Urban development scenarios

Work Package 1

Deliverable D 1.2

Part C: Synopsis – scenario results

May 14, 2010
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SUME – Sustainable Urban Metabolism For Europe

Area 6.2.1.5 – Urban development
ENV.2007.2.1.5.1 – Urban metabolism and resource optimisation in the urban fabric
Collaborative Research Project

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Part C: Synopsis – scenario results

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1. Synopsis of scenario results

Basis for the scenario building for each of the cities is the urban stock in its spatial configuration within the defined Urban Morphological Zone (UMZ). Using the Corine landcover analysis in combination with statistical data for population and work place distribution as well as data on the building stock (building type, age), for each of the selected cities a complete database for the starting year has been constructed. It is providing detailed, spatially disaggregate information for a 110 – 790 cells per city, depending on the data availability. Long—term developmental trends for each urban area have been derived from existing population projections, economic perspectives and floor space development observations.

Spatially explicit urban development perspectives for the future have been obtained from urban development and planning documents and accessible analyses of developmental trends.

The main questions to be analysed by applying a long-term spatial scenario approach are related to the basic theme of SUME – how does urban form influence the metabolic performance of an urban system. Starting from this main question, the approach consisted of three components of work:

- Spatial development scenarios 2000-2050, providing a perspective of the future development of the urban form and its spatial expansion
- An assessment of the existing and the future urban form with respect to accessibility of urban functions (centres of work, services) for the population, relating to energy use for transport, named Urban Diversity Pattern (UDP)
- Scenarios for the building related energy demand, including the transformation of existing stock and new construction

With these three work components, a number of leading questions have been tackled, particularly:

- What paths of urban development can be expected for the selected cities?
- What will these development paths imply in relation to urban form, such as growth or decline of the population, change of densities, change of average travel distances, changes of the accessibility of public transport?
- What will be the effects on the building age structure, what is the potential to improve the energy-related building qualities - with an impact on energy consumption for heating (and cooling)?
- How much can these development perspectives be influenced through alternative urban development strategies – how much do the BASE and SUME scenarios differ?

The sample of cities is providing an impression of the diversity which can be expected in future urban development in Europe, ranging from slow growth or even decline to continuous growth, from low density and scattered urban forms to high density and compact structures, from hardly existing to fully equipped public transport systems. Clearly, a larger sample would be needed to provide a complete overview of the urban development challenges, which are to be faced by European cities, but it appears to be a good starting point to have this range of diversity within the sample already.
All these questions are related to the various dimensions of the flows in urban metabolism: The resources to be put into the system to maintain it is depending to some degree also on the urban form. In this report the impacts are analysed for the metabolic flow dimensions land use; energy for transport and housing stock related energy demand (including space heating, renovation, construction and demolition).

1.1 Spatial development scenarios

With the sample of selected cities it is possible to cover some of the range of potential transformation paths for the main types of urban form and also varying developmental perspectives of cities.

Table C1  
Spatial development scenarios

<table>
<thead>
<tr>
<th>Database</th>
<th>Vienna</th>
<th>Stockholm</th>
<th>Athens¹</th>
<th>Oporto</th>
<th>Munich</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nr. of cells within the UMZ</td>
<td>470</td>
<td>787</td>
<td>236</td>
<td>111</td>
<td>126</td>
</tr>
<tr>
<td>average size of cells (km²)</td>
<td>0.67</td>
<td>0.38</td>
<td>0.94</td>
<td>2.12</td>
<td>1.84</td>
</tr>
</tbody>
</table>

Population development 2000 -2050

<table>
<thead>
<tr>
<th></th>
<th>Vienna</th>
<th>Stockholm</th>
<th>Athens¹</th>
<th>Oporto</th>
<th>Munich</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population (UMZ)</td>
<td>1,805,340</td>
<td>1,280,450</td>
<td>3,436,775</td>
<td>1,271,238</td>
<td>1,663,732</td>
</tr>
<tr>
<td>Projected development</td>
<td>+ 34.7 %</td>
<td>+ 44.3 %</td>
<td>+ 8.9 %</td>
<td>- 3.7 %</td>
<td>+ 17.7 %</td>
</tr>
</tbody>
</table>

