#110

THE EFFECT OF THE STREET NETWORK ON MOVEMENT PATTERNS AND LAND USE IN SMALL CITIES

A comparative study of three 10K cities in Thuringia, Germany

SVEN SCHNEIDER
Bauhaus-University Weimar
sven.schneider@uni-weimar.de

ABDULMALIK ABDULMAWLA
Bauhaus-University Weimar
abdulmalik.abdulmawla@uni-weimar.de

DIRK DONATH
Bauhaus-University Weimar
dirk.donath@uni-weimar.de

ABSTRACT

Thuringia -a federal state in Germany- is characterized by a low-density settlement structure with 65% of its urban population living in cities with less than 25,000 inhabitants. In order to develop plans for the future of this region of Germany, it is necessary to understand how such small cities work, and how their spatial structure influences the life of their inhabitants. One crucial aspect thereby is the movement of people that is on the one hand shaped by the urban form, and on the other shapes how spaces are used. For our study, we selected three small cities, having a population of approximately 10.000 inhabitants. In these cities, we collected empirical data describing different modes of movement and the uses of each building in each city. Finally, we investigate the relationship between the empirical data and the configuration of the spatial structure of these cities. The results of this study confirm a relationship between street network configuration, movement, as well as use of commercial space in small cities. Nevertheless, this relationship also has its specificities, in regards to the proximity of spaces on the local level, which needs to be considered in the process of spatial analysis.

KEYWORDS

Small Cities, Movement, Land Use, Metric and Angular Street Network Centrality

1. INTRODUCTION

Despite the globally ongoing urbanization processes resulting in ever growing cities of worldwide importance - so called first-tier cities or global cities (Sassen, 2001) – still the majority of the population worldwide lives in small settlements (tertiary or third-tier cities). In fact, for Germany, a country with an urbanization rate of 75%, almost half of its population (45.8%) is living in cities with less than 25,000 inhabitants (see table 1). Thus, these small urban settlements have a high influence on the countries social, economic and ecological well-being. However, despite their importance, small cities have been largely ignored by urban theorists, leading to fact that planning strategies for the future of such cities are widely missing (Bell & Jayne, 2009).

Cities by population	Number of cities	Percentage of Cities	Average inhabitants	Total Population	Percentage of population	Percentage of population in Thuringia
Total	11,059	100%	7,431	82,175,684	100%	100%
+5000	2,913	26.3%	10,850	70,309,166	85.6%	65.2%
- 25K	10,549	95.4%	3571	37,677,160	45.8%	64.8%
5 - 25K	2,403	21.7%	9,233	25,810,642	31.4%	30%
5 - 15K	1,934	17.4%	8,144	16,811,241	20.5%	17%
7.5 - 12.5K	859	7.8%	9,447	8,332,164	10.1%	5.6%

Table 1 - Area Population statistics – Germany 2016[1]

In order to support planning for the future of small cities it is necessary to understand how these cities work (in particular, how they influence the life of their inhabitants). One crucial aspect thereby is the physical spatial structure (urban form / morphology) of these cities since this is – once built – hard to change and thus has a long-lasting impact on the city and its inhabitants. The spatial structure of a city can be categorized into three layers: streets, plots and buildings (Conzen, 1960). These three layers are strongly interdependent, whereby streets can be seen as the superior structuring element of the urban form (Marshall, 2005). For example, the shape of buildings restricts the number of users and possible usages, and plots define the maximum size of buildings, whereas streets define the maximum size of plots and restrict the possibilities for plot division. Furthermore, streets largely determine the paths that are possible to take to get from one building to another and thus also shape the movement of people within the city. This in turn is said to influence how public spaces and buildings are used (Hillier, 1996). Thus, the street network can be seen as a main driver for urban life. This has been shown in many cities worldwide. According to Penn (2001) summarizing the decades of space syntax research between 60-80% of the variance in movement rates can be explained by the geometry of the street network. However, the cases considered thereby are mostly large cities or quarters in large cities. Since the here regarded small cities (also referred to as third-tier cities) are an urban category on its own, it seems hardly possible to adapt planning strategies of second- or first-tier cities to them (Siegel & Waxman, 2001). Thus, the interesting question that arises for us is, if these small cities work spatially similar to the large cities, where a strong relationship between the street network and movement and land use has been found.

Nevertheless, until now, only few studies exist, in which the influence of the street network on urban life has been quantitatively investigated in small cities. Hillier & Hanson (1984) studied small villages in southern France and northern England, whereas these studies remained mainly morphological (discovering the so called "beady ring"-structure of such small settlements). Recently, some relations between the centrality of streets and the distribution of important public services were sketched. Medeiros & Hollanda (2005) found in a comparative study of Brazilian urban layouts that small cities exhibit a higher degree of integration (means that streets and consequently their inhabitants are visually closer). Al-Gatham (2012) studies urban villages in Bahrain (in particular the movement patterns of different demographic groups), however these villages are part of a larger urban structure, making it difficult to relate their results to the small solitary cities we are interested in. Karimi & Vaughan (2014) conducted a space syntax analysis and movement counting for new towns in England (with a population of around 50,000 to 80,000). The relationships between movement rates and space syntax measurements were described qualitatively, stating that most of the people walk close to or inside shopping centres and not along the spatially most integrated streets.

1 Alle politisch selbständigen Gemeinden mit ausgewählten Merkmalen am 31.12.2016 (4. Quartal)) published on 16.01.2017 by "Der Statistische Beirat" URL: https://www.destatis.de

In the following paper, we look at the effect of the street network on movement patterns and land use in three small cities (around 10,000 inhabitants) in Thuringia. Thuringia (a federal state in Germany) is characterized by a low-density settlement structure with more than half of its urban population (~65%) living in cities with less than 25,000 inhabitants), thus the choice of our city size fairly represents the average Thuringian urban landscape.

2. THREE SMALL CITIES AND THEIR DATA

This section briefly describes the three cities and the process we used for collecting empirical data (movement and land use) and the methods used to calculate street network measures. The three cities that we used for our study are Hildburghausen, Waltershausen and Zella-Mehlis. They have almost the same number of inhabitants (around 10,000 or 10K Cities) and are of similar size regarding the built plots (3.8 sq km). However, they differ morphologically due to their geographical situation and their historic development. The plans of these cities are shown in figure 1.

