Organizing and facilitating geodesign processes: Integrating tools into collaborative design processes for urban transformation

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1 Introduction

Urban landscape conditions, structures, and processes resulting from urban development increasingly cause serious environmental and social problems, e.g., loss of biodiversity, pollution and congestion, diseases, insecurity, and alienation as well as social inequality (Sevilla-Buitrago, 2013). In addition, urban areas are confronted with major global challenges, such as climate change, migration, and fluctuations of the economy, which affect urban growth, form, and function as well as human well-being (Elmqvist, Fragkias, Goodness, GuUneralp, & Marcotullio et al., 2013). Since more than half of the world's population is already living in urban areas, there is urgent need to find ways for a more sustainable urban transformation (UN Habitat, 2012;

Childers, Pickett, Grove, Odgen, & Whitmer, 2014). Urban transformation is here defined as rapid land use change due to a conversion of natural and agricultural land into city and suburban cover and/or restructuring of settlements (Pickett, Boone, McGrath, Cadenasso, & Childers et al., 2013). Such transformation can be motivated, e.g., by the objective of a stronger and more vital community economy, coming along with population shifts caused by in-migration (Slemp, Davenport, Seekamp, Brehm, Schoonover, & Williard, 2012).

Two measures are regarded as particularly essential to solve significant social and environmental problems in complex urban settings: (1) enhancing the understanding of the multiple and cross-cutting consequences of urban transformation on the functioning of environmental, social, and economic systems (Breuste, Haase, & Elmqvist, 2013; Elmqvist et al., 2013; Slemp et al., 2012; Wu, 2013), and (2) enabling social learning and collective actions (Innes & Booher, 2004; Nassauer, 2012; Swaffield, 2013). Yet, there is little knowledge of how to facilitate such processes in urban planning, design, and management practice.

In this context, design is defined, according to Nassauer (2012), as intentional landscape change, both by formal design decisions and by actions of individual people. According to their values and demands, people use urban land for economic and commercial activities and housing, and they adapt urban structures and forms to prevent loss by external pressures, such as climate change, or to enhance recreational opportunities and other benefits from urban ecosystem services (Breuste et al., 2013; Opdam, Nassauer, Wang, Albert, & Bentrup, et al., 2013). In turn, the resulting physical urban landscape and the perceived urban landscape conditions affect

environmental quality and human well-being (Devine-Wright, 2009; Theodori, 2001). For example, increasing urban density, a key aspect of contemporary urban development, might encourage more social interaction and community spirit, more efficient operation of public transport and improved walkability, and more viable local businesses (Jenks & Jones, 2010). But it might also lead to poorer access to green spaces, poorer health, less affordable housing, stress caused by crowding, and stimulus overload (Jenks & Jones, 2010; Pacione, 2003). Hence, people's actions have interrelated effects on multiple socio-economic and ecological aspects that appear at different spatial scales (Childers et al., 2014; Elmqvist et al., 2013; Steiner, 2014). Appropriate methods should, therefore, provide insight into the systems' feedback relations in order to identify possible urban landscape designs that can provide societally valued and needed qualities within the biophysical, social, economic, institutional, and technical constraints of the space (Childers et al., 2014; Pickett, Cadenasso, & Grove, 2004; Potschin & Haines-Young, 2006). Contemporary approaches, however, are lacking in integrating scientific knowledge into design processes, which could foster a better understanding of those complex interrelationships (Childers et al., 2014). Therefore, the development of approaches and instruments which introduce the required information into the design process is the central topic of an ongoing discourse on geodesign (Wilson, 2014). Geodesign seeks to implement (digital) tools and approaches, using geographic knowledge in order to collaboratively design and improve future environments informed by systems thinking (Batty, 2013; Ervin, 2012; Flaxman, 2010; Goodchild, 2010; Steinitz, 2012, 2014). The latter means that the larger geographic context is considered, focusing on the interconnected dynamics of the landscape systems (Ervin, 2014; Meadows, 2010).

Wilson (2014), however, calls for critically reflecting upon geodesign on the outset, as it is not only about software tools, but may produce also a framing of designs in terms of the situation of a design intervention and the analytical options. He points out that geodesign as approach is a political process which can enable new forms of collaboration and of spatial solutions if soundly implemented from an ethical perspective. Yet, contemporary approaches primarily aim at end-state designs, which often are engineered solutions that are not driven by society's preferences but serve the short decision making cycles of business and politics (Childers et al., 2014; Steiner, 2014). In contrast, ethically sound design should express the cultural norms and values of the local people, within which design and science are undertaken (Opdam et al., 2013; Swaffield, 2013). Particularly, how the landscape is perceived by the local people in their everyday life and what the landscape characteristics mean to them, should be taken into account. The reason for this is that it is at the local scale at which people notice and change the environment to suit their needs (Nassauer, 2012; Pacione, 2003). Furthermore, since diverse disciplines and public interest groups have diverging conceptions and values, a sound design process should be characterized by deliberation about goals, values, interests, and outcomes. This makes a true collaboration of heterogeneous participants in the design process key, which is characterized by ongoing social learning and collective actions (Innes & Booher, 2004; Nassauer, 2012; Scholz, 2011; Swaffield, 2013).

The challenge still is how to actually establish ongoing collaborative design processes that take into account multiple economic, ecological, and social landscape aspects (Grêt-Regamey, Burlando, Girot, Lin, Shaad, & Vollmer, 2014; Pickett et al., 2004). How can knowledge from science and practice be integrated in order to provide insights into the systems of the

environment (e.g., eco-systems, transportation systems, social systems, etc.)? This might enable participants involved in the process to see their values and demands represented and, hence, raise their awareness of behavioral impacts, trade-offs, and environmental consequences of current system states (Elmqvist et al., 2013). In addition, a major barrier to implementation is that available scientific approaches, models, and tools which could support such insights, are difficult to use and do not support analysis across scale (Goodchild, 2010). Further, they often lack interoperability of individual methods, and the applied tools do not fit into collaborative design processes with different groups of participants (Ervin, 2014; Flaxman, 2014; Steinitz, 2012).

Consequently, the objective of this paper is to present a procedural concept for integrating geodesign into local collaborative design processes. Our presented approach is stepwise: it first covers the societal demands, which then are translated into desired adaptations of the landscape structure through iterative and reflexive processes (Grêt-Regamey et al., 2014; Opdam et al. 2013; Swaffield 2013;). Its further specification is illustrated by the example of a study in the Limmattal region, Switzerland. The region's current development pattern demands new strategies for sustainable urban transformation. We focus on the integration of a set of scientific methods and tools based on Geographic Information Systems (GIS), which are made interoperable to support insights into the dynamics of the urban landscape system. We discuss the strengths and weaknesses of the overall concept and the presented methods. Finally, we derive implications for the practice of geodesign, looking at new models of design practice required to solve pressing social and environmental problems.