Urban fabric 2000 (km²) *)

<table>
<thead>
<tr>
<th>Type of LUC</th>
<th>Medium dense city / Compact form</th>
<th>Low density/ Compact form</th>
<th>Very high density/ Compact form</th>
<th>Low density/ Fragmented urban form</th>
<th>Dense city/ Compact form</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vienna</td>
<td>313</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stockholm</td>
<td>333</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Athens¹</td>
<td>221</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oporto</td>
<td>235</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Munich</td>
<td>232</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Scenario results

<table>
<thead>
<tr>
<th>Scenario growth</th>
<th>Vienna</th>
<th>Stockholm</th>
<th>Athens²</th>
<th>Oporto</th>
<th>Munich</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population BASE outside UMZ</td>
<td>526,349</td>
<td>**</td>
<td>305,874</td>
<td>0</td>
<td>408,941</td>
</tr>
<tr>
<td>Scenario SUME outside UMZ</td>
<td>175,792</td>
<td>**</td>
<td>0</td>
<td>0</td>
<td>153,012</td>
</tr>
</tbody>
</table>

Urban fabric growth outside UMZ in km² / in %

<table>
<thead>
<tr>
<th>Scenario BASE outside UMZ</th>
<th>Vienna</th>
<th>Stockholm</th>
<th>Athens²</th>
<th>Oporto</th>
<th>Munich</th>
</tr>
</thead>
<tbody>
<tr>
<td>171 / 54% **</td>
<td>52 / 24% **</td>
<td>0</td>
<td>95 / 41%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario SUME outside UMZ</td>
<td>45 / 14% **</td>
<td>0</td>
<td>0</td>
<td>31 / 18%</td>
<td></td>
</tr>
</tbody>
</table>

*) Corine data: continuous and discontinuous urban fabric preparation in progress

The main results from the spatial development scenarios are displayed in the table below, comparing the different development starting situation (densities, urban form types) and the

¹ As the basic scenarios of Athens are not comparable to the other city scenarios, the numbers in this table refer only to the classic scenarios.

² As the basic scenarios of Athens are not comparable to the other city scenarios, the numbers in this table refer only to the classic scenarios.
varying developmental perspectives (projected population development). The group of cities shows quite diverse starting situations, ranging from a low-density/fragmented characterization (for Oporto) to very high density/compact type (like Athens). Also, the developmental perspectives are diverse, ranging from a decline perspectives in Oporto (after decades of very fast growth) to moderate growth in Athens and to accelerated growth in Vienna and Stockholm.

The scenarios show two kinds of results – one is the spatial dimension, the resulting growth of the so-called urban fabric between the starting and the end year 2050. The other is the related action space for policy makers, the potential to influence the future development of the selected cities’ urban form, provided through the comparison of the so-called BASE and SUME scenarios.

These two outcomes of the spatial development scenarios are used as an input for the assessment of the Urban Diversity Pattern (UDP) – the table shows only the quantitative aggregate of the UMZ expansion; the other result is the underlying spatial analysis of the distribution of population and jobs per cell, forming the basis for calculating the UDP indicator (this spatial distribution has been shown in the density maps for 2001 and 2050 in the respective scenario chapters).

The BASE scenarios show a substantial expansion of the UMZ for the cities of Vienna, Munich and Athens, ranging from a growth by 24% in Athens to 54% in Vienna. These results are due to the population increase, the proportional growth of jobs and the continuing increase of the floor space consumption per capita which has been assumed here based on the development experience of the past.

- Remarkably, Oporto does not need any expansion of the UMZ, even if the assumed increase of floor space will overcompensate the loss in population. The reason for this is a high potential for densification in existing urbanized areas, since they show a highly scattered settlement pattern.
- On the other hand, the BASE scenario for Munich results in particularly strong expansion of the UMZ if related to the population growth. The reason lies in two factors – one is a comparatively strong increase in the per capita floor space, the other rests in the fact that a very compact, densely used urban fabric in the starting year leaves little room for densification in the existing urban fabric.
- Vienna, in this respect, has more options for densification in the existing urban fabric, but the strong projected population growth together with per capita floor space expansion leads to a massive growth of the urbanized area (+54%).
- Athens, again, is quite another case: with its extremely high densities at the outset, a BASE scenario will lead to a substantial increase of the urban fabric beyond the existing UMZ delimitation (+24%), even if the projected population growth is comparatively moderate.

