by-building basis through monitoring within all three districts. The gathered data is used to extrapolate demand profiles on an urban scope. Furthermore, living lab consumption is required to validate the digital models and demand simulations. To reduce greenhouse gas emissions and increase the usage of volatile renewable power, optimal control of the energy systems is imperative. Energy management systems guarantee optimal energy system operation within a district. The SmartQuart-Hub acts as a superior energy management system and facilitates the optimal energy flow amongst the districts. During the span of SmartQuart, multiple approaches for the SmartQuart-Hub will be tested. Furthermore, the hierarchical control concept will be quantifiably evaluated regarding energy, cost, and emissions reduction.

Therefore, SmartQuart develops a modular blueprint of decentral energy and heat transition to transpose the examined compound approach to other regions and districts.
CLIMATE CHANGE ADAPTATION
Organizers: Thomas Wintgens, Frank Kemper, Andreas Witte

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The consequences of climate change can be observed worldwide in similar patterns: slower variations of weather events cause more prolonged phases of rain and heat, leading to more frequent occurrences of flooding and drought, respectively. Extreme events of precipitation, windstorms, and heat waves tend to occur with shorter return periods and locally with higher amplitudes. In short: The natural equilibrium and the ability to balance weather phenomena is tending more and more to reaching and exceeding its limits.

For instance, in July 2021, a flood disaster occurred in West Germany that also hit and damaged the region of RWTH Aachen University. The flooding incident was caused and aggravated by multiple factors: prolonged and intense heavy rain, topography, soil saturation and soil conditions in the areas of rainfall – but also by interventions in natural river courses and peripheral buildings. Unexpectedly, buildings that were supposed to offer protection were located in flooded areas. More than 180 citizens lost their lives. Besides extreme precipitation, severe wind events can also cause significant damage to the built environment and put humans at risk. In this year, a tornado has hit the city of Paderborn with 43 people injured.

While it is still not clear to what extent such severe events might increase in frequency or severeness due to climate change – it is likely that both features will be affected in an unfavourable way in the future and the mentioned events painfully demonstrate the possible impact of climate change to us. Therefore, climate change adaptation is necessarily a key topic for the planning of our future living environment and infrastructure. The construction sector is of relevance, as it contributes significantly to carbon emissions (and thus offers potential for savings), but also promises to provide opportunities for adaptation and solutions to gain resilience. Both aspects are closely interwoven with social, economic, and cultural issues. Due to this complexity, the topic demands us to bring together knowledge from different disciplines to stimulate new scientific interactions.

The threat of natural disasters, the resilience of the built infrastructure, the weighing up of security requirements and life risks in the areas of society, economy and culture should therefore also be included for future planning processes and receive more awareness amongst decision makers.

In two sessions, we invite participants to discuss significant questions in the context of climate change adaption. At the end of the second session, further individual exchange is enabled by round table exchanges to prepare the session findings for the final plenary presentation.

1 Technical adaptions to climate change. Enhancement of safety, constructions, and infrastructures to protect the living environment
   - How can we predict and guarantee structural and infrastructural safety in the future?
   - How do we need to adapt our built environment to climate change tendencies?
   - How can reliable infrastructure consider reduced carbon emission goals?

2 Implementation and transformation. Collaborative and interdisciplinary approach to implement needed change processes
   - How do we need to modify planning processes?
   - How can we moderate transformation processes and gain support of politics and society?
   - How do we need to develop higher education to raise the right experts?
DeepWarn: Multimodal Flood Forecasting System Using Deep Learning

Julian Hofmann\textsuperscript{a,b}, Sascha Welten\textsuperscript{c}, Elena Klopries\textsuperscript{a}, Thomas Wintgens\textsuperscript{b}, Holger Schüttrumpf\textsuperscript{a}, Stefan Decker\textsuperscript{c}

Recent flash flood events have highlighted the relevance of countermeasures in saving human lives and preventing property damage. In particular, urban populations are at high risk due to the threats posed by pluvial flash floods in urban areas which form rapidly and have a short forecasting time. Since heavy rainfall events can be forecasted with relatively short lead times, the subsequent prediction of urban flooding is still a significant challenge. This challenge is especially present when predicting the spatiotemporal flood processes, as slight differences in initial rainfall conditions may lead to different rainfall forecasts, e.g., spatial and temporal precipitation fields. Despite their high accuracy and success in flood modeling applications, two-dimensional (2D) flood models have long computation times and therefore are of limited use for real-time modeling. Consequently, the few warning systems in use cannot meet the requirements of an effective early warning against urban flash floods. As a result, the flood dynamics cannot be captured in the necessary detail, or the computing time of the models makes real-time deployment impossible.

Therefore, the project DeepWarn aims to develop a deep learning (DL)-based forecasting system for urban flash floods which should increase the ability to react and act in urban areas. For this purpose, synthetic heavy rainfall scenarios are generated by machine learning-supported analyses of the weather databases of the German Weather Service DWD (DeepGenerator). Subsequently, flood processes are simulated hydrodynamically and highly parallelized with the help of 2D flood models. Subsequently, the generated data sets serve as training input for another DL model (floodGAN). floodGAN overcomes the computational time problem of high-resolution flood simulations and is coupled with an innovative nowcasting system (DeepNowcast) in real-time.

DeepWarn addresses the aforementioned computational time problem by utilizing DL to learn the spatio-temporal correlation between heavy rainfall and the numerically calculated flood events. The fully trained DeepFlood model is then able to translate radar images into flooding scenarios in real time and with minimal computational effort. Based on the integrated model system, precise and city-wide flood forecasts can be issued and coupled with decision support systems for fast an intelligent counter-
measures. In addition, the forecasts can be processed and visualized with web services so that a (possibly open-source) reuse of the individual components is possible.

The project is part of a longer-term cooperation intention of IWW, ISA, and DBIS. It supports the intensified networking of the research area Water and Environment with Simulation and Production Technology, specifically the profile areas Information & Communication Technology (ICT) (RWTH Strategy 2030). As a result, the proposed project strengthens the sustainability strategy of RWTH Aachen University and, on the other hand, the interdisciplinary networking of water research at RWTH within the framework of the Project House Water. Furthermore, the results, i.e., the concept and the method of DeepWarn and first exemplary implementations (demonstrator) in the planned study area Aachen, shall develop into the starting point of comprehensive research activities around the interdisciplinary cross-domain design of DeepWarn. The final goal of the initially engineering-based activities is to provide users in the various sectors of society with new tools for more effective safety management in the face of heavy rainfall and urban flash flood events.

Figure: Framework and work packages of DeepWarn: DeepGenerator and DeepNowcast are trained once centrally and once decentrally. The results of the models are then used by the hydrodynamic model and DeepFlood. Conceptually, a web service is developed which accesses the models in the backend (dashed).
Droughts and Floods: Approaches for a Resilient Water Management in Times of Climate Change

Jens Reinert\textsuperscript{a}, Lisa Burghardt\textsuperscript{b}, Julian Hofmann\textsuperscript{c}, Felix Steudtner\textsuperscript{d}, Bastian Winkels\textsuperscript{e}, Holger Schüttrumpf\textsuperscript{f}

Due to changing climatic conditions, extreme weather events are becoming more frequent, including prolonged drought, heavy rainfall events, and resulting floods. These challenges must be met in an appropriate manner. Extreme situations challenge several areas and disciplines equally, making interdisciplinary approaches necessary. Recent events such as the July 2021 flood event in Germany have impressively shown that thinking beyond existing approaches is needed. Therefore, the following will outline approaches that overlap with other scientific fields in order to promote an exchange on the topics of droughts and floods occurring in the built and lived environment.

