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CITIES AS ACCESSIBLE DENSITIES AND DIVERSITIES:

Adding attraction variables to configurational analysis

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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 (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, 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). Importantly, these analyses are able to use the novel distance measures developed in space syntax.

Place Syntax analysis is a generic form of analysis, why we may choose to analyse the accessibility to particular socio-economic attractions, such as residents or retail, but we may also conceive of a model of 'pure' spatial form – a kind of architectural model of the city – where we substitute socio-economic attractions for attractions of spatial form. 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 2008). Such density analyses can concern density of socio-economic attractions such as residents or retail. But it can also concern analysis of density of built form, for instance transforming densities of floor space to accessibility to floor space (Ståhle 2008, Berghauser Pont & Marcus 2014).

In this paper, we extend such spatial attraction to not only include the variable of density but also diversity. Earlier empirical studies have shown strong indications that there is a correlation between the degree of land division into parcels (plots) and the diversity of socio-economic content, such as residents and retail. This can be measured as area-based measures, such as parcel density (Marcus 2000, 2001), but also as location-based measures, such as parcel accessibility (Marcus 2005). Importantly, in the latter case this can be analysed using place syntax analysis and space syntax measures of distance.

Finally, we present preliminary results from an empirical study of Stockholm, Sweden, where we test these measures both combined and individually, paving the way for more substantial empirical investigations.

KEYWORDS

Accessibility, density, diversity, attraction, configuration

1. INTRODUCTION: THE NEED FOR AN ARCHITECTURAL MODEL OF THE CITY

The last decade has produced convincing proof that the world today is facing environmental threats on an unprecedented scale (Brito & Stafford Smith 2012), and that these stretches beyond the today predominant issue of climate change (Rockström et al., 2009). In extension, current global urbanization processes, where two thirds of the world's population are expected to live in cities by the year 2050, put acute stress on urban and ecological systems to support social cohesion and human wellbeing. This brings unprecedented expectations on the future governance, planning and design of cities with knowledge demands that these practices not necessarily are prepared for; there typically is an *implementation deficit* in current research on sustainable urban development.

In response to these challenges we will in the following present progress towards what we call an architectural model of the city that may support practice in urban planning and design. The fundamental concern for any investigation of such an entity is the age-old discussion on the relation between humans and the environment, where the proposed model departs from regular conceptions of this relation through two fundamental shifts. First, the environment is here not understood as something given but rather as something created by humans. In cities, it is obvious how the environment that we take for granted as the framework for our everyday lives, not is something natural but constitute a human artefact. This has the important consequences that the environment is possible to shape according to different ideological principles that give preference to particular trajectories of socio-economic process.

Second, and closely related to this, the built environment is here not conceived of as an entity detached from humans and their activities, but as an inherent part of human progress in general; we simply cannot conceive of humans without an environment. In response to this the model presented here is rooted in a conception of urban space as an entity created not only in relation to the human body but also to human perception and cognition. More precisely, based on the theories developed by psychologist James Gibson about an ecological approach to visual perception (1979) and affordances (1977), the link between humans and the environment is here constituted by both physical and cognitive affordances emerging in the interface between human abilities and physical properties of the environment.

The outline of the paper is as follows. In the first section the proposed model will be described as fundamentally constituted in extension of the traditional gravity model, by measurable variables of distance and attractions (Wilson 2000), where in this case distance measures will be drawn from the extensive field of space syntax research and attraction measures from space syntax derived research using place syntax analysis (Ståhle et al. 2005). In the second section, such distance measures will be discussed in relation to the theory of affordances (Gibson 1986). In the following section, attractions will be defined as variables of spatial form in accordance with the overarching aim of an architectural model of the city, rather than variables of human presence or activity. This will take the shape of measures of spatial form that condition both density and diversity of human activity in cities. Importantly these measures will draw from accessibility research (Hanson 1959), but more precisely as interpreted in space syntax research (Hillier & Hanson 1984), in that they will be location based measures rather than area based measures (Berghauser Pont & Marcus 2015). Thereafter, these variables will be tested and evaluated against known socio-economic data on a set of urban areas in Stockholm. In the final section, conclusions from this evaluation will be drawn and based on these there will follow a discussion about next steps.