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119 **2 Methods**120 **2.1 Study**

121 The elaboration of a spatial development strategy for the Swiss Limmattal region provides a
 122 process requiring a collaborative approach across spatial scales. The region has an area of 18,561
 123 hectares and expands over 24 km between the cities of Zurich to Baden along the river Limmat.
 124 With about 165,210 inhabitants (as of 2010) the Limmattal is one of the most densely populated
 125 areas in Switzerland (Canton Zurich, 2010; Canton Aargau, 2010). It is characterized by a very
 126 dynamic development, that has transformed the region from a rural area with small villages to an
 127 urban agglomeration with industrial, commercial, living, agricultural, and recreation areas within
 128 a tight space (Koch, Schröder, Schumacher, & Schubarth, 2003). Further, significant transport
 129 infrastructure in form of highways and railways dominate and fragment the landscape (Fig. 1).

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131 --- insert Figure 1 about here ---

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133 As one of the major growth corridors for the expansion of the city of Zurich, the largest city in
 134 Switzerland, the region is challenged by continuing growth in population and jobs and a
 135 subsequent increase of built-up areas and mobility demand (von Wirth, Wissen Hayek, Kunze,
 136 Neuenschwander, Stauffacher, & Scholz, 2013). In turn, the pressure on remaining green spaces
 137 as well as the demand of services, such as recreational areas or calm living space, are steadily
 138 increasing. There is an urgent need to devise integrated strategies for transforming the existing

patterns of the urban agglomeration in order to secure the functioning of the urban systems and human well-being.

2.2 Procedural concept for integrating geodesign into a collaborative design process

The drafting of the urban development strategies was framed into a procedural concept depicted in Figure 2. Four guiding questions were answered with the help of different approaches, as described in the following paragraphs.

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First, we started with an analysis of the local values and asked "what are the people's demands, place preferences, and values?" Information about place preferences and values of local communities are in most cases not available with a spatial reference and have to be identified. This can be done by applying scientific methods, such as a demand analysis. In our case, we obtained statements of study participants in a workshop with regard to the strengths, weaknesses, opportunities, and threats of the region. The study participants (including representatives of authorities, of regional planning associations, of small and medium enterprises conducting projects in the Limmattal in the sectors infrastructure planning, real-estate development, and

building technology, and urban designers) prepared their statements on three major questions beforehand and presented them in the workshop: (1) what are currently the major strengths and weaknesses of the Limmattal?, (2) how will the Limmattal present itself in 2030 and 2050?, and (3) how will the Limmattal accomplish to get to the described future states? In this way, the participants' concerns and demands in the economic, spatial, social, cultural, ecological, and political realms were identified. Additionally, a questionnaire was sent to all households of two adjacent municipalities in the Limmattal region (N = 1699), to link subjectively perceived qualities with objective characteristics of the urban area (e.g., building density or accessibility by public transport). Employing Esri's ArcMap (Esri, n.d. a), the local residents' perceived quality and place preferences were mapped, based on the location of the residents' home. Then the results were analyzed in conjunction with objective locational factors.

The qualitative statements of the study participants and quantitative, spatially explicit place valuations of the local residents then informed the next step, linked to the question: "What shall we do today to fulfill the demands?" There are two basic strategies for option design (Steinitz, 2010): The first is to design a future vision of a desirable outcome and then ask "what shall we do today to get there?", which is also known as "backcasting" (Grêt-Regamey & Crespo, 2011). The second strategy is to design a scenario starting with a set of assumptions in the present and then ask "what future might be possible?" In our case, a strategy of the latter type was implemented: we ran a formative scenario analysis (Scholz & Tietje, 2002), enabling the collaborative development of regional urban scenarios and providing insights into the relational complexity of the urban systems' characteristics. Thereby, the method described in more detail by von Wirth et al. (2013) integrated knowledge from science and practice to enable an in-depth

analysis of regional impact factors. Figure 3 shows the general workflow applied for systematically developing the scenarios. Based on the demands stated by the study participants in the first step of the collaborative design process, a common guiding question for the scenario analysis was defined as follows: “What are plausible regional qualities of the Limmattal region in 2030 and 2050 with regard to the following areas: urban and architectural design; aesthetics and perception of public space; adaptability, flexibility and possibility of spatial conversion; ecological sustainability; social sustainability; and economic productivity requirements of a society based on services and knowledge?” Further, the participants’ statements on the Limmattal’s characteristics were assigned to five impact domains (politics, economics, society, technology, and environment). On this basis, impact factors were identified which were regarded as crucial for the spatial quality. Then, a system analysis was conducted with the set of impact factors, implementing three different methods. First, an impact assessment was carried out to identify the impact factors’ sufficiency and validity for representing the regional system. Second, this was followed by an analysis of the direct mutual impacts among the impact factors. In this step, the number of impact factors was reduced from 18 to 11, producing a practicable degree of complexity. Third, a loop analysis was carried out, implementing system analysis software extended by a feedback analysis module (Tietje, 2010). In this way, feedback loops were identified which represent a causal, circular relationship between at least two impact factors in a system going in one direction (Le, Seidl, & Scholz, 2011). After the system analysis, the scenarios were constructed, first by defining future levels for each impact factor, and then by calculating the internal consistency for all level combinations in order to maintain only logically possible scenarios. However, choosing development options from the range of possible scenarios that are meaningful to the people is essential (Cash, Clark, Alcock, Eckley, & Guston, et al.,

203). In addition to scientific criteria, the selection of the scenarios for further analysis and interpretation was, thus, also informed by what was desirable by the study participants.

