Studying land-use distribution and mixed-use patterns in relation to density, accessibility and urban form

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Abstract –Mixed use development, one of the "mantras in contemporary planning" is a multi-criterion and multi-scalar concept which has various definitions. For this research mixed-use is defined as functional mixed-use and our main interest is to understand the spatial conditions needed to increase the diversity of uses (mix) by combining compatible functions. To analyse the compatibility of land uses and the importance of specific spatial conditions, the three most relevant factors of urban form are chosen: density, accessibility and mixed-use composition. The chosen factors are measured by methods of spacematrix, place syntax and MXI, using the city of Rotterdam (southern part) as case study. The three levels of analysis that are used are: (1) between all the urban blocks, (2) between mixed-use and mono-functional blocks, (3) within different types of mixed-use blocks. The results demonstrate interrelationships between the intensity of land uses on different scale levels. For example, residential density in a biking neighbourhood (radius 1.000) correlates to the density of commercial services in the same or a lower radius, but with of density of cultural and recreational services in a higher radius. In other words, cultural and recreational services need a larger catchment. Furthermore it is demonstrated that mixed-use blocks are denser and have higher accessibility to residential/work and commercial functions. Concerning mixed-use blocks, the results demonstrate a complementary behaviour between the existing functions within a mixed-use block and its surrounding. For instance, blocks with a bi-functional mix of housing and amenities are located in the vicinity of blocks with more work opportunities and blocks consisted of housing and working have a higher access to amenities in their surrounding. Identifying such spatial interrelations between land uses can be of great importance for urban planning and design. It can assist in the process of decision making by providing answers to the questions such as: If we want to create a city centre here, where should we improve accessibility then? Or, where should we, based on the existing distribution of shops, increase the residential density to use the existing potential best?

Key words – Mixed-Use; Density; Land Use Compatibility; Spacematrix; Place Syntax; Accessibility; Urban Form

1 Introduction: why mixed-use?

After the Second World War, urban design has been heavily influenced by the "Functional City" paradigm proposed by the CIAM international movement. CIAM suggested, amongst other things, a separated distribution of functions in cities. It categorized main functions in four groups including housing, employment, recreation and transport. However, within the last decades, the urban design paradigm has shifted towards the opposite, mixed-use developments. In sustainable development mixed-use is regarded as one of the key factors (Bernick & Cervero 1997; Furuseth, 1997; Grant, 2005). It is further considered as part of the process of promoting urbanity, also called the *Urban Renaissance* (Stead & Hoppenbrouwer, 2004).

Mixed-use development as a field of research is high on the agenda of academics. Pros argue for advantages from various points of view. From environmental perspective, proximity of living, working and amenities, and mix of compatible functions in various scales, mixed use is an encouraging factor of greener modes of transport such as walking and biking. Although there are of course other associated factors next to mixed-use that influence this such as compactness and pedestrian friendly layout. (Moudon et al., 2006; Lee & Moudon, 2004; Moudon et al., 2007; Moudon & Lee, 2003; Cervero and Kockelman, 1997; DETR, 2001).

Others consider mixed-use related issues as effective drivers of urban vitality. These issues include the presence and combination of primary and secondary uses, variety in opening hours, the extend of variety in primary land uses, the proportion of locally owned or more generally independent businesses, the presence and size of street markets and types of specializations (Jacobs, 1961; Montgomery, 1998; Jacobs, 1994; Lynch, 1960; Sennet, 1990; Relph, 1976; Canter, 1977; Punter, 1991; Comedia, 1991).

Other benefits of mixed-use mentioned in literature are promoting more diverse social groups, greater equal opportunities in terms of access to amenities and job opportunities, making cities more attractive places to live, improving economic viability of commercial centers, increase safety, encouraging more affordable housing in town centers e.g. converting spaces above the shops and vacant commercials into residential units, optimum use of infrastructure, and so on (Grant, 2002; Stead & Hoppenbrouwer, 2004).

Results from the academic studies mentioned have been reflected in policies as well. The European Union green paper on the urban environment (1990) stresses the importance of generating and protecting the *sense of place*. It proposes diverse, multi-functional cities. The European Council of town planners plea for a high mix of housing and working, as well as other compatible uses to provide variety and viability. (ECTP's new charter if Athens, 1998) In Dutch policy documents (Grotestedenbeleid, 2001 and VROM, 1997a, 1997b, 2001a) the compact city is promoted, including a mix of housing, employment, and social-cultural infrastructures to improve the vitality, attractiveness and environmental quality of urban areas.

2 The ambiguity of the mixed-use concept

According to Grant (2002, p.71), the concept of mixed-use has became "a mantra in contemporary planning", but it still is ambiguous both in theory and practice (Rowley, 1996). The criteria to define mixed-use developments vary in different sources such as a combination of primary and secondary uses, a concentration of compatible uses which generate synergy, an increasing bureaucratic range of stakeholders involved in development and maintenance of an urban area, a mixture of tenures and housing types, and a mix of different income groups (Jacobs, 1961; Grant, 2002; Joseph Rowentree foundation, 2007; Priemus et al., 2000; VROM, 1997a, 1997b, 2001a; Ministerie van economische zaken, 1999; Coupland,1997). Further, the scales at which these mixed-use developments are defined differ from neighborhood, block, to building complex. Some refer to vertical or horizontal composition of uses in various scales and some to a time dimension in relation to mixed use (Hoppenbrouwer & Louwe, 2005; Rowley,1996).

A review of objectives and strategies used by those that advocate mix show three different conceptual levels (Grant, 2002). The first level is dealing with increasing the intensity of land uses within one category of land use, usually residential. A mix of different forms or types of dwellings is promoted to arrive at a social mix. The second level deals with increasing diversity of uses by combining compatible functions and the third level is concerned with the integration of segregated uses which mostly means that barriers imposed by urban rules need to be dealt with.

In this research we focus on the second conceptual level which looks at mixed-use from the perspective of the synergy and compatibility of land uses. Synergy, in general, refers to a situation in which effects of two or more bodies are more than the sum of the effects of them alone. Evert Jan Meijers (page 25-6, 2007, Ph.d, Synergy in polycentric urban regions, TUDelft) describes synergy in three levels. On the micro level "Synergy means that when two or more actors co-operate, there is a positive result for both of them".

Several methods of analyzing the compatibility between land uses have been developed. Most of the

methods use measurements based on spatial distance (in terms of length or time) to demonstrate the compatibility. Transport-Land use models, explore the compatibility between land uses by accessibility (for a review see Wegner, 2004). Effectiveness and efficiency factors are the most common measurements used (Bertuglia.C et al., 1994). These factors quantify service provision and population catchment of land uses by cut-off values of distance. Newly developed methods such as place syntax (Ståhle, 2008) add topological distance to effectiveness and efficiency analysis.

3 Mixed-use development and urban form

Based on the concepts of service provision and population catchment of an area, indexes such as density and accessibility are the key factors to analyse the compatibility of land uses. These are, amongst other, also the dimensions used to describe urban form. Besides density, transport infrastructure, and land use, also layout and housing/building types are mentioned as relevant to the description of urban form (Dempsey et al., 2008; Jencks, 1996). We take as point of departure that layout and housing/building types are included in the other factors mentioned as will be explained later in the paper.

The following urban form categories are therefore taken into account for this research, each with their own threshold, but also in relation to each other.

- density
- accessibility
- land use distribution

The objective of this paper is to provide researchers and urbanists a precise language for mixed-use developments taking into account the compatibility of land uses, density and accessibility. Or in other words, the main question is:

What is the relation between land use distribution, mixed-use patterns and urban form?

To arrive here the following sub-questions need to be answered:

What are the relations between land use intensities at different scales? What are the compatible functions on each scale and between the scales?

What are the differences between mixed-use and mono-functional blocks in terms of density and land use composition in their vicinity?

What are the differences between different types of mixed-use blocks, again in terms of density and land use composition in their vicinity?