2. MODELLING CITIES: CHOOSING GEOMETRIC 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 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 through the street network to different forms of attractions, for instance, residents or retail (Ståhle et al 2008). Importantly, these softwares include the novel distance measures developed in space syntax.

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 in new trajectories, since spatial form is what is structured and shaped in the practices. 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 for *representation* (Wilson 2000).

First, we address the issue of representation where one need to recognise the rapid expansion of possibilities that has taken place in recent decades in this regard, including digital techniques such as *cellular automata* and (Batty 2005). However, here we rather support our model on the rapidly developing field of network analysis (Newman 2010), that increasingly also is applied in urban modelling (Batty 2013). More specifically, we will build on the kind of architecture based description and analysis developed in space syntax research (Hillier 1996). We interpret the space syntax approach as architectural in the sense that it conceives of urban space as distinctly structured and shaped by architectural components of built form of various kinds, such as buildings, landscaping, and in some respects, traffic infrastructure. This approach differs in several essential senses from regular geographic models of cities. First, it explicitly aims to model the spatial form of cities as derived from the structure and shape of built form and nothing else. That is, it importantly does not include any socio-economic or behavioural data, a reason we choose to interpret it as a strictly architectural model. Second, there regularly are no longitudinal data in the model, that is, there is no included algorithm reflecting change over time. In this sense, it does not constitute a dynamic model, which may be another reason to call it an architectural model.

However, this does not necessarily imply that the models developed in space syntax should be conceived of as static representations or urban structure, rather we should pay attention to how the architectural origin of the models, emphasising built and spatial form and not least, putting great effort into the development of geometric representations thereof, in an original way bring back both behaviour and process to the models, at least to some degree.

First, network models, generally speaking, already imply process, since their very essence concern 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 change 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, what in the typical case is represented as entities in space syntax models, that is, the nodes or vertices between which we may describe relations by way of links or edges, is something quite peculiar, and differ from simple locations for origins and destinations, as one may find in regular urban models. In the for space syntax emblematic *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.

It is important to emphasise how this form of representation based in the human affordances of accessibility and visibility, is of great principal interest since it signifies a fundamental shift in how space normally is represented in urban modelling. More particularly, it concerns a representation based in the conditions under which humans perceive, cognise and act in the environment, the reason we call it a representation of space defined by human affordances. This means that what is represented by the network model in this case neither is spatial form or human activity but the physical and cognitive affordances that appear in the meeting between the physical properties of the urban environment and the abilities given by the human constitution (Marcus 2015). Moreover, in an urban modelling context it has the rather peculiar consequence that 'streets' become nodes in the network and 'street junctions' links, where this in most urban modelling is represented the other way around, why it represents a kind of Copernican shift in urban modelling (Marcus et al. 2013).

These representations of urban space, furthermore, find strong support in certain strands of psychology, especially in the particular direction of environmental psychology taken by James Gibson, which he calls 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, but that also is limited by the human faculty of perception. Moreover, he makes the argument that humans naturally move in the environment, which includes the movement of our eyes, the movement of our head and the movement of our body, why human cognition and action not only is informed by what is perceived in the present, but rather that places that earlier have been experienced and moved through, and our memories thereof, are an active part in determining human cognition and action. In a sense, therefore, Gibson summarises, we are always everywhere.