From this “baseline” of expected development a so-called SUME scenario has been developed for selected cities: Such a scenario attempts to show a development path, which should provide for less resource consumption (space, energy, materials) and can be reasonably achieved through concerted urban development policies. SUME scenarios focus on inner-city development, axes of high-level public transport and a more compact development in the fringes of the existing UMZ.

The SUME scenarios show quite differentiated results with diverse consequences for policy-makers:

- The Oporto perspective does not offer much opportunity to reduce land consumption, since already in the BASE scenario there is no expansion of the UMZ. The specific problem of Oporto is the low density/scattered settlement pattern, which cannot be
overcome in a situation without growth, aggravated by the weak public transport network, offering little options to use attractive non-motorized means of transport. Therefore, the SUME scenario assumed a radical focus of new developments close to the urban core area, near to existing or planned transportation axes, where the BASE scenario continues the trend to an outward oriented development, spread through the whole urban area. This is shown in the density maps and is relevant for the UDP indicator (see below).

- The SUME scenario for Munich shows a strong potential to reduce the UMZ (from +41% to 18%). Still, this reduction is not easily to be topped, since Munich has reached a very dense, compact settlement pattern, so the potential to reduce land use lies only in the compact development of the fringe areas in the UMZ.

- Vienna, as mentioned before, has a large section of the UMZ with lower densities and therefore has substantial options for densification in the existing urban fabric; focusing on existing and projected transport axes allows for a major reduction of the urban fabric growth (from + 54% to + 14%); here, the SUME strategy has the greatest potential impact, due to both elements, the starting situation and the strong growth perspective.

- In Athens, starting with very high densities, a SUME scenario shows the potential to accommodate the city’s growth within the UMZ, if the comparatively high densities are being applied in the outer sections of the city. The question remains to be answered, if such densities in the outer parts of the UMZ are advisable and adequate in terms of quality of life conditions.

Comparing the eight urban development scenarios shows, that there is a great potential to impact urban form over time, if a consistent set of policies is being applied. It also shows that the differential between the policy sets are adding up and become resource relevant, if there is substantial growth in an urban area. There is also great space for improvements, if the past spatial development has been not so consistently sustainable (as in the Vienna case). On the other hand, the Athens case also shows the limits to a further densification strategy – here, densities are already high enough to provide for attractive urban transport systems; the answer here could be the expansion and improvement of the transport system with the given (or even lower) densities.

1.2 Impact on transport and energy – UDP indicator

The urban spatial development scenarios generate an overall distribution of population and jobs for all cells within the UMZ and for the residual expansion outside of the UMZ until 2050. These spatial patterns are assessed regarding its potential impact on transportation and the energy consumption needed for transport by analysing the so-called Urban diversity pattern (UDP).

The BASE and SUME scenarios allow to draw transport related conclusions based on the current and the future shape of a city and the spatial distribution of functions. The difference of density, structure and size of the ‘Larger Urban Configuration’ (LUC) in the scenarios, which are modelled in Step 2, has impacts on the distances to be travelled in the urbanized area. The different densities of jobs and population and their spatial distribution within the UMZ also provides an indication of the (future) diversity in a city, which is relevant for transportation modes and distances.

The UDP-indicator, is composed of the three sub-indicators:
- Indicator 1 - Transport: Accessibility of high-level public transport infrastructure
- Indicator 2 – Centrality: proximity to centre functions
- Indicator 3 – Diversity: mix of economic and residential functions within a cell
Each cell in the UMZ is evaluated for each indicator through a rating procedure. The highest rating a cell can reach for each of the sub-indicators are 4 points. The highest rating a cell can reach for the UDP-indicator therefore are 12 points as from the aggregation of the three sub-indicators.