In the next paragraphs we elaborate further on the chosen definitions of density, land use and mixed use

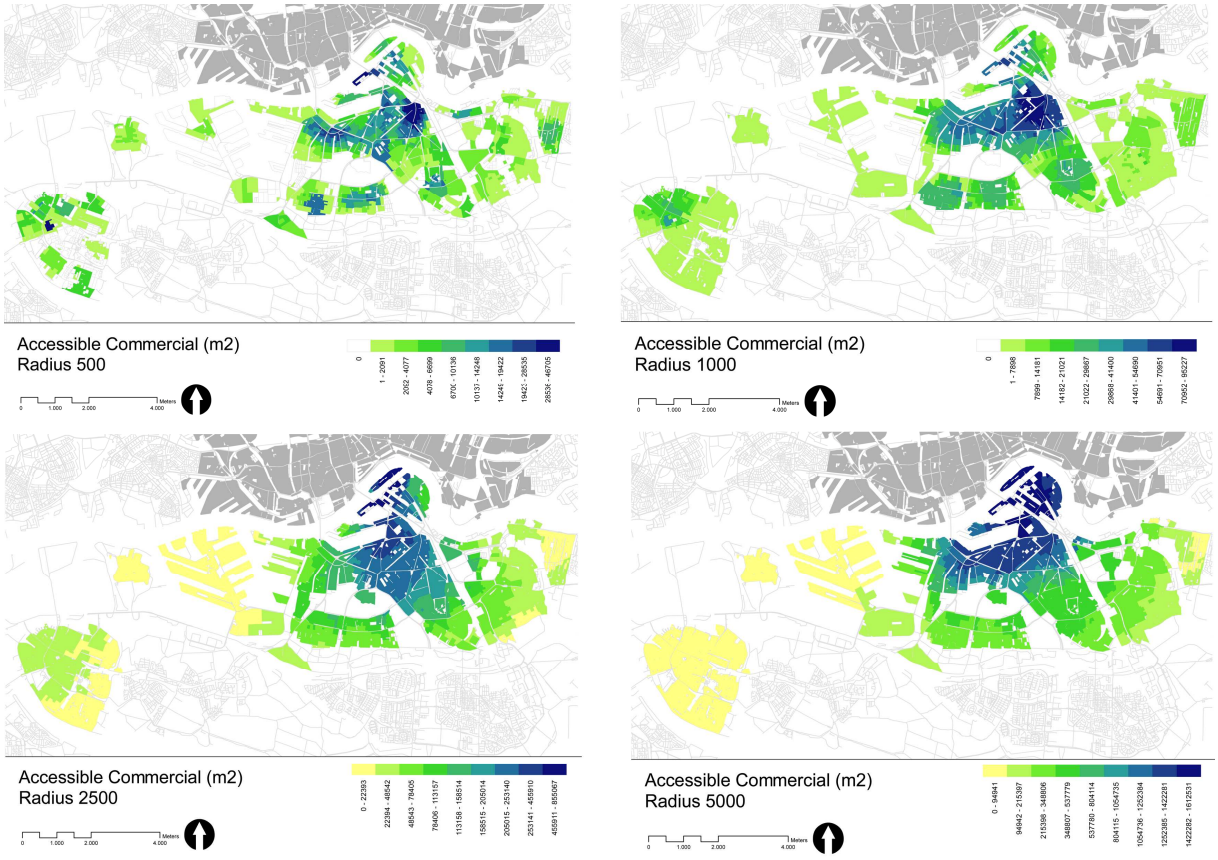


Figure 1:

Accessible commercial services in various radii

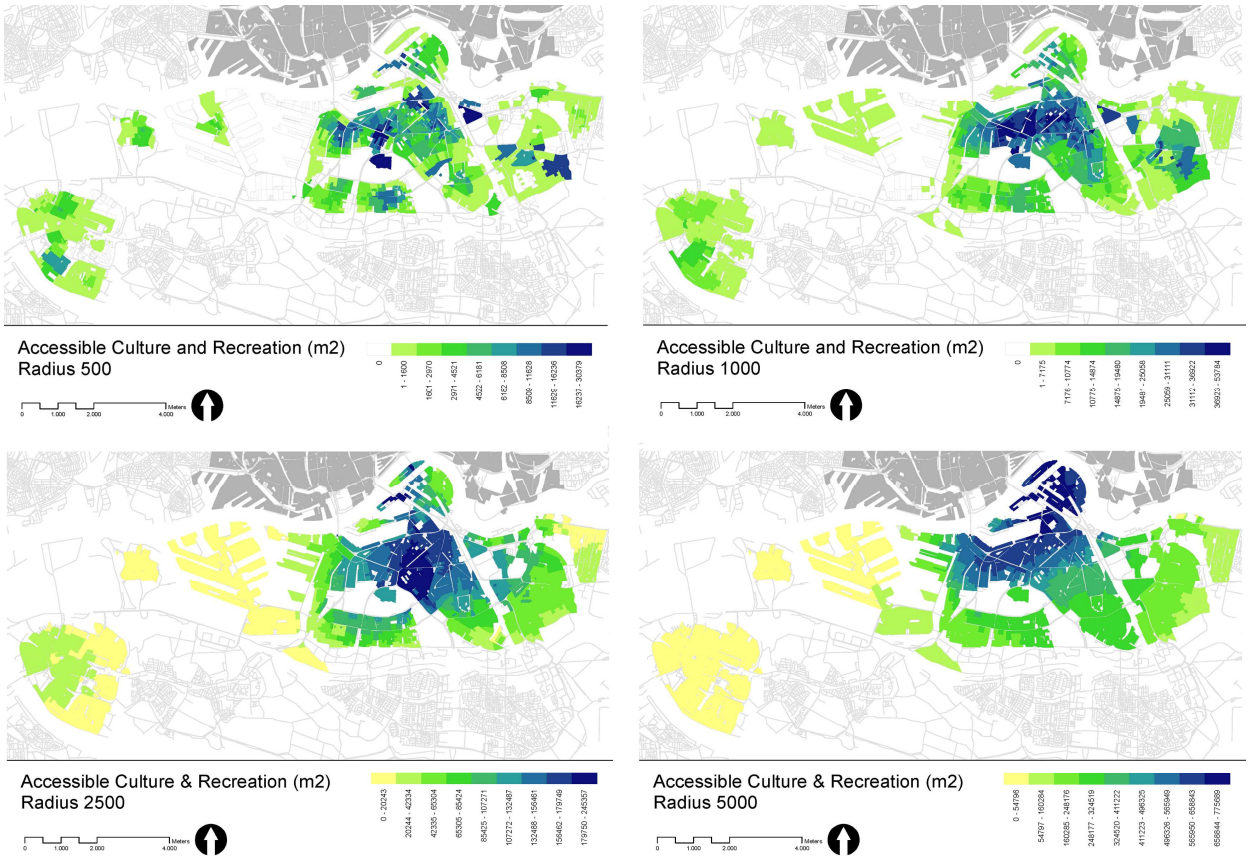


Figure 2:

Accessible culture & recreation services in various radii

patterns and accessibility, and their related measures (paragraph 4). After this we will explore the compatibility and synergy of land uses and mixed-use patterns in relation to density and accessibility (paragraph 5). The city that is used as case study is Rotterdam South which is composed of 1650 urban blocks. The paper ends with the main conclusions and suggestions for further research (paragraph 6).

4 Definitions and Methods

As mentioned in the previous paragraph the three chosen factors of urban form which are used in understanding the compatibility and synergy between land uses are density, accessibility and land use distribution. The methods applied for measuring these three categories are as following:

- Spacematrix for density (Areal density)
- Place syntax for accessibility of functions (Accessible density)
- MXI for land use distribution

4.1 Density, Spacematrix

How humans have come to use space over time – in some cases judged as too intensely, in others as not intensely enough – and the problems connected to this, have resulted in discussions concerning the application of the concept of density in urbanism. The use of the concept has varied greatly through modern planning and design. From Unwin, who proposed a standard density of 12 houses per net acre maximum (Unwin, 1909), to fifty years later, Jane Jacobs who suggested that a minimum of 100 dwellings per net acre (250 dwellings per hectare) was a necessary condition for a vital and participatory city life (Jacobs, 1961). Today high densities and the compact city are often seen as prerequisites for sustainable urbanization and economic growth (Hall, 1999, Florida, 2005, Jenks, 1996, Lozano, 2007, Newman and Kenworthy, 1999)

The concept of density in urbanism is frequently used to describe the relationship between a given area and the number of certain entities in that area. These entities might be people, dwellings, services, or floor-