Droughts are expected to increase in frequency and intensity due to climate change. Regions that have little previous experience with droughts may soon find themselves confronted with impacts such as decreases in hydro-power production, extensive damage to aquatic ecosystems, and, in extreme cases, impacts on economic and social sectors, such as shortages of drinking water supply. Yet, management plans and tools for effective drought management are lacking or non-existent. BMBF-DryRivers aims to provide a tool that can support actors throughout low-flow-management, from problem recognition over quantitative evaluation of rivers through accurate modeling to the implementation of long-term mitigation strategies. The project also involves the development of an individual risk-communication and -management strategy for the Rur river basin.

In addition to droughts, there is the opposite phenomenon of spontaneous heavy rainfall and continuous rainfall. Recent events like the flooding in July 2021 have highlighted the vulnerability of our cities and their infrastructure to heavy rainfall events and flash floods caused thereby. BMBF-KAHR accompanies the (re)construction process and makes a scientific contribution to improve flood risk management after the flood disaster to rebuild affected regions in a more resilient way. In selected focus areas, concrete flood protection and spatial planning measures will be evaluated in the course of reconstruction and affected stakeholders in the areas will be advised. One of the topics that will be addressed in the course of the project is the design of flood-proof infrastructure, for example, to ensure the functionality of bridges before, during, and after flood events.
Beneath technical options for overcoming extreme weather events, non-technical options have to be considered as well. Particularly, extreme flood events require early awareness of disaster situations and general risk awareness among those in positions of responsibility and the general population. To reach these aims it is necessary to develop guidelines for improved crisis management and communication in the event of flooding. This ranges from the prediction of hazards, warnings and alerting to operation, and the accomplishment of damage. The main objective of the BMBF-HoWas2021 project is to evaluate the actions of civil protection actors and crisis communication during the flood crisis in July 2021 both at the level of the authorities and the affected population. Based on meteorological, hydrological, and hydraulic data, the analysis of flood marks, social media information, and onsite inspections conclusions and recommendations for future flooding events will be derived.

Therefore, it should be a goal to enhance precipitation forecasts through point flood warnings and transmission of risk-based warnings to navigation devices. For an effective, timely warning and response to extreme weather events, detailed forecasts of both the location and timing of floods and their immediate impacts are therefore of central importance. To achieve an improved forecast process the mFund-ISRV project aims to develop an AI-supported and combined real-time forecasting system for heavy rain and traffic. Up to now, warnings of heavy rainfall have been based primarily on rainfall forecasts or water-based monitoring systems. The project aims to expand previous precipitation forecasts with punctual flood warnings and to transfer these advanced warnings to navigation devices.

The challenges of developing climate-appropriate adaptations and measures can be found worldwide. Thus, the DAAD-ABCD-Center conducts interdisciplinary research on water security, water resource management, safe water supply, and water treatment in order to build ecosystem resilience and nature-based adaptation measures. Especially in the international context, transfer strategies including traditional knowledge, local economies, and social acceptance have to be included. Furthermore, the topics and projects mentioned have various interfaces in neighboring and not directly related scientific fields. Therefore, a particularly intensive exchange should take place here in order to address the issues of drought and heavy rainfall as phenomena of a changing climate with the help of effective adaptation strategies.

Figure: Resilient Water Management

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Green-Blue Streets: Towards Transdisciplinary Design–Teaching for Water Sensitive Cities

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Motivation and objectives
With climate change, the number and intensity of extreme weather events will increase. Cities with their high population and infrastructure density are especially vulnerable to these events. In this situation, green and blue infrastructure (GBI) play an increasingly important role. When it comes to water, this means that public and private open spaces should both buffer heavy rainfall events and remain attractive during prolonged periods of drought. Beyond the integration of GBI in the planning of new urban areas the water sensitive transformation of the existing city becomes urgent to prevent catastrophic events while maintaining the current functions for mobility in a new way. To this end, the German government’s 2021 national water strategy envisages living laboratories for testing concepts such as the sponge city and multifunctional use of space during heavy rainfall [1]. The living lab approach for water sensitive cities requires transdisciplinary cooperation which not only includes the perspectives of experts from different disciplines dealing with water and urban planning, but also of practitioners and citizens. Designing scenarios for a water sensitive urban transformation can be an important step towards integrating different infrastructure solutions in a systemic approach to water management, adapting them to a specific context and communicating possible improvements with a larger public. For achieving this transformation we need to educate experts who can integrate and communicate their knowledge in such design approaches.

The main methods
The Institute of Landscape Architecture is taking first steps towards this since 2021 with the green-blue streets design studio series which is being organized in cooperation with the initiative lala.ruhr devoted to promoting green and blue infrastructure in the Ruhr region and RWTH Aachen University’s Faculty of Civil Engineering, namely the Institute of Urban and Transport Planning and the Chair of Urban Water Management. In summer 2021, 18 students of architecture and urban planning have elaborated master plans and detailed designs for transforming the Essen-Altendorf neighbourhood at Lake Niederfeld into a green-blue system incorporating buildings, green open spaces and streets. While in this first iteration, the transdisciplinary approach was limited to guest lectures from the Faculty of Civil Engineering and guest critics...
by representatives of lala.ruhr and the City of Essen, the second iteration in summer 2022, now dealing with the neighbourhood of Gelsenkirchen-Ückendorf, is being taught with 19 students from architecture, urban planning and transport engineering and mobility and mentors from both faculties. The transdisciplinary interaction with lala.ruhr and the neighbourhood could as well be deepened, partly also thanks to the reduction of pandemic containment measures.

The main outcomes
The studio in 2021 has yielded 9 design proposals of high quality and with a large variety of planning and design solutions. The students submitted projects which differ in their approaches to rethinking mobility within the neighbourhood and in the degree water management in public spaces is made visible and interactive to and with the users. The results have been presented on the lala.ruhr platform and in an event with 20 representatives of the city administration and local politics in Essen and obtained high interest and positive feedback. Possibilities for taking up the systemic planning approach to water, greenspace and mobility and the short-term implementation of elements from the design proposals are currently being discussed at the City of Essen.

Important ‘take-home’ messages
The approach of a design assignment for an urgent societal problem and within a transdisciplinary context, although the design studio had been started even before the catastrophic rain and flood events of June and July 2021, has proven to be highly motivational for the students. Moreover, compared to experiences from other design studios with more general assignments on urban planning, the necessity of systemic thinking for water sensitive cities has increased the quality of the design proposals. When deepening the transdisciplinary approach in 2022 however it becomes clear that for cooperation between different RWTH faculties dealing with the Built and Lived Environment, some curricula need to become more flexible.

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Strategic Decision Support for Municipal Climate Change Adaptation in the City of Duisburg

Mark Braun, Eleni Teneketzis, Vivien Heider, Eleonore Hövel

The effects of climate change have been more and more evident in Germany during the recent years. Along with the increased frequency of small-scale rainfall extremes and the resulting floods, prolonged periods of drought, for example the summer of 2018, have been also occurring resulting into low water levels in rivers and reservoirs. The German population and economy are insufficiently prepared for the impacts of both extremes. In order for political stakeholders to make investment decisions for climate change adaptation measures, an objective basis for decision-making is necessary.

