Location-based density and differentiation – adding attraction variables to Space Syntax

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Abstract. *The central variables in any urban model are distance and attraction (Wilson 2000). Space Syntax research has contributed to the development of new geometric descriptions and measures of distance that have proven successful when it comes to capturing pedestrian movement. However, the description and measurement of attractions has not been central to the field. An important exception is the development of Place Syntax analysis, which concerns new methodologies and software that opens for analysis not only of different kinds of accessibilities in the street network in itself, but also analysis of the accessibility within the network to different forms of attractions, for instance, residents or retail (Ståhle et al 2005). Place Syntax analysis is a generic form of analysis, why we may choose to analyse the accessibility to particular socio-economic attractions, but we may also conceive of a model of 'pure' spatial form – a kind of architectural model of the city. For instance, Place Syntax analysis has been applied in different kinds of density analysis, transforming density measures from area-based measures to location-based measures (Ståhle et al 2005). In this paper, we extend such spatial attraction to not only include the variable of density but also diversity and present results from an extensive empirical study including four European cities, paving the way towards a more complete architectural model of the city including both the analysis of distance and attractions.*

Keywords: Accessibility, density, differentiation, attraction, configuration

Introduction: the need for an architectural model of the city

We will in the following present progress towards what we call an architectural model of the city. The fundamental concern for any investigation of such an entity is the relation between humans and the environment, where the proposed model departs from regular conceptions in two fundamental ways. First, the environment is here not understood as something given but as something created by humans. This implies that the environment is possible to shape according to different ideological principles. Second, the built environment is not conceived of as an entity detached from humans and their activities, why urban space is conceived as an entity structured and shaped in relation to both the human body and human perception and cognition. The latter is supported by psychologist James Gibson's theory of affordances (1977, 1979), where affordances constitute what emerges in the interface between human abilities and physical properties of the environment.

The paper is structured as follows. First,

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the proposed model will be described as fundamentally constituted in accordance with the traditional gravity model, that is, the variables of distance and attractions (Wilson 2000), albeit, distance measures will be drawn from space syntax and attraction measures from space syntax derived research using place syntax analysis (Ståhle et al. 2005). Second, such distance measures will be discussed in relation to the theory of affordances (Gibson 1986). Third, attractions will be defined as variables of spatial form that condition both density and differentiation of human activity. Thereafter, these variables will be tested and evaluated against socio-economic data in Stockholm. In the final section, conclusions will briefly be drawn and next steps suggested.

Urban models: distance, attraction and representation

The central variables in any urban model are distance and attraction (Wilson 2000). Space syntax research has contributed to the development of new geometric descriptions and measures of distance that have proven most successful, not least when it comes to capturing pedestrian movement (Hillier & Iida 2005). However, the description and measurement of attractions has not been central to the field. An important exception is the development of Place Syntax analysis (Ståhle et al. 2005), which concerns new methodology including software that open for analysis not only of different kinds of accessibilities in the street network in itself, but also analysis of the accessibility through the street network to different forms of attractions, for instance, residences or retail (Ståhle et al 2008).

Hence, by an urban model we here mean a model of urban space based on physical and cognitive affordances for humans (Marcus 2015; Marcus et al. 2016). The benefit of such a model is that it allows us to better understand the interaction between spatial form and human activity, which is the primary driver in most urban systems. In extension, this opens up for the practices of urban planning and design to reshape the conditions for human activity and thereby redirect this into new trajectories. Importantly, this opens for intervention also in more aggregated urban systems of human activity, such as social cohesion and local markets. In principle, it also opens for intervention in urban ecosystems (Marcus, et al. 2013).

As a generic point of departure for our endeavour to construct such a model, we have chosen the classic gravity model since it, however out-dated in many respects, extricates the essential variables for any model of cities. Hence, according to Alan Wilson the gravity model identifies three necessary components for an urban model, that is: means to measure distance, means to measure attraction, and a form of representation (Wilson 2000).