Hildburghausen (in the following referred to as HH), a city in the south of Thuringia (close to the Bavarian border), started as a settlement in the 9th century and got city-rights in the 13th century. The number of inhabitants grew from mid of the 19. century from ca. 5,000 to ca. 12,000 inhabitants in the 1980s. From then on the population slightly shrank to ca. 10,100 today. HH is located in a valley directly at a river (Werra). This river cuts the city into a northern part (in which the historical core is located) and a southern part (which consists on the one hand of an industry park and a quarter of detached houses).

Waltershausen (WH), a city in the mid-west of Thuringia (close to an important motorway A4 and the capital Erfurt), was firstly mentioned in the beginning of the 13th century. Its population grew from mid of 19. century from about 4,000 inhabitants to 15,000 in the 1950s. It shrank to approximately 10,300 till today. WH is located on a rather flat terrain. However, a hill in the south of the city restricted city growth in this direction. Thus, the historical core is nowadays located at the edge of the city.

Zella-Mehlis (ZM) is a city in the Thuringian forest, formerly being two villages (Zella and Mehlis) founded in the 12th resp. 13th century. They were merged to one city in 1919. ZM reached 17,000 inhabitants in the 1950s, from then on its population shrank to 10,600 inhabitants in 2015[2]. ZM is surrounded by hills and exhibits a hill in its geometrical centre, causing this part of the city to be unbuilt.

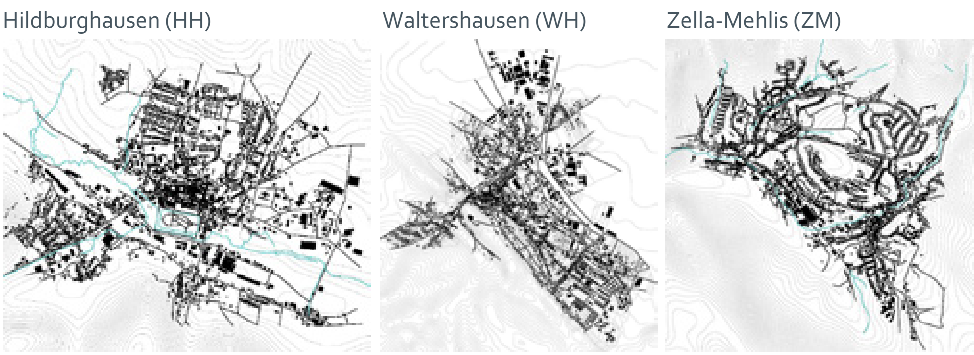

Figure 1 - Figure Ground Plans of the three cities with historic centres marked with a red dot (from left to right: Hildburghausen, Waltershausen, Zella-Mehlis)

2 This number remained almost stable since 2011

Concerning the building types all three cities exhibit a historical part (with densely packed row houses), condominium housing districts, built in the 1960s to 1980s, districts with detached houses (mainly one-family) and industrial zones. In HB and in WH the industrial zones are located at the edge of the city (in the east and in the south-east in HB and in the north in WH). In ZM industrial buildings -from the late 19. Century- are located in between the formerly two villages. Today there is a large industrial zone between ZM and the neighbouring city Suhl (this was excluded in our urban model, since it is not directly connected to the city itself separated by the railways).

Regarding the morphology of the three cities, HH exhibits the most compact city shape (almost circular) with the historic core in the geometric centre, while WH has an almost rectangular shape rotated towards the northwest with its historic core at the western city border (only followed by a suburban one-family district). Finally, ZM exhibits two historical centres due to the fact that this city emerged from two formerly separate villages (as shown with the red dot in Figure 1).

2.1 DATA COLLECTION

The city models (street network, plots, and building footprints) were created based on the official data provided by the federal state[3]. The data for movement and land use was collected in October 2016 (with students in the course of a seminar). The number of pedestrians passing was categorized into three age groups (children, adults, elderly) and the number of vehicles in two types (bicycles or cars). The movement direction and how many times each user passed, was not considered. The counting was conducted twice, once in the morning (from 10:00 – 11:00) and once in the afternoon (14:00-15:00). Each counting took 15 minutes. The usage as well as the building height (number of storeys) was recorded. Regarding the building usage, we prepared a list of typical usages (as residential, trade, services, education, industrial or vacant). The data for movement and land use was collected in October 2016 (with students in the course of a seminar on computational urban analysis).

The counting and mapping was done manually on paper and later digitalized. For this purpose, we developed a tool (for Rhinoceros3D[4] / Grasshopper[5]) that enables to flexibly visualize and analyse spatial data. In Figure 2 the results of the counting and land-use mapping are shown. In all three cities, the old centres exhibit high pedestrian flow specially near the market square, almost half of the passing pedestrians were old people, most of the main roads showed an increase in passing vehicles, and almost 90% of them were cars, Commercial buildings cluster in the old centres, and there is a noticeable amount of vacant spaces in each city. In Figure 2 the results of the counting and land-use mapping are shown. It can be seen that in all three cities the old centres exhibit high pedestrian flow specially near the market square, almost half of the passing pedestrians were old people, most of the main roads showed an increase in passing vehicles, and almost 90% of them were cars. Commercial buildings cluster in the old centres, and there is a noticeable amount of vacant spaces in each city.