The aim of the research project R2K-Klim+ is the development of a tool that will provide stakeholders in local politics with objective and quantifiable decision-making support for investments regarding climate change adaptation measures. During the three-year project period, the consortium will carry out a vulnerability analysis concerning important sectors with respect to certain climate change impacts for the pilot region of the city of Duisburg. Specific climate impacts considered for the city of Duisburg are: high and low water in the Rhine, heavy rainfall events, drought and urban heat. In addition to the micro-scale analysis of the city of Duisburg, the effects of climate change on a regional level (macro-scale) will be also investigated, in this case the Rhine catchment area. The joint project is funded by the Federal Ministry of Education and Research (BMBF) as part of the ‘RegIKlim – Regional Information on Climate Action’ directive and is supported by the German Aerospace Centre (DLR).

In order to address the effects of climate change and to identify the potential correlation and synergies between adaptation measures and their impact on different climate extremes, the consortium is approaching the problem from a wider perspective. The FiW is in charge of the project coordination and is contributing to the project at the topics of flood (fluvial) modelling, flood damage assessment and the development of a climate change adaptation measure concept. Along with the FiW, which, as a transfer institute, pursues the transmission from research into practical application, five other partners are involved in the research project. The city of Duisburg is responsible for defining the requirements from the municipality’s and end user’s point of view as well as for evaluating the feasibility of the target product. The Research Institute for
Ecosystem Analysis and Assessment at RWTH Aachen University (gaiac) is contributing in the topics of urban ecology for the city of Duisburg and ecological modelling for the Rhine catchment area. The engineering company Dr. Siekmann und Partner mbH is involved in the topics of hydrological modelling of the Rhine catchment area and the development of a climate change adaptation measure concept. The Rhine-Ruhr-Institute for Social Research and Policy Advice at the University of Duisburg-Essen (RISP) has taken over the analysis of the socio-ecological impacts of climate change on a regional and a municipal level. The development and programming of the decision support tool will be carried out by geomer GmbH. geomer GmbH is also responsible for the urban (pluvial) flooding modelling. With respect to the fields of transport and logistics, two additional partners are involved in the project: the Prognos AG, responsible for transport modelling on the Rhine, and the Centre for Logistics and Transport at the University of Duisburg-Essen (ZLV) which analyses especially the consequences for the port of Duisburg and traffic on the micro-scale.

At the current phase of the project implementation, the following initial general insights have already been obtained:

- In the future, adaptation to climate change will be an integral part of the municipal planning processes.

- In order to determine the climate change adaptation needs of a municipality, macro-scale challenges should be transferred to the local level (micro-scale).

- Potential climate change adaptation measures have to be analysed in a way that they can provide quantifiable information regarding their economic, ecological and social impacts to decision-makers.

- Analysis of climate change as well as urban development scenarios are urgently recommended.

- In order to achieve a holistic assessment, stakeholders should be able to contribute with insights regarding local requirements to the assessment methodology.

A further goal of the project is to achieve its transferability to other model regions. To this end, there is a regular exchange with the other projects of the RegIKlim directive in the context of working groups of the accompanying research.

The current project phase runs until May 2023. You can find out about the progress of the project and current reports on the project homepage: www.r2k-klim.net
Climate Resilience of Urban Infrastructures in Central Europe

Mirko Friehe, Frank Kemper, Michael Leuchner

For the structural design of buildings and infrastructure, the safety requirements are based on a specific return period and combination of climatic influences. For this reason, historical data of weather observations were considered and analyzed with respect to expected extremes, assuming a consistent distribution of weather effects [1]. However, it is difficult to predict which consequences were caused in detail due to climate change and global warming. Most likely, the tendency towards extreme weather events will increase (due to the higher amount of energy in the earth system) and the duration of regional extreme events will be extended (due to the decelerated jet stream). In consequence, the impact of precipitation and wind as climatic factors for civil structures tend to become more severe – at least they will become more uncertain from today’s perspective.

As a potential consequence of climate change, it can be expected that the impact of large-scale weather-conditions will be influenced to a more significant amount by local extreme events like precipitation with singular convective cells (10–100 km) [2], thunderstorms (3–10 km), or tornados (0.05-1km). The reliable prediction of local events based on conventional methods (considering observation data) is limited due to the spatial distance between the meteorological observation stations (average distance 15km in Germany) and the ‘overall statistics’ in the wind zone maps which are used for the structural design [1].

Thus, the design rules for civil structures also need to consider the risk of local events, e.g., based on historical records of satellite observations (s. Fig. 1, left). A persistent analysis of a database, which is merged by observation stations and satellite data could significantly enhance the reliability level of the extreme value prediction. Furthermore, extremes can be formulated with different levels of uncertainty, considering a distinction between large-scale synoptic events (with higher reliability) and small-scale events (with less reliability).

Small-scale extreme events have a low frequency of occurrence for a specific location. However, they are accompanied by a significant damage capability. Currently, the infrastructure and the built environment is not designed for such events, as they are not included in the underlying statistical data base. For instance, in Central Europe there exists no design rules with respect to tornado...
events, although there are 300 of such severe events per year [3] (s. Fig. 1, right). The present safety assessment considers synoptic extreme storms (gust speeds up to 150 km/h), while already tornados of level F1 (according to the Fujita scale) exceed this level of wind speed (F1: 118-180 km/h / F2: 181-253 km/h / F3: 254–332 km/h).

Like in other world regions, a discussion about the aimed level of structural safety is necessary as it is obviously not reasonable to design all buildings and infrastructure to withstand the worst-case scenario and its enormous wind-induced forces and those induced by flying debris. Much more important is an early warning system which allows residents to escape the zones with a current tornado risk in due time. However, it is recommended to assess the safety level of significant infrastructure and to ensure a higher level of protection, e.g., for hospitals and other important parts of primary infrastructure. For this reason, it is meaningful to investigate the actual level of safety considering local effects as described before and to allow for specific design rules [4-6]. At least, guidelines for a potentially safer usage of existing infrastructure should be clearly formulated and distributed as a precautionary measure.

The resilience of buildings and infrastructure is principally achievable for large-scale weather events, assuming slow trends of extremes due to climate changes processes. For small-scale events there is no consideration so far and we recommend their consideration based on satellite observations to enrich the data base. Doing so, the design requirements would drastically increase. While this is not meaningful for the vast majority of civil structures, a discussion about the public safety requirements, which buildings need to be safe in local extreme events, seems necessary in this context.

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Green Roofs and Walls: Ideas for Interdisciplinary Living Lab Teaching
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Motivation and objectives
Climate change is a dominant issue for politics and society. Especially the existing building stock is an enormous potential and challenge in climate change adaptation (see Figure 1). Systems for building greening do exist, but, especially for facades, are characterized by a massive construction, are applicable only on the 2-dimensional facade area not reaching into the surrounding periphery (see Figure 2), and imply high costs. Through an interdisciplinary approach as part of the RWTH Aachen University sustainability strategy we intend to make RWTH’s existing building stock a Living Lab for greening buildings. In order to create a sustainable effect on the microclimate and biodiversity with the existing building stock as well as to implement CO\textsubscript{2} storage, aesthetic design, noise and water protection researchers and students from the Institute für Textiltechnik (ITA) and the Institute of Landscape Architecture (LA) of RWTH Aachen University will develop the prototype of a greening kit for existing buildings. An innovative approach is the greening of the entire available three-dimensional space between building facades and streets or courtyards as a vertical garden to multiply the effects described above. The central idea is to use lightweight, textile-based greening systems that span green zones on building walls. Especially for existing buildings, including those with historic facades, the targeted systems are highly relevant: because the great potential of greening with lightweight textile structures lies in their flexibility and changeability in terms of shape and appearance, their low weight combined with high strength, and their ability to be functionalized, e.g. by nutrient and water supply.