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Following the development of the alternative scenarios of spatial development, the next question was "what are the impacts of these future system states?" For reasons of scientific credibility, the criteria for assessing the impacts should be based on the current state of the art (Cash et al., 2003). But as it depends on the societal values, what are good or bad transformations, the choice of indicators and the calibration of their levels additionally need to have local relevance (Alberti, 1996; Schetke, Haase, & Kötter, 2012). Thus, deliberating about indicators with the local study participants is essential. Due to time restrictions, however, this step could not be completed in the scope of the study. Instead, a set of indicators was elaborated based on a literature review. According to the set of impact factors derived from the previous step, indicators were chosen which address key concerns to be faced by decision makers for urban development, such as housing, accessibility, preservation of open spaces and recreation areas, social diversity, and economic viability. We then calculated the indicator values and mapped them for an integrated

analysis. The spatially explicit manner is particularly important because the aim is to come up with solutions and decision support for spatial design. Hence, the data on which these recommendations are based should be spatially explicit from the beginning. In our case, an agent-based model was chosen for this task. First, the qualitative scenarios were translated into quantitative and spatially explicit visualizations. According to a consistent logic that the group of scientists developed for all four scenarios, the land use regulations defining permissible uses and densities of future development were altered for all parcels in the region using Esri's ArcMap. This step is comparable with generating alternative zoning plans. Second, the resulting ArcGIS shapefiles (vector data format for geographic information system (GIS) software) of the parcels' zoning information for the scenarios were then input data to an integrated land use and transport simulation model called UrbanSim (Waddell, 2011). In this agent-based simulation model, the households and the employees of the study area make choices for spatial relocation based on their individual characteristics, such as household income and size or the employees' branches of business, and their respective demands for locations and building area. The results illustrate the spatial implications of the agents' choices with regard to the development of the built environment in the scenarios. Third, the simulation output was prepared as ArcGIS shapefiles and used as input for the calculation of indicators in Esri's ArcMap according to the methods applied by Efthymiou and colleagues (2013). The indicators address economic, social, and environmental aspects of urban quality on regional, district, and neighborhood scale and allow an integrated analysis of the policy interventions' possible long-term effects across multiple aspects and scales.

Due to resource limitations and conflicting targets for the provision of certain services to fulfill the people's demands, not all urban qualities can be maximized everywhere (Matsuoka & Kaplan, 2008). For instance, different needs, such as human aesthetical and recreational desires and the preservation of ecological habitats, might require the same spatial area but different spatial configurations or facilities are required. Trade-offs are, thus, necessary to come up with mutual concepts, defining what target levels should be achieved at which places (Mabelis & Maksymiuk, 2009). Following the approach of Neuenschwander and colleagues (2012), a tool for multi-criteria decision analysis (MCDA) was set up. It enabled study participants to iteratively test different rankings of certain development goals resulting in optimal options for spatial development. GIS-based indicator maps of the initial state of the land use parcels with respect to an identified goal were calculated with existing, official data of the municipalities. They form the basis for optimization modeling using a linear goal-programming algorithm. Due to the generic structure of the model, the indicator maps of the simulation results can also be used as input data, which allows for chaining a scenario's impact analysis with the adaptation of the target levels in the scenario. The resulting spatial development options were displayed as an overlay to Google Earth (Google, n.d.). Further, shapefiles of the resulting spatial development options of the MCDA were used as input data for Esri's CityEngine System (Esri, n.d. b), a GIS-based procedural 3D modeling software. With this software, the possible effects of the new ranking of the targets on the urban form were visualized as a 3D city model.

Going through the four steps of the approach, the involved participants get multiple insights into the landscape system. The better understanding of the effects of a target's implementation on the other demands, might change their priorities for different goals. This means a shift in the

participants' values and demands, which can also affect their potential actions (Elmqvist et al., 2013; Pickett et al., 2004). These changes in demands can raise further questions on the systems' behavior, which then can initiate the next iteration of the procedural approach.

3 Results

In this section, we briefly describe the outcomes of the four steps. A focus is laid on the integration of the people's values into the outcomes of the single steps and the linking of the methods. Further, the insights into the urban systems provided by the different methods are presented.

The first question about the people's demands was addressed with two different methods for demand analysis. The first was obtaining the study participants' statements in workshops, and the second was mapping local residents' place attachment by a questionnaire to the households and analyzing the outcomes spatially explicitly with regard to locational factors. The participants' statements on the strengths, weaknesses, opportunities, and threats of the region revealed concerns and demands for future development. In turn, these led to the definition of major impact factors which characterized the study area. Main impact factors included culture of planning, community structure, economic development, population development, life style groups, segregation, energy efficiency, transport infrastructure, local identity, ecological connectivity, and density of uses. On these impact factors, the whole analysis of the regional system as well as the construction of scenarios was based.

However, the study participants' concerns and demands were difficult to assign to local areas on the neighborhood scale. In contrast, results from a following questionnaire-based study revealed the values people assign to places. For example, the map on place attachment of the residents (Fig. 4) shows that the strength of emotional relatedness in the neighborhoods of two adjacent municipalities differs spatially. The strength was found to correlate with neighborhood characteristics defining the local quality. This information was used in the next step of option design to specify target levels for enhancing urban quality on a local level. Whereas the study of the participants' statements, thus, specified suitable interventions on the regional and communal scale—e.g., building a light train (tram line with a speed of up to 60 km/h) running through the valley—the information on the residents' place attachment was used to describe the possible mix of social milieus and their place attachment in correlation to alternative urban forms.

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The interventions were compiled to scenarios, which reflect alternative rankings of the study participants' demands and corresponding political targets by emphasizing design, technological, economic, or ecological aspects respectively (Fig. 5). The results were four alternative possible scenarios of the region, prepared as qualitative storylines. These storylines, first, specify the functional area and the role of the Limmattal region in Switzerland with regard to national and international relationships, functional associations, connectivity, dynamic of development, predominant societal values, culture of planning, and the community structure. Second, they

depict the quality of places in form of interventional layers on the regional (spatial and infrastructure planning interventions), communal (revision of communal and district plans), and local scale (small-scale interventions generating form by urban design, architecture, and design of open spaces). Third, the storylines describe the quality of living conditions, the attractiveness of business locations, and the quality of ecosystem services. With this structure, the characteristics of the main impact factors defined by the study participants were specified in detail for the alternative scenarios.

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The outcomes of the regional system analysis complemented the storylines by providing insights into systemic interactions in regional transformation. They identify economic and demographic development as major drivers for regional development. However, culture of planning, i.e., the form and level of collaboration of planning partners, was also found to influence the spatial appearance of the region. A more differentiated understanding of the regional feedback relations driving urban transformation, was supported by the results of the analysis of direct mutual effects between impact factors. The result was the most important feedback loop characterizing a core process of socio-spatial interrelatedness, spanning the factors of demographic development,

social structure, transport infrastructure, community structure, and spatial appearance, relating again to demographic development. The research team informed the study participants about the findings on the regional impact dynamics in a workshop, in which the results were discussed. The feedback loop reflects the systems' internal dynamics as perceived today by the participants and was interpreted as follows: alteration in the regional demographic development affects the social structure of the population. The values and preferences of the population and their correlating behavioral patterns, e.g., of mobility choices, lead to different modal splits and, thus, demand for transportation infrastructure. Region-wide planning and investments in transportation infrastructure require the collaboration of communities, which fosters changes in community structure, such as amalgamation of communities, which are already discussed in the Limmattal region. The new organization of community structures in terms of political and planning authorities and subsequent spatial development interventions affect the spatial appearance. The spatial appearance, however, is a trigger for migration from outside the region, affecting demographic development, which closes the loop. This loop was regarded as an additional systemic driver of urban development in the agglomeration, which should be taken into account in strategy development.

