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Compact or cool? The impact of Brownfield redevelopment on inner-city micro climate

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Highlights

- We evaluate potential tensions between the Ecosystem Service of regulating the micro climate and urban densification processes using the case of the brownfield redevelopment of Bayerischer Bahnhof in Leipzig, Germany.
- Our findings demonstrate that a co-existence between regulating the urban micro-climate and dense urban structures is possible.
- Smart urban planning approaches can lead to cool *and* compact urban areas. Through ENVI-met modeling and virtual reality display system visualization, the complex connections between cool and compact could be assessed.

Abstract

While research has demonstrated that brownfield sites and vacant lots in inner-city areas have a cooling effect on the micro climate, less is known about how this effect changes during the redevelopment of a brownfield. It is often argued that redevelopment will lead to a loss of cooling effects. The connection between cool and compact cities is especially of interest as brownfield redevelopment is an important element of sustainable urban development strategies such as the dense city. We evaluate potential tensions between the Ecosystem Service of regulating the micro climate and urban densification processes using an empirical example, the case of the brownfield redevelopment of Bayerischer Bahnhof in Leipzig, Germany. We apply ENVI-met modeling and a virtual reality display system visualization to assess the complex connections between cool and compact cities. Our findings demonstrate that a co-existence between regulating the urban micro-climate and dense urban structures is possible. Smart urban planning approaches can, if properly implemented, reduce the so called “paradox of the compact city” and lead to cool *and* compact urban areas. Through ENVI-met modeling and virtual reality display system visualization, the complex connections between cool and compact could be assessed.

Keywords:

Brownfields; Revitalization; Micro climate; Ecosystem Services; Planning strategies; Trade-offs;

1. Introduction

Urban planning is acknowledged to be one key instrument to make cities more sustainable and to contribute to a more sustainable development on a global scale (UN, 2015; WBGU, 2016). One crucial aspect of sustainable urban planning is sustainable land use i.e. a more careful approach on what kind of land is utilized for urban development. Especially in cities with a growing population, decisions on which spaces are most appropriate for future development need to be made. Within this discussion re-developing formerly used but now vacant areas such as brownfields for new urban development projects seems to be a promising approach, especially if they are located in central locations (Bartke & Schwarze, 2015). A brownfield is defined as “any land or premise which has previously been used or developed and is not currently fully in use, although it may be partially occupied or utilized” and “may also be vacant, derelict or contaminated” (Alker et al., 2000). Another definition emphasizes the location and development needs and indicates that brownfields are mainly situated in developed urban areas and require intervention to bring them back to beneficial use (CABERNET, 2006). In this sense, brownfields differ from bare soils or non-used agricultural areas. Brownfields have been part of the urban structure and vacant buildings, abandoned production facilities or contamination due to former industrial uses are often visible signs of their former purposes. Brownfields which are located in the inner-city, close to the inner-city or close to other urban sub-centers possess in general a good connection to existing technical and social infrastructures. Through their re-use consumption of land in the outskirts can be reduced. Reuse/Redevelopment (both terms are used synonymously in this article) of brownfields is therefore part of popular and wide-spread sustainable urban design principles such as the compact city and densification (Haaland & van den Bosch, 2015, Greenberg et al., 2001; Dorsey, 2003) and is highlighted also in policy documents such as the Leipzig Charta or the New Urban Agenda (UN Habitat, 2016). Glaeser even considers the density of a city as decisive element of the “triumph of the city” and the reason why cities make their inhabitants “richer, smarter, greener, healthier, and happier” (Glaeser, 2011). Through the reuse of inner-city brownfields, land use change from agricultural land or forests to urbanized land can be diminished and urban sprawl tendencies reduced. In order to limit land consumption, the German planning law for example champions inner development before outer development. In Germany, the idea of an efficient use of land is considered as a general principle of urban planning (§1a (2) German building law code, see also §13a German building law code, for further details see Gstach & Berding, 2016). The premise *Inner development before outer development* (“Innenentwicklung vor Außenentwicklung”) shows that the re-use of inner brownfields is prioritized over the new sealing of land.

However, the ostensible consensus towards re-using brownfields as part of sustainable urban development strategies is challenged through recent urban practices such as adaptation to climate change or the consideration of Ecosystem Services in urban planning. While the creation of compact urban structures has been for a long time the mantra of sustainable urban planning, the role of non-build areas in inner-city locations (f.e. parks, green spaces and also brownfields) has received increasing attention (Gomez-Baggethun & Barton, 2013; Atkinson et al. 2014; Baro et al., 2014). Non-build areas can provide a range of different Ecosystem Services such as climate regulation, air purification, pollination, opportunities for recreation and experiences contributing to health benefits

and many others more (Faehnle et al. 2015). Those ESS are hard to find in denser urban structures with few non-build areas.

This more critical view on densification is also supported by the “paradox of the compact city”, which says that the most compact and dense structures in cities are those which have the most negative balance for almost every urban Ecosystem Service. However, exactly those build structures are favored by the urban planning community for being the most energy efficient and supportive for social cohesion (Larondelle et al., 2014; Larondelle & Lauf, 2016).

This trade-off between Ecosystem Services and compact cities is not a new phenomenon for urban development and planning: Acknowledging that land-use decisions are highly complex and synergies and trade-offs between different types of Ecosystem Services (Haase et al., 2012), as well as between other social and economic targets exist, should be part of the job description of any urban planner. This way, urban planning can be described in a broad sense as achieving the common good however difficult a clear definition of the common good in specific urban contexts may be (Fainstein, 2010). The aim of our article is not to develop a general decision making tool which helps to choose between densification through brownfield redevelopment or maintaining urban Ecosystem Services on vacant sites. As we believe that those decisions depend highly on the local situation, the place-specific definition of urban sustainability and the specific needs and constraints of each city, we chose a more modest objective of our article: We evaluate potential tensions between one specific Ecosystem Service, the regulation of the micro climate and densification processes through brownfield redevelopment using an empirical example, the case of the brownfield redevelopment of Bayerischer Bahnhof in Leipzig.

Our objective is two-fold: Through combining micro-climate modeling, visualization, urban design proposals and socio-economic data we show how different disciplines (urban studies, meteorology as well as computer science) work together and develop interdisciplinary methods on how to assess the question of cool or compact cities. The second aim is to show the potential effects of brownfield redevelopment and to reflect on the paradox of the compact city in this specific empirical case.

