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URBAN CLIMATE, CLIMATE TWINS & ARTIFICIAL INTELLIGENCE A CONTRIBUTION TO AN INTEGRATED PLANNING APPROACH TO LOCAL CLIMATE RESILIENCE

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1. INTRODUCTION*

Today, it is more important than ever to find answers to the climate problem in urban areas. For urban planning, this means that environmental and urban climate aspects must be considered in more detail. With the help of climate equivalents, climate research creates an explanatory approach that offers directional certainty and a future perspective. In addition, it opens up the possibility of introducing further steps for optimised urban adaptation to climate change and building a bridge to applied, planning-oriented urban climatology, which is of immense relevance in this field of tension. The development of AI-supported processes can offer a "climate inventory" of settlement areas based on satellite data, among other things, in order to offer rapid identification of local climate risk areas.

2. PROBLEM & CHALLENGE

The effects of climate change on humans, animals and plants as well as the overloading of infrastructures occur primarily in urban areas. As these increasingly critical situations don`t occur in isolation, but are part of the global system, the comparative search for similar problems and fields of action in other cities such as Vienna (Pfanner 2022) or regions such as the greater Aachen area (Reuter et al. 2023) has proven its worth, even if these studies are only concerned with testing the calculation of the "climate twin" and not, as in this article, with the corresponding adaptation to the local climatic situation and its consequences for municipal planning. A target-oriented potential lies in the consideration of urban structures whose current local climate indicates future developments and effects for other urban areas. These climate forecasts in combination with specific spatial examples are referred to as "climate twins". They offer an attempt at an explanation that enables a comparison between regional and local areas, but varies the aspects of time and place. Climatic analogue regions are created in which a region A currently experiences climatic conditions that are comparable to the projected future local climatic conditions of a region B. This approach provides useful information about today's general infrastructure and living conditions that are already adapted to today's climate. It offers a rough projection and a realistic and useful insight into the future climate and its impacts.

The initially technical perspective on the part of climate research creates an explanatory path with the help of the "climate twin" described above, which provides certainty of direction for spatial planning and thus also future prospects. The spatial planning approach complements further steps with regard to optimised adaptation to climate change in the scientific and practical planning discourse. This builds a bridge to applied, planning-oriented urban climatology (Henninger, Leitte 2017), which is of immense relevance in the field of tension mentioned, because dealing with the consequences of climate change (including urban overheating, increase in precipitation intensity, summer droughts) is one of the central social challenges. This makes adaptation to climate change a central task. To this end, the adaptability and resilience of an urban area to the effects and consequences of climate change that have already occurred and are expected in the future must be strengthened. In order to achieve such resilience, spatially adapted measures must be identified that enable and promote rapid, targeted and efficient action by stakeholders (Henninger, Weber 2020).

The implementation of the measures is the responsibility of the municipalities, but also of private stakeholders. Municipal administrations and state decision-makers are faced with the challenge of developing and implementing solutions for complex contexts – often with very limited financial and human resources. In addition, municipal decision-makers are often faced with the dilemma of not being able to look into the future. In order to avoid major criticism, the strategy often chosen is to wait until something happens (e.g. flooding caused by a heavy rainfall event or a high number of heat-related deaths due to overheating in cities caused by prolonged high-pressure weather conditions) and then react. In practice, the dilemma often arises that the implementation of preventive measures is not honoured to the extent that one would have imagined in advance. The statement "*There is no glory in prevention*" describes the so-called “prevention paradox” in which our society finds itself (Drosten 2020). Preventive measures, whether to combat extreme events or to adapt to the consequences of climate change, appear unattractive. Preventing climate and natural disasters is laborious, costs money and brings no glory.