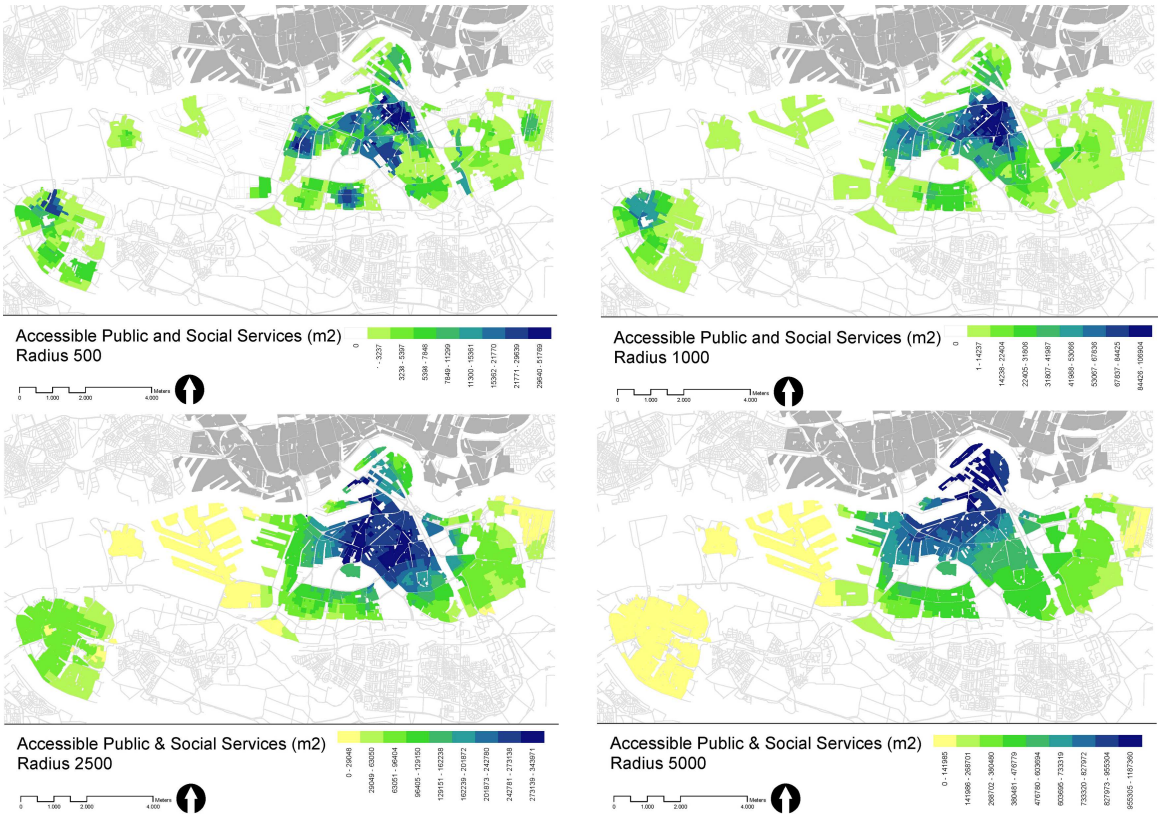


Figure 3:

Accessible public & social services in various radii

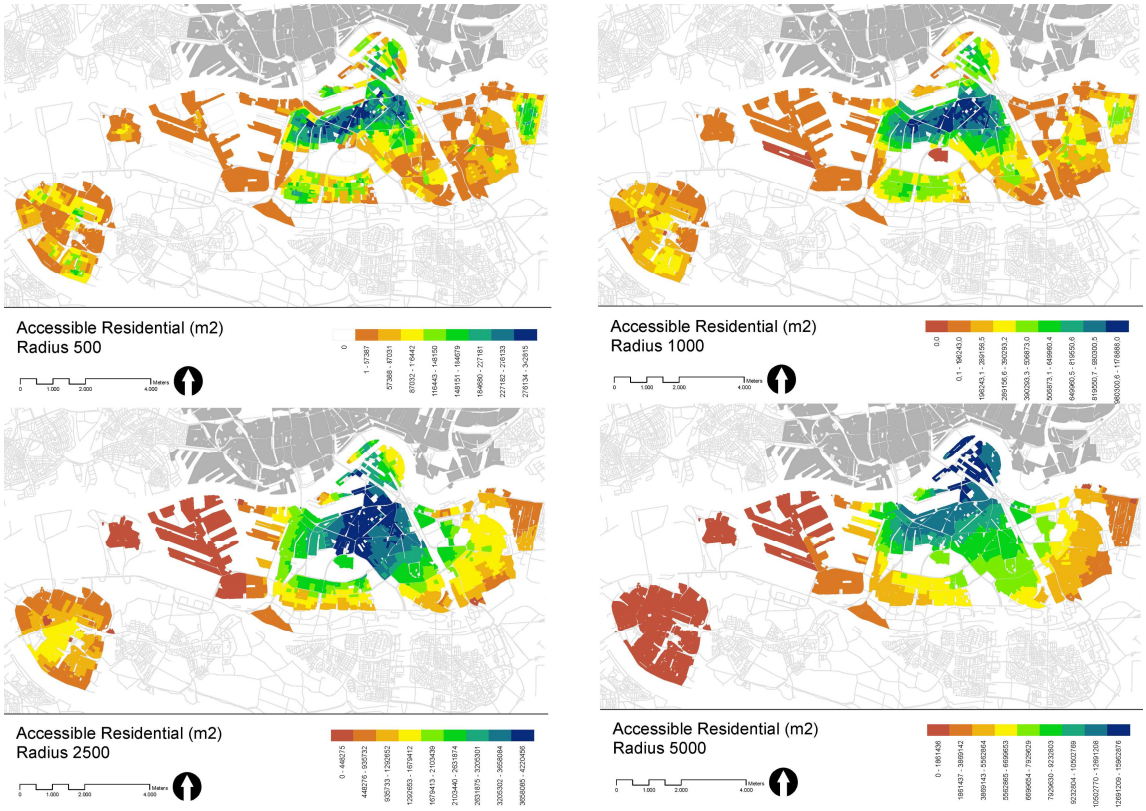


Figure 4:

Accessible residential density in various radii

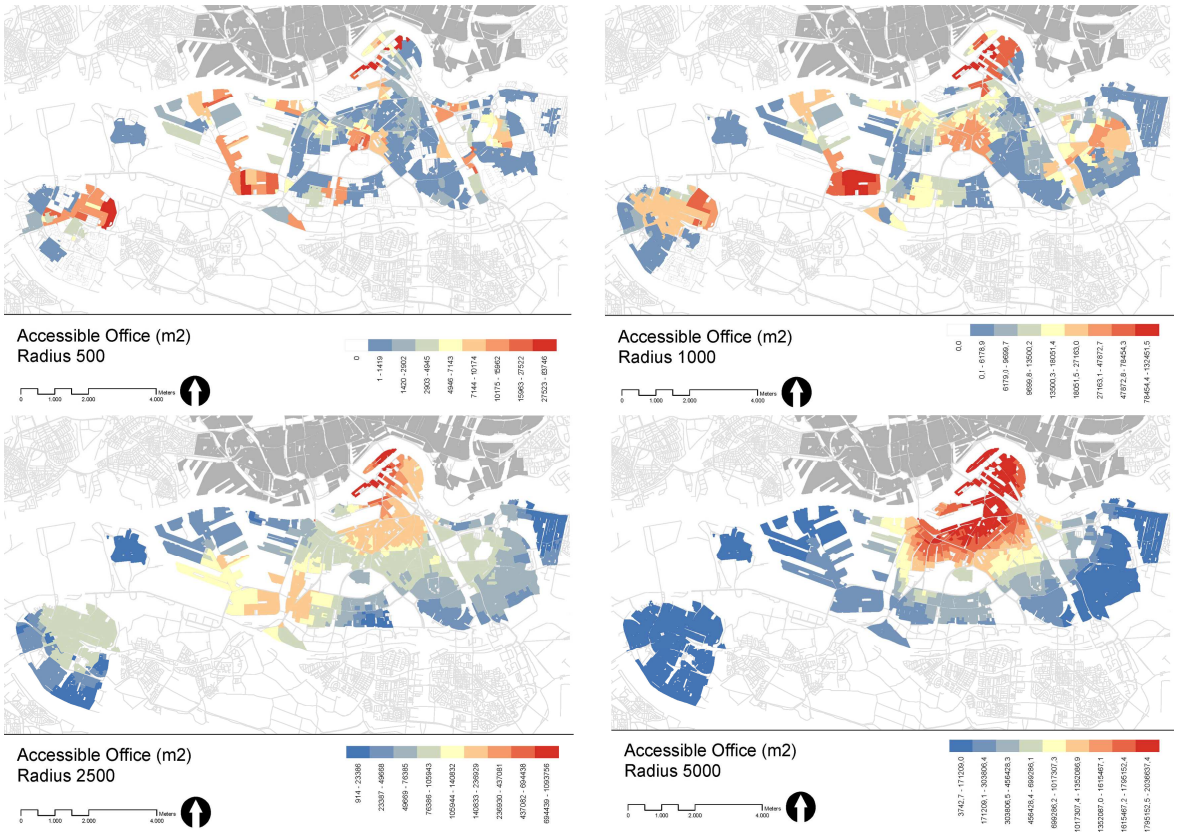


Figure 5:

Accessible offices in various radii

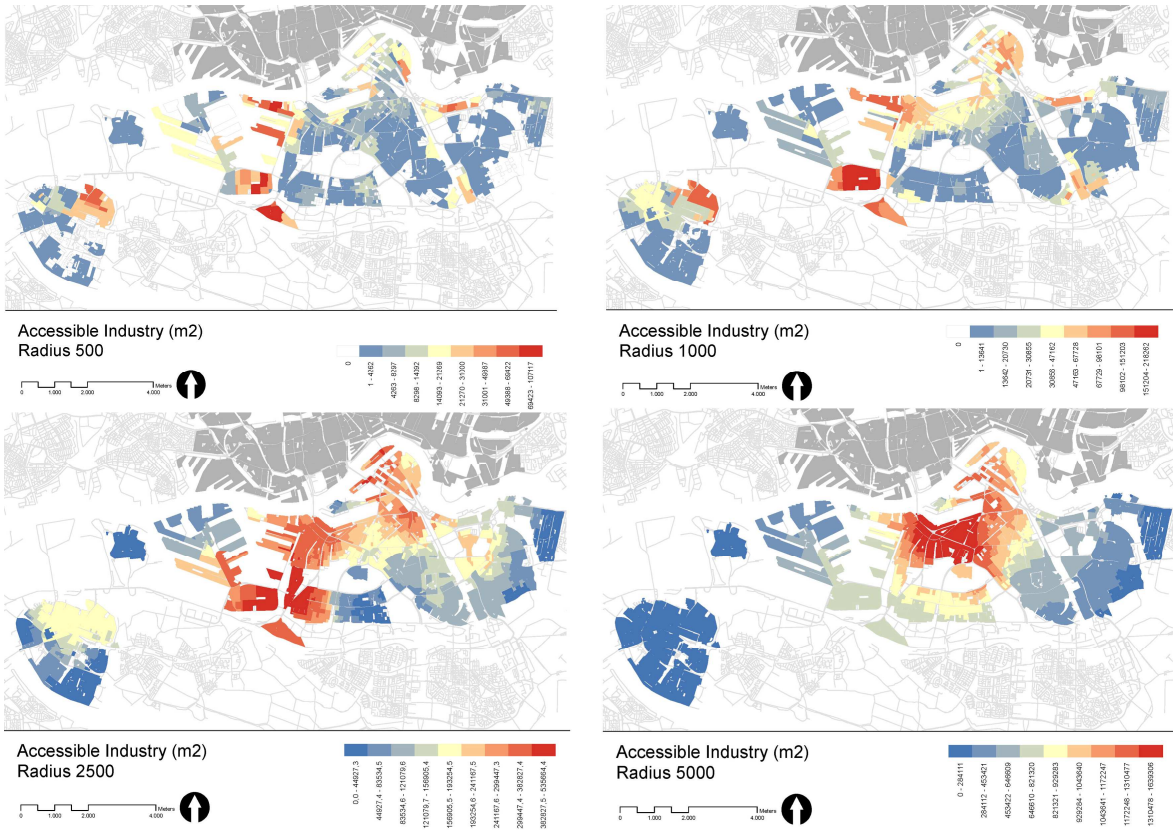


Figure 6:

Accessible industries in various radii

space. In spite of the practical advantages of the concept of urban density in urban planning, critics have argued – especially since the revolt in the 1970s against the quantitative methods of modernist planning – that the use of density for anything but statistical purposes is questionable, as it is perceived as a too elastic concept that poorly reflects the spatial properties of an urban area. Professionals, as well as researchers, hold the opinion that measured density and other physical properties are independent of each other (Alexander, 1993; Forsyth, 2003; Lozano, 2007)

The Spacematrix developed by Berghauser Pont and Haupt (2010) makes it possible to link the urban form and structural types to density and the amount of open space. To make this possible, Spacematrix treats density as a multivariable phenomenon, approaching and defining it in terms of three indicators, in contrast with the usual practice of using a single indicator, such as the number of dwellings per hectare or FSI.

In Spacematrix density is thus defined not only as intensity (FSI), but as a combination of intensity, compactness (GSI), and network density (N). For the purpose of this research we limit ourselves to the first two indicators which together also determine the average building height (L) and pressure on non-built space (OSR). To assess FSI, GSI, L and OSR simultaneously one of the projections of the Spacematrix is used, the Spacemate. The FSI on the y axis gives an indication of the intensity in an area and the GSI on the x axis reflects its compactness. The OSR and L are gradients that fan out across the diagram. The last two variables enable us to gauge the pressure on the open space and the average number of floors respectively. Combining these four variables gives every project a unique 'spatial fingerprint'.

On the scale of the island (or urban block) and the urban fabric this definition of density has proven to be efficient to differentiate between urban form. By looking at density at different scale levels, information can be found about the amount of tare space added from one scale level to the other. For instance is the street network added as tare space between the density measured on island and fabric level. However, the confusion regarding the definition of plan boundaries and the scale at which these are measured are an issue of constant debate amongst planners, designers and scientists. All area measurements have an inbuilt 'ecological fallacy' well known in geography as 'The Modified Area Unit Problem' (MAUP), which basically means that statistics are arbitrary since the definition of the 'area' is subjective (Ståhle, 2008). MAUP occurs when point-based measures of spatial phenomena are aggregated into districts, because the resulting summary values are influenced by the choice of these boundaries. The same problem is found in Spacemate. To deal with this problem the concept of accessible density is introduced by Ståhle (2008).

4.2 Accessible density, Place Syntax

In the concept of accessible density, developed by Ståhle (2008), simple density analysis are combined with space syntax. Space syntax considers the city as a set of open spaces such as squares, alleys, streets, roads, avenues, boulevards, highways, paths, pavements, subways, bridges, stairs, etc. All these kinds of urban spaces shape a grid or network—a potential pattern of movement. The urban grid is defined to be "the pattern of public space linking the buildings of a settlement, regardless of its degree of geometric regularity" (Hillier 2002). What space syntax measures are the two primary all-to-all (all street segments to all others) relations. On the one hand it measures the to-movement, or accessibility, potential, of each street segment with respect to all others. With other words, it measures the location potentials for various urban centres. On the other hand it measures the through-movement potential of each street segment with respect to all pairs of others. To say it differently, it measures the spatial potentials for streets with the highest flow of movement.

Hillier does not take into consideration attractions as he argues that for more traditional town centres with evenly distributed densities and attractors the results of space syntax are convincing (1989). Ståhle (2008) shows that especially in urban areas where the distributions of densities and buildings are uneven (most areas planned after the 1930s), space syntax is not precise enough and we need to take attractions into consideration as well to predict movement. This combined analysis tool is called Place Syntax and can be used to map accessible density.

Accessible density thus takes into account both the gross floor space of an area (for instance the urban block) and the accessible floor area within a certain radius. By doing so, the density of a low dense block can increase in case it is embedded in a high dense context. Or vice versa, a high dense block can have a very low accessible density if it is extremely segregated from its context.

For this paper we have used a similar tool in ARCGIS , network analyst. All these distances are measured according to the existing road network of Rotterdam. Four different catchment area based on metrical distance (Figure 7):

- walking distance: radius 500 meter
- biking distance: radius 1.000 meter
- car distance: radius 2.500 meter
- car distance: radius 5.000 meter

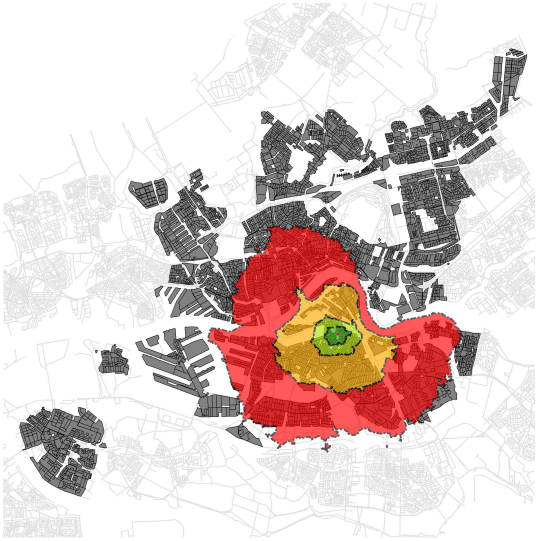


Figure 7: Accessible areas of a block are unique. They cover 500, 1000, 2500, and 5000m distance from the block and are dependent on network configuration.

4.3 Land use distribution and mixed-use types, MXI

The combination of FSI and GSI as used in Spacemate has proven to distinguish between urban forms. However, it does not show whether an area is mixed or mono-functional. To arrive at an indication of mixed-use, Joost van de Hoek developed the Mixed Use Index (MXI) to show how the available total floor area is divided between the three primary uses: residential, major employment and service functions. The MXI shows in percentages how these functions are distributed. Together they are always 100%. To represent these three components a ternary phase diagram is used. Each triangle vertex corresponds to a pure component, in this case residential, major employment and service functions. The three corners of the diagram correspond to areas where the gross floor area is composed of only of function, 100% housing, working or services. The other positions in the diagram correspond to a certain mix of uses.