The main methods
As a first step towards the greening buildings Living Lab a joint course offer is being organized in summer 2022. Designs for the greening of the Reiff-Museum will be set up in an elective module for students of architecture and textile technology of RWTH Aachen University and exhibited at the Zukunft Bau Pop-up campus from 29.6.2022. Joint lectures, interdisciplinary student workshops and a site visit on a best-practice example will test the compatibility of teaching approaches while the Reiff Museum will be a first attempt towards a wider greening strategy for RWTH Aachen University buildings.
In the second step towards the Living Lab in late summer/autumn, we plan another joint course for designing and testing a simple building greening kit with students from both disciplines. The goal is to develop a kit which may be flexibly used on RWTH buildings and can be provided to the entities by the university. These will form the basis for implementation in the form of the Living Lab method in the coming semesters. For this purpose, further specific buildings of RWTH Aachen University will be selected and the designs iteratively tested.

The main outcomes
The approach of combining interdisciplinary university teaching with a real live application can be a key element in educating the necessary experts for climate change adaption in the building sector. Students will be made aware of the importance of creating greener and more liveable cities. The Living Lab component in the teaching approach including the development of a prototype for a specific application on RWTH buildings will make sure that green facades are understood as a living system which needs to be adapted to technical and administrative barriers and has to include solutions for maintenance and durability. This teaching approach will provide future practitioners in architecture, engineering and urban planning with the expertise and awareness on greening buildings and its aesthetic and societal benefits and prepare them for interdisciplinary cooperation in their working life. It will extend their technical knowledge and encourage knowledge exchange for integrating new construction solutions in their projects.

Important ‘take-home’ message
Interdisciplinary teaching can only be a first step towards the intended Living Lab approach. To achieve a wider impact within RWTH and beyond, this first initiative needs to be extended in a quad helix innovation approach. The helix classically being composed of academia, government, economy and civil society, a RWTH-adapted Living Lab on greening buildings should include researchers from relevant disciplines, the university administration, namely the facility management, students in their curricular and extracurricular activities and university staff of all kinds engaged in greening their working environment. We hope to achieve this transdisciplinary engagement within the RWTH sustainability strategy.
Objective

Sustainability is an essential part of decision-making in all sectors – especially in the construction industry, as the construction industry is responsible for positive and negative values in society, economy and environment. Life Cycle Sustainability Assessment (LCSA) as framework is considered to provide a valuable support to decision makers (DMs), by extending the scope of the known Life Cycle Assessment (LCA). The LCSA framework extends the scope of the well-known Life Cycle Assessment (LCA) and covers all three dimensions of sustainability: environmental (LCA), economic (Life Cycle Costing/LCC) and social (Social Life Cycle Assessment/S-LCA). The formal LCSA describes the idea of applying the three methods in a complementary and timely manner to the same functional unit and equivalent system boundaries. In the LCSA interpretation, no weighing is applied between the three pillars, the three assessments are equivalent, and an underperformance of one pillar cannot be compensated by a better performance of another pillar. At present, the number of published LCSA studies in the construction sector is comparatively small.

The main goal of the actual study was to promote the partnership between LCSA and the construction sector – to gain an understanding of the background and opportunities for LCSA application in this sector. Three surveys on sustainability and LCSA in general and explicitly in the construction sector will provide first answers and generate directional approaches.

Methodology

Based on a previous conference participation, on a detailed literature review and on personal interviews with German construction experts as well as students of civil and environmental engineering, three relevant target groups (TGs) were defined. TG 1 represents international LCSA experts. Through this expert target group, it should become clear whether and how the LCSA framework can be modified or simplified to reduce the application threshold and complexity. TG 2 contains environmental and civil engineering students. As future decision makers (DM) in the construction sector, students have a special importance in the field of sustainability assessment. TG 3 consists of current DMs in the construction sector, including personal (industry) contacts and research collaborations from the construction sector. This target group will reveal wheth-
er and to what extent practitioners are aware of LCSA and what chances and challenges exist. Surveys (qualitative & quantitative) were conducted with all three target groups using the deductive method. The target group-specific questionnaires were created using an online questionnaire. The method of data collection is thus based on an anonymous online survey.

Results

The questionnaire results show that in TG 1 the application of LCSA is very difficult for 57% and 35% find it partially difficult to implement all three pillars equally. Only 8% of respondents do not find it difficult to define the same system boundaries for all three assessments. Only 3% of the questioned LCSA-experts find it easy to make a good and simple selection of appropriate indicators. Further, 87% of the respondents are convinced that the LCSA should be linked to the Sustainable Development Goals (SDGs) – which is not yet well elaborated. Regarding TG 2 – students, 62% indicate that sustainability is generally a focus in their studies. However, only 38% of respondents are aware of the LCSA, while in contrast, all respondents call for more LCA to be conducted in the building sector as a pillar of the LCSA (not being at the beginning of their studies). Less than 10% of the students surveyed have already engaged in a sustainability assessment in practice. More than 70% of students would like to see more courses and seminars on sustainability, as they are more interested in the topic and would like to have more hands-on practice with sustainability assessment. 94% of today's DM (TG 3) name LCA as important and relevant for construction sector. Yet, over 60% have never conducted a life cycle assessment (as one pillar of LCSA). LCC and S-LCA were never assessed by any of the requested DMs. If an LCA was assessed, this only happened as it was asked by clients. When being asked about LCSA, 51% of all respondents indicated that they have heard of LCSA. None of the respondents ever did or questioned a LCSA. Further, actual DM seem to ignore the equality of the three pillars as they rate the economic pillar as most important: economic > environmental > social (pillar).

Conclusion & Take home message

LCSA is hardly known among actual and future decision-makers in the construction sector. Concerning knowledge, above all, teaching (at universities) has a special future task to increase this knowledge and to better educate (future) DMs about LCSA and also the individual three pillars of sustainability – using e.g. the construction sector for practical examples. Current DMs know the LCSA framework in rudimentary form, but have very rarely implemented any of the three pillars themselves and have never applied a complete LCSA, e.g., to base decisions on it. From the results of the LCSA experts, it is clear that there are difficulties in the final interpretation of the LCSA, the weighting and the communication. Standardization is repeatedly called for and the majority of experts' state that a set of predefined indicators and an adequate visualization tool are needed for improved implementation and support of DM – in general and in particular for the construction sector.

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Problem-Based Learning for Future Challenges in Engineering Education

Ann-Kristin Winkens

To address and deal with global challenges, as described in the Sustainable Development Goals, engineering graduates need to acquire competencies that go beyond purely technical knowledge and expertise. At its heart, this includes the ability to solve complex problems, which requires competencies such as dealing with uncertainty and complexity, systems thinking or decision-making [1]. Several international accreditation guidelines, such as the American Accreditation Board for Engineering and Technology (ABET) or the European Network for Accreditation of Engineering Education (ENAE) already address those competencies as required learning objectives within engineering programs [2,3]. The same applies for the syllabus of the engineering education initiative CDIO (Conceive-Design-Implement-Operate), an educational framework for systematic and integrative curriculum design [4].