The article is structured as follows: In section 2 we describe the Ecosystem Service of regulating the micro-climate and its relation to brownfield redevelopment. Section 3 explains the methods we used, followed by the presentation of our research results and a brief description of our case study city (Section 4). The results are then discussed in the final section of the article.

2. Brownfields and the Ecosystem Service of regulating the micro-climate: Compact or cool cities?

The concept of Ecosystem Services gained importance in the last years and is considered to have the potential to contribute to sustainable urban transformations (Ahern et al. 2014; Brink et al., 2016; Gomez-Baggethun & Barton, 2013; Krellenberg et al., 2016; Wamsler et al., 2014). Ecosystem Services (ESS), defined as the contributions that ecosystems make to human well-being (Haines-Young & Potschin, 2010) are seen as crucial element to increase the quality of life of urban dwellers (Gomez-Baggethun & Barton, 2013). Research has identified a broad array of ESS which emerge in cities (TEEB_DE, 2016). As a result of the dense, heterogeneous and dynamic land cover patterns of urban regions a variety of overlaying ecosystem processes, functions and services can be found in cities (Haase et al., 2010). These urban ESS contain local climate regulation, recreation and biodiversity potential, food supply, above ground carbon storage, reductions in the air pollution, enhanced public ecological knowledge as well as direct health benefits as for example lower prevalence of early childhood asthmas (Faehnle et al., 2015; Haase et al., 2012; TEEB_DE, 2016). In line with the Millennium Ecosystem assessment (MA, 2005) and the TEEB approach (TEEB, 2010) also urban ESS

can be divided in provisioning services, regulating services, habitat or supporting services and cultural services. These ESS are provided by different types of urban areas (Faehnle et al., 2015): Besides green and blue infrastructures such as parks and water areas, also private gardens, community-managed pocket parks, green roofs or brownfields are ESS sources (Dennis & James, 2016; Haase et al., 2012).

Concerning the urban micro-climate, it has been shown that urban green spaces have cooling effects and are therefore important instruments to counteract the Urban Heat Island effect (Jaganmohan et al., 2016; Brebbia & Mander, 2006). The effect depends on the type of urban green space; for example the cooling effect of urban forests is higher than of urban parks (Jaganmohan et al., 2016). Brownfields also influence the local climate and have cooling effects, depending on their form of vegetation (Mathey et al., 2015). Furthermore, brownfields may not only help to regulate the local climate, but also store CO₂ and may provide food through urban gardening activities (Rosol, 2006). Nevertheless, the ESS literature has yet hardly focused on brownfields even though the importance of these types of areas for urban ESS is acknowledged (Haase et al., 2012).

This article deals with the relation between brownfield re-use, urban planning and the ESS of regulating the micro-climate. While research has shown that brownfields can provide micro-climatic cooling effects little is known about the effect of brownfield re-use on this kind of ESS. Further knowledge is required in order to reveal potential contradictions between compact and cool cities.

This article focuses on the tension between the urban planning strategy of compact cities and prioritization of brownfield revitalization on the one hand and maintaining the existing Ecosystem Service on regulating the micro climate on the other hand. While both strategies refer to sustainable urban development they seem to be contradictory and mutually exclusive.

In the German urban planning context, this tension has been discussed as “doppelte Innenentwicklung” (double inner development). Double inner development signifies to address the requirements of dense urban structures but at the same time upgrade the existing non-built areas in order to maintain free spaces and the benefits they provide for the quality of life (Gstach & Berding, 2016). How this concept is implemented in current urban planning practices however, is not clear yet and requires further investigation (Böhm et al., 2015).

Recently, a shift of the research focus concerning the relation between green infrastructure and social cohesion can be observed. New approaches such as Haase et al. (2017) or Hansen & Pauleit (2014) consider green infrastructure not as something per se positive which leads automatically to socially sustainable outcomes. Rather, it is argued that for example the construction of parks may result in outcomes such as rising housing prices which are connected with social polarization and gentrification issues. While this approach mainly focuses on the social impacts of new green infrastructure and is therefore not directly directed to brownfield redevelopment, it reminds us that cities are socially heterogeneous entities and changes concerning existing ESS might have different outcomes for different social groups. In this way, this research strand relates closely to the concept of environmental justice (Wolch et al., 2014).

3. Methods

Our article analyzes how inner-city land-use changes from vacant to re-used urban land influence the micro-climate, especially the urban heat. In contrast to other research (Atkinson et al., 2014) our focus is not exclusively on the transformation of brownfields to greenspace but on re-using derelict land as location for new urban elements like streets, housing but also private gardens and parks. We analyze in an ex-ante approach what effect this kind of re-use will have on the ESS of regulating local

climate. This is done in the case study, the brownfield Bayerischer Bahnhof in Leipzig, Germany using micro-meteorological modeling tools and comparing the current situation with the urban design concept which is envisaged to be implemented in the next couple of years.

One of the main challenges is to merge data from different origins: Data from climate modeling, from urban design concepts as well as socio-economic data. We argue that an integrative view on the different data is urgently needed in order to grasp the complexity of brownfield revitalization. This way, our approach has an explorative character and is considered to be transferable to questions of brownfield re-development in other urban contexts.

Our research is focused on one brownfield site and the surrounding neighborhoods (approximately a 200 m buffer). The ENVI-met simulations were made for a study area of around 12,1 ha and include a large part of the whole Bayerischer Bahnhof area and its surrounding neighborhoods. The micro-meteorological modeling tool ENVI-met (Bruse, 2009) was applied for a hot summer day in combination with Geographical Information System (GIS) based analyses of socio-economic data as well as the evaluation of the planning process and the legal framework. Furthermore, remote sensing data as well as Google Earth data have been used and compared with photos of site visits in order to capture the current state of the brownfield site. In cities, the thermal comfort is strongly modified by the urban structure. To study this impact of land use changes, ENVI-met calculations were made, which simulate the micro-scale interactions between different urban surfaces and the urban atmospheric boundary layer. Important aspects are the soil sealing (Fini et al., 2017; Barthel et al. 2017) and the type of vegetation cover (Jaganmohan et al., 2016) that can modify urban thermal conditions by means of changed evapotranspiration. The variation of boundary conditions allows considering the influence of climate change by representing different meso-scale conditions.