For this research we use 7 types as represented in figure 8. Three types are considered mono-functional. Here more than 80% of the total gross floor area (GFA) is either residential, working or services (type 1, 2 and 3). Type 4, 5 and 6 are composed of a combination of two functions and in type 7 all different land uses are represented by at least 10% GFA. (see Figure 8)

In addition to the division in primary uses, employment is in this research specified further into industrial and office employment, and services are subdivided in commercial, culture & recreation and public & social services.

Residential

Working
- Offices
- Industries

Services
- Commercial uses
- Cultural & recreational uses
- Public & social functions

Density, be it FSI, Spacematrix or accessible density, as we have discussed in the earlier paragraphs can be specified further by introducing the differences in land-use within. We can speak of a service FSI or an accessible service density to analyse the relation between overall density and this specific land use density, or to study correlations between different land uses and between different radii of accessibility. (see Figure 1-6).

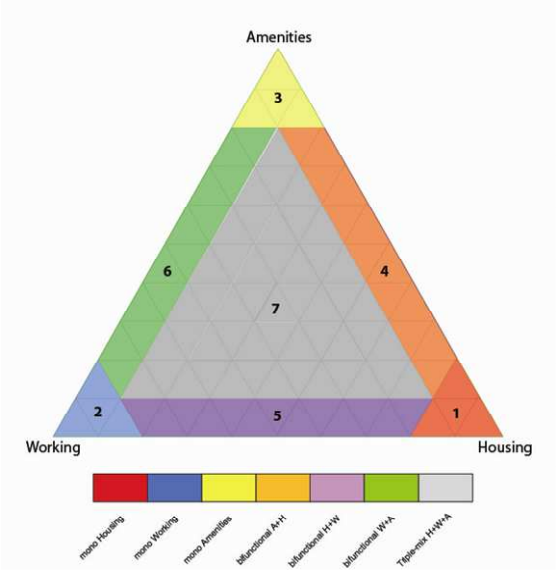


Figure 8: Categorizing mixture of function, MXI (based on Van Den Hoek, 2011)

5 Result for Rotterdam South

As mentioned before, the main research question is:

What is the relation between land use distribution, mixed-use patterns and urban form?

In order to answer this main research question and the three sub-questions (see paragraph 3), we analyzed the urban blocks in Rotterdam South on three levels.

In the first level we explored the general synergies between land uses in the urban blocks in Rotterdam South, including mono-functional and mixed-use blocks. Although the results have been formulated only for the

urban blocks in Rotterdam South, the northern part of Rotterdam is also taken into consideration. To answer the first level question, we calculate the Pearson correlation between all the possible combinations of areal and accessible density.

After demonstrating general synergies between land uses, we explored in the second level differences between mixed-use and mono-functional blocks. In other word, we search for significant differences between areal and accessible density measures which distinguish between mixed-use and mono-functional blocks (which all fit in general synergy rules of first level).[1]

After distinguishing between mixed-use and mono-functional blocks within general synergy rules, in the third level we focused on differences between mixed-use types. Based on the MXI method, we define four types of mixed-use blocks.[2]

5.1 General synergies between land uses (level 1)

To understand the relation between land uses en general all accessible functions for all different radii are correlated to one another. In first instance we will focus on the correlations within one and the same proximity neighbourhood. That is to say within a neighbourhood defined by walking distance (radius 500 meter), biking distance (1.000 meter) and car distance (2.500 and 5.000 meter). Figure 9 shows an interrelated pattern of distribution of residential land uses and services within the radius of 500 meter. The amount of services and residential floor area might be low or high in different cases, but they change with the same rate. Moreover there is not a considerable correlation between areal density of a block and intensity of accessible land uses. This is not a strange result due to dependency of areal density to geometry of plot and urban rules.

5.1.1 *Correlations within one and the same proximity neighbourhood*

Walking neighbourhood (radius 500 meter):

Within the radius of 500 meter there is high correlation between the amount of gross floor areas of the three types of services and residential land uses (all above R2 0,5). The highest correlation is found for commercial and public services followed by the cultural and recreational services. The amount of accessible work within the same radius is almost independent from the amount of service and residential land uses. In addition, the accessible densities of the different types of work (industrial and office) are independent from each other.

Biking neighbourhood (radius 1.000 meter):

When looking at the correlation between service and residential gross floor area within the biking neighbourhoods (radius 1.000 meter), the same conclusion as was the case for the walking neighbourhoods can be drawn. The correlation is even stronger. Between commercial services and residential land uses R2 is 0,87 and also the others have a correlation of above 0,75. And as was the case in the walking neighbourhood, the amount of accessible work is independent from the amount of service and residential land uses within the biking neighbourhood. There is however one difference as the amount of industrial and office function show a high correlation with one another in this radius which means that there seems to be a dependent relation between industry and offices within a radius of 1.000 meter.

Car-based neighbourhood (radius 2.500 meter):

There is a very high correlation between service and residential gross floor area in the radius of 2.500 meter. In other words, the accessible service density and residential density are almost completely dependent. The difference with the other two proximity neighbourhoods is that the cultural and recreational services show a higher correlation with the residential land uses than the other two service types do. Apparently, cultural and recreational services have a higher catchment than most commercial and public services. Inside the 2.500 accessible areas of an urban block, work is still rather independent from the amount of services and residential land uses. However, the commercial services now correlate highly (R2 > 0,75) with the accessible office floor space which points towards a dependency between office clerks and shops and restaurants accessible within a radius of 2.500 meter. Inside this radius, there is further a rather high correlation between different types of work (industrial and office).

Car-based neighbourhood (radius 5.000 meter):

Within the radius of 5.000 meter all the accessible land uses follow a similar pattern. The reason is that for Rotterdam South, which is about 5km wide, the different proximity neighbourhoods with this high radius have so much overlap that differences disappear. In other words, higher radii show more similar behaviour. We will therefore not include the results of the highest radius in the text that follows.

5.1.2 *Correlations between different proximity neighbourhoods*

[1] *we compare means of mixed-use and mono-functional blocks using the bivariate method of student's t-tests to find significant differences.*

[2] *We use the multivariate method of comparing means of Analysis of Variance (ANOVA) to find significant differences.*

In the former paragraph the relations between different accessible land uses within the same radius were at stake. Now we want to see whether the accessible land uses within one radius is influenced by the accessible