3. MODELLING DISTANCE: UNIVERSAL DISTANCE OR CENTRALITY

Such a conception of humans and their relation to the environment corresponds well with the notion of centrality, where each location not is defined by its limited relation to one particular other location, but rather to all other locations in the system. This brings us to the discussion about measuring distance in a network model defined in this fashion. In space syntax, distance is measured in a rather original manner. 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 2009:4), while our minds interact with the city through seeing, that is: "as a system of *visual distances*" (Hillier 2009:4). 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 which bring together and relate very large collections of people. The critical spatial properties of cities are not then just the relation of one part to another, but of *all parts to all others*" (Hillier 2009:4). "We need a concept of distance which reflects this" (Hillier 2009:4), Hillier concludes and proposes the notion of *universal distance as opposed* to *specific distance*, where the latter concerns our regular idea about distance, that is, as 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 are geometrically represented as lines, which here thereby becomes the 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.

This conception of distance as cognitively defined that we find explicitly developed in space syntax and discussed in more principal terms in spatial cognition, furthermore proves most powerful when tested empirically. Extensive tests conducted 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, perhaps *the* essential, 'intermediate system' in explaining the influence of spatial form on such urban phenomena.

4. MODELLING ATTRACTIONS: ACCESSIBLE DENSITY AND DIVERSITY

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 located in space, that is, by variables that capture how spatial form structures 'people and things' in space, rather than variables that capture 'people and things' in space themselves. 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 through the addition of walls and other forms of boundaries, whereby more categorical differences in 'people and things' can be delimited (Cf. Bobkova et al. 2017). The relevance of these variables is supported by an extensive review of the last decades' publications on Smart Growth, where variations on the variables distance, density and diversity proved to consistently reoccur (Colding et al. forthcoming).

For these dimensions of spatial form, we have chosen not to add further geometric description to our model but rather incorporate these dimensions by adding values for both densification and differentiation as attributes to the already existent nodes represented by lines in the model. This has the advantage of providing the possibility to, apart from distance, also measure densification and differentiation as variables defined by human affordances. What in effect is measured in our model is the accessibility *through* space to variables of density and diversity from particular locations, 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 concrete 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 where this distance is measured in accordance with space syntax measures of distance 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, in principle, through such densification to increase the number of people and things that are accessible from a particular location. This accords with the aim of our model to capture the general spatial potential of locations, rather than the specific and more momentary situation of concrete people and things found at a location, since the latter varies far more rapidly than the former. What our model captures here is therefore the long-term capacity of space to condition the number of people and things accessible to a specific location but not the more specific articulation of these people and things, which vary over time. However, we argue this to be an essential and critical property that on a most profound level conditions urban processes, not least from a sustainability point of view.

In a similar manner, our measure of *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 its buildings – why we need to look for a more generic spatial 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). We argued that this is the spatial unit that harbours and allows for the most fundamental of urban uses of space, that is to build, where to build here is understood in a broad sense and concerns the need in any land use to manifest, support and express any use in some kind of built form.

Since this means that we move to a spatial unit that primarily is defined by *legal institutions* rather that *physical form* it is important to stress the principal dimension of our variable here. While the legally defined spatial unit of the parcel may prove suitable to the level of cities, the physically defined spatial unit of the individual room would most likely prove appropriate at the level of the building and, stressing the principal character of the variable, we could even apply our measure in calculating the differential capacity of a chest-of-drawers by measuring its number of drawers (Cf. Bobkova et al. 2017).

Technically, the variable of differentiation is measured similar to densification, that is, as the number of parcels accessible through 'the street network' within a certain radius, where distance, again, is measured as a combination of physical and cognitive distance according to the discussion above. 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 measures.

5. TESTING AND EVALUATION: MODELLING ATTRACTION IN STOCKHOLM

In this section, we will test these fundamental measures of densification and differentiation, measured as location based measures, by making use of a large central portion of Stockholm, Sweden, where both the socio-economic characteristics as well as land-use distributions are well known. We will start by evaluating the measures individually and proceed to also look at them combined.