ENVI-met is a three-dimensional non-hydrostatic model together with a vegetation model, an atmosphere model including radiative transfer model, and a one dimensional soil model (Bruse & Fleer, 1998; Helbig et al., 2015). The user of ENVI-met has to implement the geometry of the study area (size ca. 1.100 m x 1.100m) into the area-input file which represents buildings, plants and different surfaces in a regular three-dimensional grid (for example, see Fig. 4). A grid size of 3m x 3m x 1m was used with a 20% increase in grid cell heights. In the simulations of the analyzed brownfield sandy and loamy soil, asphalt roads, brick roads, and concrete pavement as well as dense grass, hedges, and trees (15m height) have been included according to the current and planned land use. The current situation as well as the planned development has been also used for the simulation of the built structures. The area consists mainly of 4 to 6 story buildings in block structures with heights between 12 and 20 m and with green courtyards. In addition, data including start and boundary values for the iterative solution of the partial differential equations is utilized. These parameters include, among others, air temperature and relative humidity at 2,500 m height, wind speed and wind direction at 10m height, cloud coverage, inside temperature of all buildings, albedo of roofs and walls, soil temperature and moisture in three different depths.

By conducting multiple simulation runs with ENVI-met it is possible to simulate different weather situations and to compare different building scenarios. The latter comprise scenarios with green cover (brownfield scenario) and with buildings constructed according to the re-urbanization plan (re-densification scenario). For analyzing ENVI-met simulation results 2D (Leonardo for ENVI-met) and 3D (ParaView, Ahrens et al., 2005) scientific visualization software is used. Multi-variate three-dimensional simulation results can be explored with a self-developed ENVI-met ParaView-plugin (Bilke, 2016). Especially complex wind flow behavior in combination with related parameters such as potential temperature is best explored interactively using a Virtual Reality (VR) display

system (Bilke et al., 2014) to convey its influence on temperature differences between simulation scenarios (Helbig et al., 2015). Based on simulations of the different building scenarios, the impact of the re-urbanization measures on thermal comfort is assessed.

Furthermore, data on socio-economic development of the surrounding neighborhoods was evaluated in order to view the effects of the brownfield revitalization on existing social structures. As the ENVI-met simulation is realized on a smaller scale, also the data on socio-economic development was used on a small, disaggregated level. Therefore, official block-level data from the statistical office of the city of Leipzig displaying population development but also the share of households living from public subsidy was analyzed and displayed (see Fig. 10 and 11). Due to the protection of privacy data, the selection of available data is limited and only selected indicators regarding socio-economic development on block-level were considered.

The 3D visualization of data in such complex scenarios is challenging regarding data integration and application of suitable visualization methods (Helbig et al., 2017). The synthesis of heterogeneous data from various sources needs the implementation of interfaces used to integrate all related data in one framework suitable for interactive visualization and presentation in VR environments (Rink et al., 2017). These environments provide high immersion and intuitive interactions with scientific data sets. They are predestinated for our study by providing intuitive visualizations which are easy to interpret even by non-experts thus facilitating the discussion between stakeholders in urban planning processes.

The application of suitable visualization methods for the scenario is challenging because of the number of relevant parameters which have to be displayed simultaneously. The visual representations of the parameter values have to be chosen carefully to avoid clutter and occlusion. For the relevant parameters of the scenario, the following representations have been chosen:

- **Buildings** (from the ENVI-met simulation) are represented by simplified models; the social data on block level has no detailed information about buildings, therefore a block of buildings is automatically generated based on the blocks footprint shape
 - **Vegetation** is represented by images projected on the virtual ground (surfaces textures); for trees rectilinear-aligned half-transparent images (billboards) are used
 - **Wind** is represented by streamlines, velocity values are represented by color
 - **Temperature** is represented by texture, values are represented by color
 - **Population development** is represented by the color of the roof of the buildings
 - **Social structure** is represented by spheres in between the respective block, values are represented by the size of the sphere (high values are thereby more present than low ones)
- In addition to these parameters related to the physical surrounding, also other aspects influence the local climate. Land use changes linked with human behavior lead directly and indirectly to anthropogenic emissions of heat due to the use of air conditioning, industrial production and traffic (Girgis et al., 2016). Furthermore anthropogenic air pollutants might attenuate the sun radiation and change the heating of the surface (Hirano & Yoshida, 2016). However, as this article focuses on the role of urban planning, the anthropogenic influence on the micro climate has not been considered in the modeling. Previous studies concluded that urban structures play the most important role (Rizwan et al., 2008); in addition further analyses on the relation between physical surrounding and human behavior will be needed.

4. Case study Leipzig – Bayerischer Bahnhof - ESS and brownfields in a re-growing city

The case of Leipzig exemplarily presents a re-growing city: After decades of decline, Leipzig is now one of the fastest growing cities in Germany. The city encountered a long period of population decline after the political turnaround in 1989 from 530.010 inhabitants in 1989 to 437.101 inhabitants in 1998. After the incorporation of some suburbs, around 495.000 inhabitants were living in Leipzig in the years from 2000. During this time, planning instruments such as low-density housing (e.g. town houses), renaturation of brownfields, and renovation of vacant housing were implemented in the frame of the Stadtumbau-Ost national funding scheme to maintain the inner-city structures despite a declining population (Haase & Rink, 2015). Leipzig has become a forerunner city concerning the handling of brownfields: innovative interim use strategies or the creation of urban forests (Rink & Arndt, 2016; Rall & Haase, 2011) were developed in order to deal with an increasing amount of brownfields. Since the first decade of the 2000s population is increasing at fast pace and currently more than 560.000 people live in Leipzig. This growth needs new spaces and makes interim uses for brownfields less important. New neighborhoods for more than 10,000 inhabitants are planned in inner-city or close to inner-city areas, which are mainly directed at middle class households (Haase & Rink, 2015). The population density of Leipzig is with 1,882 inhabitants per km² still considerably lower than the average of German cities with more than 500,000 inhabitants (2,702 inhabitants per km²) and therefore potentials for denser and more compact urban structures seem to exist in Leipzig. However, the population density increased in the last years and Südvorstadt and other inner-city neighborhoods already have high density number of over 10,000 inhabitants per km² (Destatis, 2017). Referring to sustainable urban design strategies such as the compact city, the masterplan of Leipzig states that the provision of new areas for urban expansion should primarily be found within the urban pattern. Vacant land and brownfield areas with formerly industrial or residential uses need to be redeveloped in order to reduce land-use at the outskirts and to re-densify inner-city areas. Also the new housing concept of the city of Leipzig highlights the need for the construction of dense residential areas on brownfields.