More in-depth insights into the dynamics of the socio-economic and environmental systems were provided by the results of the quantitative impact analysis of the possible changes described in the scenarios. Figure 6 presents an example of the indicator maps. They show for the regional, the district, and the neighborhood scale the state of different urban qualities of the status quo and the "Pure Dynamics" scenario. Indicators on the regional scale demonstrate that in the central area of the region the utility of the public transport increases, while the supply with public open

space becomes insufficient. Zooming in on the district scale, the pattern of rent prices for housing gets more evenly as they adjust at a low to medium level, with less housing in the low as well as in the high rent price segment than in the status quo. At neighborhood scale, the building density increases significantly. While higher building density and transport utility are actually central goals in the region, the effects of the urban change on supply with public open space and on house prices should be assessed fairly critically. The latter may trigger processes of gentrification and lead to a successive displacement of social groups with low income (Keddie & Tonkiss, 2010). Insufficient public open spaces can affect human physical activity, recreation and health (Breuste et al., 2013; Nassauer, Wang, & Dayrell, 2009), social cohesion (Maas, van Dillen, Verheij, & Groenewegen, 2007), and cultural integration (Kazmierczak, 2013). These integrated insights into mutual effects of the spatial change brought the initial political targets for urban development in the scenarios into question. In particular, the goals stated by the participants in the workshop at the beginning of the process, namely to foster public transport and the development of urban centers with high building and population densities, required a better balancing against the protection of open areas. The ranking of the targets needed to be negotiated.

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379

380 In order to rank the conflicting demands, the multi-criteria trade-off decision analysis served the
 381 study participants to interactively test alternative weightings of targets. The results were optimal
 382 areas for urban and real estate development according to the ranking of different targets (Fig. 7).
 383 With the concrete 3D visualization of urban form (Fig. 8), the effects of the urban development
 384 options on the local level became more tangible and understandable. In turn, demands for future
 385 development and according scenarios could be further refined and tested again in another loop of
 386 the collaborative design process.

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390 **4 Discussion**

391 We presented a procedural concept for integrating geodesign into existing collaborative planning
 392 processes, which can support insights into socio-spatial interdependencies affecting spatial
 393 quality and human well-being in urban landscapes. In particular, we demonstrated how societal
 394 demands can be translated into desired adaptations of the urban landscape structure and form
 395 through iterative and reflexive processes facilitated by a set of scientific methods. In the
 396 following sections, we first reflect on the procedural concept with regard to lessons learned on
 397 the organization and facilitation of the integrated approach. Second, we discuss the choice of
 398 methods, focusing on their strengths and weaknesses in terms of making scientific methods and

GIS-based tools interoperable to support collaborative design and its improvement informed by systems thinking.

4.1 Reflection on the organization and facilitation of the integrated approach

In the presented approach, people's demands frame the collaborative process to design future environmental development possibilities. They provide local place preferences and societal values as starting point for designing and selection of desirable design, guide evaluation, and lead ranking of conflicting values. In this way, the societal values are embodied in the design outcomes. In common design processes, these values as well as the local and community-based knowledge are often overlooked, leading to designs insensitive to the environmental and social context (Steiner, 2014). In contrast, with societal values framing the process, an essential prerequisite can be fulfilled for politically legitimate and socially relevant and acceptable landscape design which can recognizably meet people's needs (Grêt-Regamey et al., 2014; Swaffield, 2013).

An inseparable part of this collaborative design process are the scientific methods. As demonstrated in the study, they can shape local understanding of the functioning of the landscape systems. For example, the insights gained from the quantitative indicators suggested that the involved study participants should adjust their targets for building density to avoid negative impact on other quality aspects of the urban environment in the long run. Known reasons for the failure of linking scientific systems knowledge to local actions, are misunderstanding and mistrust of science or the failure of scientists to communicate spatial relationships (Steiner,

2014). Since in the study the scenarios and the indicators were chosen according to the people's values, the scientific information can be regarded as legitimate (information production is fair, unbiased, and respects divergent values) and salient (relevant to decision making). Hence, another essential characteristic, in which geodesign processes should make a difference in the way of designing, is a common deliberation of science and practice partners for defining the goal and contents of analysis as well as the indicators. Nassauer and Opdam (2008) also point out that the extent to which science is part of the societal discussion may contribute to larger credibility, i.e., the scientific adequacy of evidence and arguments based on the methods and tools (Cash et al., 2003). This makes active communication between science and the practice communities, translation of information to improve mutual understanding, and active mediation of multiple participants' conflicting views important prerequisites for a successful implementation of the collaborative design process.

With regard to enabling social learning and access to systems thinking, the iteration of the process is regarded as an essential element. Thereby, the focus is less on elaborating a final plan, e.g., a master plan, which has known shortcomings in adjusting promptly and flexibly according to identified undesired developments or people's demands (Kim & Rowe, 2013). The suggested process output is rather an ongoing adaptation of the development strategy due to the system insights gained in collaboration of science and practice partners. Also Pickett and colleagues (2004) and Collier and colleagues (2013) stress the importance of continual testing, demonstration, and re-designing as time progresses. In this way, the collaborative processes can potentially lead to landscape change of higher quality, and to people's actions that hopefully do add up to results that everyone desires. However, we do not know yet what people learn from going through this process. Secondly, we also do not know whether the people's values actually

do change, and thirdly, how insights based on scientific analyses influence political decisions and the implementation of designs. In order to identify how people respond to and affect urban landscape change, a monitoring of the social learning effects of the process over time is required (Albert, Zimmermann, Knieling, & von Haaren, 2012; Pickett et al., 2004). To this end, the described procedural concept and its possible implementation with the presented tool set should be tested in practice.

4.2 Reflection on the strengths and weaknesses of the methods

We illustrated the possible implementation of the procedural concept on a combination of methods developed in the Limmattal region. In general, the presented methods are not new. Rather sophisticated methods and tools were applied. New is that they all share one GISdatabase, which is iteratively enriched with inputs from the planning partners and outputs from spatial models in the course of the collaborative process. This can be seen as a key element of geodesign: facilitating access to very different representations of one dataset of the real environment, which help to solve specific planning questions by giving insight into parts of complex interrelationships. In this way, spatially explicit knowledge is organized, and targeted use of heterogeneous disciplines' competences is made possible.