Modelling cities: choosing geometric representation

Concerning representation, we support our model on network analysis (Newman 2010), which increasingly is applied in urban modelling (Batty 2013). More specifically, we will build on the kind of description and analysis developed in space syntax research (Hillier 1996). We interpret this approach as architectural in the sense that it conceives of urban space as distinctly structured and shaped by architectural components of built form, such as buildings, landscaping, and in some respects, traffic infrastructure. This approach differs essentially from regular geographic models of cities. First, it explicitly aims to model urban space as structured by built form and nothing else; that is, it importantly does not include any socio-economic or behavioural data. Second, these model does not reflect time in the sense that they change in themselves over time, which may be another reason to call it architectural.

However, this does not necessarily imply that space syntax models should be conceived as static representations of urban structure; rather we should pay attention to how the architectural origin of the models, emphasising spatial configuration structured by built form, bring back both process and behaviour to the models, at least to some degree.

First, network models, generally speaking, already imply process, since their very essence concerns relations between entities and nothing else (Newman 2010). Relations here typically imply some kind of interaction between entities, usually expressed as flows (Batty 2013). Hence, while not being dynamic in a regular sense, where the structure of the model in itself changes over time, we see that processes may still be written into the model by the fact that what it in the end represents is relations.

Second, the particular version of network models developed in space syntax are grounded in representation based in the human affordances of accessibility and visibility, why they concern the basic conditions under which humans perceive, cognise and act in the environment. This means that what is represented in these models neither is spatial form or human activity but the physical and cognitive affordances that appear in the meeting between the two (Marcus 2015), why we may argue that human behaviour, in a sense, is written into the model.

In the for space syntax emblematic form of representation the axial map, and its many derivations (Stavroulaki et al. 2017), urban space is defined by built form, in the manner discussed above, and broken up into spatial units defined by human visibility and accessibility, represented as straight lines (axial lines). Hence, in analysis, urban areas are represented as the least amount of axial lines covering all accessible space defined by built form. Moreover, network representations in space syntax are peculiar in that they treat 'streets' as nodes and 'street junctions' as links, whereas this normally is treated the other way around, again putting human perception first.

This form of representation, finds strong support in certain strands of psychology, especially in the particular direction taken by James Gibson: an ecological approach to visual perception (Gibson 1979). Gibson supports the idea that humans perceive the environment as a spatial continuum defined by physical form, whether natural or man-made, conditioned by humans' particular faculties of perception. Moreover, he makes the argument that humans typically perceive while moving through the environment, why human cognition and action not only is informed by what is perceived in the present, but also by our memories of places earlier experienced.

Modelling distance: universal distance or centrality

This brings us to the issue of measuring distance in a network model defined in this fashion. Hillier maintains, in accordance with the idea of human affordances, that we interact with space in cities both through our bodies and through our minds and argues that: "in bodily terms the city exist for us as a system of metric distances" (Hillier 2009), while our minds interact with the city through seeing, that is: "as a system of visual distances" (Hillier 2009). The argument for the axial line as a metric of distance can then be made: If we make a straight line crooked "we do not add significantly to the energy effort required to move along it, but we do add greatly to the informational effort required" (Hillier 2003).

Hillier next argues that: "we also need to reflect on the fact that cities are also collective artefacts […] The critical spatial properties of cities are not then just the relation of one part to another, but of all parts to all others […] We need a concept of distance which reflects this" (Hillier 2009:4). Hillier proposes the notion of universal distance as opposed to specific distance, where the latter concerns distance between an origin A and a destination B, while the first concerns the distance from all possible origins to all possible destinations in a spatial system. This distance measure is in spatial analysis more generally known as centrality.