An aggregate UDP-indicator for a whole urban area is generated by calculating the population-weighted average UDP indicator. This is produced for the starting year and the two scenarios for the year 2050 (see table and figure below).

Table C2  Scenario results for the Urban Diversity Pattern

<table>
<thead>
<tr>
<th>The 3 sub-indicators of the UDP</th>
<th>Vienna</th>
<th>Stockholm</th>
<th>Athens</th>
<th>Oporto</th>
<th>Munich</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport (status quo)</td>
<td>3.13</td>
<td>**)</td>
<td>3.29</td>
<td>2.60</td>
<td>3.31</td>
</tr>
<tr>
<td>Transport (BASE)</td>
<td>2.71</td>
<td>**)</td>
<td>3.23</td>
<td>2.58</td>
<td>2.90</td>
</tr>
<tr>
<td>Transport (SUME)</td>
<td>2.86</td>
<td>**)</td>
<td>3.46</td>
<td>2.67</td>
<td>3.19</td>
</tr>
<tr>
<td>Centrality (status quo)</td>
<td>2.60</td>
<td>**)</td>
<td>2.95</td>
<td>1.93</td>
<td>2.45</td>
</tr>
<tr>
<td>Centrality (BASE)</td>
<td>2.26</td>
<td>**)</td>
<td>2.75</td>
<td>1.90</td>
<td>2.16</td>
</tr>
<tr>
<td>Centrality (SUME)</td>
<td>2.31</td>
<td>**)</td>
<td>2.91</td>
<td>1.98</td>
<td>2.30</td>
</tr>
<tr>
<td>Diversity (status quo)</td>
<td>2.85</td>
<td>**)</td>
<td>3.60</td>
<td>1.60</td>
<td>2.56</td>
</tr>
<tr>
<td>Diversity (BASE)</td>
<td>2.39</td>
<td>**)</td>
<td>3.42</td>
<td>1.48</td>
<td>2.16</td>
</tr>
<tr>
<td>Diversity (SUME)</td>
<td>2.74</td>
<td>**)</td>
<td>3.72</td>
<td>1.63</td>
<td>2.45</td>
</tr>
</tbody>
</table>

**) preparation in progress
Source: ÖIR, WP 1

With great differences in the densities, the fragmentation of the UMZ and the transport system, it seems no wonder there are also great differences between the cities in the sub-indicators and the total UDP-indicator.

- With its highly scattered settlement pattern and low densities, Oporto shows by far the lowest values in all three sub-indicators; this holds for both, the outset and the scenario end-states, since there is little potential for improvement, even in consequently applied SUME scenario (as shown above)
- On the other hand, Munich and Vienna show remarkably similar, high indicator values; in both growing cities it is clearly visible that the expansion of the urban area with the BASE scenario results in a major deterioration of the transport situation, since a much higher share of the population and jobs will be located in the UMZ fringes or even outside, which results in a worsened access to transport lines and centres of work and services. Both cases also show, that a SUME scenario has a great impact, keeping the reduction of the UDP-indicator to a minimum (for a larger total population)
- Resulting from the high densities and the central location of a large share of work places, Athens has by far the highest indicator values; as said before, the SUME scenario keeps densities rather high even in the outer sections of the urban area, and in

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3 As the basic scenarios of Athens are not comparable to the other city scenarios, the numbers in this table refer only to the classic scenarios.
context with the proposed extensions of the Athens subway system, this even leads to a slight improvement in the total UDP indicator. This is only an indication of what could be reached in the future, if the metro system would be expanded beyond the lines included in the scenarios.

Figure 1  
**Scenario results for the (aggregate) UDP-indicator**

Concluding from this overview, it seems important to note that

- A trend development – as intended to present in the BASE scenarios – in a growing city situation leads to a deterioration of the spatial preconditions for providing attractive transport systems: Densities in the accessed areas of transport lines tend to be low, a lot of growth is happening in spaces between axes or out of reach; both factors reduce the level of service on one hand and raise the distance to stops of transport lines on the other, contributing to a less attractive transport system.

- Growing cities have the option to counter this automatism through a clear spatial focus for their development strategies, as captured with the SUME scenarios.

