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THE DENSITY OF SUSTAINABLE SETTLEMENTS

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BRIEF

This paper is the initial result of a cross-disciplinary attempt to encircle an answer to the question of optimal densities of sustainable settlements. Urban density is an important component in the framework of sustainable development and influences not only the character and design of cities but also the architectural and technical strategies of buildings. The paper is based on literature studies in the fields of urban mobility, urban ecology, urban design, architecture and civil engineering. It concludes that neither detached houses nor extremely dense cities are optimal answers to the sustainable challenge.

KEYWORDS

Urban density, urban mobility, urban greenery, building energy use, architecture.

INTRODUCTION

The last four decades holds numerous examples of self-named sustainable, ecological or low energy buildings also in Nordic settings. In a Danish context such initiatives including passive houses tend to have a strong focus on heat savings and less focus on non-heating energy purposes, tend to disregard aspects of infrastructure and human mobility and tend to sometimes conflict with architectural quality (Lauring and Marsh, 2008). On the other hand architecture and urban design can and should contribute to sustainability (Lauring and Marsh, 2009). Energy supply and other infrastructural matters may be practiced most sustainable in dense urban contexts. But many people choose green, suburban or even rural settlement as their human habitat if they can afford so. In this crucial conflict between energy efficiency and human preferences urban architecture stands as a key mediator with density as a key parameter. But just how dense must a sustainable settlement be? This article tries to explore the matter of density and sustainability in the light of what is considered three important issues: Urban mobility, urban greenery and building energy use.

METHODS

Literature studies.

URBAN MOBILITY

The relationship between density, urban mobility and sustainable environment is the key focus in this section of the paper. Much evidence exists to document that dense urban settings produces different urban mobility patterns than scattered urban developments. Furthermore, there is reason to believe that negative environmental consequences are the main result of increased urban mobility in regions with low density. This however is dependent on the society in question since factors such as technological development, material growth, and infrastructure plays a key role in the way environmental externalities as consequences of urban mobility manifests itself. Here we shall use the debate on 'sprawl' as a shorthand for the complex relationship between density and urban mobility and this mainly focus on the density-urban mobility relationship.

Urban mobility. State of the art.

In 2008, for the first time in history, the majority of the world population was living in urban areas. Following this trend, it is estimated that the global urban population will reach 5 billion by 2030, which will represent 60% of the world population. In parallel, population densities in the largest urban areas have been rapidly declining since the second half of the 20th century when the urban world started to experience intense sprawl, characterized by the wide decentralization of the city outwards. The (European Environmental Agency, 2006) defines urban sprawl as the "physical pattern of low-density expansion of large urban areas, under market conditions, mainly into the surrounding agricultural areas". The conjunction of fast urbanization, population growth and sprawling is raising the demand for travel and increasing transport related GHG emissions. Therefore, reducing the travel demand and, consequently, the consumption of fossil fuels (oil, coal and gas) is a key issue in the efforts to promote a sustainable development.

In this context, policy makers, architects and planners have been searching for alternatives to urban sprawl. Urban policies have been implemented to control or reverse sprawl under different names such as compact city, urban consolidation, urban intensification and smart growth (Williams et al, 1996; Andrade, 2010). These policies have as common factor the densification of urban cores in order to reduce energy consumption and car-dependency. There are several studies providing strong evidences that there is a direct relationship between density and use of public transportation and per capita petrol consumption where higher density is related to higher use of public transportation and lesser per capita petrol consumption (Gilbert and Pearl, 2010, Newman and Kenworthy, 1989). Newman & Kenworthy (1999) measured the consumption of fuel per capita and the population density in several cities around the world. As result, they found a correlation between per capita petrol consumption and population density. When analyzing the relationship between travel patterns against urban densities, Newman (1992) found that private car use increases exponentially with a density of 20-30 dwellers per hectare. On the other hand, walking and biking decrease with a density of 20-30 dwellers.

Hester (2006) points that concentrated density creates resilience in several ways – including reduction of commuting distances and, consequently, reduction of per capita petrol consumption. Hester suggests that neighborhoods should have at least densities approaching fifty units per acre and the mentions as example the Victorian row houses which are often forty-eight units per acre.

According to Hester, Victorian row houses are a good example of high density and combined with good spatial qualities where it is still possible to provide private or shared gardens for most dwellings. Studies in a number of cities in different countries have shown that inner-city residents center travel less than suburbanites. Moreover, inner-city residents carry out a higher proportion of their travel by bike or by foot (Fusco, 2003; Næss 2009a; Næss 2009b).

Despite of decentralizing trends, most Scandinavian cities still have a higher concentration of workplaces, educational facilities, retail, public agencies, cultural events and leisure facilities in the urban center and its surroundings than in the periphery. Therefore, the distances to this concentration of facilities will be shorter for inner-city dwellers than for suburbanites. Concluding, average trip distances could be expected to be shorter among inner-city residents than among suburbanites (Næss 2009a; Næss 2009b). Næss (2009a; 2009b) carried a detailed study about residential location and mobility in Copenhagen. According to Næss, the proportion of distance traveled by non-motorized modes is considerably higher among inner-city dwellers than suburbanites. According to Næss, this result reflects the fact that a high proportion of suburbanites have to travel to destinations beyond acceptable walking or biking distance in order to reach the facilities they use on weekdays – particularly workplaces and educational facilities. Finally, Næss suggests that inner-city living is directly associated with lower energy-demanding travel modes. While suburbanites travel considerably longer by energy-demanding travel modes than their inner-city counterparts do.