However, the solution of complex real-world problems and learning from failure or past disasters are seldomly integrated in engineering curricula [1]. Studies with engineering students have shown that there are gaps of knowledge and understanding regarding the relevance and need for resilient infrastructure. Closing this gap is especially important in the context of climate change adaptation, as increasing natural disasters caused by climate change require innovative and interdisciplinary solutions and adaptive and forward-thinking approaches. Innovative and student-centered teaching approaches, which are well established within engineering education are required to enable students to gain those competencies and to apply their theoretical knowledge to real-world problems. Notably, problem-based learning (PBL) represents a central teaching approach in the context of active learning. PBL describes a teaching method based on problem orientation to engage active learning, thereby integrating elements of collaborative and team-based learning [5].

Exemplary, this teaching method was performed in a master's course at RWTH Aachen University for students of environmental, civil and business administration engineering (the teaching concept is presented in detail in 6). The goal of the course was to enable students to develop and evaluate resilience strategies on a local level by applying scenario planning methods, thereby enabling students to understand interactions and interdependencies of complex systems. Based on a given case regarding the
COVID-19 Pandemic, a complex, open-ended and ill-defined real-world problem was the starting point for the course. Moreover, students had to consider different stakeholder perspectives to reflect on different perspectives of the society. The learning content includes an introduction to current discourses on and approaches to resilience as well as interdisciplinary approaches to design resilient and adaptive systems, especially with regard to socio-technical systems, such as urban infrastructure. Students had to work in groups of five on a given case and the acquisition of intended learning outcomes was assessed via team reports, oral presentations and peer assessment among the students. Additionally, they had to fill out a pre and post course survey with regard to the acquisition of competencies. Overall, the course showed a positive development of students’ competencies, as the teaching approach successfully enhanced creative, critical and systems thinking about complex and uncertain futures and outcomes. The positive development was confirmed by students' self-assessment of competence acquisition before and after the course. Notably, competencies which describe a higher complexity level according to Bloom's taxonomy, such as analyzing, evaluating and even creating, increased most. At the same time, these were precisely the competencies that were not pronounced before taking the course, indicating a successful implementation of the PBL teaching approach. This results in two key lessons for engineering education: First, teaching approaches such as active learning and PBL can work very well if they are tailored to students’ specific backgrounds and address students' needs for enhancing their competencies to deal with complexity and uncertainty as well as the application of their theoretical knowledge to real-world problems. Second, a consequent alignment with well-established frameworks for engineering curricula and teaching, notably the CDIO framework, can further enhance the quality of higher education. In order to consistently educate engineering students to address and solve complex global challenges, to create adaptive solutions and to think holistically, this must be done in an integrated curriculum design and cannot be done completely on a course level. Therefore, a more systematic and integrated perspective on engineering curricula is required, as it is described in the CDIO framework [1, 4]. Implementing the CDIO standards into engineering curricula could enhance the development of a next generation of engineers, able to deal with complex problems in a creative, innovative and interdisciplinary manner.
Sustainability in Teaching – The Role of Interdisciplinary and Cross-University Courses

Julia Berg

As evident in the 17 Sustainable Development Goals (SDGs), sustainability and sustainable development are society-wide challenges that require collaboration and interdisciplinary solutions. Universities can play a central role as innovation drivers of sustainable development through research and education of students. By integrating sustainability into university curricula, students become aware of sustainable development, and they can build up subject-specific and interdisciplinary competencies and thus contribute to the shaping of a sustainable future. The literature shows that students need to be equipped with different competencies to be prepared to solve sustainability challenges. For example, the UNESCO listed eight competencies related to the SDGs ranging from systems thinking competency to collaboration competency or critical thinking competency. Besides, students need to develop interdisciplinary and transdisciplinary competencies highlighting the need for offering interdisciplinary courses.

Thus, addressing the different competencies requires that universities develop interdisciplinary courses that teach a holistic view of sustainability and address ecological, economic, and social sustainability. In addition, courses are needed that go beyond building subject-specific knowledge by using active learning approaches like challenge-based learning or case-based learning. A possibility to promote the development of the necessary competencies of students and, in particular, interdisciplinary competency is to offer cross-university courses. These courses enable the collaboration of students differing in study programs, prior knowledge, and experience on sustainability. Therefore, by involving students from different universities and study programs in joint sustainability courses, students have the opportunity to solve sustainability challenges in interdisciplinary teams and get a holistic view of sustainability.

Thus, based on the important role of universities in sustainable development and the need for interdisciplinary collaboration and development of different competencies, RWTH Aachen University, FH Aachen University of Applied Sciences, and Katholische Hochschule Nordrhein-Westfalen, Aachen, developed an interdisciplinary and cross-university course on sustainability to address the demand for interdisciplinary collaboration. Since 2021 the three
universities have been offering the joint course ‘Sustainability and Transformation as an Opportunity and Challenge for Society’. The course is offered to students from all three universities in order to sensitize students to a holistic view of sustainability and enable them to experience interdisciplinary work during their studies. On the one hand, the collaboration of the three universities addresses the need for cooperation regarding the SDGs and, on the other hand, offers students the opportunity to gain interdisciplinary experience in the field of sustainability. The teaching concept is based on an active learning approach, the most appropriate approach to achieving Education for Sustainable Development2. Therefore, in addition to lectures by experts in ecological, economic, and social sustainability, students work in interdisciplinary and cross-university groups on problems related to the SDGs and develop solutions for these challenges. Thus, this course allows students to learn from each other, gain a holistic view of sustainability, and experience collaboration in interdisciplinary teams. At the end of the semester, students reflect on their learning by discussing how collaboration in interdisciplinary groups has changed their perspective on sustainability. The evaluation of reflection papers shows how integrating different subject and university perspectives can raise students’ awareness of all dimensions of sustainability. Furthermore, the reflection papers provide evidence of the opportunities and challenges the interdisciplinary and cross-university collaboration on sustainability has for students from different disciplines and universities. Finally, the results show that the course concept promotes a holistic view of sustainable development among students and that interdisciplinary collaboration in sustainable development provides an excellent opportunity to prepare students for their future careers.

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Transformative Research as a Motor for Change – Lessons from the Research Project KlimaNetze

Britta Rösener

Everyone can do something to protect the climate, but people often fail to come together when it comes to joint tasks. This was the initial observation for the transformative joint research project KlimaNetze (2016-2019), which was funded by the BMBF. In the project, two real world laboratories were used to test how the cooperation of actors in Bielefeld’s climate protection could be improved. The project was successful in every respect: the project found two real world laboratories; they were implemented by local project groups. Both real world laboratories help to advance sustainable mobility in Bielefeld: In a small inner-city street, car traffic is being reduced in favor of amenity qualities, and the infrastructure for cyclists is being expanded. Stakeholders from business, civil society, administration and politics worked together closely with the research team. New, good relationships were established, and they are still having a positive effect today. The participants in the KlimaNetze project were so convinced of the qualities achieved that they jointly wanted to perpetuate the KlimaNetze project. In the follow-up project KlimaNetze 2.0, a ‘KlimaTriebwerk Bielefeld’ is now being developed since January 2020. The ‘Klima-Triebwerk’ is intended to accelerate climate protection in Bielefeld in the future as a ‘forum for those involved in climate protection’ (see www.klimatriebwerk.de).