- High-density cities have a great opportunity to improve their transport system, make it effective and contribute to reduced transport energy consumption, with or without population growth. High density provides the spatial preconditions for optimal access and high levels of service of transport systems. In the Athens case, e.g. it seems important to continue with contained and dense urban development (still under consideration of quality of life), but the innovative accent here will be the expansion of the modern metro system.
The spatial distribution of population and jobs for the future UMZ will be used as an input for the spatially explicit metabolism model, which is being developed in WP 2, with the perspective of calculating the resource flow impacts of the spatial development scenarios (energy, materials).

1.3 Building stock transformation - Energy for space heating, renovation, construction and demolition

Energy demand for space heating

Generally, the specific energy demand for space heating will be decreasing substantially (in terms of energy demand per square meter as well as in total). This is mainly due to a transformation process of the existing housing stock (which may show different speeds and qualities) and due to the improvement of construction standards for new buildings towards reduction of energy demand for space heating (also related to EU-directive EPBD Energy Performance of Buildings Directive expected to be re-announced in 2010 and according national requirements on building quality). The decreasing specific energy demand for space heating (per m2) also compensates rebound effects (as given by the increasing per capita floor space) in terms of total energy demand for space heating.

The options for energy saving for space heating by transforming the existing housing stock are estimated to be very high. Over the period 2000-2050, the average savings for space heating in the transformed housing stock range between 13 – 24% in BASE scenarios and 34 – 49% in SUME scenarios.

Referring to the yearly average, the energy demand for space heating decreases in the analysed regions by 65% between the year 2001 and the year 2050 in the BASE scenario and by 80% between the year 2001 and the year 2050 in the SUME scenario.

Figure 2: Housing stock-energy demand for space heating per m2 (kWh/m2/a) in the years 2001, 2050 BASE and 2050 SUME
Relating to global warming, an increase of average global temperatures of (at least) 2°C is to be expected, which may reduce energy demand for space heating further. At the same time, an increase of energy demand for space cooling is being expected due to this development⁴.

**Total housing stock related energy demand**

The following figure exemplifies the effects of the simulated scenarios in terms of the total housing stock related energy demand in average per square meter and year (average over the total period 2000-2050). The comparison comprises a minimum scenario with highly ambitious renovation and building exchange measures and a maximum scenario (no measures set at all) with the results of the energy demand under BASE scenario and SUME scenario conditions.

**Figure 3**  
*Total housing stock – average energy demand per m² and year within the period 2000 – 2050 (kWh/m²/a)*

Source: OIR

Considering the underlying assumptions for BASE scenario and SUME scenario (as described in part B⁵) an improvement in terms of housing stock related energy demand is the calculated result for all urban regions. This reduction of energy demand already includes the energy needed for implementing the considered measures (renovation and building exchange).

In absolute terms, differences between the analysed urban regions are caused mainly by differences in the age structure of the residential building stock and by the varying specific energy

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⁴ Currently, the share of energy demand for space cooling is still limited in the residential sphere – with higher importance for urban regions in warm climate conditions – but already considerable and steadily growing especially relating to office and trade buildings. Nevertheless, expecting an increase of average temperature levels of (at least) two degrees, the need for space cooling is expected to grow also in the residential sector, especially in urban regions in warm climate conditions. A balancing of this unfavourable development might be achieved partly by supporting a consequent transformation of the existing building stock to buildings with high quality thermal envelopes.

⁵ 1.1.2 ‘Data inputs and basic assumptions as a basis for the calculation of building related energy demand’
demand for space heating relating to climatic conditions, quality of the building stock and user behavior. The latitude of options differs considerably concerning their effects. The total effect of policy measures taken in BASE scenario and SUME scenario (in absolute terms as well as in relative terms) is much higher in Vienna, Munich and Stockholm than it is in urban regions with warm climate conditions.

On the basis of similar renovation rates and shares of building exchange (reconstruction) this is again related to the age of the building stock, but even more to differences concerning the potential effects of such measures in relation to the energy input needed for implementation.