Taken together this means that distance is measured as the mean distance from each node to each other node in the system, where these nodes in our case are geometrically represented as axial lines, which thereby also become a distance unit. In regular network analysis, there are two primary measures of centrality; on the one hand closeness centrality, which measures the mean distance from each node to each other node in the system and, on the other hand, betweenness centrality, which measures how often a particular node is part of routes between all nodes in the system.

The conception of distance developed in space syntax proves most powerful when tested empirically. Extensive tests in space syntax research, demonstrate how distance measured topologically as amount of changes in direction, or geometrically as amount of angular deviation, both performs considerably better when it comes to predicting human movement behaviour than traditional metric measures of distance (Hillier & Iida 2005). Similarly, it has been shown over a broad range of thematic studies, including the perception of safety, the distribution of retail and the use of urban green spaces, how human movement is an essential 'intermediate system' in explaining the influence of spatial form on such phenomena.

Modelling attractions: accessible density and differentiation

Next, we address the issue of attractions, where we first stress the need to define attractions as an aspect of spatial form rather than as particular functions or amenities (people and things) located in space. We identify two fundamental variables of spatial form originating in the practices of architecture and urban design, first, the densification of space through the addition of floor space, whereby more 'people and things' can be stacked in the same location; second, the differentiation of space by the addition of walls and other forms of boundaries, whereby more categorical differences in 'people and things' can be delimited. In short densification adds space and differentiation divides space (Cf. Bobkova et al. 2017).

For these dimensions of spatial form, we have chosen not to add new geometric descriptions but rather add values for both densification and differentiation as attributes to the already existent nodes in the network model. This has the advantage of providing the possibility to, apart from distance, also measure densification and differentiation as variables defined by human affordances, since what in effect is measured odel, is the accessibility from particular locations through space to variables of density and differentiation, rather than measures of these variables as located in space as a local attribute to that particular location (Cf. Koch 2007).

More particularly, our measure of densification concerns the entity of built floor space, but not as conventionally measured, that is, as amount of floor space per area of land, but as amount of floor space accessible 'through the street network' within a certain radius and then divided by the amount of plot area accessible in the same manner and within the same radius (Berghauser Pont & Marcus 2014). Importantly, distance is here measured in the manner developed in space syntax discussed in the previous section. This adds up to a measure of human accessibility to floor space within a certain radius from a particular location. Obviously, what we are after is not floor space as such but the ability of built form to increase the number of people and things that are accessible from a particular location. This accords with the aim to capture the spatial potential of locations, rather than the specific and momentary situation at a location.

In a similar manner, differentiation concerns the concrete entity of built walls, and other boundaries that define discrete spaces. However, in an urban context this entity multiplies to a degree that soon becomes unintelligible – there simply are too many physically defined spaces in a city if we include the interiors of buildings – why we need to look for a more generic definition. We have identified this to be what in different contexts is called the plot, lot or parcel, that is, the spatial unit defined by land division, equally present in agricultural as in urban landscapes (Cf. Marcus 2000, 2001, 2005; Bobkova et al. 2017). Technically, the variable of differentiation is measured similar to densification, that is, as the number of plots accessible through 'the street network', where distance, again, is measured according to space syntax methodology. The two measures of densification and differentiation are then combined to constitute a variable of attraction, designated as attributes of each node in our network model.

Together, we argue, this constitute, a robust model of the city that at bottom is quite sophisticated, in that it embodies several original shifts from regular urban modelling, while keeping within a set of quite simple but established representations and variables.