We showed that the methods can be chained in a way that the output from one method is the input to the subsequent one. However, the interoperability and flexibility of the software tools should be further enhanced. For example, the translation of the qualitative scenarios to spatial representations could only be done by one person and was very time consuming. Also the impact

analysis with the agent-based simulation model UrbanSim, followed by the calculation of indicator maps were separate steps. Finally, communicating the impacts and interactions across aspects and scales to study participants was challenging, mainly due to a lack of understanding of the data processing and the rather abstract presentation of the results. From a technical point of view, therefore, a focus on interface design for better integration of the tools in software platforms is recommended. New developments in this context are already very promising. For example, UrbanCanvas became available only recently (Synthicity, n.d.). It is a cloud-based, interactive 3D GIS platform, which connects to UrbanSim and other geospatial models. With a suite of tools, geographic data can be edited and visualized in 3D in its larger context with built-in base maps. Scenario outcomes of UrbanSim, for example, can be visualized to study alternative scenarios, and they can be altered by composing scenarios from different combinations of interventions, using a shared database. The latter function would be particularly useful for subsequent iterations of the collaborative design process, because the formative scenario analysis does not lead to design options which actually would work in the practice realm. For instance, study participants stated that neither of the scenarios was likely to be implemented but a mixture of parts of them would be a desirable development option. Scenarios, by definition, present no likely future possibilities but plausible options (Shearer, 2005). However, a suitable approach to generate a design option based on the scenarios would be, e.g., to step-wise assess and identify the interventions in the scenarios all collaboration partners agree with (C. Steinitz, personal communication, May 23, 2014).

Another innovation is that the methods and tools are implemented mutually in a process with frequent communication with heterogeneous planning partners. A further dimension of the

methods' interoperability is, thus, the interface to those planning partners. In our case, communication with heterogeneous groups of study participants took place throughout the collaborative process but not with all groups with equal intensity. Whereas practice actors belonging predominantly to the groups of public authorities and professionals actively collaborated with scientists, the local residents remained rather passive in the whole process. Their participation was limited to the provision of information on their perception of the spatial quality and their place attachment. Since the local residents' preferences and demands are regarded as very important for identifying societal accepted solutions (Nassauer, 2012), collaboration with local residents should be made more active from the beginning. For example, the residents could be activated through the implementation of methods, such as crowd-sourced data gathering, where local people are equipped with smartphones to collect photos and comments on specific places the people are concerned about (Badenhop & Seeger, 2014), or where people create posters of their visions about their life in the future on a web platform (www.life2040.eu campaign).

Also for trade-off analysis, the implemented tool was primarily suitable for practitioners. The practitioners immediately imagined situations for implementation of the tool in their daily business. For example, in municipal council meetings spatial impacts of conflicting targets could be easily visualized to foster a more differentiated discussion for neighborhood development. However, only a small group of representatives would then define the relative importance of different development targets. This is seen very critically, because designing a better future essentially depends on drawing together diverse public and enabling discourses which can influence the dynamic and alter the network of political power relations (Miller, 2012; Wilson,

2014). The ranking of targets should, thus, also be done with methods which are able to better include the trade-offs that the diverse people actually make. Overall, we agree with Opdam and colleagues (2013), who suggest that the scientific tools should be co-constructed and adapted with local planning partners and their effectiveness be monitored in order to adjust their flexibility, validity, and effectiveness in practice.

The procedural concept is open to the implementation of alternative sets of scientific methods. Other methods for identifying the people's values and demands are, e.g., choice experiments, in which preferences for the design of certain places are clearly stated, based on a trade-off decision of different services, expressing the ranking of values (Grêt-Regamey et al., 2014). For choosing the most suitable methods for the four steps, an evaluation of how to interact best with the local participants should be made. Thereby, also the respective context (also the political), the goals of the participants, and the resources in terms of money, time, and expert capacity available should be taken into account. Furthermore, an open access database of tools should be generated in order to increase information on what is already available. This might help to avoid duplication of similar tools at different places and instead speed up adaptation of existing tools to user abilities and needs.

5 Conclusions

The transformation of landscapes is a constantly occurring process. Particularly in human dominated landscapes, this transformation is heavily influenced by human actions based on their perception, values, and demands. For the active transformation of landscapes towards more

resource efficiency supporting human well-being in the long run, deliberative and collaborative decision making processes on landscape change are seen to be key. Such decision-making requires an intense cooperation of science and local groups of heterogeneous practitioners in iterative approaches. Additionally, to suggest practice-oriented solutions that will influence landscape change, the framing of these processes by the societal values is crucial. This means that the development of the tools for geodesign cannot be separated from generating the procedural approach how to integrate participants' perceptions and societal values into geodesign. The procedural approach and the tools are inextricably linked and should be developed closely together.

We presented and discussed an approach and a suitable tool set that is driven by the societal values to support adaptation of local landscapes to future demands. Such a collaborative process is supported by methods for demand analysis, option design, impact, and trade-off analysis. It integrates knowledge from science, practice, and design in a way that can foster understanding of the landscape systems' feedback dynamics. Furthermore, implementing the approach can facilitate a change of different participantgroups' perspectives. Overall, the presented approach has a high potential to organize future oriented mutual sustainability learning and capacity building among local participants, planning experts, and scientists. This should be tested by implementing the procedural concept in practice. Thereby speeding up the processing time of different models to deliver the outputs more timely, is a crucial technical challenge. However, even more attention should be turned to customize the input and output formats of the geodesign tools to the user requirements.

556

557 Ervin (2014) notes that putting adaptive loops in collaborative settings into practice is quite
558 difficult to achieve. As one important prerequisite he sees a cooperative attitude of the science
559 and practice partners. This basic willingness to cooperation might be fostered through
560 institutionalizing the collaboration. Thus, collaborative platforms should be established at the
561 regional scale as a starting point for continuous collaborative design processes, which may in the
562 long term improve the systems thinking skills and competences to address complex issues of the
563 people in a region.