A response that can be described as resilient and future-orientated is of course not guaranteed by simply waiting, as the predicted future effects are still subject to major uncertainties despite all the progress made in terms of the possibilities of computer-aided climate scenarios. It is completely irrelevant whether we are dealing with a sudden catastrophic natural event (e.g. heavy rainfall) or a slowly emerging trend (steadily increasing average tem-

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peratures, longer periods of drought, etc.). However, it is not only the fear of criticism and the "outcry" from the public when measures are taken, but these are apparently implemented at great expense, especially financially, and then nothing of what one should protect against/adapt to occurs over a longer period of time. Rather, this reluctance is also due to the fact that there is still a lack of tools that enable practical access to information and recommendations for action on climate adaptation in order to make well-founded decisions for the planning and implementation of measures on the ground. This is despite the fact that a whole range of different options for action already exist, most of which are of a general nature and cannot be applied across the board to every region. It is therefore important to take account of the heterogeneous structure of an area under consideration by always providing recommendations for action that are specifically tailored to this area and enable local stakeholders to integrate preventive measures into existing work processes within the municipality by providing information at the lowest possible threshold

3. METHODOLOGY & PROCEDURE

The project "ÖkoHaSie 2050 – Ecological recommendations for action in residential areas" aims to significantly simplify the planning process for climate adaptation measures by combining (1) the planning-oriented settlement-climatic "matrix method", (2) the identification of "climate twins" and (3) the AI-supported recording of the current situation. This combination enables better and faster consideration of climate adaptation in municipal urban land-use planning. Planning processes should not be delayed by the consideration of necessary climate adaptation measures, but should be substantiated and accelerated. To this end, easy-to-use modules are being developed for local authorities that identify and prepare recommendations for action tailored to locations or local climatic problem areas.

3.1 "Matrix method" - Settlement climate analysis

Possible local effects of climate change must be recognised at an early stage, as adaptation to the expected consequences of climate change is necessary. Mathematical simulations are currently being used to identify microclimatic problem areas and fields of action within settlement areas and to recommend appropriate strategies. However, the interactions between the various climate elements and the heterogeneous building structure in urban areas are complex, making it difficult, time-consuming and, above all, cost-intensive to make clear predictions. Instead of numerical simulation, the "matrix method" developed at the University of Kaiserslautern-Landau (Germany) can be used (Fabisch 2017). This makes it possible to take stock of a municipality's settlement climate in order to make evidence-based and thus locally climate-resilient statements about the need for climate-adapted changes in existing buildings.
The "matrix method" is not based on in-situ measurements or simulations of various climate parameters, but on the estimation of probabilities of occurrence depending on various indicators relevant to the urban climate (soil quality, degree of sealing, green structure, etc.). These are not considered in isolation, but are compared in pairs in a matrix. For this purpose, the study area is divided into grids in order to be able to indicate the probability of occurrence, e.g. of overheating, for the corresponding grid field based on the intensity of the various indicators (Fabisch & Henninger 2018; see Fig. 1).

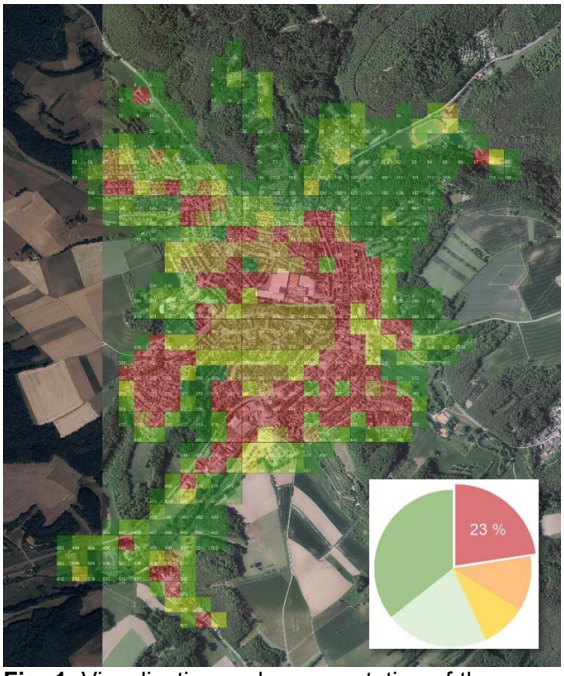


Fig. 1: Visualisation and representation of the areas within the municipality of Otterberg, Germany, with a high risk of local overheating (red areas).