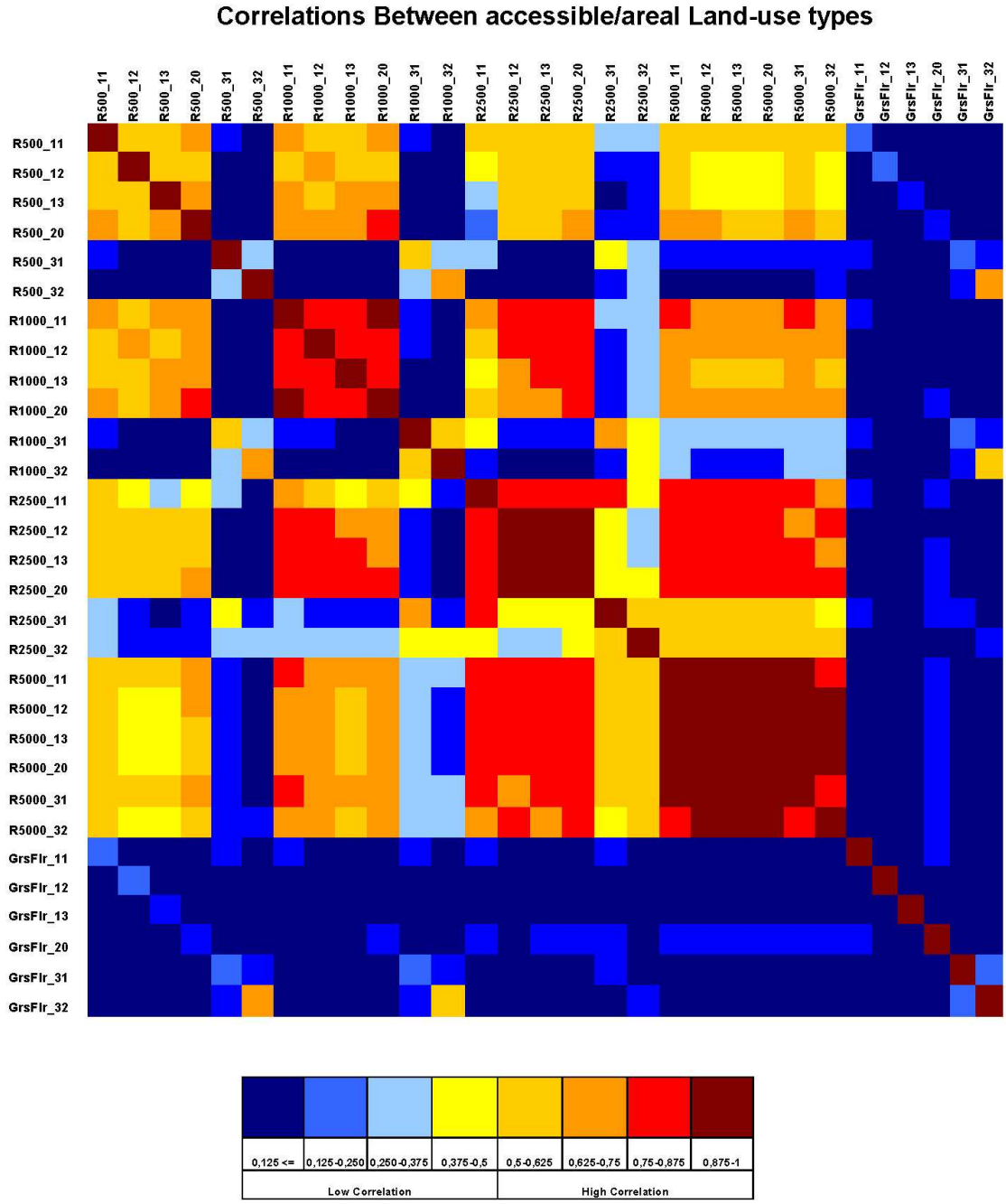


Figure 9: Correlations between intensity of different types of accessible land use and gross floor area of blocks Type codes: (11) Commercial, (12) Culture & Recreation service, (13) Public & Social service, (20) Residential, (31) Office, (32) Industry

density within another radius. The central question of this paragraph is thus: What is the relation between different radii considering land use distribution?

Walking neighbourhoods in relation to the other proximity neighbourhoods

The accessible residential density (gross floor area) within a walking neighbourhood (500 meter) is highly correlated with the amount of all three service functions inside its biking neighbourhood (1.000 meter), but not related to the amount of commercial services within a radius of 2.500 meter. The three accessible service densities in radius 500 are highly dependent on their own type of accessible service density at a higher radius (1.000 meter), except for the public services. The accessible public service density in radius 500 shows a relatively high correlation with the accessible commercial service density in radius 1.000, but a low correlation in radius 2.500 (R2 <0,4). In general we can conclude that the correlations between radii 500 and 2.500 meter are low. The accessible employment in radius 500 is completely independent from the other land uses in the same radius, but it is also independent from these land uses in other radii.

Biking neighbourhoods in relation to the other proximity neighbourhoods

The accessible service densities in radius 1.000 meter correlate to their own accessible density in the lower and the higher radii. The commercial services are further dependent on the accessible public services on the lower scale (radius 500) and the higher scale (radius 2.500 meter) and on the accessible cultural and recreation services on the higher scale and not on the lower scale. When looking at the accessible residential floor space it becomes clear that the highest correlation can be found within the same proximity neighbourhood (radius 1.000). The correlation becomes less strong when taking the lower or the higher scale into consideration. Although the correlation is in most cases still rather higher (R2= 0,6), it is significantly lower than when considering only the correlations within its own radius. Especially the correlation between accessible residential density in radius 1.000 meter and commercial services in radius 2.500 or cultural and recreational services in radius 500 is low (R2 0,5). In other words, commercial functions within car distance and cultural and recreational services within walking neighbourhoods do not correlate with the accessible residential density in radius 1.000. The two types of accessible work space in radius 1.000 show a correlation with themselves in other radii. Offices correlate to radius 2.500 and industry to radius 500.

Car-based neighbourhoods in relation to the other proximity neighbourhoods

The correlations between the accessible densities between radius 2.500 and 500 meter are in general rather low. Especially the accessible commercial service density in radius 2.500 has a low correlation with the accessible densities in radius 500 (R2 < 0,5), and also for radius 1.000 the correlation is relatively low.

5.1.3 Conclusions on the synergies between land uses

A general conclusion when looking at figure 3 is that higher radii behave more similar to each other than lower ones. In other words, there are more similarities between radii 2.500 and 5.000 than between radii 1.000 and 500. This is, as has been discussed already in the former paragraph, due to the fact that differences thin out when taking higher radii into account. Further, correlations between 500 en 2.500 proximity neighbourhoods are in general low.

The highest compatibility between service and residential functions is found in the biking neighbourhood (radius 1.000 meter). Commercial and public services seem to be dependent on their catchment on a very local scale (500 meter radius) as cultural and recreational services are dependent more on a catchment on the larger scale (2.500 meter radius). Work seems in general to behave rather independent from all other functions in all radii. The only correlation we found concerns the fact that industry seems to profit from clustering on the lower scale (radius 500 and 1000 meter correlate stronger) and offices on the higher scale (1.000 and 2.500 meter correlate stronger).



Figure 10: Mono-functional blocks (black) and mixed-use blocks (red).

5.2 Differences between mixed-use and mono-functional blocks (level 2)

Earlier research by Van den Hoek (2011 expert meeting) in Amsterdam and Rotterdam has indicated that a relation exists between FSI and mixed use developments (Figure 10). Mixed areas[3] with a density lower than 0,50 are not so common and areas with densities (FSI) higher than 1,50 are almost always mixed. We can thus conclude that a correlation exists between density and the mix of land uses. However, an FSI of 1,50 can be realized with very different urban layouts ranging from a high rise development to a traditional block layout. Within this range of building types (having the same FSI), the mix of land uses differ as well as has been shown in a research by Berghauser Pont et al (2011) in Rotterdam South. More than 60% of the cells[4] dominated by low rise developments can be defined as mono-functional. In the mixed areas where each of the function is at least represented by 10% of the gross floor area, around 40% of the cells is low rise and when the mix level rises (each function has at least 20% of GFA), the amount of low rise cells decreases to 30%. The amount of mid-rise developments and especially those with a higher GSI increase when the mix level rises. We can thus conclude a higher FSI and GSI create a better condition for areas to mix. This does however not say that low densities can never mix or that high densities always create more mixed environments.

When considering all the mixed blocks the share of floor area used for commercial services such as shops and restaurants show the highest difference with the mono-functional blocks, followed by the share of cultural function, social services, offices and industries. In other words, the service function and especially the commercial functions dominate the mixed blocks. The share of work is less spectacular as can be seen in figure 11.

The share of housing reduces significantly in the mixed blocks. A mixed block has 21% less gross floor area for housing than a mono-functional block. This is not so strange as the other functions need more space in order to make the blocks mixed. The increase in FSI in the mixed blocks alone is not enough to realize the mix and thus is the amount of residential floor area reduced in favour of the other functions.

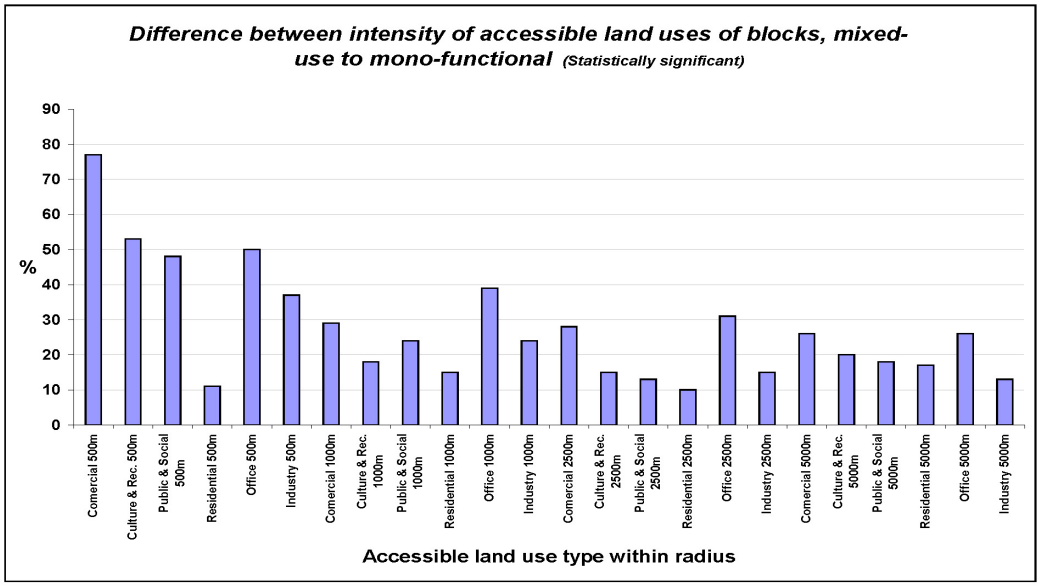


Figure 11:

Difference between mixed-use and mono-functional concerning intensity of accessible land uses of blocks.