From the KlimaNetze projects we can learn for transformation tasks in climate adaptation. Methods and solutions will not be transferable one-to-one, because the framework conditions, tasks and actors in climate adaptation are different from those in climate protection. But what we can see and use for climate adaptation is (1) how transformative research projects could become motors for change (1). We can also learn what we should do, if we want to activate actors in politics, administration and society to participate (2).

(1) The core of the KlimaNetze project was the process of the real world laboratories. Real world laboratories were defined as ‘projects in which the aim is to test desired changes in practice and to evaluate them with regard to possible stabilization. In the process, science and practice should learn from each other.’ (Fox-Kämper et. al 2020:37). In the KlimaNetze project this was successful because of the role setting that was chosen: Real lab teams from the field implemented their own project ideas...
with high motivation and on their own responsibility. Professional process designers with experience in practice and science shaped the communication in the project and supported the real lab teams. Researchers developed a research methodology that took into account the interests of the practitioners; they realized their research and supported the transformation process. An onsite facilitator maintained close contact with all project participants, he identified communication needs, mediated between the actors and supported the real lab teams, too. In addition, other relevant stakeholders, such as politicians and administrators, were involved at appropriate times and in an appropriate manner. We assume, this setting could potentially also be applied in climate adaptation projects.

(2) The KlimaNetze project has succeeded in getting stakeholders from politics, administration and urban society to participate. These are a few reasons for this: The project partners from practice were able to work on tasks that were very close to their deep wishes and for which they wanted to commit themselves. For the practitioners, the expected benefit was higher than the effort they invested in the project; communication and process design must be oriented to this! With key persons who were needed for the implementation of the project, it was clearly agreed who would contribute what to the project. Key persons and key groups needed for learning processes and for stabilization were involved in the research project at an early stage. And last but not least: Communication was (largely) attractive and mostly even fun.

Transformative research projects consist largely of communication. There are many experiences in urban development on the question of how complex participation, cooperation and change processes can be designed. We should also use them in research!

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AGILE INFRASTRUCTURE
Organizer: Stefan Böschen

SHORT PRESENTATIONS AND DISCUSSIONS

- Temporal Orgware for Agile Infrastructure: Rhythmic Reconstructions for Space-Specific and Adaptive Urban Development
- Reusing Decommissioned Open-Cast Coal Mines for District Heating and Cooling
- Designing with Nature-Based Solutions for a Resilient and Co-Produced Green Infrastructure
- Lessons Learnt from Community-Led Responses to the Pandemic
- Living Lab Research Infrastructures: One-Trick Ponies or Agile All-Rounders
Re-Thinking Infrastructure Against the Background of Transformational Change

The flood disaster in North Rhine-Westphalia in the summer of 2021 clearly showed how dramatic the need for adaptation to climate change is, even in Central Europe. At the same time, it highlighted the particular sensitivity of critical infrastructures (water and wastewater, transport, rescue and telecommunications, power supply, telecommunications). The reconstruction of these infrastructures is of particular urgency. However, it cannot be a matter of reconstruction alone. The real task is to make infrastructures adaptable to future development demands at the time of their (re-)construction.

This is also evident, albeit in a different way, regarding transformation processes such as the one in the Rhenish mining area. Old infrastructures must be ex-novated, new ones built, and at the same time future development options must be considered now (i.e., has to be anchored materially in the infrastructure). This presents itself as a multi-layered problem. Infrastructures are typically monuments of stability. They must also be designed in such a way to provide services of general interest. So how can flexibility be built into them? Posed differently, how can experimental elements be built into infrastructures - and if so, how should they be designed? Which areas could lend themselves well for implementation of these infrastructures? Finally, what are the consequences of these designs on multiple and various developments? Should they also be interlocked, i.e. synchronized?

Put succinctly, communities need infrastructures that are agile, participative and capable of being updated - An intimidating task. How can this be achieved? How do we have to think and design infrastructures so that they can meet such demands? It is clear that this task can only be tackled in an interdisciplinary way. Even more, it requires a tailored form of interdisciplinarity. The session is dedicated to the exploration of main topics in this area which should be addressed while thinking about this kind of solutions. be observed worldwide in similar patterns: slower variations of weather events cause more prolonged phases of rain and heat, leading to more frequent occurrences of flooding and drought, respectively. Extreme events of precipitation, windstorms, and heat waves tend to occur with shorter return periods and locally with higher amplitudes. In short: The natural equilibrium and the ability to balance weather phenomena is tending more and more to reaching and exceeding its limits.

For instance, in July 2021, a flood disaster occurred in West Germany that also hit and damaged the region of RWTH Aachen University. The flooding incident was caused and aggravated by multiple factors: prolonged and intense heavy rain, topography, soil saturation and soil conditions in the areas of rainfall - but also by interventions in natural river courses and peripheral buildings. Unexpectedly, buildings that were supposed to offer protection were located in flooded areas. More than 180 citizens lost their lives. Besides extreme precipitation, severe wind events can also cause significant damage to the built environment and put humans at risk. In this year, a tornado has hit the city of Paderborn with 43 people injured.

While it is still not clear to what extent such severe events might increase in frequency or severeness due to climate change - it is likely that both features will be affected in an unfavourable way in the future and the mentioned events painfully demonstrate the possible impact of climate change to us. Therefore, climate change adaptation is necessarily a key topic for the planning of our future living environment and infrastructure. The construction sector is of relevance, as it contributes significantly to carbon emissions (and thus offers potential for savings), but also promises to provide opportunities for adaptation and solutions to gain resilience. Both aspects are closely interwoven with social, economic, and cultural issues. Due to this complexity, the topic demands us to bring together knowledge from different disciplines to stimulate new scientific interactions.

The threat of natural disasters, the resilience of the built infrastructure, the weighing up of security requirements and life risks in the areas of society, economy and culture should therefore also be included for future planning processes and receive more awareness amongst decision makers.
Temporal Orgware for Agile Infrastructure: Rhythmic Reconstructions for Space-Specific and Adaptive Urban Development

Robin Chang\(^a\), Agnes Foerster\(^b\)

In 2018, the World Economic Forum published a white paper as a preemptive response to the demands of the fourth industrial revolution and how cities could set up for the transformative challenges through ‘agility’ (Forum, p. 4). While this report was prepared to reconcile targets set by the UN Sustainable Development Goals, Paris Agreement on Climate Change and New Urban Agenda, as well as trends towards innovation, little did it anticipate the urgency for agility as cities were accosted by the uncertain changes of the global Pandemic in 2019 (Chang, 2021). This contribution proposes a new means of tracing agility in urban development and in particular, agile infrastructure that might respond to climate change, energy or mobility transition as a part of the orgware for solutions that intervene and innovate. This new means of tracing agile infrastructure highlights through a temporality lens the diverse and syncopated trajectories of temporary uses that have become a ubiquitous part of urban transitions.