One of these brownfields is the area of Bayerischer Bahnhof, a former railway station and train repair area which hasn't been used since 2003 (Figure 2). The size of the area is around 40 ha and currently only a few buildings used formerly as train maintenance facilities are located on the site. The rest of the site consists of vegetation, mainly grassland but also areas with higher trees (see Figure 3).

The area is only partially accessible and no official uses take place there. Increasing population pressure and the short distance to Leipzig's inner-city caused a rising interest in this area. The city of Leipzig and the Deutsche Bahn AG as the former owner of the area organized an urban design competition for a new urban district in 2010 (Stadt Leipzig, 2011). The winning concept intends to restructure the area and provide space for new residential and commercial uses. The area has been bought by a private company which aims to develop it in accordance with the guidelines of the winning design competition concept (see Figure 4 for the design concept).

Until now, discordance prevails on when the concept will be implemented due to land property issues and discussions between the city authorities and the investor. Nevertheless the municipal planning authority developed a masterplan based on the winning design concept and while some changes concerning details may occur, it can be assumed that the general ideas of the concept will be implemented. In order to grasp the relation between the ESS of local climate regulation and urban planning practices, we compare the current situation and the supposed future situation (after the

realization of the built development). We focus on the center part of the masterplan, where most construction will take place and therefore the biggest effects on the micro-climate are expected.

4.1 Regulating the local climate

The simulations have been done for the 21st of July, 2015, which was a representative day for hot summer weather situations in Leipzig (maximum temperatures exceeding 30° C, minimum temperatures near 20° C, www.dwd.de, weather station #10469, Leipzig/Halle, we used Kelvin for relative and Celsius for absolute temperatures). Leipzig (560,472 inhabitants on 297.36 km² at 144m altitude located at 51.3396955° N, 12.3730747° E in Central Europe) has Cfb climate (temperate humid warm summer climate according to Köppen-Geiger; 512mm annual precipitation). Prevailing wind directions are between W and SW and wind speeds up to 30km/h (at 10m height). Excessive heat episodes often occur during high air-pressure situations, when wind comes from East.

Two different land-use scenarios have been implemented: The first scenario represented the current situation, in which the area is a vacant brownfield area with only a few, mainly abandoned houses and succession vegetation, which emerged unplanned as a consequence of a decade without uses (see Figure 5 for the representation of the area input data in ENVI-met). The second scenario implemented the design outcome of the planning competition, comprising seven new housing blocks and a green space area. The modeling was done for the three wind directions east, west and south and for daytime (1 pm) and night time (11 pm). The calculated spatial distribution of air temperature 1.5 m above ground was considered in the following comparative discussion.

The modeling revealed that changes of the current situation of the brownfield not only have effects on the former brownfield area, but also influence the neighboring districts. Differences concerning the day/night time and the wind direction can be easily identified using scientific visualization software. Comparing micrometeorological simulations for the current land-use situation (Figure 5) with simulations based on the planned restructuring (Figure 4), we assess the impact of brownfield revitalization on microclimate in an ex-ante approach. Atmospheric conditions will become modified in following ways:

- a) During day time in a south wind direction, the realization of the new urban design concept would result in partly increasing temperatures on the revitalized site. Mainly in the southern part of the new construction area, places with higher temperature will appear due to the new houses which act as obstacles and avoid that cooling air can enter the area (Figure 6). Nevertheless, the new construction will also lead to cooling effects. This happens on the site itself, but more importantly, also the neighboring northern part of the area will have cooler temperature (up to 0.6 K lower) due to changing wind patterns. If we compare this situation with other wind direction scenarios, similar effects appear. For example, in an east wind scenario, the cooling effects will be mainly in the western part of the area Bayerischer Bahnhof (Figure 6). The newly constructed blocks cause changing wind streams (Figure 7) which results in cooling effects for the existent buildings and lead to a temperature reduction of 0.5-1.0 Kelvin. Analogously, west wind causes cooling effects mainly in the eastern part of the area (not shown here).

- b) During the night, the new buildings will mostly increase air temperatures by up to 0.5 K. This pattern is basically different from the cooling induced by the new buildings during daytime. For example, at 11 pm for a south wind scenario the area of Bayerischer Bahnhof itself but also the bordering northern part encounters higher temperatures of up to 1 K (not shown here). A similar situation appears in the east and west wind scenario: East wind (Figure 8) causes higher temperatures in the western part of the area and the bordering neighborhood and west wind leads to increasing temperatures in the eastern part of the area and the building blocks located at the Eastern fringe of the area.
- c) The local wind conditions change fundamentally (Figure 10). As a result of the newly constructed houses the wind tends to form jets along the streets and canyons between the new houses and this is continued to the surrounding neighborhoods and affects the comfort of their inhabitants.

These results show the two-fold impact on local climate of a potential revitalization of the brownfield: During day time, a cooling effect can be identified, not only on the area of Bayerischer Bahnhof itself but also for the bordering neighborhoods. During night time, the situation changes, temperature increases are visible on the area and the surrounding neighborhoods.

We can state that as a result of the urban design concept with its park-like greenspace the ESS function of local climate regulation is not in general at risk through the redevelopment.

4.2 Brownfield revitalization embedded in existing social structures

Environmental justice literature and recent ESS work (Wolch et al., 2014; Hansen & Pauleit, 2014) emphasized the need to consider the social context in discussions on urban sustainability: Which social groups do benefit from ESS and which not? Do brownfield revitalization projects even entail growing ecological inequalities? It is beyond the scope of this article to discuss the connections between brownfield revitalization and environmental justice in general, however the question of whether construction on a vacant lot and the related ESS changes have different impacts on different social groups seems to be important for an integrative view on social and ecological aspects of sustainable development. As mentioned earlier, our article therefore explores how data on social and ecological issues can be jointly analyzed and interactions between those two dimensions identified.