In relation to a ‘zero scenario’ only urban regions in cold to moderate climate show improvements for both scenarios within the period 2000-2050. In comparison to a ‘zero scenario’ (estimating the energy demand due to no changes in terms of renovation or exchange of buildings) urban regions in cold to moderate climate conditions are able to diminish their overall energy demand in the period 2000-2050 considerably due to the measures undertaken in BASE scenario as well as – even to a higher extent – in the SUME scenario.

In contrast to this relation, urban regions in warm climate areas are able to improve their overall energy demand due to renovation and building exchange (within the period at hand) only if very ambitious measures are implemented (SUME scenario).

Total building related energy demand (reconstruction, renovation, heating) for the housing stock compared to a (theoretical) ‘zero scenario’ ranges from + 6% to −16% in BASE scenario and between −3% to −38% in SUME scenario.

Conclusions for the transformation of urban regions

The comparison of different development paths concerning housing stock transformation and their resulting total energy saving options for housing stock related energy demand show a considerable but limited amount of potential savings. The development shown in the assessment of housing related energy demand clearly points out that saving impacts from housing stock transformation can be achieved only by starting action as soon as possible. Even in case of immediate start of building related improvement measures savings are limited within the analysed period of 2000-2050 due to the counteracting energy demand for implementation of these measures (energy demand for renovation, reconstruction and demolition). Referring to the total saving potential for housing related energy demand, the assessment for the urban regions at hand shows a range of about −26% (Stockholm) and about −8% (Oporto).

Taking the Climate Change Agenda overall target of a maximum 2°C temperature increase into consideration, it is important to observe not only the average energy demand and the related yearly emissions, but also the cumulated total amount of energy (and resulting emissions in a following step) over the period 2000 – 2050. Thus the following figure highlights the potential of housing stock transformation in the analyzed cities in relation to the cumulated total energy demand over the full period.

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6 Due to the fact, that in the calculation empirical data for energy demand for space heating is used, user behaviour is included in the sample together with building related aspects as there are mainly building quality and climatic conditions (with heating degree days and the temperature difference between indoor and outdoor temperature as factors with major impact on energy use for space heating).
Especially in cities of cold-moderate climate the high relevance of space-heating energy demand leads to positive effects of measures in both categories – the reduction of energy demand for space heating in the end of the period is accompanied by a reduction of the total energy needed in the period 2000-2050 (for space heating, renovation and reconstruction measures during the implementation phase). This result clearly emphasizes the need and justifies enforced transformation of the existing building stock.

Due to the high saving options through transformation of the existing housing stock in urban regions with cold to moderate climate conditions, and due to very low energy demand for space heating in new buildings, total housing related energy demand (including energy needed for construction) can be reduced even in regions with relatively high population growth (as in the analyzed sample of urban regions: Vienna + 35%, Munich + 17%, Stockholm +44%).

Particular attention has to be paid to the total energy demand within the period 2000-2050 (including implementation of transformation measures as reconstruction, renovation and demolition), especially in warm climate cities. As shown above, the total energy demand (reconstruction, renovation, heating) for the housing stock compared to a (theoretical) ‘zero scenario’ actually increases in case of a BASE scenario for urban regions located in warm climate conditions. Thus those urban regions are able to improve their overall energy demand (within the total period) only if very ambitious measures are implemented (SUME scenario).

Nevertheless, measures of building stock transformation to be taken will have to be even more carefully balanced in cities in warm climate conditions in terms of:

- the effects on the overall housing stock related energy demand within the period 2000-2050 and

7 In case of consideration of energy demand for cooling, building quality is stated to be of higher relevance also in warm climate cities, thus positive effects could be achieved possibly even in BASE scenario in all urban regions.
their long-term effect on energy demand for space heating (and cooling, in respect to reduction of savings due to lock-in effect)

as well as the issue of costs and economic feasibility of such measures and the use of financial means.

In order to balance decisions related to building stock transformation, it seems important to take the combined effects of transforming urban spatial structures into a joint consideration. Th energy-related reconstruction can also be used to generate additional positive effects on urban form with the metabolic dimensions of land use and transport related energy consumption.
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Chapter 2 – Urban Diversity Pattern


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