What we also found is that this reduction of residential floor area within a block is compensated for by an increase of residential density in proximity of the block in question. This can be studied by measuring the accessible residential density. We see that in the mixed blocks the residential density decreases with 21%, but the accessible residential density of mixed blocks is significantly higher than that of mono-functional blocks . The accessible residential density increases with 11% within a radius of 500 meter and 15% within a radius of 1.000 meter (see figure 12).

The distribution of the accessible functions shows the same pattern as the distribution of the functions within the mixed-use blocks. Mixed-use blocks have a higher service provision, more job opportunity and

Based on the results of a more in depth study of Rotterdam South we can now conclude that FSI in the mixed blocks is significantly higher than in the mono-functional blocks. The FSI is 27% higher in the mixed blocks than in the mono-functional blocks.

[3] Mixed areas are here defined as having at least 10% of the three main land uses housing, working and services.
[4] A cell is 200x200 meter.

residential catchment in all the radii. Service provision and job opportunity show higher difference than residential catchment. These differences are statistically significant. The result is the same by testing detail categories of services (commercial, cultural & recreation, public & social services) and work (office, industry). Within walking distance (radius of 500 meter) of a mixed block the distinction in commercial service provision is the most distinctive (77%) and job opportunities in industry show the least distinction (37%). Within biking distance (1.000 meter) the differences between mixed and mono-functional blocks thin out and job opportunities (offices) take the lead with 39%, followed by commercial service provision (29%). In other words, for mixed blocks the proximity of enough commercial services on walking distance is of great importance. On biking distance enough office clerks need to be present. Within car distance (2.500/5.000 meter) both commercial and offices are equally distinctive (around 30%).

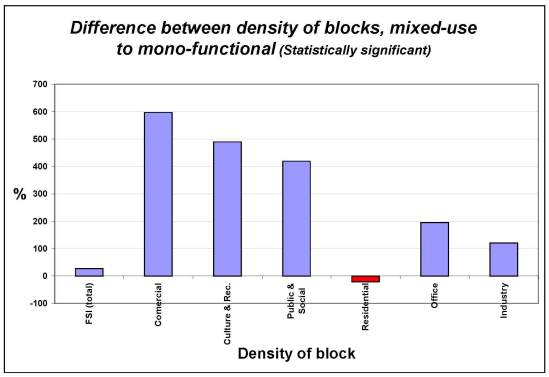


Figure 12: Difference between density of blocks, mixed-use to mono-functional

5.3 Differences between different types of mixed-use blocks (level 3)

In the last part, we searched for significant differences between mixed-use and mono-functional urban blocks in Rotterdam South. In this part, we explore whether there are also distinctive differenced between mixed-use types. For this purpose we only look at the four types of mixed-use as were discussing earlier (see Figure 8) and focus on the differences between them. It concerns the three bi-functional mixed types (type 4, 5, 6) and the triple-mixed type (7).

(4) residential - services :
Blocks which contain housing and services in a way that none of them is dominant (more than 80% GFA), and share of emplyment is low (less than 10% GFA).

(5) residential - employment:
Blocks which contain housing and work functions in a way that none of them is dominant (more than 80% GFA), and share of service functions is low (less than 10% GFA).

(6) employment - services:
Blocks which contain work and service functions in a way that none of them is dominant (more than 80% GFA), and share of housing is low (less than 10% GFA)

(7) triple-mix (residential - employment – services):
Blocks which contain housing, amenities, and work in a way that none of them is dominant (more than 80% GFA), and share of none of them is low (less than 10% GFA).

The significance of the results depend on the difference between average density measures within mixed-use types (areal or accessible) and the size of samples. Before mentioning the significant relations found, we start with discussing the main categories without any significant result (see Figure 13).

5.3.1 Non-distinctive factors between different types of mixed-use blocks

Car accessible land uses

According to the results obtained in the second level, service provision, job opportunity and population catchment within car-based neighbourhoods (2.500 and 5.000 meter) are significantly higher in case of mixed-use blocks. However, accessible densities within car-based radii show almost no significant difference between different type of mixed-use blocks. Within radius of 5.000 meter, none of the land use classes show significant differences. In the lower car-based radius (2.500 meter) just some of the classes show distinctive difference between two types. In other words, car-based accessibility is positively related to mix of functions in an urban block, but for the emergence of various types of mixed-use types it is not distinctive.

Presence of Office-employment

According to the results obtained in the second level, accessibility density of offices significantly differentiates between mixed-use and mono-functional blocks. Within biking neighbourhood, accessible office density shows the most distinctive difference between mixed-use and mono functional blocks (39%). However, accessibility of offices does not represent a significant difference between mixed-use types. This is partly the result of the even distribution of mixed-use blocks around offices in Rotterdam South. In other words, almost all types of mixed-use are provided with the same amount of offices in their vicinity. Therefore this factor is not distinctive within different types of mixed-use.

Areal density (FSI)

FSI does not show a significant difference between mixed-use types either. According to the results in the second level and earlier research, a high FSI is a

precondition of mixed-use development. Therefore, where all the mixed-use blocks have a relatively high FSI, this can not lead to a distinctive measure within mixed-use types.

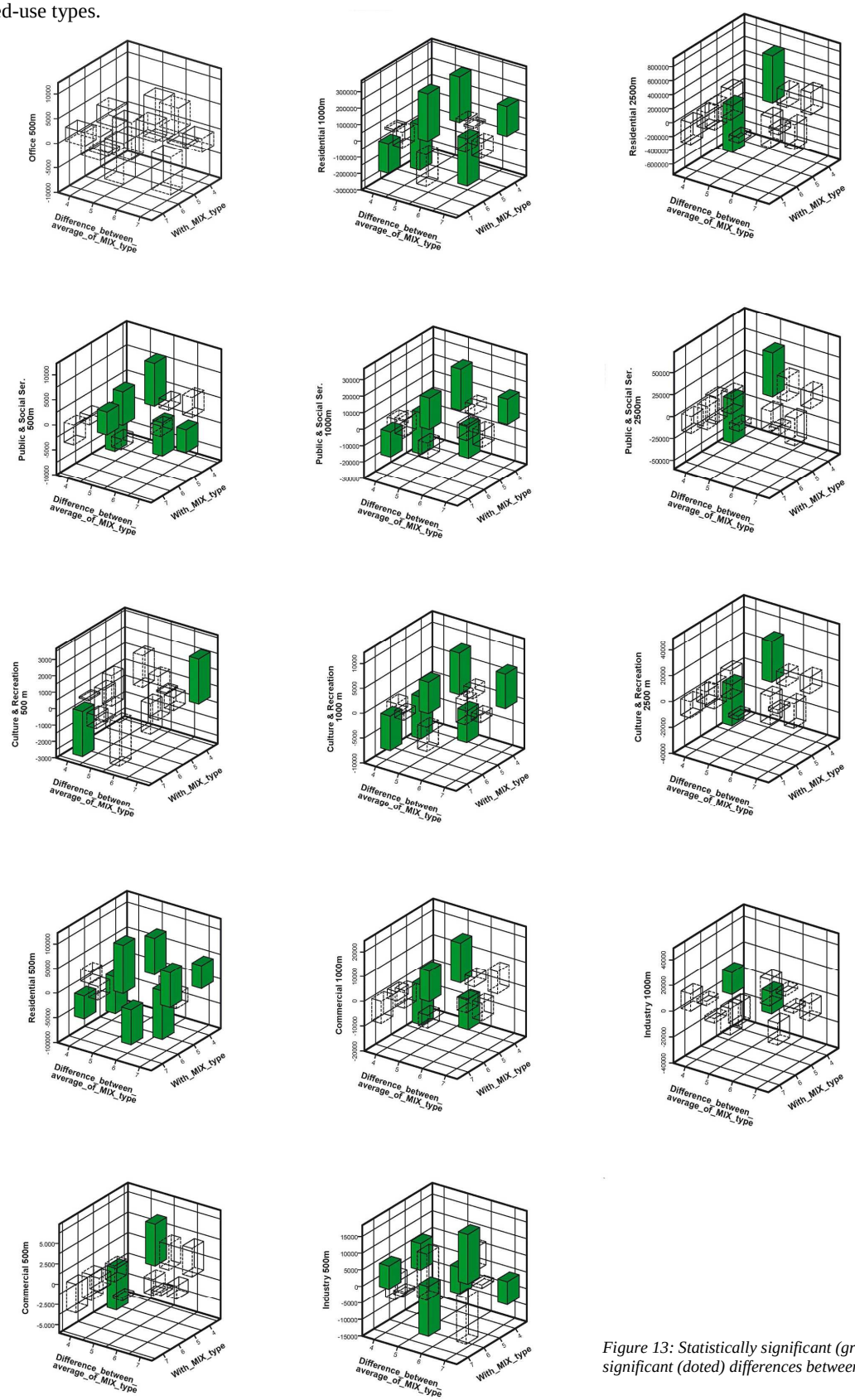


Figure 13: Statistically significant (green) and non-significant (doted) differences between mixed-use types

5.3.2 Distinctive factors between different types of mixed-use blocks

Intensity of accessible land uses within walking neighbourhoods

Mixed-use type 5 (residential – employment), has a significantly higher accessible social service density than the other types. In addition they show a higher accessible commercial service density than type 4 (residential - services).