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6 References

1. Albert, C., Zimmermann, T., Knieling, J., & von Haaren, C. (2012). Social learning can benefit decision-making in landscape planning. Gartow case study on climate change adaptation, Elbe valley biosphere reserve. *Landscape and Urban Planning*, 105, 347-360.
2. Alberti, M. (1996). Measuring Urban Sustainability. *Environmental Impact Assessment Review*, 1, 381-424.
3. Badenhop, J., & Seeger, C. (2014). Emplaced Mapping and Narratives within the Participatory Planning Process. In U. Wissen Hayek, P. Fricker, & E. Buhmann (Eds.), *Peer Reviewed Proceedings of Digital Landscape Architecture 2014 at ETH Zurich* (pp. 180-186). Berlin/Offenbach - Herbert Wichmann Verlag, VDE Verlag GmbH.
4. Batty, M. (2013). Defining geodesign (= GIS + design ?). *Environment and Planning B: Planning and Design*, 40, 1-2.
5. Breuste, J., Haase, D., & Elmqvist, T. (2013). Urban Landscapes and Ecosystem Services. In S. Wratten, H. Sandhu, R. Cullen, & R. Costanza (Eds.), *Ecosystem Services in Agricultural and Urban Landscapes*, Oxford - A John Wiley & Sons. doi: 10.1002/9781118506271.ch6
6. Canton Aargau (2010). Cantonal and Communal Statistics. Statistical Office Canton Aargau.
7. Canton Zurich (2010). Cantonal and Communal Statistics. Statistical Office Canton Zurich.
8. Cash, D. W., Clark, W. C., Alcock, N. M., Eckley, N., Guston, D. H., Jäger, J., & Mitchell, R. B. (2003). Knowledge systems for sustainable development. *PNAS*, 100(14), 8086-8091.
9. Childers, D. L., Pickett, S. T. A., Grove, J. M., Odgen, L., & Whitmer, A. (2014). Advancing urban sustainability theory and action. Challenges and opportunities. *Landscape and Urban Planning*, 125, 320-328.
10. Collier, M. J., Nedović-Budić, Z., Aerts, J., Connop, S., Foley, D., Foley, K., Newport, D., McQuaid, S., Slaev, A., & Verburg, P. (2013). Transitioning to resilience and sustainability in urban communities. *Cities*, 32, S21-S28.
11. Devine-Wright, P. (2009). Rethinking NIMBYism. The role of place attachment and place identity in explaining place-protective action. *Journal of Community & Applied Social Psychology*, 19, 426-441.
12. Efthymiou, D., Farooq, B., Bierlaire, M., & Antoniou, C. (2013). Agent-Based Indicators Analysis in the Context of Policy Evaluation. STRC, 13th Swiss Transport Research Conference, Ascona. Retrieved from – [http - //www.strc.ch/conferences/2013](http://www.strc.ch/conferences/2013)
13. Elmqvist, T., Fragkias, M., Goodness, J., GuGueralp, B., Marcotullio, P. J., McDonald, R. I., Parnell, S., Schewenius, M., Sendstad, M., Seto, K. C., Wilkinson, C., Alberti, M., Folke, C., Frantzeskaki, N., Haase, D., Katti, M., Nagendra, H., Niemelä, J., Pickett, S. T. A., Redman, C. L., & Tidball, K. (2013). Stewardship of the biosphere in the urban era. In T. Elmqvist, M. Fragkias, J. Goodness, B. Gueralp, P. J. Marcotullio, R. I. McDonald, S. Parnell, M. Schewenius, M. Sendstad, K. C. Seto, & C. Wilkinson (Eds.), *Urbanization, Biodiversity and Ecosystem Services. Challenges and Opportunities. A Global Assessment* (pp. 710-746). Springer - Dordrecht.
14. Ervin, S. (2014). BioComplexity, Systems Thinking, and Multi-Scale Dynamic Simulation. Foundations of Geodesign. In U. Wissen Hayek, P. Fricker, & E. Buhmann (Eds.), *Peer Reviewed Proceedings of Digital Landscape Architecture 2014 at ETH Zurich* (pp. 160-169). Berlin/Offenbach - Herbert Wichmann Verlag, VDE Verlag GmbH.
15. Esri (n.d. a). ArcGIS for Desktop. Retrieved October 22, 2014 from - [http - //www.esri.com/software/arcgis/arcgis-for-desktop](http://www.esri.com/software/arcgis/arcgis-for-desktop)
16. Esri (n.d. b). Esri CityEngine. Transform 2D GIS data into smart 3D city models. Retrieved November 18, 2014 from - [http - //www.esri.com/software/cityengine](http://www.esri.com/software/cityengine)
17. Flaxman, M. (2010). Fundamentals of Geodesign. In E. Buhmann, M. Pietsch, & E. Kretzler (Eds.), *Peer Reviewed Proceedings of Digital Landscape Architecture 2010 at Anhalt University of Applied Sciences* (pp. 28-41). Berlin/Offenbach - Herbert Wichmann Verlag, VDE Verlag GmbH.
18. Flaxman, M. (2014). Geodesign in Professional Practice. Methods & Directions. In Paper presented at the GeoDesign summit Redlands, CA, Retrieved from - [http - //video.esri.com/watch/3160/geodesign-in-professional-practice-methods-_and_-_directions](http://video.esri.com/watch/3160/geodesign-in-professional-practice-methods-_and_-_directions)