In order to reveal the socio-economic situation of the surrounding neighborhoods, the population development between the years 2000 to 2014 as well as the share of dwellers receiving unemployment pay ("Arbeitslosengeld 2-Empfänger") on block level was analyzed (see Figure 11, the share of Arbeitslosengeld 2-Empfänger is displayed in the category SBGIIA14 and the population development is displayed in the categories EWV00-14). The results show a clear division between the eastern and the western part of the area. While in Südvorstadt (the western part) a population growth in most of the blocks can be stated, in most of the blocks in Zentrum Süd-Ost (the eastern part) the population was shrinking. Compared to the development of the whole city, which faced a population increase of 10.4 % between 2000-2014 Südvorstadt registered an above-average growth and Zentrum-Süd an below average loss of population. The difference between Südvorstadt and Zentrum Süd-Ost also exists when we analyze the share of dwellers receiving unemployment pay. In the blocks of Zentrum Süd-Ost the percentages are higher than in Südvorstadt (see Fig. 11) and are also higher than the percentage on city-wide level which is 12,7%.

Even though the availability of two indicators only allows limited insights in the socio-economic development of the area, general tendencies are visible. While Südvorstadt faces a very dynamic

development, this process is slower in Zentrum Süd-Ost. Also, Zentrum Süd-Ost seems to provide a higher percentage of housing for poorer households.

Environmental justice literature has highlighted that environmental burdens are not socially equally distributed but that socially disadvantaged groups also often face environmental disadvantages. In our example, the question is, whether the planned construction on Bayerischer Bahnhof leads in neighborhoods with a socially more disadvantaged population to higher risks of urban heat than in neighborhoods with a more affluent population. While this does not allow drawing conclusions on the vulnerability or resilience of different social groups facing urban heat it shows whether potential changes in the ESS of regulation the micro climate are socio-spatially equally distributed or not.

Depending on the wind direction, cooling effects can be found in Südvorstadt but also in Zentrum Süd-Ost. The effects on the surrounding neighborhoods hardly differ, which allows us to conclude that the ESS changes concerning regulating the micro-climate have in both neighborhoods widely the same effects. There are no increasing risks of urban heat in the socially more disadvantaged neighborhood and increasing environmental injustice concerning cooling effects has not been detected in the climate modeling.

5. Discussion

This study has shown, that the redevelopment of an inner-city urban brownfield affects the local climate, not only on the site itself but also radiated to the surrounding neighborhood. Concerning the ESS of regulating the local climate and mitigation the urban heat island effect, the expected effects of the brownfield reuse were not necessarily negative. Different patterns (divided between day and night and wind directions) emerge but the general assumption that the creation of denser urban structures automatically reduces the ESS of regulation the micro-climate can be denied. Rather a co-existence (or, more positively coined a win-win-situation) between regulating the urban micro-climate and dense urban structures can be found for this case. In addition, the benefits of the increasing cooling effects are in the socially disadvantaged neighborhoods of Süd-Ost equal than in the more affluent neighborhoods of Südvorstadt.

Our case study does not allow for the conclusion that brownfield revitalization as part of compact city urban development strategy and the possibility to regulate the micro climate through green infrastructure are always compatible and the effects are in poor and more affluent neighborhoods always the same. We rather argue that reconciliation between compact and cool cities is possible and trade-offs do not automatically emerge. Smart urban planning approaches are needed and may, if properly implemented reduce the paradox of the compact city and lead to cool *and* compact and not to cool *or* compact cities. We acknowledge that only some aspects which are important for brownfield revitalization were considered in our study, while others such as the potential impact of brownfield development on housing prices in the neighborhood, or on how new construction impacts existing biodiversity on the brownfield were neglected. Furthermore, the approach presented here could be enlarged and different urban designs as well as different weather scenarios could be tested. Considering these issues in further research would enhance our understanding of the complexity of urban sustainability.

This paper also argues that the complex interactions between different dimensions of urban sustainability such as compactness, thermal comfort and environmental justice do require an integrative perspective on brownfield revitalization. Applying new modeling and visualization techniques and combine those with existing socio-economic data on a small scale helps to grasp the complexity of sustainable urban planning. Through adequate visualization methods, this complexity can also be communicated to local stakeholders and/or inhabitants and increase the transparency of the impacts of urban planning ideas which is known to be critical for the realization of planning projects. Ultimately, the best and most sustainable urban design concept remains useless, if it won't be implemented.

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Figure 1: 3 D-Visualization and interactive presentation of the modeling results of Bayerischer Bahnhof (Photo: Karsten Rink)

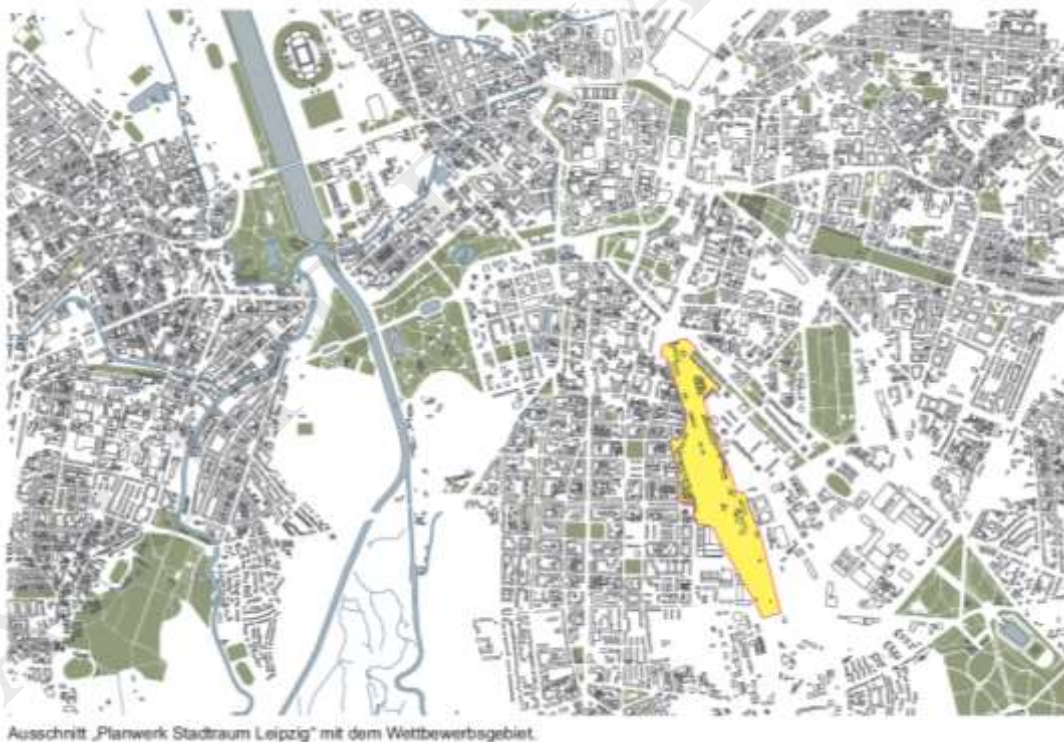


Figure 2: A map of downtown Leipzig with the study region (around Bayerischer Bahnhof) indicated in yellow (Stadt Leipzig, 2011).