The visualisation in Figure 1 indicates the areas that represent spaces with a high potential for overheating or heat stress (red areas) in the summer months within the example municipality of Otterberg, Germany, due to the interaction of various factors (e.g. degree of sealing, proportion of green spaces, building density). At present, around 23% of the municipal area can already be identified as local climatic risk areas, which corresponds to an area of around 96 football pitches.

3.2 Determination of the climate twin

Once the "matrix method" has been completed, the calculated local results are linked with the search for a climate-equivalent twin. For this purpose, a calculation method developed by RWTH Aachen University (Germany) and Forschungszentrum Jülich (Germany) is used, which makes it possible to transfer the municipality of today into a predicted local climatic situation of tomorrow (Reuter et al. 2023). This makes it possible to use innovative applied planning-oriented urban climatology, which bases the planning of the present on a local climate scenario of the future, on the basis of knowledge of the "climate twin" and its climate adaptability for future-oriented, climate-adapted designs and recommendations for action (see Fig. 2).

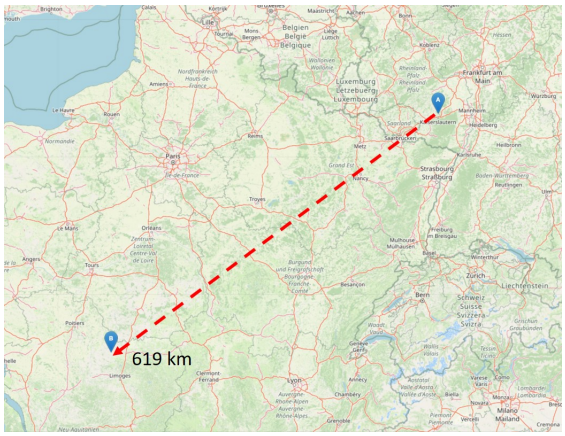


Fig. 2: Exemplary illustration of the ‘migration’ of the municipality of Otterberg, Germany, according to the calculation of the “climate twin” to the region of the French municipality of Le Dorat.

The calculation of the “climate twin” of the example municipality of Otterberg results in a shift in regional climatic conditions of around 600 km in a south-westerly direction, which roughly corresponds to the location of the French municipality of Le Dorat. Otterberg would therefore have to expect an increase in the average air temperature of about 1.9 K by 2080 and a lack of precipitation in the summer month.
The calculation of the "climate twin" is based on data from the CORDEX project for calculating climate analogues. The "Coordinated Regional Climate Downscaling Experiment" is an international initiative for regional climate modelling. The aim of CORDEX is to develop high-resolution climate simulations for regions in order to better understand the effects of climate change at regional level. The initiative focuses on the development and application of regional climate models that are tailored to specific geographical areas. These models can simulate climate elements such as temperature, precipitation, wind speed and wind direction on a much finer spatial scale than global climate models.