By drawing on empirical work that compares temporary uses in Bremen and Rotterdam, this contribution highlights how temporary users’ collective capacity to experiment and learn (software) while adapting built structures and spaces (hardware) contribute to a less fixed and more flexible trajectories of urban development. This is not only the metaphorical but also material emergence of agile infrastructures, which requires new and temporal frames in order to recognize how they develop and move across space (Chang, 2022). The contribution will highlight policies that were developed or came out of municipal experimentation with temporary uses in the context of urban regeneration to explicate the short, mid- and long-term impacts of how temporary uses culminate from both synergies and innovations in urban development. These synergies and innovations are best understood through multiple, layered, and interpenetrating temporalities from which agile infrastructures can be designed, programmed, or crafted through policy. These possibilities for agile infrastructures, however, require understandings (orgware) that are less fixed in space and instead, equally if not more aware of temporalities and pace, for how activities and functions might be incubated and transitioned across and throughout a city and its communities. A temporality framework that delineates trajectories and rhythmic temporalities as a part of spatial processes will help illuminate syncopated patterns of place-making and place-based innovations.
The outcome of this work invites consideration for how to better visualize or represent the temporal patterns along with its spatialities. It also strives for more critical considers regarding what this means for conceptions of space, spatial processes and the potential for place-making or place-based innovations. This temporally analytical approach aims less for the strategic visioning of urban futures and more so for the processual confrontation with building policies, transitionary densification, or adaptive programming of functions as means towards spatial solutions (Foerster et al., 2020). This leverages analytical expertise for ‘proactive impact-oriented design interventions’ (Wiese et al., 2014, p. 8). This also advocates for temporal sensitivity (Chang, 2022) in the emergence of agile infrastructure as a part of design, planning, and governance capacities (Forum, 2018).

References

Figure: Pop-up benches at a public plaza of the Ruhr-Universitaet Bochum. Source: Robin A. Chang

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Coal-fueled power plants, the most CO₂ intensive sources of energy, must be decommissioned before 2050 to cut down GHG emissions [1]. The closure of the mine supplying coal will follow the power plant decommissioning, achieved by creating pit lakes in the case of the Ruhr mining region [2]. The pit lake's construction phase may prove a unique opportunity to develop a shallow geothermal system that provides district heating or cooling (DHC) to nearby population centres. Energy would be extracted, rejected, or stored using heat exchangers buried or submerged in the pit lake or direct heat exchange with pumped water. Few documented cases of the reuse of open-pit coal mines are found in the literature [3, 4]. The lack of existing implementations is attributed to 1) the distance of open-pit mines to population centres, 2) the relatively recent shift in mentality from pit lakes as residual mining liabilities to opportunities for development, and 3) previous technological limitations in district heating network (DHN) which required high supply temperatures due to limited insulation in buildings [5-7]. Pit-lakes are an abundant source of low-grade geothermal energy, and their exploitation as a geothermal source techno-economic feasibility has not been explored in detail yet.

The first objective of this project is to assess the feasibility of the long-distance provision of heating or cooling using the pit lake and its surroundings as a source, sink or storage. For this purpose, a techno-economic assessment framework is performed using Python. A first approach considers modelling the operation of a long-distance DH as a linear programming (LP) energy dispatch optimisation problem. The system is modelled as a centralised source, generation plant and storage located in the mine or its vicinities, supply and return water pipelines serving a transmission line, and an aggregated consumer representing a nearby population centre. The levelised cost of heat (LCOH) is estimated for each analysis case, allowing the comparison between different configurations and with other existing technologies (individual gas boilers, air-source heat pumps). The techno-economic assessment framework will let us identify potential mines or pit lakes that could be reused for geothermal purposes and which variables must be explored in more detail for future work.
Preliminary results have been obtained for the case of a DHN fed by a centralised large scale heat pump, using water extracted from the mine as a source. Weather data from the Ruhr Area [8] was used as an hourly input for the analysis. The heat demand profile was estimated considering a homogeneous low-density population centre with multiple single-family typical German houses. The transmission line length and number of connected homes parameters were varied to assess their impact on the system LCOH for each consumer. The model results show that the effect on the LCOH of a long transmission line depends on the number of connected homes. For less than 200 houses, the transmission line investment cost represents almost 2/3 of the total LCOH, which is reduced to 1/3 of the LCOH for five times the number (~1000) of homes as the investment cost is amortised between more consumers. Compared with individual heat supply through gas boilers, the system is economically competitive only in the first 100 m – 1000 m, depending on the number of connected houses. The previous result is expected due to the low heat density considered for the calculations. Future work considers the provisioning of cooling, which could use the same infrastructure, decentralised heat generation through district ambient-temperature distribution with individual heat pumps for each consumer, and integration with other renewable energies.

The geothermal reuse of the pit lake could be complementary to other projects considered for the post-mining landscape. Even more, the availability of economical heating or cooling with low CO2 emissions could increase the attractiveness of the nearby land for further development, serving as a cornerstone for the economic transition of nearby population centres after the closure of the coal mine.
Motivation and objectives
Existing infrastructure mainly relies on technical, engineered solutions. This makes their services calculable and reliable in normal situations, but also has downsides: most classic infrastructure is monofunctional, not self-sustaining and dependant on intensive maintenance with high associated costs. Its calculated but limited capacity can lead to breakdowns in extreme events.

In contrast to grey infrastructure, green infrastructure (GI) is gaining importance. First conceptualized as the ‘functions of nature’ [1] in the 1990s the importance of nature has been more widely recognized in the concept of ecosystem services (ES) of the millennium ecosystem assessment [2] and other approaches [3,4]. Acknowledging the importance of ES provided by natural capital has led to EU policies on GI which is defined as ‘a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. It incorporates green spaces (...) and other physical features in terrestrial (...) areas. On land GI is present in rural and urban settings.’ [5] GI relies on nature-based solutions (NBS), ‘(...) inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes, and seascapes, through locally adapted, resource-efficient and systemic interventions.’ [6] When compared to technical solutions, NBS have the advantages of being partly self-sustaining, adaptable in their capacities, and resilient to external shocks. Challenges in using GI and NBS are knowledge gaps in the predictability of their functions and services, difficulties in integrating them with grey infrastructure and technical solutions and thus with established infrastructure planning procedures and calculation norms which prevent the application of systemic and locally adapted solutions.

The main methods
GI and NBS cannot be engineered in the pure sense of the term. They need to be adapted to the local context and the services needed in a systemic design process which can also address potential co-benefits. The latter are also a key feature of NBS improving their acceptance and support.
by local communities. For the local adaptations of NBS and their long-term management it can be beneficial to draw on local knowledge during the design process and on co-production of GI, an approach which already has proven to be successful in other public services and infrastructures [7]. How can we organize such co-design and co-production processes for a better application of GI and NBS as agile infrastructure solutions?

RWTH Aachen University’s Institute of Landscape Architecture is exploring this as coordinator or work package leader for national and international consortia in different transdisciplinary research and teaching projects in recent years. These include the use of productive NBS as GI for post-industrial urban areas (H2020 IA proGIreg), the implementation of NBS for improving health and wellbeing in urban areas (H2020 IA GO GREEN ROUTES), the design of green-blue streets for urban stormwater management (teaching) and the co-production for conserving and enhancing regional GI (BMBF CoProGrün).

Depending on the projects, the research methods vary, ranging from co-design in stakeholder work-shops, training students through design studios in systemic thinking, to full living lab processes. For the latter, this starts with temporary local interventions as co-design kick-off events, passing to co-implementation and co-monitoring of NBS, and finally assessing the implementation barriers encountered and the business models used.