Figure 3: Current state of the brownfield area around Bayerischer Bahnhof. (Photos: Florian Koch)



Figure 4: Details of the new concept for restructuring the region around Bayerischer Bahnhof (Stadt Leipzig, 2011).



Figure 5: Area input data illustrating the current land-use situation around the Bayerischer Bahnhof for modeling with ENVI-met. Note that this region is dominated by a large brownfield with uncultivated vegetation (meadows, lines of trees; plotted in green color) surrounded by residential blocks (in grey color).

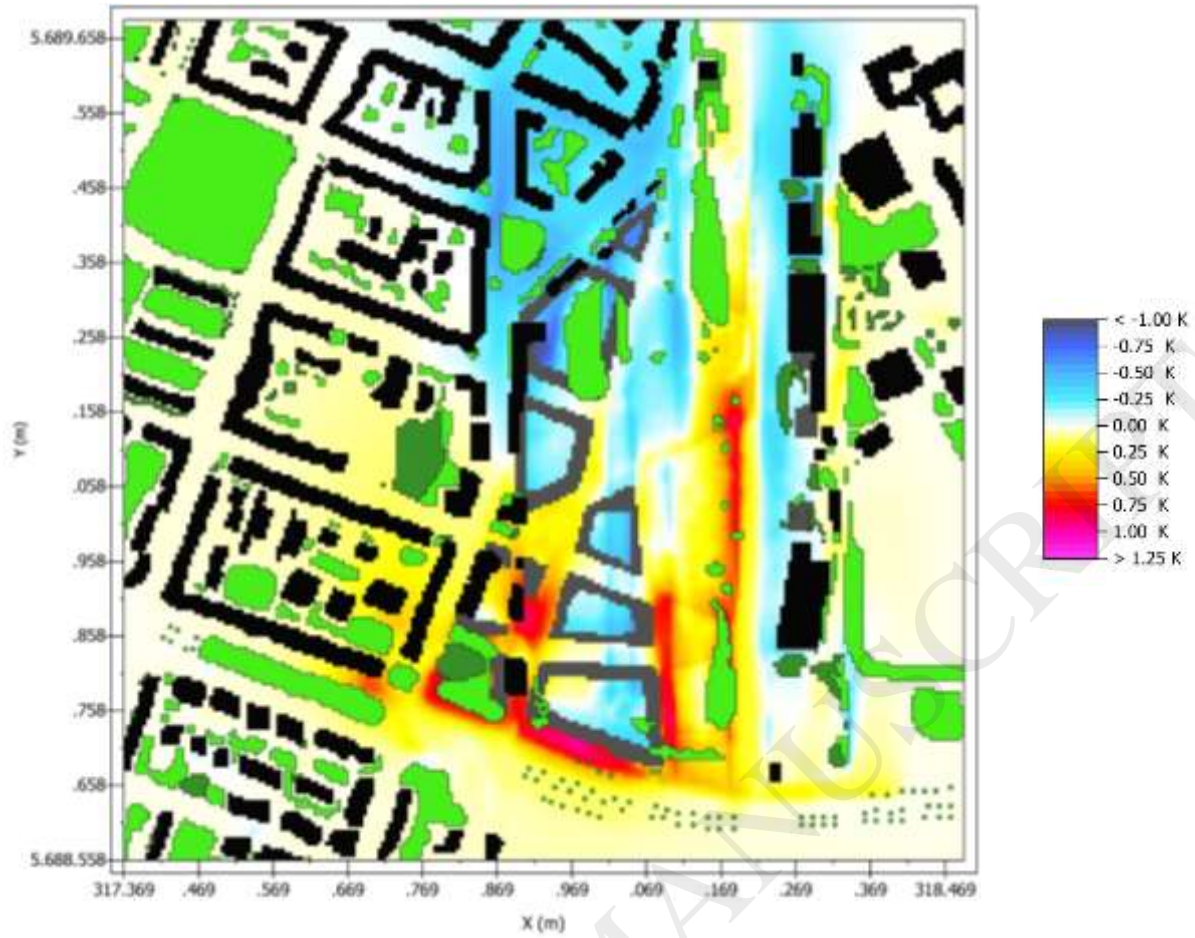


Figure 6: Differences of day-time air temperatures (1.5m above ground, 1 p.m.) between revitalized and current land-use scenarios. UTM coordinates, vegetation (green color), existing buildings (black) and new buildings (grey) are plotted. Simulation is valid for July 27th, 2015, 13:00 and wind from South (193°). Wind speed 4m/s at 10m above ground; roughness length 0.1m; initial temperature of atmosphere 20°C, 38% relative humidity 2m above ground, specific humidity 5.5 g/kg at 2500m above ground, initial soil temperature 20°C, albedo walls (0.3) roofs (0.4), building inside temperature 22°C, heat transmission walls (1.94W/m²K) roofs (6.0W/m²K), data update every 30 seconds.