However, densification as an alternative towards sustainable development is not a general consensus. A number of authors have been arguing that the influence of urban density on travel and per capita petrol consumption is likely to be insignificant, especially when compared with other factors such as household characteristics, fuel prices, and transport technology (Breheny, 1995; Gordon and Richardson, 1989. Moreover, there is a discussion about 'good and bad' density as when al-Asad argues that densification may backfire and lead to a rash of high-rise buildings randomly popping up and thus that in order to be 'good densification' it must be accompanied by strong zoning regulations (al-Asad, 2009). Likewise does Wendell Cox in a Goldwater Institute report document that in certain US cases urban density intensifies traffic congestion and air pollution and makes the rather simple but often overlooked argument that *'… one thing is sure. If more of something is put in a smaller space, it will get more crowded. This undeniable truth seems to have eluded the proponents of new urbanism'*(Cox, 2000:11). Alongside this critical appraisal of the sprawl critique and the pro-densification argument Kolb states that '*density should not be confused with a demand for historical authenticity, which is a different notion to apply'* (Kolb, 2008:73).

Despite of continuing sprawling, there are findings that highlight that average traveling distances in decentralized cities have tended to remain stable or fall during the two decades (Gordon & Richardson, 1989; Levinson & Kumar, 1994; Handy, 1992; Bae, 1993). Their premise is that suburb-to-suburb commuting patterns are increasing due to co-relocation of people and jobs. Moreover, there is not an accurate definition of how dense a city should be, no consensus on what scale should be take in consideration when implementing a densification strategy and no precise definition on which elements of the densification strategy contributes towards sustainable development. Finally, there is also a counter-discourse indicating an inherent contradiction between global sustainability and urban local sustainability: strategies globally good would not be necessarily beneficial in the local scale and vice-versa. Favoring strategies towards global sustainability, compressed transport infrastructure, lighting and heating in dense cities reduce per capita consumption of energy. On the other hand, dense cities suffer undesirable effects of the increase production of waste and its hazards impact which compromises the regeneration of the local ecosystem (Pauleit et al, 2005).

Urban mobility. Critical discussion and utopian alternatives/visions.

The previous section hopefully illustrates some of the complexities and dilemmas of finding out what the actual repercussion of densification might mean. Many more issues are at stake such as the scale one applies (i.e. what might be sustainable densification at a local level might not be so at a regional or even global scale). One need not go all the way to a provocative position almost defending sprawl like Bruegmann (2005) to illustrate that the debate over sprawl and densification also has to do with values and norms. Accordingly we would argue that a dimension of this discussion has to do with the imagining of future urban development trajectories. Here we find it useful to consult key thoughts of utopian and critical urbanism (Jensen, 2010) and bridge those to contemporary critical scenario thinking (Dennis and Urry, 2009). The interest in organising and orchestrating future urban development has been on the mind of philosophers, architects, city planners and academic schollars writ large. Pinder points with a reference to Lefebvre to the fact that utopian thought works as a stimulus for imagining change (Pinder, 2005:14). According to Pinder there are at least three distinctly different ways to define utopian thought. One would be to focus on the content of the 'good society', another to put emphasis on form, and the third to focus on function. The latter seems to carry the pragmatic dimension to utopian thought as it is concerned with what utopia is for and how it works for particular purposes (Pinder, 2005:17), thus utopian imaginaries becomes pragmatic rather than simply visionary. Finding such notions within Marxian writers as Lefebvre, Marcuse, Frederic Jameson and Ernst Bloch the re-thinking of utopianism takes on very concrete aims as when the latter reconceptualises it as an 'anticipatory consciousness' and a 'principle of hope' situated at the level of everyday life (Pinder, 2005:17). In the words of Planning Theorist John Friedman, utopian thought has to do with the capacity to imagine that which is not (Friedman, 2002). That is to say, not only will the utopian mind work towards new ways of thinking, but equally important a utopian reflection carries a critical potential to break through the 'barriers of convention'. Friedman argues that utopian thinking has two moments; critique and constructive vision (Friedman 202:104).