The main outcomes
The mentioned design and living lab projects create application cases, which help to prove the feasibility of NBS and GI solutions and their co-production in real life environments. Through the involvement of researchers, students, government, practitioners, and civil society, new communities of practice are fostered, which can integrate the project approaches in future planning processes and standards.

Important ‘take-home’ messages
As a take home from the projects conducted so far, the capabilities for transdisciplinary work and systemic thinking still need to be improved especially in some research disciplines. The monitoring and evaluation methods for NBS often lack sensitivity and adaptability for local contexts and potentially fail in detecting some of the benefits of this new form of infrastructure. Improving these approaches to better support new infrastructure approaches should be an important task for the Built and Lived Environment growth area at RWTH Aachen University.

References
Lessons Learnt from Community-Led Responses to the Pandemic

Martin Bangratza\textsuperscript{a}, Agnes Förster\textsuperscript{b}

Urban infrastructures face ever more diverse and pressing demands. Global crises including climate change, pandemics or war demonstrate that infrastructure must be both resilient and adaptive if they are to deliver lasting benefit to mankind. Authors such as Chester and Allenby (2018) have thus called for infrastructure that is flexible and agile in order to better address the increasingly complex and dynamic nature of these challenges. While the centralized provision of infrastructure is arguably one of the most important sovereign duties for national and subnational governments, they are prone to perpetuating lock-ins and path dependencies of infrastructures that are then all but impossible to adapt to changing circumstances (Chester and Allenby 2018: 15). At the same time, civil society gives rise to more and more initiatives that develop, adapt, and use their own infrastructure. Especially in the current age of datafication of urban infrastructures, multiple challenges and opportunities arise when people apply digital technologies in their practices of appropriating and co-producing the city (cf. De Waal and De Lange 2019). In this paper we want to share observations of such civil society responses specifically during the early phase of the COVID pandemic in 2020-21 in order to highlight their possible contributions to urban infrastructure. We frame our observations through the lens of justice in terms of access to infrastructure, grounded in theories on the governance of urban and digital commons (cf. Beckwith, Sherry and Prendergast 2019; Heeks and Shekhar 2019; Foster 2013).

In the period of curfews and social distancing that met residents in Germany and around the world more or less unprepared, we began with casual observations of grassroots initiatives on social media platforms. In developing a new blog and podcast called What/Next, we were able to gain deeper insights through interviews with ten different initiatives we identified as ‘digital citymakers’ (www.pnd-what-next.de). In this paper, we will go into details on some of the most relevant examples to illustrate our findings. This includes examples such as a location-based crowdfunding platform in Vienna, a virtual platform for artists in Wuppertal, and a crowdsourced local vacation platform from Belgium.
On one level, the outcomes show the reasons for citizen initiatives to develop their own infrastructures, such as a lack of service, or defiance against tech monopolies by market players. But the article also highlights the potential benefits of the resulting infrastructures including agility, digital sovereignty, resilience, and more equitable access. Reflecting on these outcomes, we find that the newly developed infrastructure is not meant to compete with or replace existing systems, but to complement what’s already there but may be more rigid and thus less readily adapted to sudden crises. Looking back from a post-lockdown perspective allows some initial conclusions regarding if and how the solutions have been perpetuated or scaled, integrated into official systems, or continue to exist alongside them. The article presents further conclusions regarding actor constellations, the mix of physical infrastructure and digital, organizational and other elements that constitute the nature of communal infrastructures in the digital age. It can be argued that the locally embedded, yet decentrally available infrastructure has proven both resilient and responsive to change in the face of global challenges with local impacts. Ultimately, the findings can serve as evidence for policies that aim to learn from, support, and integrate such grassroots efforts.

References


Living Lab Research Infrastructures: One-Trick Ponies or Agile All-Rounders

Julia Backhausa, Stefan Johna, Ana de la Vargaa, Gabriele Gramelsbergera

As manifestations of a ‘new deal’ between science and society (Lieven and Maasen 2007), Living Labs have emerged as infrastructures for integrated, inter- or transdisciplinary research enabling experimentation in the search for sustainable solutions (Caniglia et al. 2017). Often framed as the answer to calls for more open innovation (Leminen et al. 2012) and the co-design, co-production and co-evaluation of knowledge (Wanner et al. 2018), Living Labs have become ubiquitous – also at RWTH Aachen University. At the same time, and partially due to its popularity, the notion of the Living Lab remains elusive. Research showed that Living Labs are caught between different tensions, such as between an open and messy approach to the co-creation of knowledge vs. controlled experimentation as well as between ‘learning from failure and public demonstration of success’ (Engels et al. 2019, p. 1). In other words, as research infrastructures geared towards tackling societal challenges, Living Labs can provide the basis for agile and participatory experimentation but may not always do so in practice. Therefore, the main objective of this contribution is to examine Living Lab research infrastructures at RWTH Aachen University with respect to their agility, i.e. their ability to flexibly respond to internally or externally changing conditions and to address local, regional or global issues of concern.

Between March and November 2021, 33 interviews were conducted with scientific staff of RWTH Aachen University involved in a Living Lab. On average, the interviews lasted about one hour and were subsequently transcribed verbatim as well as coded using MAXQDA. Following the suggestion by Ballon and Schuurman (2015) to study concrete examples of Living Labs even if they go by another name, the research infrastructures included in the study were selected based on a pronounced focus on societal transformation and an integrated inter- or transdisciplinary research approach with a clear orientation towards testing, applying, learning and embedding the work in multi-stakeholder activities. To capture the variety of Living Labs that can be found at and around RWTH Aachen University (Backhaus et al. in press), this contribution considers a broad spectrum of socio-institutional constellations that are or can be labelled ‘Living Lab’ (in German: Reallabor). The research was carried out as part of the Living Labs Incubator, a measure within the Excellence Strategy of RWTH Aachen University (2019–2026) funded by the German state and national governments.
Our findings suggest that an important distinction can be made between Living Labs that take a problem as a starting point and organise key stakeholder groups around the in-depth understanding of the problem, as well as the identification and implementation of possible solutions. Most Living Labs of this kind can be found in the realm of local (often urban) or regional development but their innovation focus varies from a stronger technological (e.g., Living CoastLab) to a more social orientation (e.g., ACademie für kollaborative Stadtentwicklung). Another distinctive group of Living Labs takes a solution as a starting point and involves various stakeholder groups in context-tailoring measures to increase chances of success (at the market or, more generally, in society). Living Labs of this kind share a technological orientation but may have a narrow focus on technology optimisation (Al-denhoven Testing Center) or a broader focus on the social embedding of a technological innovation, including organisational, legal or institutional aspects (e.g., proGIreg, BioökonomieREGION). Examples of the latter kind are often concerned with regional structural changes (StrukturwanDEL) and involve the establishment of new collaborations or new (regional) supply-chains. Crucially, all Living Labs involve agile process management, requiring researchers and managers alike (which, in a university context, may be the same person) to adapt to available funding streams and respond flexibly to (often changing) contextual conditions. However, agile research infrastructures that can flexibly respond to changing understandings of problems and appropriate solutions only emerge in the context of Living Labs that follow an integrated inter- or transdisciplinary approach to both problem definition and solution development.

From this realisation follow three important lessons for research policy and practice: Transformational research towards smart and sustainable societies requires 1) integrated inter- and transdisciplinary project consortia and approaches, 2) time (funding) for multi-stakeholder processes to collaboratively explore core problems and possible solutions, and 3) long-term monitoring and evaluation.

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