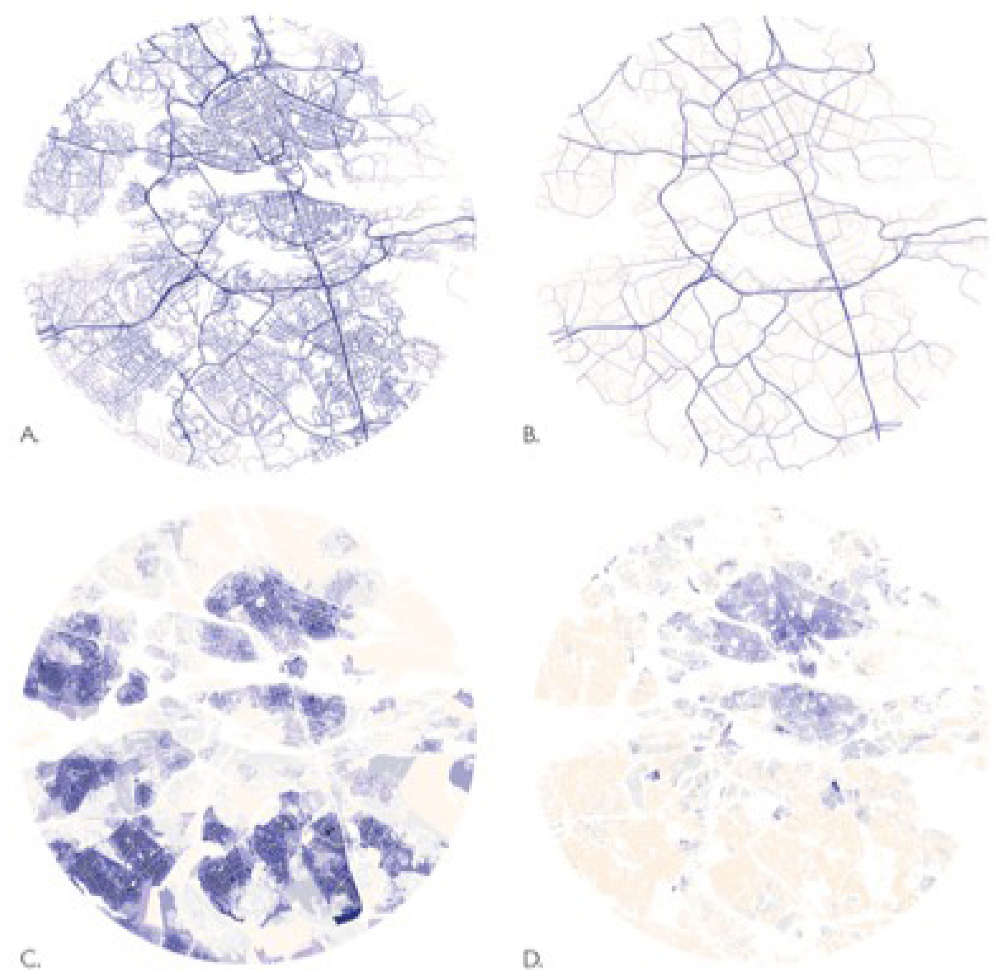

Figure 1. Spatial variables of the model. A. Distance measured as Closeness centrality by angular deviation within a radius of 10 km. B. Distance measured as Betweenness centrality as number of shortest paths that pass through within a radius of 10 km. C. Attraction measured as Accessible number of plots within 500m walking distance. D. Attraction measured as accessible FSI (building density) within 500m walking distance.

Empirical testing: modelling attraction in Stockholm

In this section, we will test these measures of the variables distance, densification and differentiation proposed here by correlating them with socio-economic data. We will run through them individually, first, for the whole central area of Stockholm and, second, for two typo-morphologically distinct areas constituted by, on the one hand, two sections of the inner city and, on the other hand, two villa areas.1 We start with a straight-line correlation of distance and flows typical for space syntax research, where distance is measured as closeness centrality and betweenness centrality in the street network, based on typical representations for space syntax, that is, for closeness, as angular deviation between street segments, and for betweenness as number of shortest paths. These variables are correlated with average daily vehicular flows. We find substantial and significant correlations with both variables and at all radii, why we conclude that we are able to repeat the correlations often found in space syntax research. We may also note that the

Correlations		
Betweeness centrality Motorized Network		Average Daily Flow_
R2km	Correlation coefficient	.457**
	Sig. (2-tailed)	.000
	N	145902
R5km	Correlation coefficient	.581**
	Sig. (2-tailed)	.000
	N	145902
R10km	Correlation coefficient	.653**
	Sig. (2-tailed)	.000
	N	145902
R30km	Correlation coefficient	.734**
	Sig. (2-tailed)	.000
	N	145902
**. Correlation is significant at the 0.01 level (2-tailed).		