3 URL: http://www.geoproxy.geoportal-th.de/geoclient/
4 URL: http://www.grasshopper3d.com/
5 URL: https://www.rhino3d.com/

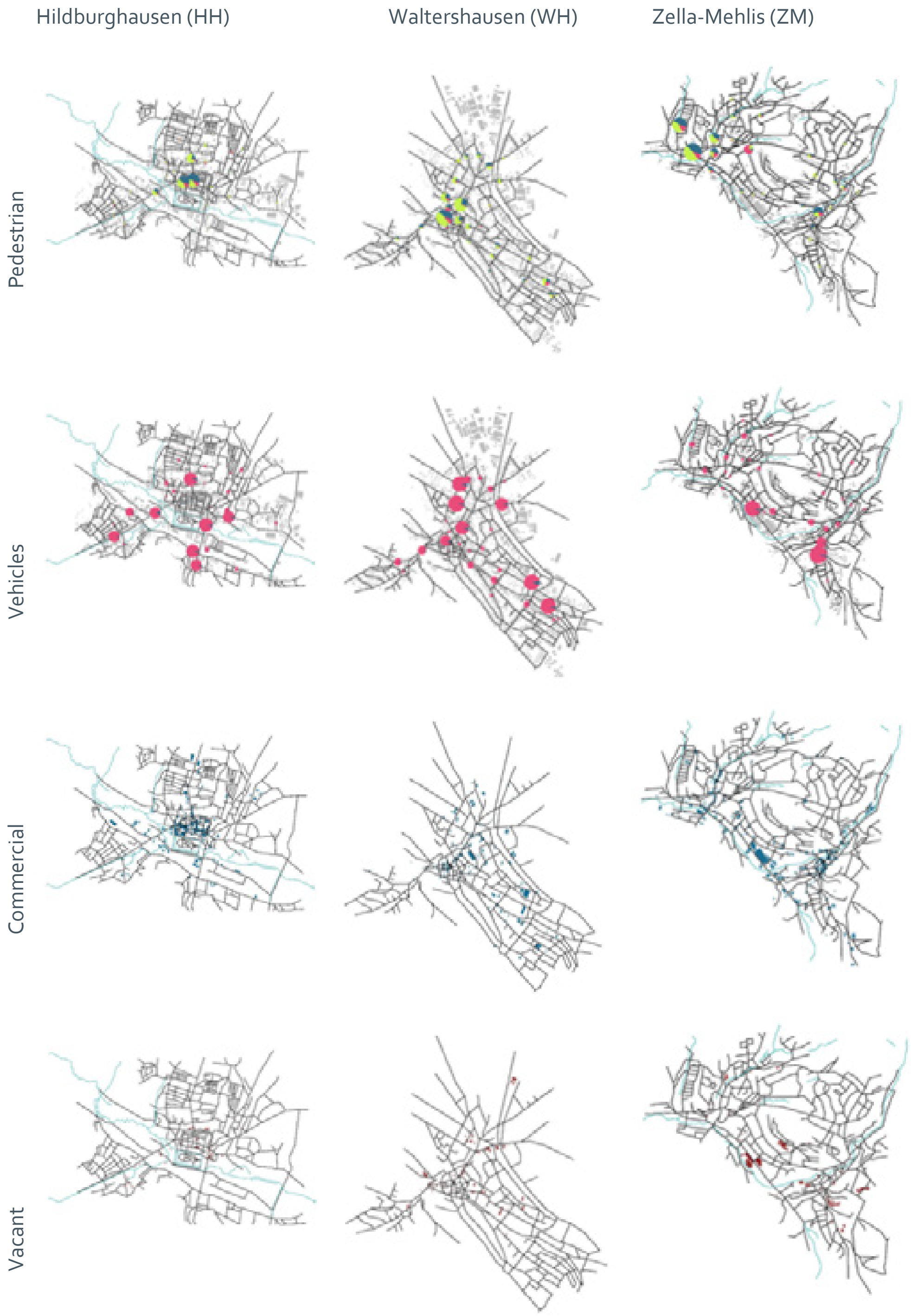

Figure 2 - Mapping of the data collected in the three cities: first two rows show mapping of pedestrian and vehicle movement with pie charts, whereby the diameter represents the total number, and the sections of the pie represent the ratio of different users (elderly, adults, children for pedestrians and cars and bicycles for vehicles). The last two rows display the locations of both commercial and vacant buildings.

2.2 STREET NETWORK ANALYSIS

Street Network properties describe how streets relate to other streets. Therefore, typical graph measures such as Closeness Centrality (Integration) or Betweenness Centrality (Choice) are used. Whereas the former indicates how close a street is to other streets, the latter indicates how often a street is passed on the shortest paths to other streets. The distance between streets can thereby be measured metrically (physical / walking distance) as well as by angles (which is said to be more related to psychological distance). The latter is usually used in Space Syntax, claiming that this is more appropriate for predicting movement patterns (Hillier & Iida, 2005; Turner and Dalton, 2005; Varoudis et al., 2014) and the subsequently following land use. However, studies exist, show that network centralities based on metric distance also have a significant correlation to the distribution of commercial uses (Sevtsuk, 2010), and empirical research shows that people are neither choosing their ways purely on basis of Euclidian distance (Golledge, 1999; Mallot & Basten, 2009), nor exclusively on the basis of cognitive effort (Li & Tsukaguchi, 2005; Takeuchi, 1977). Therefore, in our study we use both, angular and metric distance, in order to understand which is more suitable for our small towns.

For conducting both types of analyses we used the segment map (Turner, 2001) as a model for representing the street network. The segment maps of all three cities were drawn manually. Therefore, we adjusted the road-centre-line-based network of the official data in order to respect the visual connections from one segment to the other. For example, T-intersections that are close to each other have been joined to an X-intersection to avoid two 90° turns where in reality there is almost no turn necessary. Furthermore, additional segment for crossing public squares have been inserted.

The parameters of the centrality measure have influence on the results, since it mathematically defines the travel distance which people are willing to overcome. These parameters are described through the proximal distance, and angular distance and how the network is mapped, in different radii. We defined our radii starting from at 200 m until 2000 meters (R200, 300, 400, 500, 600, 800, 1000, 1200, 1600, 2000 and radius n). Although there are no clear boundaries between these scales (Vale & Pereira, 2016), we here refer to a local scale from 200 up to ~600 m and the global scale from 2000 m and larger[6]

The measures were calculated in DepthmapX[7], and then exported to our analysis toolbox for further analysis and visualisation. In Figure 3 some of the analysis results for angular analysis are shown (Choice and Integration, each R300 and Rn). The results for metric analysis can be found in the appendix. The results intuitively coincide with the structure of the cities: the main roads are highlighted in the global centralities. The centre of the cities can be identified on the local scale. Here it should be noted, that also the two separate centres of ZM (formerly two villages) are well visible.