19. Goodchild, M. F. (2010) Towards Geodesign. Repurposing Cartography and GIS? *Cartographic Perspectives*, 66, 7-21.
20. Google (n.d.). Google Earth. Retrieved June 26, 2014 from - [http - //www.google.com/earth/](http://www.google.com/earth/)
21. Grêt-Regamey, A., & Crespo, R. (2011). Planning from a future vision. *inverse modeling in spatial planning*. *Environment and Planning B*, 38, 979-994.
22. Grêt-Regamey, A., Burlando, P., Griot, C., Lin, E. S., Shaad, K., & Vollmer, D. (2014). Digital Methods and Collaborative Platforms for Informing Design Values with Science. In U. Wissen Hayek, P. Fricker, & E. Buhmann (Eds.), *Peer Reviewed Proceedings of Digital Landscape Architecture 2014 at ETH Zurich* (pp. 46-56). Berlin/Offenbach - Herbert Wichmann Verlag, VDE Verlag GmbH.
23. Innes, J. E., & Booher, D. E. (2004). Reframing public participation. *strategies for the 21st century*. *Planning Theory & Practice*, 5(4), 419 – 436.
24. Jenks, M., & Jones, C. (2010). Issues and Concepts. In M. Jenks, & C. Jones (Eds.), *Dimensions of the Sustainable City. Future City 2* (pp. 1-19). Dordrecht, Heidelberg, London, New York - Springer.
25. Kaźmierczak, A. (2013). The contribution of local parks to neighbourhood social ties. *Landscape and Urban Planning*, 109(1), 31-44.
26. Keddi, J. & Tonkiss, R. (2010). The market and the plan: Housing, urban renewal and socio-economic change in London. *City, Culture and Society*, 1, 57-67.
27. Kim, S., & Rowe, P. G. (2013). Are master plans effective in limiting development in China's disaster-prone areas? *Landscape and Urban Planning*, 111, 79 – 90.
28. Koch, M., Schröder, M., Schumacher, M., & Schubarth, C. (2003). Zürich/Limmattal. In A. Eisinger & M. Schneider (Eds.), *StadtlandSchweiz* (pp. 260-293). Basel - Birkhäuser.
29. Le, Q. B., Seidl, R. Scholz, R.W. (2011). Feedback loops and types of adaptation in the modelling of land-use decisions in an agent-based simulation. *Environ. Model Softw.*, 27–28, 83–96.
30. Maas, J., van Dillen, S. M. E., Verheij, R. A., & Groenewegen, P. P. (2009). Social contacts as a possible mechanism behind the relation between green space and health. *Health & Place*, 15(2), 586-595.
31. Matsuoka, R. H., Kaplan, R. (2008). People needs in the urban landscape. *Analysis of Landscape And Urban Planning contributions*. *Landscape and Urban Planning*, 84, 7 – 19.
32. Mabelis, A. A., & Maksymiuk, G. (2009). Public participation in green urban policy: two strategies compared. *International Journal of Biodiversity Science & Management*, 5(2), 63-75.
33. Meadows, D. H. (2010). *Thinking in Systems - A Primer*. London/Washington, DC - earthscan.
34. Miller, W. R. (2012). *Introducing Geodesign. The Concept*. Redlands, - Esri. Retrieved from - [http - //www.esri.com/library/whitepapers/pdfs/introducing-geodesign.pdf](http://www.esri.com/library/whitepapers/pdfs/introducing-geodesign.pdf)
35. Nassauer, J. I., & Opdam, P. (2008). Design in science: extending the landscape ecology paradigm. *Landscape Ecology*, 23, 633 – 644.
36. Nassauer, J. I., Wang, Z., & Dayrell, E. (2009). What will the neighbors think? Cultural norms and ecological design. *Landscape and Urban Planning*, 92(3-4), 282-292.
37. Nassauer, J. I. (2012). Landscape as medium and method for synthesis in urban ecological design. *Landscape and Urban Planning*, 106. 221-229.
38. Neuenschwander, N., Wissen Hayek, U., & Grêt-Regamey, A. (2012). Integrated Multi-Criteria Modeling and 3D Visualization for Informed Trade-Off Decision Making on Urban Development Options. In H. Achten, J. Pavlicek, J. Hulin, & D. Matejovska (Eds.), *Digital Physicality - Proceedings of the 30th eCAADe Conference - Volume 1* (pp. 203-211). Prague - Czech Technical University.
39. Opdam, P., Nassauer, J.I., Wang, Z., Albert, C., Bentrup, G., Castella, J.-C., McAlpine, C., Liu, Jianguo, Sheppard, S., & Swaffield, S. (2013). Science for action at the local landscape scale. *Landscape Ecology*, 28, 1439-1445.
40. Pacione, M. (2003). Urban environmental quality and human wellbeing - a social geographical perspective. *Landscape and Urban Planning*, 65(1-2), 19-30.

41. Pickett, S. T. A., Cadenasso, M. L., & Grove, J. M. (2004). Resilient cities: meaning, models, and metaphor for integrating the ecological, socio-economic, and planning realms. *Landscape and Urban Planning*, 69, 369-384.
42. Pickett, S. T. A., Boone, C. G., McGrath, B. P., Cadenasso, M. L., Childers, D. L., Ogden, L. A., McHale, M., & Grove, J. M. (2013). Ecological science and transformation to the sustainable city. *Cities*, 32, S10-S20.
43. Potschin, M. B., & Haines-Young, R. H. (2006). Editorial - Landscapes and sustainability. *Landscape and Urban Planning*, 75, 155-161.
44. Schetke, S., Haase, D., & Kötter, T. (2012): Towards sustainable settlement growth: A new multi-criteria assessment for implementing environmental targets into strategic urban planning. *Environmental Impact Assessment Review*, 32, 195-210.
45. Scholz, R. W. (2011). *Environmental Literacy in Science and Society: From Knowledge to Decisions*. Cambridge - Cambridge University Press.
46. Scholz, R. W., & Tietje, O. (2002). *Embedded Case Study Methods. Integrating Quantitative and Qualitative Knowledge*. Thousand Oaks/London/New Delhi - Sage publications.
47. Sevilla-Buitrago, A. (2013). Debating contemporary urban conflicts. A survey of selected scholars. *Cities*, 31(0), 454-468. doi - 10.1016/j.cities.2012.08.006
48. Shearer, A. W. (2005). Approaching scenario-based studies: three perceptions about the future and considerations for landscape planning. *Environment and Planning B: Planning and Design*, 32, 67-87.
49. Slemp, C., Davenport, M. A., Seekamp, E., Brehm, J. M., Schoonover, J. E., & Williard, K. W. J. (2012). "Growing too fast:" Local stakeholders speak out about growth and its consequences for community well-being in the urban-rural interface. *Landscape and Urban Planning*, 106, 139-148.
50. Steiner, F. (2014). Frontiers in urban ecological design and planning research. *Landscape and Urban Planning*, 125, 304 – 311.
51. Steinitz, C. (2010). Landscape Architecture into the 21st Century – Methods for Digital Techniques. In E. Buhmann, M. Pietsch, & E. Kretzler (Eds.), *Digital Landscape Architecture 2010 at Anhalt University of Applied Sciences* (pp. 2-26). Berlin/Offenbach - Herbert Wichmann Verlag, VDE Verlag GmbH.
52. Steinitz, C. (2012). A Framework for Geodesign – Changing Geography by Design. Redlands - Esri.
53. Steinitz, C. (2014). Geodesign with Little Time and Small Data. Post-tsunami Restoration in Soma City, Fukushima Prefecture, Japan. In U. Wissen Hayek, P. Fricker, & E. Buhmann (Eds.), *Peer Reviewed Proceedings of Digital Landscape Architecture 2014 at ETH Zurich* (pp. 2- 14). Berlin/Offenbach - Herbert Wichmann Verlag, VDE Verlag GmbH.
54. Swaffield, S. (2013). Empowering landscape ecology-connecting science to governance through design values. *Landscape Ecology*, 28, 1193 – 1201.
55. Synthicity (n.d.). UrbanCanvas. Retrieved November 18, 2014 from - [http - //www.synthicity.com/urbancanvas](http://www.synthicity.com/urbancanvas)
56. Theodori, G. L. (2001). Examining the Effects of Community Satisfaction and Attachment on Individual Well-Being. *Rural Sociology*, 66, 618–628.
57. Tietje, O. (2010). *SystaimSystemQ*. Zurich - Systaim GmbH.
58. UN Habitat (2012). *State of the world's cities 2012/2013. Prosperity of Cities*. Malta - Progress Press Ltd.
59. von Wirth, T., Wissen Hayek, U., Kunze, A., Neuenschwander, N., Stauffacher, M., & Scholz, R. W. (2013) Identifying urban transformation dynamics. Functional use of scenario techniques to integrate knowledge from science and practice. *Technological Forecasting & Social Change*, in press, doi - 10.1016/j.techfore.2013.08.030
60. Waddell, P. (2011). Integrated Land Use and Transportation Planning and Modeling. Addressing Challenges in Research and Practice. *Transport Reviews*, 31(2), 209-229.
61. Wilson, M. W. (2014). On the criticality of mapping practices. Geodesign as critical GIS? *Landscape and Urban Planning*, doi - 10.1016/j.landurbplan.2013.12.017