Correlations		
Closeness centrality Motorized Network		Average Daily Flow_log(x+2)
R2km	Pearson Correlation	.455**
	Sig. (2-tailed)	.000
	N	145902
R5km	Pearson Correlation	.707**
	Sig. (2-tailed)	.000
	N	145902
R10km	Pearson Correlation	.748**
	Sig. (2-tailed)	.000
	N	145902
R30km	Pearson Correlation	.730**
	Sig. (2-tailed)	.000
	N	145902
**. Correlation is significant at the 0.01 level (2-tailed).		

Table 1. Correlations of Betweenness centrality and Closeness centrality with Average daily vehicular flows at the radii 2 km, 5, km, 10 km and 20 km.[2,3]

correlations increase for both variables with greater radii, which makes sense, given that we here correlate with vehicular flows.

Next, we correlate our attraction measures, accessible number of plots and accessible FSI with socio-economic variables: number of residential population, number of ground-floor activities and diversity of ground-floor activities, all measured as location-based measures, that is, measured as accessibility through the street network within a set radius, which in our case is 500 m for all measures. We also include the earlier distance measures as comparison. We here see how accessible FSI correlates strongly and significantly with all the socio-economic variables, especially with both number of ground-floor activity and diversity of ground-floor activity. Accessible plots, however, correlate much weaker, but show a significant correlation with number of residential population and to some degree diversity of ground-floor activity.

We may here conclude that the attraction measure for densification, accessible FSI, proves to correlate very strongly not only to amount of 'people and things' in the form of residential population and ground-floor activity, but also diversity of ground-floor activity, while the attraction measure for differentiation, accessible plots, only weakly correlates with diversity of 'people and things', and actually correlates better with amount of 'people and things', at least in the form of residential population. We may here suspect that amount of 'people and things' to a great degree co-varies with diversity of 'people and things', since a greater number of things is also more likely to contain a greater diversity of things, why we next move to a regression analysis to separate the impact of the different variables. First, however, we may also note that the attraction measure, accessible FSI, correlates better than any of the distance measures.

In our regression model, we are able to identify the relative significance for each measure in relation to the three different socio-economic variables. Starting with residential population we see that the complete model here has the weakest explanatory power of the three, while at the same time being highly significant at 0.42. More importantly, we see that accessible FSI has the highest significance for the model of our measures at 0.44 and that Accessible plots is not so far behind at

		Accessible Res.Population_500m _Log(x+2)	Accessible Activities_500m _Log(x+2)	Accessible Diversity of Activities_500_ Log(x+2)
Closeness centrality (Motorized Network r10km)	Pearson Correlation	.456**	.592**	.450**
	Sig. (2-tailed)	.000	.000	.000
	N	286860	286860	286860
Closeness centrality (NonMotorized Network r3km)	Pearson Correlation	.336**	.476**	.522**
	Sig. (2-tailed)	.000	.000	.000
	N	286860	286860	286860
Betweenness centrality (Motorized Network r1km) _Log(x+2)	Pearson Correlation	.194**	.183**	.131**
	Sig. (2-tailed)	.000	.000	.000
	N	286860	286860	286860
Betweenness centrality (NonMotorized Network r1km) _Log(x+2)	Pearson Correlation	.186**	.127**	.096**
	Sig. (2-tailed)	.000	.000	.000
	N	286860	286860	286860
Accessible No of Plots _500m_Log(x+2)	Pearson Correlation	.291**	-0,053	.041**
	Sig. (2-tailed)	.000	.000	.000
	N	286860	286860	286860
Accessible **FSI**_500_Log(x+2)	Pearson Correlation	.500**	.822**	.754**
	Sig. (2-tailed)	.000	.000	.000
	N	286860	286860	286860