6 It should be notated, that for global scale radius 2000 m and radius n will be treated similarly, since in our small cities the longest distance from one end to the other is not larger than 3500m, the analysis results - Pearson correlation coefficient- in radii larger than 2000m correlate very strongly to the results with Radius n (r > 0.9)

7 https://varoudis.github.io/depthmapX/

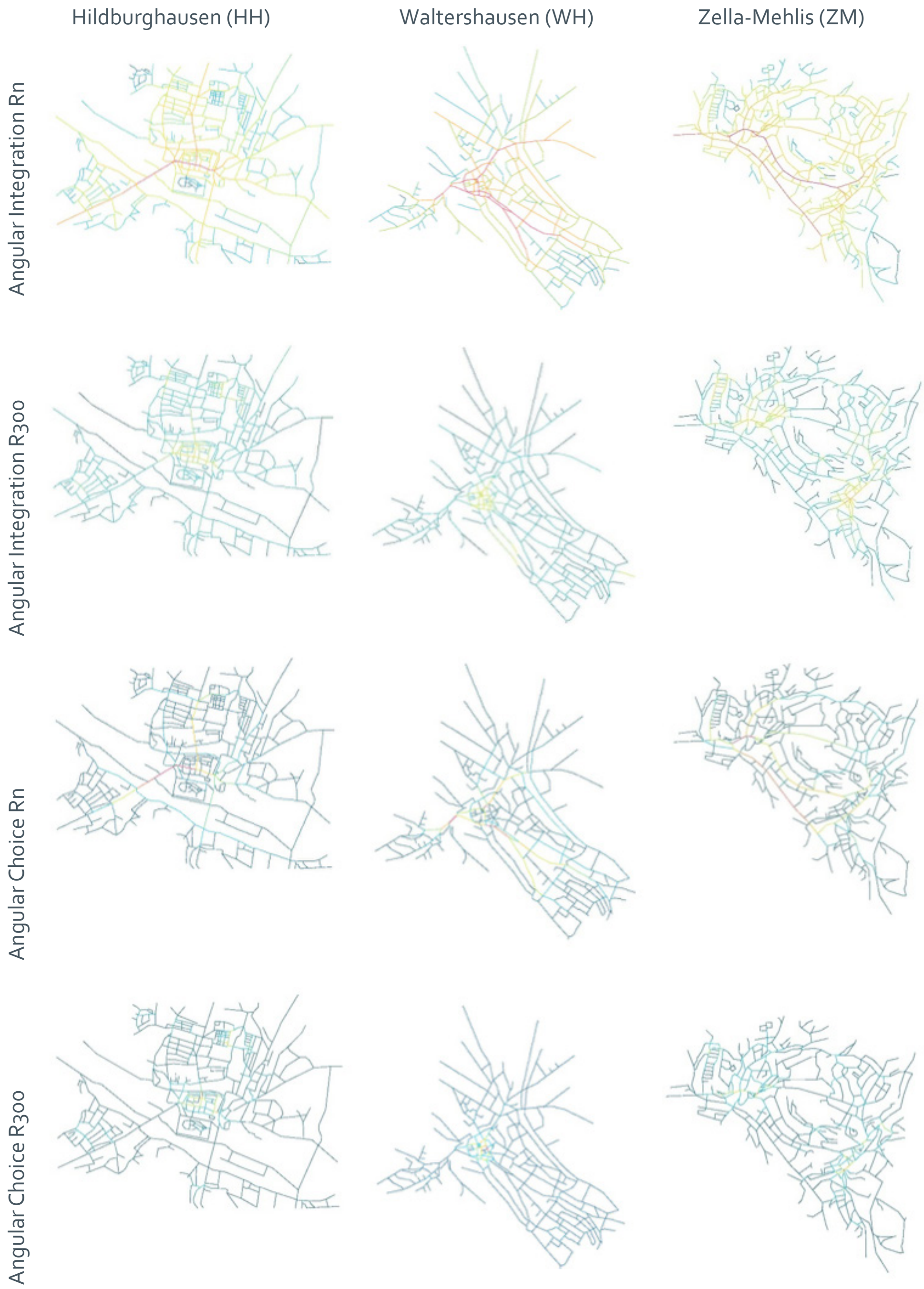

Figure 3 - Space Syntax Accessibility Measures (Angular only) for the three cities

2.3 MAPPING LAND USE TO STREET SEGMENTS

To correlate street network properties to empirical data, the data needed to be mapped to the street segments. In the case of movement counting, this is rather simple, because the countings were conducted in a certain street segment. In the case of land uses a mapping is necessary, because these were recorded for each building and not per street segment. E.g. we want to know how many buildings with commercial use are assigned to a street segment. Thereby, however, it is not useful to only map all the buildings that are directly attached to the street segment, because the number of buildings is highly dependent on the length of the segment. Since street network properties are not dependent on the length of a segment (also very short segments can exhibit a high closeness or betweenness centrality) a different kind of mapping is necessary.

In this paper, we propose a method for mapping buildings to street segments based on visibility. Thereby we search for buildings visible to a segment within a certain range. As a range we use the maximum distance for a pedestrian to well recognize an object (e.g. a sign that indicates the use of the building). Here we use 100 meter (according to Gehl & Svarre, 2013). The method works as follows: First, we divided the segment to a sequence of points in a distance of appr. 5 meters. From each point we shoot a perpendicular ray (100 m long). At the segment ends, we shoot 180° isovist rays away from the segment. If a rays hits a building, that the exhibits a certain use (e.g. commercial), than this building is assigned to the segment. In Figure 4 this is exemplified: the red- and blue coloured buildings are commercially used, grey buildings exhibit other uses. Commercial buildings within the visible range (colored in blue) are assigned to the segment. The building colored in red, (although the also hosts commercial uses) fall outside the visibility range and are therefore not considered for this segment.