3.3 AI-supported data acquisition of the current situation

Although the "matrix method" is very transparent, user-friendly and, above all, transferable, the inventory reveals a high personnel and time expenditure. In order to reduce this, the settlement-structural characteristics and climate as well as environmental information required for the survey are to be automated as far as possible with the help of AI-based processes. The aim here is to make the assessment even more accessible and easier to use and to make it transferable to all areas even more quickly. Accordingly, the University of Kaiserslautern-Landau and the German Research Centre for Artificial Intelligence (DFKI) in Kaiserslautern are developing an AI-based process that largely takes over the urban climate inventory of the "matrix method" through the intelligent aggregation and analysis of relevant data sources such as cadastral and remote sensing data. DFKI in Kaiserslautern has already developed various AI applications in this context, which, for example, makes it possible to recognise different tree species on the basis of remote sensing data in order to create a tree register (Mayer et al. 2022). This knowledge is to be used to train the AI on the basis of the results of the "matrix method" so that these necessary parameters no longer have to be determined "by hand" and "on foot", but are recognised directly by the AI. The development of this AI-based approach makes it possible to quickly record the current state of the municipality and, based on this, to identify appropriate fields of action for a municipality and derive planning-oriented, climate-adapted measures after analysing the results on the basis of the "matrix method". By further processing the municipality's existing climate and geodata (to verify the AI data) and using remote sensing data (including satellite data), a planning-relevant real-time scenario is developed for the respective municipality in which the AI visually delineates different spaces or grids. Based on these grids, it is then possible to divide the area under consideration, e.g. a district or neighbourhood, into different areas that provide information on whether they are areas with an increased risk of flooding due to heavy rainfall or areas with a tendency to overheat. On this basis, future-oriented recommendations for action can be derived, as this AI-generated and spatially visualisable representation enables rapid identification of local climatic risk areas depending on, for example, heat stress or heavy rainfall events (Mayer et al. 2024).
The combination of the "matrix method" (urban climate inventory in order to make evidence-based and adequate statements on the need for climate-adapted change in existing buildings), the calculation of the "climate twin" (climate-equivalent twin) in the present and an AI-supported recording of the current situation (settlement-climatic inventory using cadastral and remote sensing data for rapid identification of local climatic risk areas) enables the development of innovative, future-oriented, climate-adapted designs and recommendations for action on the basis of future local climatic scenarios. This is a promising new tool, particularly for future, adapted and resilient urban development, which enables interdisciplinary planning for local authorities. With this tool, so-called "what-if scenarios" can be integrated into AI-supported, future-orientated planning processes (see Fig. 3).
The visualisation of Figure 3 indicates a future scenario for the areas that represent areas with a high potential for overheating or heat stress (red areas) in the summer months within the example municipality of Otterberg, Germany, due to the interaction of various factors (including degree of sealing, proportion of green areas, building density). The forecast is based on knowledge of the potential temperature rise up to 2080 from the calculation of the "Le Dorat" climate twin (see Fig. 2). What is striking is the growing proportion of heat-prone areas to 33.6%, which corresponds to an area of around 140 football pitches. It is primarily the yellow and orange transition areas shown in Fig. 1 that will suffer a negative local climatic effect in the future due to the lack of climate adaptation measures.



Fig. 3: Visualisation of the future forecast for the year 2080 of the areas within the municipality of Otterberg, Germany, with a high risk of local overheating (red areas) without having implemented preventive climate adaptation measures.

4. OUTLOOK & CHALLENGE

By pooling knowledge, extensive scientific information is to be made available to local authorities directly on site in line with their needs. This will create a basis for accelerated and at the same time scientifically sound decisions on urban and municipal climate adaptation. The aim is to enable stakeholders to better deal with uncertainties. As already mentioned, the greatest challenge of climate change is that it is difficult to predict which of the predicted impacts will actually materialise and, above all, when. The available tools are intended to bring about a rethink in planning practice in order to implement the appropriate future-oriented strategy in the present in order to be resilient for "tomorrow". The so-called "no-regret strategy" in particular offers an approach for implementing measures to increase resilience and enhance the adaptability of an area (Hartz 2011). These measures are selected and designed in such a way that they are recognised as useful and generate added value regardless of the occurrence of the projected climate change impacts. The implementation options can be selected and designed according to the specifications of the approach generated in the project in such a way that they are recognised as sensible and forward-looking regardless of when the projected climate impacts occur. This includes a second strategy - the so-called "soft" strategy (Hartz, 2011) - as complex and cost-intensive technical solutions are not always appropriate or necessary. With increasing uncertainties and risks in an area, specially adapted uses, support programmes and monitoring systems can represent sensible alternatives. Long-term investments in highly uncertain change processes are often expensive mistakes. Therefore, in some areas, "smaller" medium-term solutions can certainly be an option. These are made available to the user as examples and serve as a local decision-making aid for municipal decision-makers for the next steps (see Fig. 4).