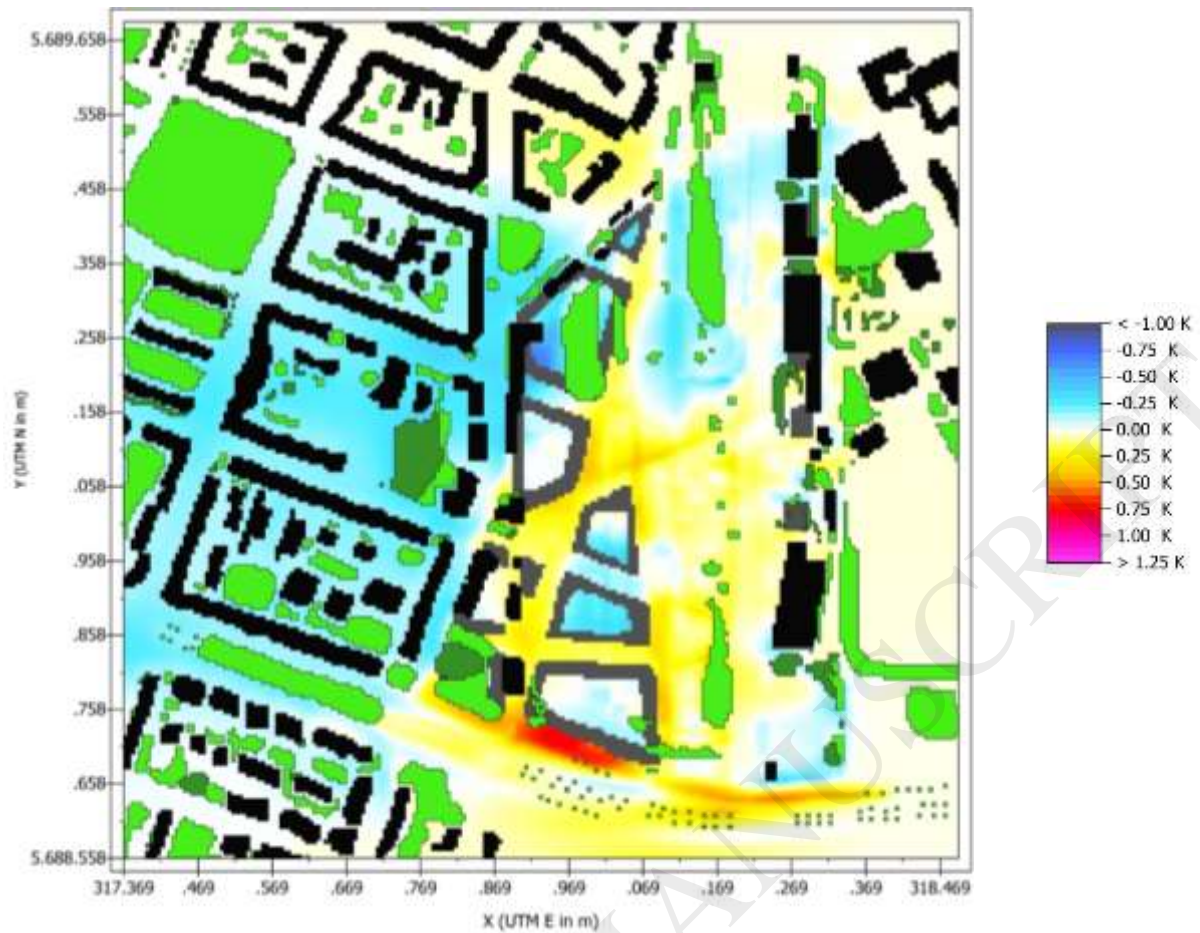


Figure 7: Differences of day-time air temperatures (1.5m above ground) between revitalized and current land-use scenarios. Same parameters as in Fig. 5, but for wind from East (103°)

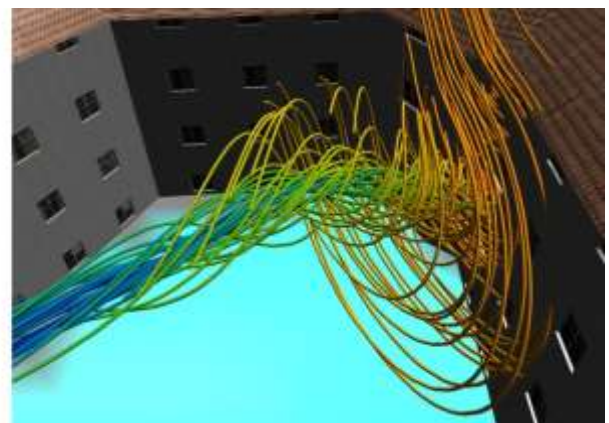
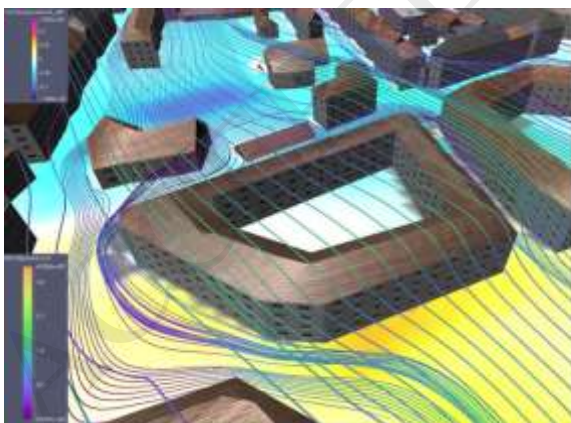


Figure 8: Warmer air is lifted to higher levels by new building facades (left). Turbulences (although with small velocities < 0.1 m/s) can occur leeward in inner courtyards (right).