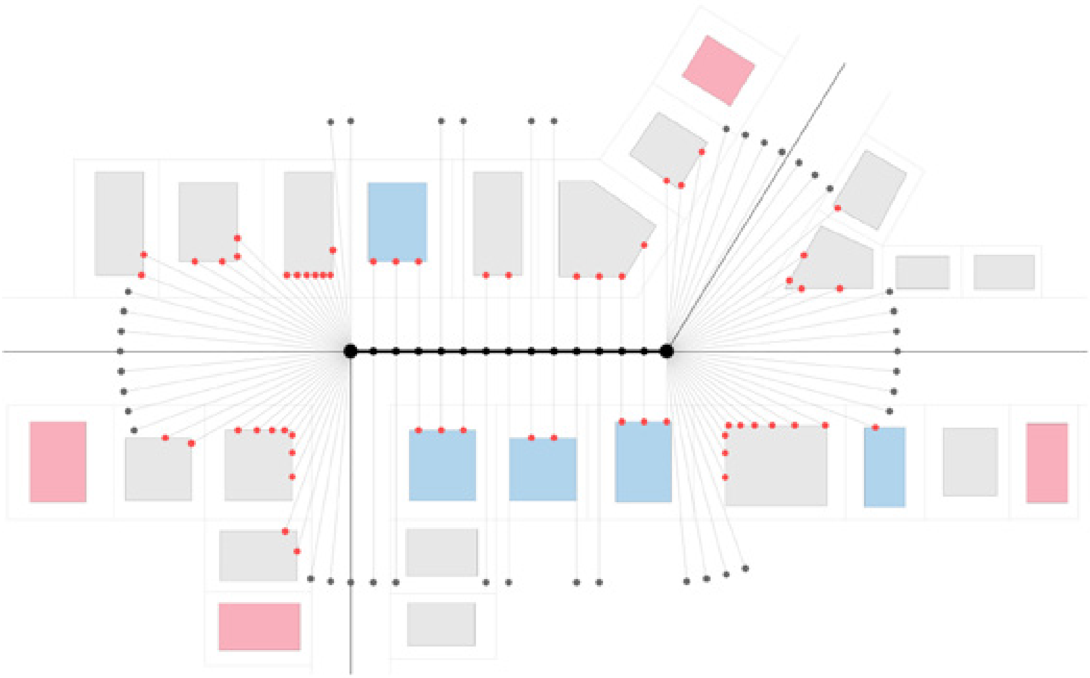

Figure 4 - Using rays for mapping building uses to a segment (buildings with red points are counted for the respective segment, others not)

After the buildings are assigned to a street segment, the number of buildings as well as the floor area of the buildings with a certain use can be computed for each segment. To avoid the influence of the street length on the results, the data was normalized (divided by the length of the segment).

Figure 5 - Building Usage (Commercial & Vacant) mapped to street segments

3. CORRELATIONS

In the following we look at the relationships between street network and empirical data. Therefore, we tested the relationships between both dependent and independent variables using Pearson's correlation coefficient r. This measure not only shows the strength of the relationship but also the direction – positive or negative – of the relation. For our statistical analysis process, we used a toolbox for statistical analysis for Grasshopper, based on R[8] (Abdulmawla et al., 2017).

From our empirical data, we selected for the movement countings both the aggregated pedestrians and the aggregated vehicles. For the land use we selected commercially used and vacant buildings. These - compared to other usages such as schools, hospitals, governmental (whose position is most often decided top down) - typically developed other time (bottom up, regarding the individual location qualities). Thus, we assume that buildings with commercial use are positioned in commercially attractive locations (with a high amount of pedestrian traffic) and the presence of vacant houses reflects unattractive locations (not well accessible, or no pedestrians). As values, we use the number and area of commercially used and vacant buildings. Both values are interesting, because they indicate different kinds of types of a certain building, which might also be addressed to different spatial locations. E.g. we assume many small commercial buildings in the spatially more integrated parts of the city and a fewer number (however with a large building footprint) at the more segregated parts.

To summarize, in our statistical analysis we tested the relation between the six empirical datasets (pedestrian and vehicle movement; number and area of commercial and vacant buildings) and four centrality measures (angular choice and integration and metric choice

8 R Core Team (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

and integration) in different radii starting at 200 m up to Rn. The outputs of the correlation process are matrices of values between -1 and 1. In order to speed up both the reading and the comparison of these matrices, the data was visualized using R heatmap[9] as shown in **Fehler! Es wurde kein Textmarkenname vergeben.**figure 6 and 7. The red colours show high positive correlation and the blue shows high negative correlations. The correlations were clustered into five categories (strong and medium for both positive and negative and weak for no relation)[10].

3.1 AGGREGATED DATASET (ALL THREE CITIES AT ONCE)

To get a general picture of the relation between street network and movement and land use in small cities we first take a look at the correlations in an aggregated dataset of all three cities. The heatmap is shown in Figure 6. When we look at the relation between movement and street network, we can see a medium positive correlation between pedestrian movement to both global and local angular Choice and Integration peaking at local radii (R300 to R800 with r~ .55 to .6), to local metric choice (R200 to R800 with r~ .39 to .53), as well as to global metric integration (R1000 to R2000 with r~ .34 to .46). Regarding vehicular movement, there is a medium positive correlation between the number of vehicles and global angular choice (Rn with r = .38).

When we look at the relation between commercial buildings and street network, there is a strong positive correlation between number of buildings with commercial uses to local angular and metric choice (R200-R600 with r~ .63 to .82, with a peak at radius 300m), a medium positive correlation to angular integration across all radii (r~ .42 to .65, with a peak at R400, r = .65), as well as metric integration (above R600 with r~ .33 to .42). Furthermore, there is a medium correlation between the area of commercial use and global metric integration (Rn with r = .42).