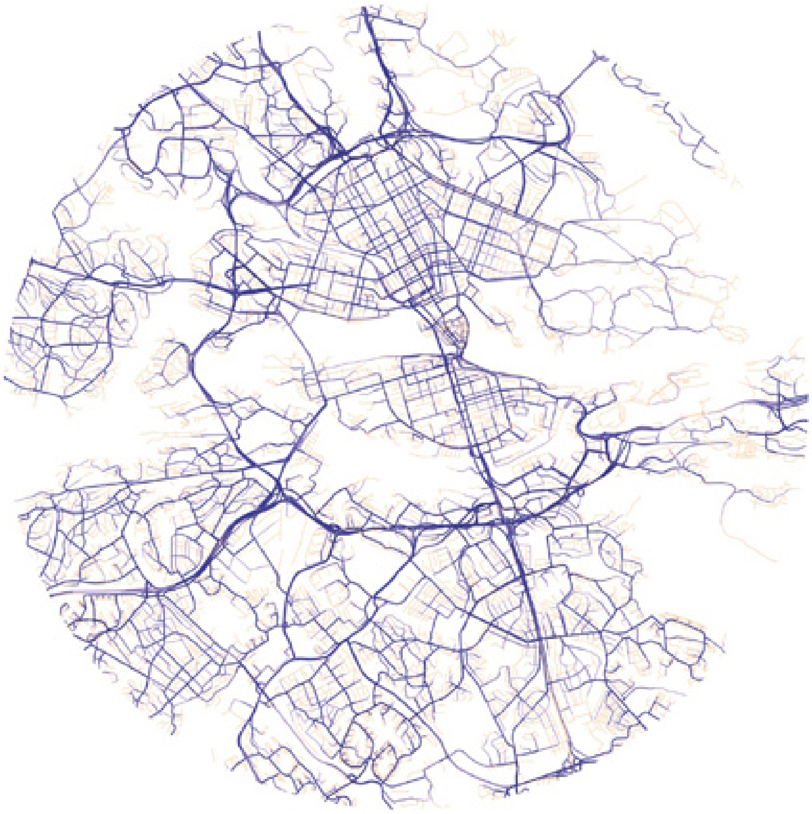

Figure 1 - Betwenness, radius 2 km.

5.1 BETWEENNESS CENTRALITY: GENERAL CHARACTERISTICS OF THE CASE

We may start by using the regular betweenness analysis as a means to characterize this portion of Stockholm. We see how the city is set within a landscape heavily fragmented by water into islands, with a central core defined by a rectilinear street network outside of which we find a far more hierarchical street structure with several loops and dead-ends. Also, these parts are in this sense fragmented into islands turning the over-all structure into a distinct archipelagic pattern, whether given by water or not. For the outer city, it is difficult to draw any distinct socio-economical conclusions from this comprehensive analysis, where we find similar patterns both for well-off single-family house areas and less well-off multi-family house areas. What stands out is the distinct difference between the inner city and the outer city, where there currently is a strong process of gentrification taking place due to increasing number of apartments being privately owned and therefore sold on the market, while earlier having been leased to set prices. As regular in cities framed by market prices, we see how centrality or accessibility to attractions, generally speaking, is a central driver of the socio-economic distribution of inhabitants. That this does not only is true in relation to geographic distance to the center, but also by the morphological structure of space as defined by built form is expressed by the discontinuity between the inner and outer city due to their distinct morphological difference, which also is reflected in housing prices (Bernow & Ståhle 2012). This is further reflected if looking at another variable sensitive to market prices, that is, retail distribution, which in the inner city follow the betweenness structure very strongly, while it in the outer city demonstrate a duality between, on the one hand, local centers planned in parallel with many of the multi-family house areas in the postwar era, and more spontaneous development along main traffic arteries serving these areas, where the first in many instances are facing decreasing market demand (Sayyar & Marcus 2013).