62. Wu, J. (2013). Landscape sustainability science: ecosystem services and human well-being in changing landscapes. *Landscape Ecology*, 28, 999-1023.
63. www.life2040.eu campaign (n.d.). How would you like to live in 2040? Retrieved November 18, 2014 from - [http - //www.life2040.eu/](http://www.life2040.eu/)

Captions for figures

Fig. 1: Location of the Limmattal region within the agglomeration of Zurich. (Source of base map: Swisstopo, 2011)

Fig. 2: Procedural concept of a collaborative design process with the people's values framing the scientific methods for analysis and design as well as the choices they include. (VIS = Visualization; GIS = Geographical Information System)

Fig. 3: General workflow applied in the formative scenario analysis. The three steps of system analysis in the middle – (1) impact assessment of the chosen variables to evaluate the sufficiency and validity for representing the regional system, (2) analysis of direct mutual impacts, and (3) analysis of feedback loops - were carried out solely in the research realm. The other steps for goal and scope formation (first three steps), scenario construction and interpretation (last three steps) were characterized by different intensities of science-practice collaboration.

Fig. 4: Place attachment of the residents in the municipalities of Schlieren and Dietikon, defined as residents' emotional relatedness to their neighborhood. The higher the score (range 1-5) the higher the residents' place attachment.

Fig. 5: Illustration of the scenario matrix defining the respective levels of the impact variables in the current state of 2010 and the four scenarios of the Limmattal region in 2030 and correlating pictograms. From left to right: "Character City", with a clear sequence of attractive centers and a mix of contrasts in land uses and architecture; "Smart City" characterized by highest possible energy efficiency through high densities of services, short distances, and implementation of cutting-edge technology; "Pure Dynamic" reflects the emphasis on economic aspects leading to a fuzzy mix of commercial areas, settlements, green spaces, and transport areas; in "Charming Valley" the region is characterized by a robust and cross-linked system of green spaces, which guides settlement development.

Fig. 6: Indicator maps of the Region Limmattal for the current state in the year 2000 and the scenario "Pure Dynamic" in the year 2030.

Fig. 7: Optimal urban and real estate development areas resulting from the ranking of high accessibility of public transport over all other targets.

Fig. 8: GIS-based procedural 3D visualization of a scenario at a neighborhood scale.

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Impact variables (d _i)	Current state	Character city	Smart city	Pure dynamic	Charming valley
Culture of planning (d ₁) Form and level of collaboration and participation of planning actors.	Medium level of public participation; poor collaboration with other communities	Higher level of public participation ^a ; cooperation within/good connections to other communities	Medium level of public participation ^a ; good collaboration within/connections to other communities.	Medium level of public participation ^a ; no cooperation within the community	Medium level of public participation ^a ; good collaboration within/good connections to other communities.
Community structure (d ₂) Amount, size and administrative responsibilities of the communities.	16	Limmattal City	Limmattal City	16	16
Economic development (d ₃) Economic performance and the population's economic wellbeing.	117,949 employees ^b	138,000 employees ^c (growth: + 17%)	138,000 employees ^c (growth: + 17%)	138,000 employees ^c (Growth: + 17%)	138,000 employees ^c (growth: + 17%)
Population development (d ₄) Demographic development.	165,210 inhabitants ^b	196,600 inhabitants ^c (growth: + 19%)	196,600 inhabitants ^c (growth: + 19%)	196,600 Inhabitants ^c (growth: + 19%)	196,600 inhabitants ^c (growth: + 19%)
Life style groups (d ₅) Standard of living, social structure and population groups' main characteristics	Life style diversity, market driven	Dynamic life style diversity, steered by planning	Focusing on different lifestyle groups	Dynamic life style diversity, steered by socio-economic market drivers	Dynamic life style diversity, steered by planning
Segregation (d ₆) Intensity of polarization and spatial disaggregation of different population groups.	Mixed society within the valley, rather separated within the community, building blocks and buildings	Mixed society within the valley and community, separated in building blocks and buildings	Mixed society within the valley, separated within the community, building blocks and buildings	Mixed society within the valley, separated within the community, building blocks and buildings	Mixed society within the valley, mixed within the community, mixed in building blocks, separated in buildings
Energy efficiency (d ₇) Efficiency of buildings and transport.	Reference year	BFE scenario III ^d (− 19%)	BFE scenario IV ^d (− 31%)	BFE scenario I ^d (− 3%)	BFE scenario III ^d (− 19%)
Transport infrastructure (d ₈) System characteristics of traffic infrastructure for all transport modes.	No light train "Limmattalbahn"	With "Limmattalbahn"	"Limmattalbahn", further public infrastructure, cross connections in the region	Without "Limmattalbahn"	"Limmattalbahn", further public infrastructure, cross connections in the region
Local identity (d ₉) Identification of the population with the region.	No own character	Developing a strong own character	Developing a strong own character	Developing no own character	Developing a strong own character
Ecological connectivity (d ₁₀) Connectivity of green and open spaces as well as their design and age.	Poor connectivity crossing the Limmattal and poor regional connectivity	Connectivity is enhanced but bad on a regional level	Connectivity is enhanced but bad on a regional level	No active enhancement of connectivity	Optimal on regional level
Density of uses (d ₁₁) Concentration of uses and functions per area and intensity of uses.	Core centers Utilization Factor (UF) = 1.2 ^e Living areas Utilization Factor (UF) = 0.5 ^e	Moderate densification in core centers; mild densification in living areas; higher multifunctionality Core centers UF = 1.9 ^{e,f} Living areas UF = 0.9 ^{e,f}	Strong densification in core centers; moderate densification in living areas; very high multifunctionality Core centers UF = 2.3 ^{e,f} Living areas UF = 1.3 ^{e,f}	Moderate densification in core centers; mild densification in living areas; higher multifunctionality Core centers UF = 1.9 ^{e,f} Living areas UF = 0.9 ^{e,f}	Mild densification in the core centers; higher multifunctionality Core centers UF = 1.6 ^{e,f} Living areas UF = 0.6 ^{e,f}

Figure 6

Figure 7

Figure 8

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