**. Correlation is significant at the 0.01 level (2-tailed).

Table 2. Correlations to Residential Population, Accessible Ground-floor Activities, Accessible Diversity of Ground-floor Activities[4,5]

0.33, while the distance measures have less significance. When it comes to amount of ground floor activity, our model proves very powerful, explaining 75% of the dependent variable. Among the measures accessible FSI clearly stand out as the strongest at 0.72, while the second strongest is closeness centrality at 0.20, while the others are very low. Finally, also our model for diversity of ground floor activity proves powerful at 0.63, where, the relative significance of the different measures closely reflects the model for amount of ground-floor activity, and again accessible FSI proves the most significant measure.

We may conclude that the earlier finding that the attraction measure for densification, accessible FSI, proves to have great explanatory power for both amount and diversity of 'people and things', as measured here, is confirmed, but also that it stands out among our different variables, also confirming the earlier conclusion that accessibility to number of people and things also implies accessibility to diversity of people and things. However, we

a)Accessible Residential Population

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.645[a]	**.416**	.416	1.00571940577728	1.508

Rank		**BETA value** ('relative significance')
4	Betweenness r1km	0,049
3	Closeness r10km	0,195
2	Accessible No of Plots_r500m	0,329
1	**Accessible FSI_r500m***	**0,444**

b)Accessible Ground-floor Activities

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.852[a]	**.725**	.725	.53309264367816	1.591

Rank		**BETA value** ('relative significance')
4	Accessible No of Plots_r500m	0,015
3	Betweenness r1km	0,085
2	Closeness r10km	0,203
1	**Accessible FSI_r500m***	**0,718**

c)Accessible Diversity of Ground-floor Activities

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.795[a]	**.631**	.631	.01359468771832	1.752

Rank		**BETA value** ('relative significance')
4	Betweenness r1km	0,022
3	Accessible No of Plots_r500m	0,064
2	Closenesss (Non- Motorized, r3km)	0,231
1	**Accessible FSI_r500m**	**0,670**

Table 3. Regression models for all Stockholm. Independent variables: Closeness centrality, Betweenness centrality, Accessible number of plots, Accessible FSI. Dependent variables: Accessible residential population, Accessible ground-floor activity, Accessible diversity of ground-floor activities.

Type: Center
On the left: Ostermalm
On the right: Sodermalm

a)Accessible Residential Population

R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
.658ᵃ	.433	**.433**	.98442025585724	1.975

Rank		BETA value
4	Betweenness r1km	-0,095
3	Accessible FSI_r500km²	-0.354
2	Closeness r10km	0,176
1	**Accessible No of Plots_r500**	**0,762**

b)Accessible Ground-floor Activities

R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
.832ᵃ	.693	**.692**	.49528358317410	1.875

Rank		BETA value
4	Betweenness r1km	0,119
3	Closeness r10km	0,145
2	Accessible No of Plots_r500	0,404
1	**Accessible FSI_r500m²**	**0,490**

c)Accessible Diversity of Ground-floor Activities

R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
.757ᵃ	.573	**.573**	.04039833050854	1.900

Rank		BETA value
4	Betweenness_r1km	0,160
3	Accessible No of Plots_r500	0,178
2	Closeness (Non-Motorized Net., r3km)	0,303
1	**Accessible FSI_r500m²**	**0,381**

Type:Villas
On the left: Stureby
On the right: Malarhojden

a)Accessible Residential Population

R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
.678ᵃ	**.460**	.459	.35800630071440	2.051

Rank		BETA value ('relative significance')
4	Betweenness r1km	0,167
3	Closeness r10km	0.229
2	Accessible No of Plots_r500	0,503
1	**Accessible FSI_r500m²**	**0,716**

b)Accessible Ground-floor Activities

R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
.602ᵃ	**.362**	.361	.48580251153926	1.970