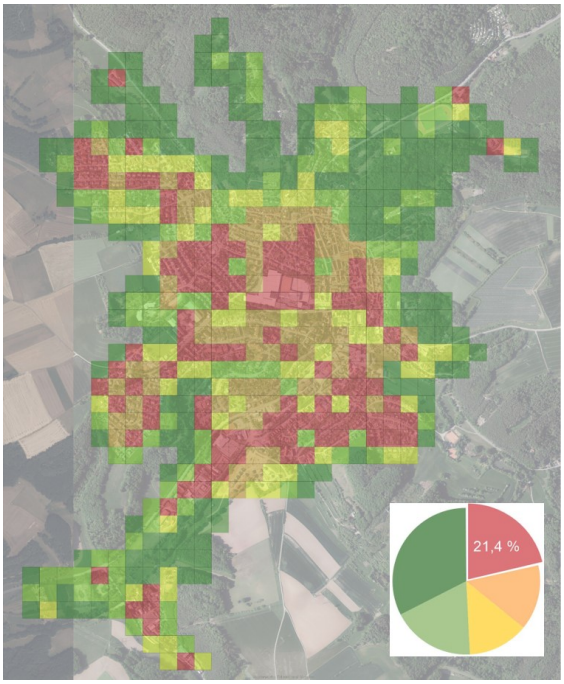


Fig. 4: Visualisation of the future forecast for the year 2080 of the areas within the municipality of Otterberg, Germany, with a high risk of local overheating (red areas) with preventive climate adaptation measures implemented.

The visualisation and comparison of two future scenarios in Figure 2 and Figure 4 offers areas with a high potential for overheating or heat stress (red areas) in the summer months within the example municipality of Otterberg due to the interaction of various factors (e.g. degree of sealing, proportion of green areas, building density). Whilst figure 2 shows the increased number of risk areas without corresponding adaptation measures in the present, Figure 4, in contrast, indicates the future scenario for the year 2080, but with climate adaptation measures implemented in advance based on knowledge of the current risk areas. As a result, the area at risk from heat can be significantly reduced and there will be no significant deterioration in the local climate in 2080 and reaches a value of 21.4% (89 football pitches) risk areas for overheating.

The project "ÖkoHaSie 2050" is based on a concept that has a very broad technical basis and, as a result, provides a tool that is easy to understand, easy to use and transferable at any time due to its simple approach and can serve as a decision-making aid in the context of the planning implementation of local climate adaptation measures.

The digital tool and the application-oriented, climate- and location-adapted planning are being developed and processed in line with requirements within the framework of the overarching scientific question in a transdisciplinary manner on the basis of scientific expertise from the fields of computer science, mathematics, physical geography and urban planning

and further developed in close cooperation with local authority stakeholders.

In an integrative, transdisciplinary approach, the project will combine various key topics, as different relevant issues and research needs will be addressed and linked in order to ensure a clear reference to the objective of "ÖkoHaSie 2050".

The overarching aim is to establish a link between the current local situation and how this can be adapted to the potential local climate changes of the coming decades against the backdrop of climate change. The development and provision of an intelligent planning and decision support tool enables interested municipalities to calculate a "climate twin" in order to identify the local climatic fields of action or risk areas, e.g. from the perspective of urban overheating or heavy rainfall events, and how action should be taken in the present from a planning perspective. This enables targeted, future-oriented municipal climate adaptation action in order to generate urban development and land-use planning findings today from the areas that are already adapted to local climate events, e.g. those forecast for the example municipality of Otterberg, Germany, (see Fig. 4) for the years 2080 and 2100.

Due to its ease of use and transferability to other areas, "ÖkoHaSie 2050" can be applied regardless of the uncertain regional effects of climate change and extreme weather events, which are already difficult to predict. However, this brings the precautionary aspect, dealing with uncertainties and learning processes more to the fore. This is a central prerequisite for spatial development strategies for climate change. The tool developed enables a future-oriented approach and initiates an important and often underestimated learning process in urban and regional development, which ties in with the concept of "learning urban regions" (Stein 2007) and takes on an additional, sustainable dimension in times of climate change and the associated risks.

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