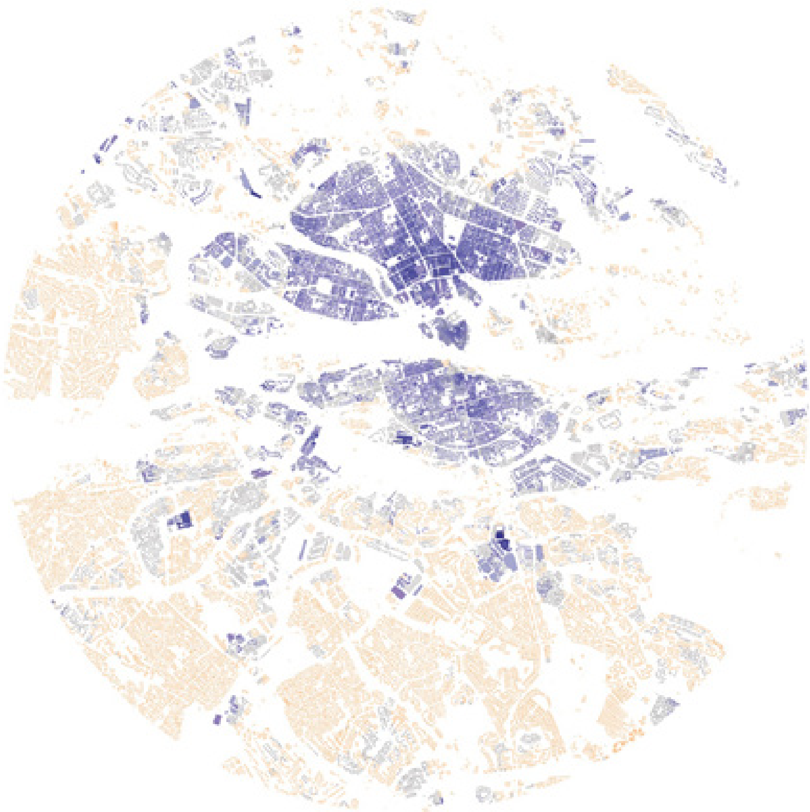

Figure 2 - Accessible Floor space, radius 500 m.

5.2 ACCESSIBLE FLOOR SPACE: FINE-TUNING SPATIAL CENTRALITY

Looking at accessible floor space, the earlier image is enhanced with an even more distinct leap between the inner and outer city, now created not only be a greater accessibility due to the grid-like street network, but further enhanced due to a generally far higher building density. Importantly, however, we also detect distinct chunks of very high accessibility to floor space in the outer city, which on closer examination turn out to be areas highly exploited for offices. Apart from these we also see a clear separation of the outer city into areas with low accessibility to floor space and areas with medium accessibility to floor space, reflecting, generally speaking, areas of single-family houses and areas of multi-family houses. Similar differentiation into areas can also be detected in the inner city, albeit not as accentuated.

Importantly, these varieties between areas in both the inner and outer city were not identified in the pure centrality analysis. Hence, we can see how the model proposed here, not only comprising measures of centrality within the street network, but adding to this the varying capacity for space in different locations to carry people and things, brings forth a richer image of the spatial form of the city and the socio-economic potentials it creates. One way of describing this is saying that by adding the distribution of floor space to the analysis, we achieve a more life-like image of the spatial centrality of the city, since it can be argued that centrality in this sense not only concerns accessibility within the street network, but accessibility to useable floor space.