Rank		BETA value ('relative significance')
5	Betweenness r1km	Not sig.
4	Closeness (Non-Motorized Net., r3km)	0,180
1	Accessible No of Plots_r500	0,311
2	**Accessible FSI_r500m²**	**0,739**

c)Accessible Diversity of Ground-floor Activities

R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
.578ᵃ	**.334**	.333	.00379638732028	1.982

Rank		BETA value ('relative significance')
4	Betweenness r1km	Nit sig.
3	Accessible No of Plots_r500	0,186
2	Closeness (Non-Motorized Net., r3km)	0,197
1	**Accessible FSI_r500m²**	**0,670**

Table 4. Regression models for Type: City centre and Type: Villa areas.

may now suspect that this may vary depending on types of urban areas, why we now move on to a regression model of two distinct urban types.

In the regression model of two urban types, inner city and villa areas, we see that all three models of socio-economic diversity have medium to strong explanatory power, varying between 0.43 and 0.69. Interestingly, for residential population the variable accessibility to plots proves most significant and for amount of ground-floor activity it is second best, almost as strong as the strongest variable, accessible FSI. For diversity of ground-floor activity it is only third, but still fairly strong. Hence, for this particular type of urban area, we may conclude that accessible plots seem to be significant, even though being weakest where we imagined it to be strongest. Even so, this asks for further research.

For the villa areas, we are back to accessible FSI as the most significant variable, however, again accessible plots also prove consistently strong also here. This confirms again the strength of accessible FSI, but also that accessible plots may prove a fruitful measure.

For both types, we also find that the distance measures have the lowest significance in explaining the socio-economic variables.

Conclusion: towards an architectural model of the city

While these results are preliminary and any conclusions drawn by necessity will be premature, we believe to have found intriguing indications that a typical space syntax model, focusing on the centrality of the street network, may be augmented into a richer model of the spatial form of cities by adding attraction variables of the kind proposed here. However, at this stage it is only accessible FSI that proves truly convincing, while accessible plots need further investigation. Of particular importance for the latter, we suggest, is a more nuanced categorisation of socio-economic diversity.

Notes

[1] The software used was IBM SPSS. All variables not normally distributed are normalised using Ln(x+2). The variables included in the regression models were chosen after collinearity tests. The radii for network variables were chosen among 30 different radii for each variable, based on their correlation to the dependent variables.

[2]Motorized network includes roads which are accessible to vehicles, while pedestrian streets, alleys, paths, bicycle lanes etc. not are included. Non-motorized network includes all streets and paths accessible for people walking or cycling, including those that are shared with vehicles. All streets where walking or cycling is forbidden, such as motorways, highways, or high-speed tunnels, are not included.

[3] Source traffic flow data: The official road authority of Sweden (Trafikverket) (downloaded from lastkajen.trafikverket.se, 15-03-2017). The datasets include vehicular traffic for selected road segments in values of average daily flows. What is counted is the number of vehicles per year for each section measured (road segment) and it is based on 2 to 6 measurements per weekday and weekend in a randomly chosen point within the section. The flow can also be an estimated value. For every road included in the Traffic flow dataset, we calculated the average value of the closeness and betweenness centrality of its road segments.

[4] Besides accessible FSI (Floor space index), also accessible GSI (Ground Space index), accessible footprint and accessible gross floor area were correlated to Accessible Population and Activities. While they all correlated, accessible FSI exhibited the highest results.

[5] Source Population data: SCB (Statistiska centralbyrån) downloaded from geodata.se, 13-02-2017. Source of Building use/activities: Open Street Maps, downloaded from geobabrik.de, 20-02-2017. The software used for calculating Network and Attraction measures is PST (Place Syntax Tool). Download at: smog.chalmers.se/pst.

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