The accessible industrial density is higher in the bi-functional mixed blocks that lack industry themselves (type 4 and 6). In other words, mixed-use blocks that lack a certain function within its own block, seem to be located in areas where that function is present. This can be described as a strategy of compensation.

Accessible residential density is higher in type 5 and 7 (respectively mix residential - employment and triple-mix) than in type 4 and 6. In other words, both types 5 and 7 are located in neighbourhoods with higher accessible residential densities, measured within radius 500.

Intensity of accessible land uses within biking neighbourhoods

The same strategy of compensation was found within biking distance neighborhoods (radius 1.000 meter). Type 5 (residential – employment) has a higher service provision, in all three classes, than the other two bi-functional types (type 4 and 6). Triple-mix blocks (type 7) have higher accessible service densities than type 4, at least when considering culture & recreation and public & social services.

In addition, type 5 blocks are located in biking neighbourhoods with a higher residential catchment than the other two bi-functional types (type 4 and 6). This is the same when comparing the triple-mix type and type 4/6. In other words, type 5 and the triple-mix blocks seem to perform rather similar.

And again, as we have also seen in the walking neighbourhood, the blocks where employment is lacking (type 4: residential - services) show a higher accessible industrial density than in type 5.

5.3.3 Conclusions on the differences between different types of mixed-use blocks

In most of the cases, the blocks with a mix of residential and employment and the triple- mixed blocks are provided with higher accessible services density, higher accessible residential density, and total density. The other two have a higher accessible density of work. In other words, the lacking function within the block is compensated for by its presence in the surroundings.
In cases with no significant differences, for instance between type 6 and 7, either the allocation of types is influenced by other dimensions of urban form (transport, layout, building type) or the sample size of mixed blocks of Rotterdam South is not large enough for a significant conclusion.

6 The relation between land-use distribution, mixed-use patterns, and urban form

In the case of the general correlation between land use locations (level 1), we can conclude that residential land uses and services correlate highly in all radii, There are also differences between the service classes. Within the 1.000 meter radius the commercial service functions correlate strongest with residential land uses and within the 2.500 meter recreational and cultural services correlate strongest. Work is rather independent from the other land uses in all radii. Within the radius of 1.000 meter the different work types (industry and office) become interdependent and within the radius of 2.500 meter accessible office floor space correlates with the accessible commercial services. This conclusion might be explained by the rather heavily segregated position of work in Rotterdam South.

When comparing correlations between different neighbourhood scales the results are slightly different. For the walking neighbourhood (radius 500) the accessible densities of radius 1.000 meter are quite important. For the biking neighbourhood this is less the case. The correlations are in general highest within the same radius of 1.000 meter. Another interesting conclusion is that to serve residents in a biking neighbourhood (radius 1.000) commercial services should be offered in the same or a lower radius, but cultural and recreational services in a higher radius.

Work space continues to be rather independent of other functions and accessible densities on different scales. However, offices seem more dependent on other accessible offices space on a higher scale as industry seems more dependent on accessible industries on a lower scale. In other words, industries cluster stronger than offices, but both are rather independent from other functions in their proximity.

Comparison between mixed-use and mono-functional blocks (level 2) shows that mixed-use blocks have a higher accessible density in all the radii and land use classes. The difference is more distinctive in lower radii. In walking distance the accessible commercial service density is 77% higher in mixed-use blocks than in mono-functional blocks. Within biking distance, the presence of work is the most distinctive, where it differs 39% between mixed-use and mono-functional blocks.

As general conclusion, mixed-use development is likely allocated in the areas with greater provision of different land use classes which from Place Syntax perspective can be called as location value.

Moreover, mixed-use blocks have greater areal density. FSI is 27% higher in mixed-use blocks. In addition, the areal density of service functions and employment are greater in mixed-use blocks (which is different from service and work percentage within the block). However, the residential density is less in mixed-use blocks. This is not so strange as mixed-use blocks need to open space for other classes of land use.

The comparison between different types of mixed-use blocks (level 3) show that the mixed-use types 5 and 7 (respectively residential - employment mix and the triple-mix type) behave in almost the same way. The other two types (residential-services and employment-services) show the same pattern as well. There is further a complementary behaviour within bi-functional mixed types. Mixed-use types are located closer to the classes of land use which they lack inside the block. For instance, type residential-employment has more accessible service than the other types.

Knowing all this gives the discussion concerning mixed-use developments much more depth. We know now that higher densities (FSI) indeed gives more potential for functions to mix. We even know that in a city context the difference in FSI between mixed-use and mono-functional blocks is 27%. We also know that commercial services need less catchment than cultural services. This means that when developing an area, it is important to scan the available cultural functions in the neighbouring area. The effects of a new area will also take place on that scale (radius 2.500 meter). The most important conclusion therefore is the knowledge how a local change has effects on the city as a whole. This paper is a start in understanding this dynamics considering land use distribution.

7 Further research

In this research we explored the relations between synergies of land use and mixed-use developments by means of Spacematrix, Place Syntax, and MXI. The methods are related to three dimension of urban form: density, land use, and accessibility. However there are more dimensions of urban form to include (layout and building types) which may effect the land use distribution. Earlier research in Rotterdam South (Berghauser Pont et al., 2011) show for instance significant greater integration values for mixed-use blocks. In addition, a lot of other factors are missing such as public transport, population density, land prizes, accessibility to public space, etc. Further research needs to be done to understand the role of these factors. To do so, more factors and dimension should be added to the here presented research frame.

Moreover, the mixed-use status has until now only been measured for urban blocks. The concept of mixed-use however, can also be measured, mapped and analyzed in accessible neighbourhood scale (see Figure 14). Further research will address the relations between mix of land uses in walking and biking neighbourhoods and will include other urban form factors.

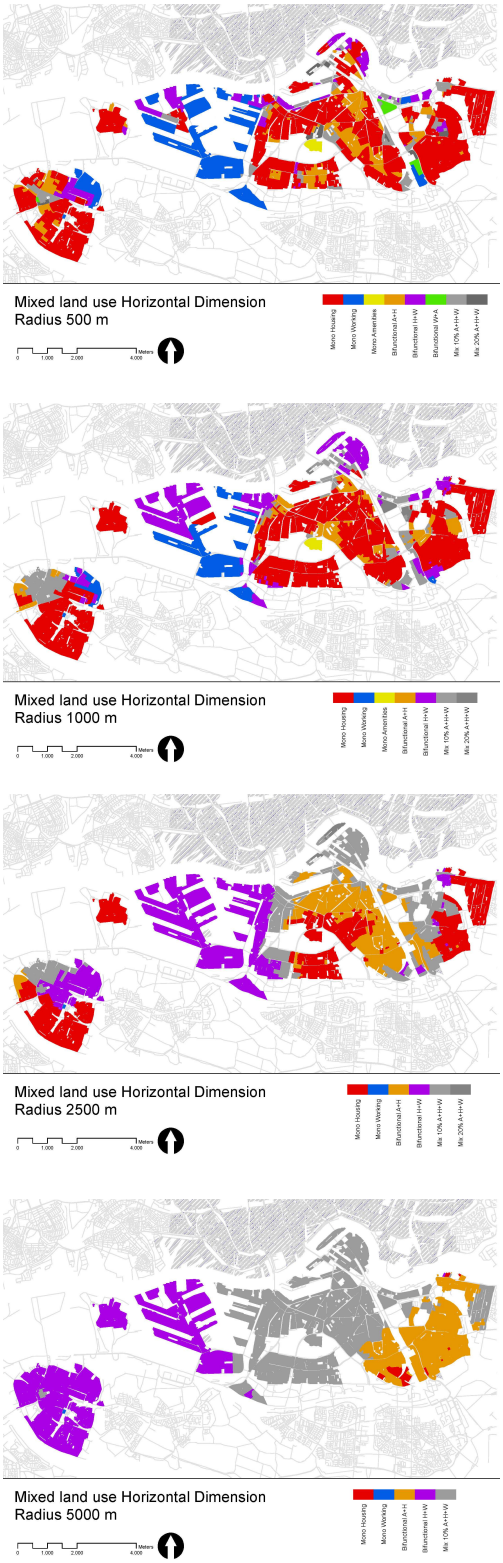


Figure 14: Mixture of functions within accessible neighbourhoods of a block

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