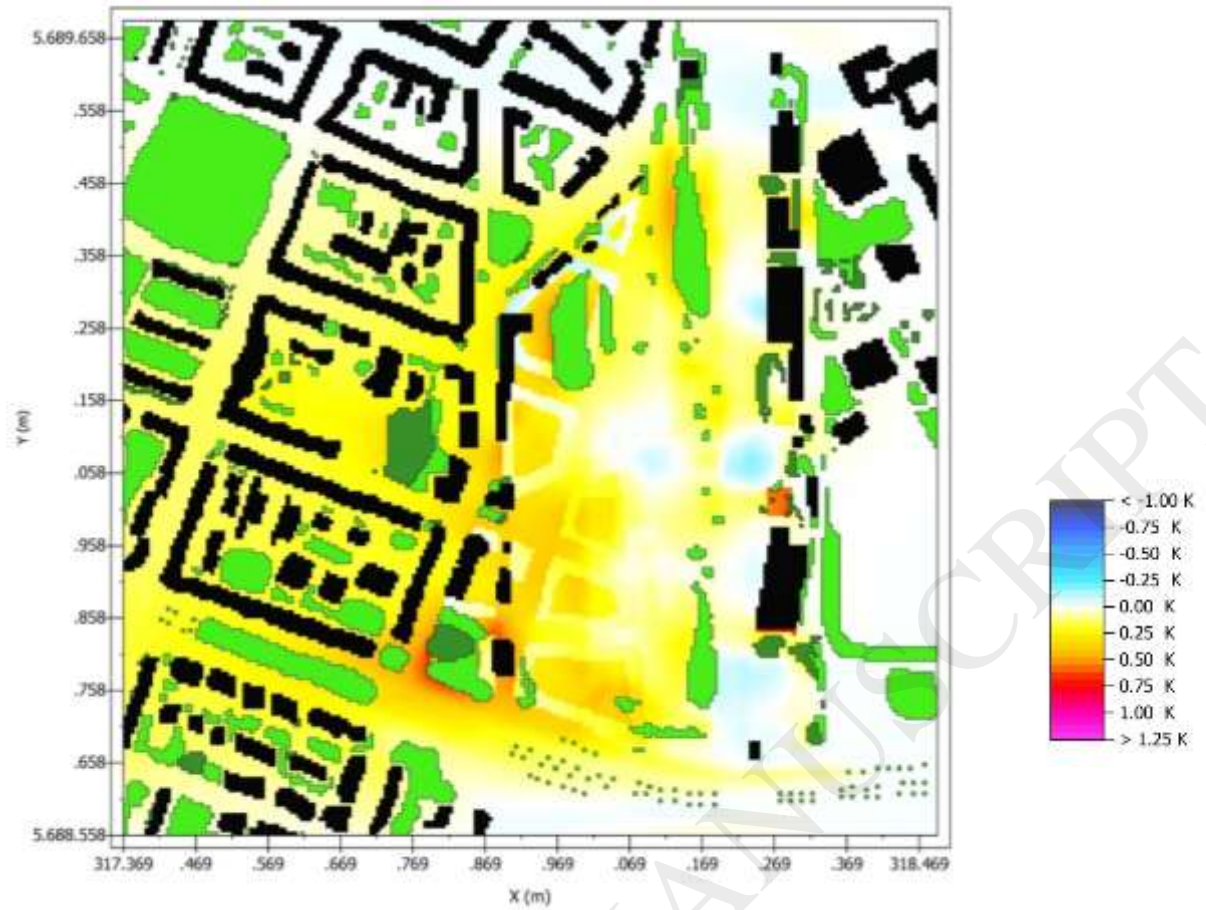


Figure 9: Differences of night-time air temperatures (1.5m above ground, 11 p.m.) between revitalized and current land-use scenarios. Same parameters as in Fig. 6, but for wind from East (103°)

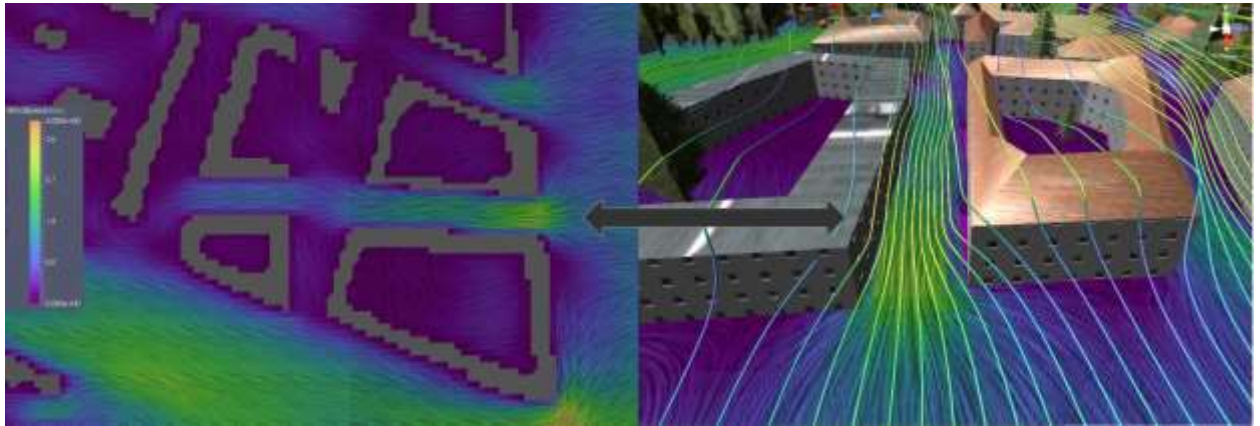


Figure 10: Wind jet effects in the revitalized region; colors represent wind velocities. Jet patterns are clearly identifiable when two building blocks are perpendicular to the wind direction (east-wind in this case). Advanced visualization algorithms such as line integral convolution (left) and 3D streamlines (right) help to identify areas of interest in complex data sets.

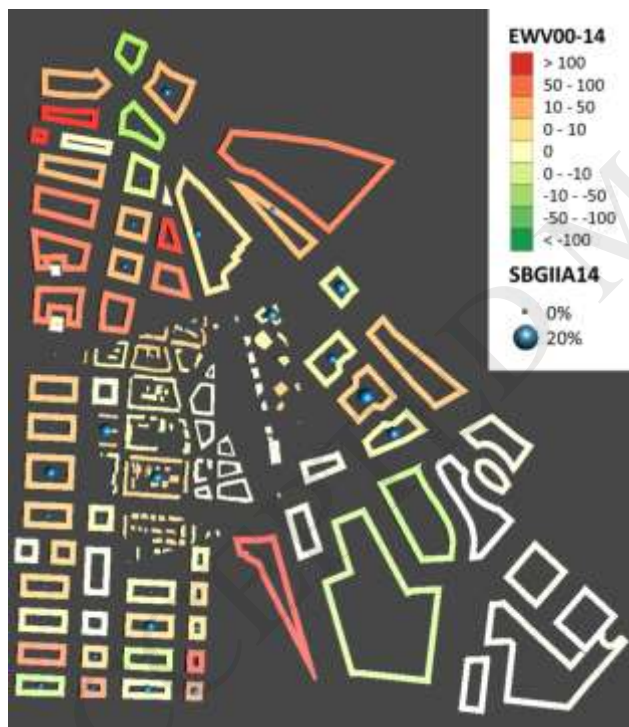


Figure 11: Population change between 2000 and 2014 in % (EWV00-14) and share of population in % which received unemployment pay in 2014 (SBGIIA14) in the areas surrounding Bayerischer Bahnhof