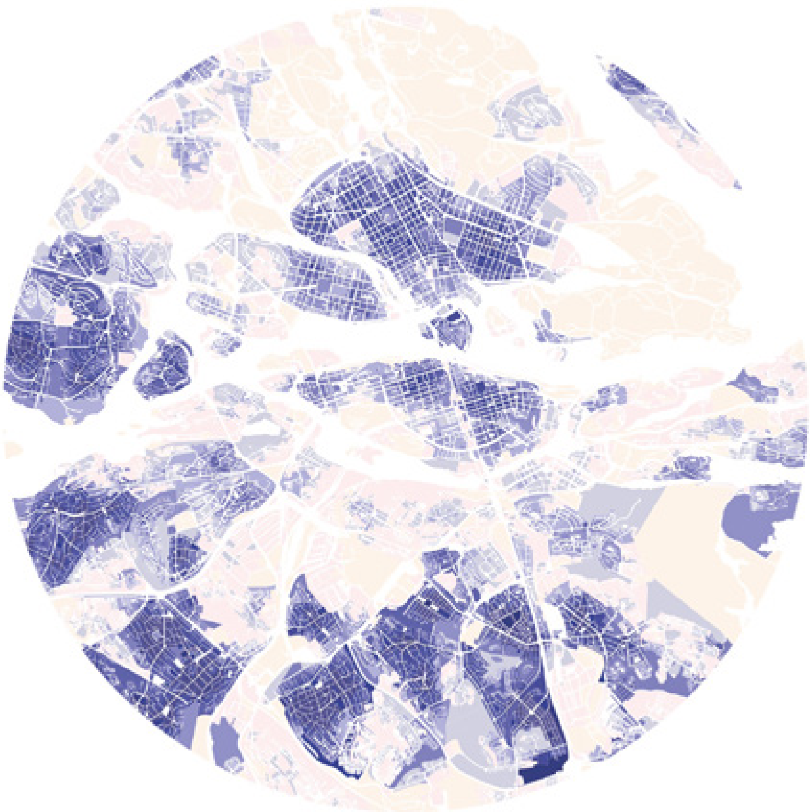

Figure 3 - Accessible Plots, radius 500 m.

5.3 ACCESSIBLE PLOTS: ADDING DIFFERENTIATION

While accessible floor space has been analysed and illustrated many times before in the attempt exactly to develop richer descriptions of urban density (e.g. Ståhle et al 2005; Berghauser Pont & Marcus 2015), the measure of accessible plots must be considered quite original with few precedents (Marcus 2001; 2010). In the image (Fig. 3), we also see a more unusual structure that immediately is not so easy to interpret. For one thing, we see how the outer city here to a substantial measure have higher numbers than the inner city. What we see are areas of rather small single-family houses set in rather grid-like street structure, thereby over-performing even the inner city, which in general also has very high numbers in this analysis. Interestingly, this analysis distinctly distinguishes the multi-family house areas from the post war era in the outer city, typically built within a far larger property rights structure than both the single-family house areas and the far older inner city. What also stands out are the areas for industrial use, with their typically isolated locations, albeit often with an internal grid-structure, and large plots.

The hypothesis that this structure somehow would reflect socio-economic diversity or diversity in land use, does not immediately seem validated by this analysis. Rather we would interpret areas with small single family houses as socio-economically quite homogenous (middle-class) and mono-functional (residential uses). However, if we ponder this question and take into account the strong influence on land-use regulations and building typology, we may detect rather strong indications that there is a quite powerful process of differentiation at work in these areas. Compared to the areas with multi-family housing, distinguished by their much larger plots, we may look at the far greater diversification in how both buildings and gardens/green areas are treated in the two areas, where this is far greater in the first areas despite the fact that far fewer people live there. We may interpret this as an indication that what may vary within the rather strict land-use regulations found in both these areas, such as maintenance of buildings and gardens, truly seems conditions by the degree land is divided into plots. While the differentiating capacity of urban plot structure then seems easy to overrun by other forms of regulations, we do see a strong indication that this fundamentally morphological variable plays a part.

Hence, we do see a rather exciting image here, disclosing something that neither the pure accessibility to the street network or the accessibility to floor space displayed, and that actually seems to have something to do, not with amount and numbers, as the accessibility to floor space did, but with differentiation and degree of diversity. We may therefore see how this variable adds to the others, contributing to a richer architectural model of the city, which now not only captures the centrality of the city as structured by the street network, or how this centrality is biased towards amount of accessible floor space, since these places have the potential to carry more people and things, that is, the potential to carry more attractions. Now the model also captures the potential degree to which these attractions may be diversified, thus constituting a rich architectural model of the city describing the continuous landscape of potential accessibility to number and diversity of people and things that it presents.