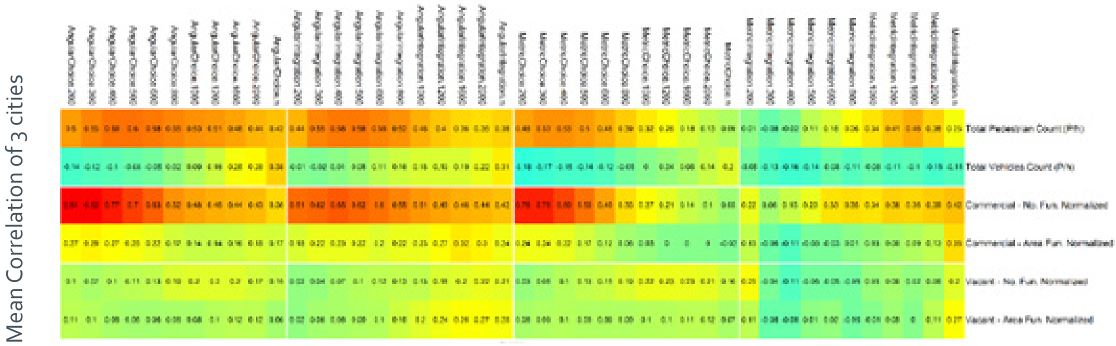

Figure 6 - Mean correlation heatmap for the three cities

Regarding the relation between vacant buildings street network, there are only weak correlations, peaking at global radii (r ~ 0.2-0.27).

The correlations found in the aggregated dataset, coincides with body of research on space syntax: it shows that places with high local accessibility also have higher local pedestrian movement, followed by commercial activities. Although low, there is a trend that vehicle movement correlates stronger to global radii, followed by the size of commercial buildings.

9 Gregory R. Warnes, Ben Bolker, Lodewijk Bonebakker, Robert Gentleman, Wolfgang Huber Andy Liaw, Thomas Lumley, Martin Maechler, Arni Magnusson, Steffen Moeller, Marc Schwartz and Bill Venables (2016). gplots: Various R Programming Tools for Plotting Data. R package version 3.0.1. URL https://CRAN.R-project.org/package=gplots

10 Five correlations categories:

Between	-1.00 to -0 .60	strong negative correlation
Between	-0.59 to -0.30	medium negative correlation
Between	-0.29 to 0.29	weak to almost no correlation
Between	0.30 to 0.59	medium positive correlation
Between	0.60 to 1.00	strong positive correlation

3.2 COMPARING THE THREE CITIES

When looking into the cities individually, we can see some notable deviations from the average correlation matrix presented above. Therefore, we created heatmaps for each city (Figure 7). In this section, we look at the deviations exhibited compared to the aggregated dataset and try to formulate hypotheses for the reasons of these deviations based on our experiences from the field trip.

3.3 MOVEMENT

In HH there is an increase to high positive correlation between number of pedestrian movement to both Angular Choice & Integration (all radii with r~ .60 to .83, with a peak at r = 300m), to local Metric Choice (R200 to R500 with r~.63 to .76, with a peak at r = 300m). This coincides with our experience of HH as the one of the three cities with the most lively city centre. Furthermore, in HH we can observe an increase to medium negative correlation between vehicle movement and local Angular & Metric Choice (R200 to R300 with r~ .37 to .4, with a peak at r = 200m). This might be due to the location of market square where there are street segments for pedestrian use only.

In WH there is also an increase to high correlation between pedestrian movement and both local Angular and Metric Choice (R300 to R800 with r~ .58 to .83, with a peak at r = 500m), the correlation to both Metric and Angular Integration are similar to the aggregated dataset.

Opposite to HH and WH, in ZM there is a drop to almost no correlation between pedestrian movement and both Angular and Metric Choice. There is a medium positive correlation to Angular Integration R500 to R800, r ~ .34), medium positive correlation to Metric Integration (R1200 to R1600, r ~0.47). This low correlation might be due to the dispersed city structure (formerly two villages), whose global structure does not support the local centres (see figure 3). Regarding vehicle count there is an increase in medium positive correlation of vehicle count to both Angular Choice (Rn, r = .53) and Metric Choice (Rn, r = .35).

3.4 COMMERCIAL BUILDINGS

In HH there is an increase to a high positive correlation between the number of commercial buildings to Angular Choice (All Radii with r~ .61 to .91, with a peak at r = 300m), to global Angular Integration (R200 to R600 with r~ .70 to .80, and R1600 to R2000, r~.65), to local Metric Choice (R200 to R500 with r~.6 to .76, with a peak at r = 300m), as well as a medium correlation to global Metric Integration (Rn, r = .56). There is another increase to medium positive correlation between the area of commercial buildings to both Angular Choice & Integration at all radii (r~ .42 to .6, with a peak at around r = 300 m to 600 m) and to local Metric Choice (R200 to R500 with r~.42 to .55).

WH has almost identical correlations as the aggregated dataset, except a small increase in the medium positive correlation between number of commercial buildings and Metric Integration (R500 to Rn, r~ .4 to .55) and an increase to medium correlation between the area of commercial buildings and local Angular Choice (R300 to R600, r~ .3 to .37).

ZM exhibits an increase to medium positive correlation between number of commercial buildings and Metric Integration (R200, r = .53, R600, r = .41 and R1200, r = .51), an increase to medium negative correlation between global Metric Integration and area of commercial buildings (R1000 to R1600 with r~ -.30 to -.39). This confirms with the fact that the shopping centres are located at the edges of the city.

3.5 VACANT BUILDINGS

Regarding vacant buildings in HH there is only an increase to medium positive correlation to local Metric Integration (R200, r = .50) and global Metric Choice (R1000 to R1200, r = .31).

In WH, there is a general increase to medium positive correlation between the number of vacant buildings to both Angular Choice & Integration and Metric Integration at all radii except R200 in

Choice (with r~.34 to .64), to global Metric Integration (R1000 to Rn, r ~ .33 to .44). Regarding the area of vacant buildings there is an increase to medium correlation between to both Angular & Metric Choice (R200 to R2000 with r~.32 to .63), to Angular Integration at all radii, as well as, to Metric Integration at various radii (R600, r = .34, R1200 to Rn, r ~ .32 to .52).

ZM exhibits an increase to medium negative correlation between number and area of vacant buildings to global Metric Integration (R1000 to R1600 with r~ -.33 to -.42), to local Metric Choice (R500 to R600, r ~ -.30 to -.33), as well as, an increase to medium positive correlation between the area of vacant buildings and local Metric Integration (R200, r = .32).

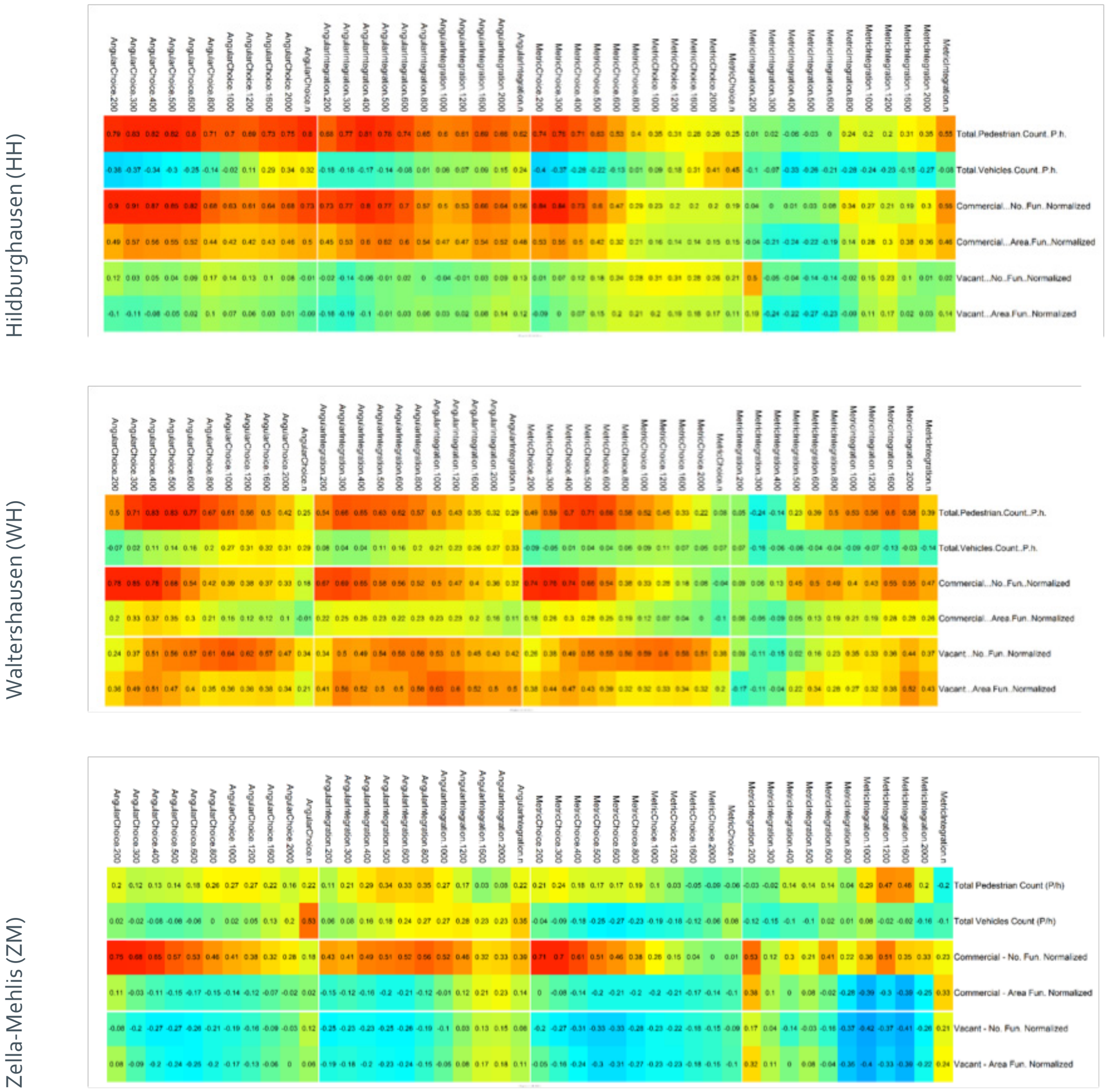

Figure 7 - Heatmaps showing correlations (r) between street network measurements and movement / land use

4. CONCLUSION & OUTLOOK

Small cities are an urban category in its own and therefore need special consideration in the conception of planning strategies. In this paper, we studied the relationship between the street network and the movement patterns and land use in small cities. We correlated countings of pedestrians and vehicles, as well as the number and area of commercial and vacant buildings to Angular and Metric Choice and Integration. When looking at the aggregated dataset of all the three cities, we could find a high correlation between both pedestrian movement and commercial activities to the local centrality measures. However, when look at each city individually we found significant deviations, which might be due to each cities particularities. However, what remained almost constant in all three cities was a high correlation between the number of commercially used buildings and local Angular Choice.

Furthermore, we found that the relation between spatial configuration and how people move and land use is highly dependent on the analysis radius. The strongest correlations could been found at relatively small radii (200 – 300m). This contrasts with previous studies conducted in cities of larger size (where pedestrian movement it is often referred to at radii of 600 m to 1000 m). Which indicates that the pedestrian movement might be affected by the scale of the city (the willingness to walk might increase with city size).

While in this paper we only could give a small insight into the role of the street network on the functioning of small cities, we hope to, in the future, gain deeper insights on this topic. Therefore, we will on the one hand look closer at the reasons for the differences between the cities. On the other hand, we will include other spatial metrics (e.g. density, plot sizes, origin-destination based path models).

REFERENCES

Al-Gatham, W., 2012. Cultural movement patterns and social implications in space of villages absorbed by cities in Bahrain, *Proceedings of 8th International Space Syntax Symposium*, Santiago, PUC.

Bell, D. & Jayne, M., 2009. Small Cities? Towards a Research Agenda, *International Journal of Urban and Regional Research* 33 (3) September 2009.

Conzen, M., 1960. Alnwick, Northumberland A Study in Town-Plan Analysis, *Orge Philip & Son*, London.

Medeiros, V. & Hollanda, F., 2005. Urbis Brasiliae: Investigating topological and geometrical features in Brazilian Cities, A. Van Nes (ed.), *Proceedings of 5th International Space Syntax Symposium*, Delft, Faculty of Architecture, Section of Urban Renewal and Management.

Gehl, J. & Svarre B., 2013. *How to study public life*, Island Press.

Hillier, B. & Hanson, J., 1984. *The Social Logic of Space*. Cambridge: Cambridge University Press.