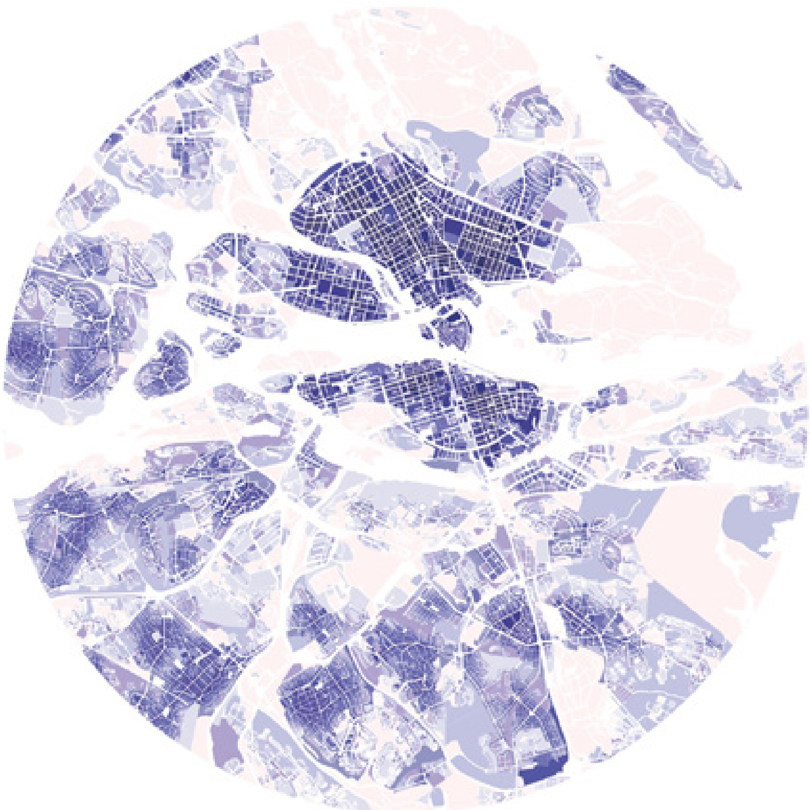

Figure 4 - Accessible Floor space and plots, radius 500 m.

5.4 ACCESSIBLE FLOOR SPACE AND PLOTS: AN ARCHITECTURAL MODEL OF THE CITY

Finally, we may combine the two measures of accessible floor space and accessible plots into one measure of spatial attraction, that is, capturing the spatial potential of locations to harbour both variations in number and differentiation of attractions, thus completing our proposal for an architectural model of the city. The procedure here is a simple multiplication of the numbers for both accessible floor space and accessible plots for each location. A tentative adjustment that need further study is to divide accessible floor space by 1000 due to the typically much larger numbers in this analysis than accessible plots. Naturally, this procedure needs further testing. However, albeit these being preliminary studies that need a lot more calibration, this measure capture a very life-like pattern throughout the city in terms of socio-economic characteristics and land-use distributions.

The inner city dominates with the highest numbers, but within this part of the city we also see a differentiation that quite closely follows the distinction of the inner city into areas of more varied content, what may be called the more busy areas, and the more residential parts. More distinctly, we see how we still find the highest numbers in the outer city in the single-family house areas, which may question how the model is calibrated in these particular analyses, but also makes the fact apparent, how these areas, while clearly being less dense than the multi-family house areas actually in many respects are more diverse. Interestingly, some of the more recent multi-family house areas with a far greater density than the post-war era areas and a greater centrality due to their location close to the inner city, stand out in the outer city with numbers coming close to the inner city.

6. 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 most intriguing indications about how a typical space syntax model focusing on the universal distance or centrality of the street network, may be augmented into a richer model of the spatial form of cities by adding on the one hand, a variable of accessibility through the street network to floor space, and, on the other hand, accessibility to plots, also through the street network, which combined can be conceived of as capturing accessibility to potential attractions, thus constituting an architectural model of the city, displaying the capacity of the spatial form of the continuous landscape of cities to carry number and differentiation of people and things.

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