Hillier, B., 1996. Cities as movement economies, *Urban Design International*, 1 (1), pp. 41-60.

Hillier, B. & Iida, S., 2005. Network and psychological effects in urban movement. Cohn, A.G. & Mark, D.M. (Eds.) *Spatial information theory - International Conference*, COSIT 2005, Ellicottville, NY, USA, 475-490.

Karimi, K. & Vaughan, L., 2014. An evidence-based approach to designing new cities: The English New Towns revisited. Carmone, M. (ed.) *Explorations in urban design*, Ashgate, Surrey, UK, pp. 261-276.

Marshall, S., 2005. *Streets & patterns*. Oxon: Spon Press.

Penn, A., 2001. Space Syntax and Spatial Cognition - Or, why the axial line?, *Proceedings of the 3rd International Space Syntax Symposium*, Atlanta, 11:1-11:17

Sassen, S., 2001. Cities in the global economy, Paddison, R. (ed.) *Handbook of Urban Studies*, SAGE Publications.

Sevtsuk, A., 2010. Path and Place: A Study of Urban Geometry and Retail Activity in Cambridge and Somerville, MA, PhD dissertation in *Urban Design and Planning*, Massachusetts Institute of Technology.

Siegel, B., & Waxman, A., 2001. *Third-tier cities: Adjusting to the new economy*, Somerville: Mt. Auburn Associates, Inc.

Turner, A., 2001. Angular Analysis, *Proceedings of the 3rd International Symposium on Space Syntax*, Georgia Institute of Technology, 30:1-30:11.

Turner, A. & Dalton R., 2005. A simplified route choice model using the shortest angular path assumption. *8th International Conference on GeoComputation*, Michigan, USA, 31 July-3 August 2005

Varoudis, T., Law, S., Karimi, K., Hillier, B., & Penn, A., 2013. Space Syntax Angular Betweenness Centrality Revisited. *Proceedings of the 9th International Space Syntax Symposium* (ed YO Kim, HT Park, KW Seo), Seoul, Korea, 31 October-3 November 2013, pp. 1–16. Seoul: Sejong University Press.

APPENDIX

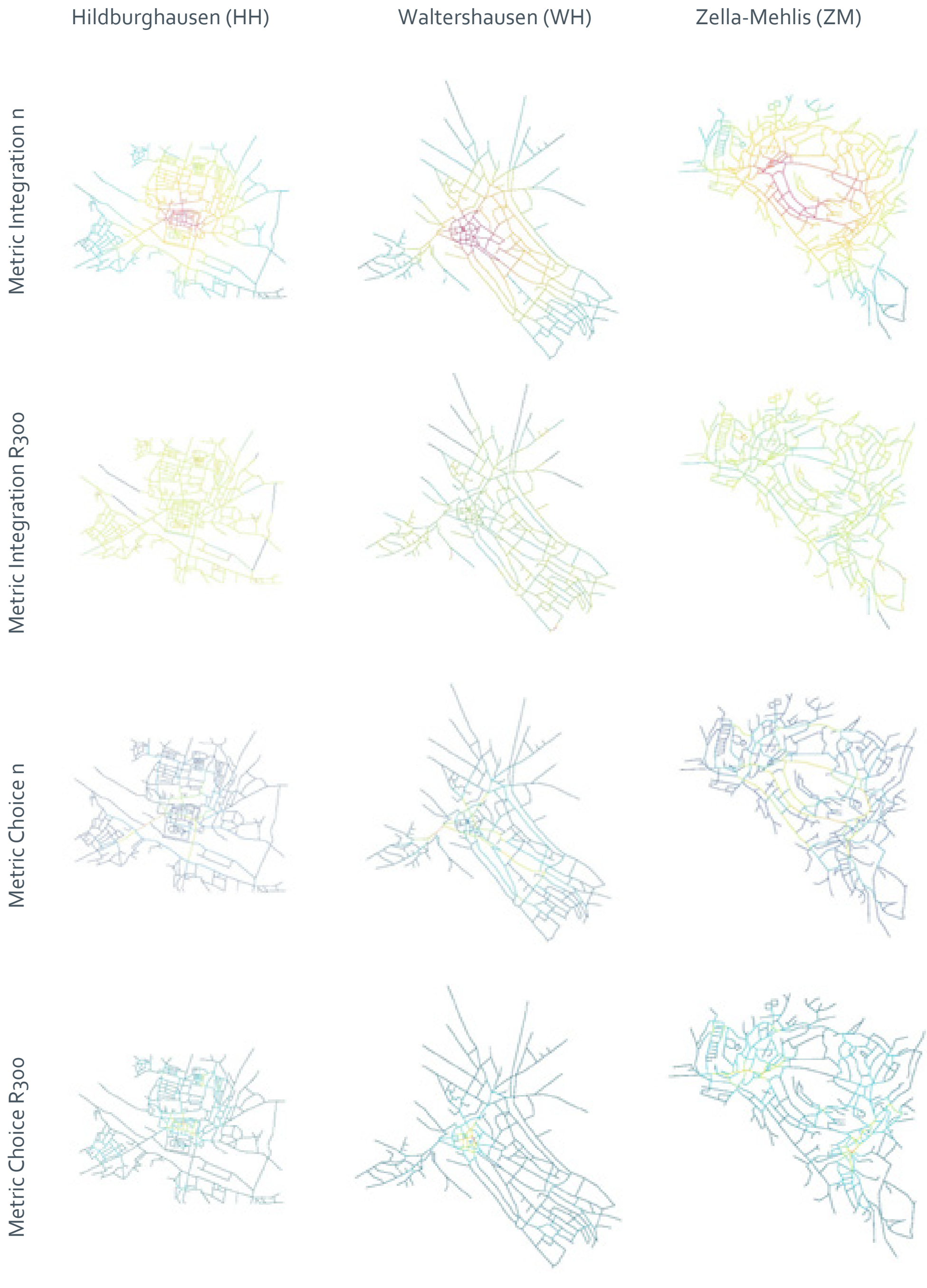

Figure 9 - Space Syntax Accessibility Measures (Metric only) for the three cities