This is important since utopian thinking then becomes both a question of critically to challenge the given and established, but equally important the utopian reflection will be committed to an exploration of fruitful potentials and constructive vision. David Harvey argues that we may even discriminate between utopian thought that is 'degenerate' or neo-conservative utopias for urban development (Harvey, 2000). The former might be Disneyland and the latter New Urbanism. Needless to say this rests on a complex normative and value-based discussion. However, Harvey is certainly not doing away with the utopian thought but rather giving it the Marxian touch that has become the hallmark of his decades of critical urban studies. More interestingly though, Harvey insists that to embark upon utopian thinking is to be explicitly spatiotemporal (Harvey, 2000:182). That is to say, there is no utopian imagination without a 'where' and 'when' that immediately will have repercussions to the geographical imagination as one effect, but also as a window into discussions about the mundane, ordinary and concrete. The capacity to imagine material interventions before embarking on these is exactly one of the defining features of humans (Marx, 1887/1972:233). So the imaginary capacities are an important and (potentially) creative feature that we may engage with in order to push the limits of the future systems and design catering for mobility. The importance of a 'critical scenario thinking' cannot be underestimated if we are facing mobility challenges that in the current situation looks like they are 'locked in' to certain ways of designing, organising and practicing (Dennis and Urry, 2009).

Much literature confirms that the private car is a major challenge to the environment and health in the contemporary city (see e.g. http://www.nutramed.com/environment/cars.htm and Rogers (1997)) and thus represents a major mobility challenge. Many studies substantiate that the way we live separating housing from work as well as an increased amount of leisure travel by car all add up to a serious mobility challenge (Næss and Jensen, 2005). On such a background imagining a new 'post-car system' is as Dennis and Urry engages with is a demanding task (see Mitchell (2010) for an attempt to re-invent the Automobile). But the discussion of such alternative scenarios may be immanently linked to visions of compact development and dense settlements. One such imaginary vision is the one articulated by Rogers & Gumuchdjian (1997). Accordingly, the 'dense city' model was rejected due to the nightmarish conditions of the early industrial cities, which were dense indeed but not livable places. What Rogers & Gumuchdjian therefore proposes is a re-interpretation of the dense city as a 'compact city' which is defined as: 'a dense and socially diverse city where economic and social activities overlap and where communities are focused around neighborhoods' Rogers & Gumuchdjian (1997:33). Here the before mentioned risk of romanticizing the 'old, dense, historic European city' seems very close.

The program for compact cites are accordingly cities that are just, beautiful, creative, organic, enhancing social interaction, compact and polycentric and culturally diverse.

URBAN GREENERY

Urban greenery acts as a crucial part of urban identity, quality and attraction be it Central Park, London squares or Berlin alleys. In a sustainable perspective urban greenery may be one of the main factors in order to make people accept denser ways of settlement than detached house suburbia. In a strict physical perspective urban greenery influences the circulation of water and the climate of cities.

Urbanity and water. State of the art.

Access to drinking water is a basic determinant for human settlement and historically seen presence of drinking water has had far greater importance for choice of site for settlement than for instance the presence of fuel or building materials (Hansen, 1971). Today the ways of supply and consumption varies a lot comparing different countries and regions. In Denmark the household water consumption rose up till 1985 (Danmarks Statistik, 2002) due to general increased standards of living (Marsh and Lauring, 2005). By 2000 it had declined 30% to 138 liter per capita per day, primarily due to more effective water installations and increased awareness of saving water. But even with this reduced consumption there is shortage of useable drinking water especially around Copenhagen. The ground water resources are overexploited in big parts of Zealand and Funen where the accessible resources are now halved (Henriksen and Sonnenborg, 2003).

The Danish supply of drinking water comes mainly from high quality ground water which apart from overexploitation is threatened by agricultural use of pesticides. Ground water may be replaced by other types of water, but these will have poorer quality: Either surface water for instance from lakes that have to go through cleaning processes including the use of chlorine, which influences the taste of the water. Or in last instance sea water, the use of which implies a very energy demanding process to take away the salt. Obviously there are many good reasons to protect existing ground water reserves and to secure that they are renewed by letting rainwater filtrate back into the ground for instance in green areas. There are also – with big regional differences – good reasons to reduce cities need for supply of water, for instance by substituting part of the drinking water supply with rain water. This can be done relatively simple in relation to outdoor functions such as the watering of parks and gardens. If rainwater is to be used indoor an extra water tube system is required along with initiatives to control growth of bacteria (Marsh and Lauring, 2005).

Water ways in the form of rivers, fiords and sea have had crucial influence on which settlements could grow to become cities and metropolises. Originally the water ways also served to lead away garbage and spill water as is still the condition in many third world cities. All ready in 1850 the river Thames were so polluted that only bacteria could live down stream (Store Danske Encyclopædi, 2001). This also influenced the whole pattern of settlement. Before the river reached central London the water was fresh, causing the higher classes to buy attractive sites along the Thames upstream west of the city, while working people had to settle for East End (Allinson, 2006).

Establishing a reliable drinking water supply system and an effective sewer system – and not mixing the two! – may be characterized as the most important health initiative of the modern city. In Denmark and most Northern European cities tap water can normally be drunk without any health risk, while the sewer systems still present problems. Partly because some systems are worn and leaky giving access to rats, partly because spill water and rain water are led into the same sewer/drainage-system. This means flooding during those extreme rain storms appearing far more often now due to climate changes. The problem increases as a growing part of the city ground is covered by hard, non permeable materials, from where rain water is led directly to the sewer/drainage system. This phenomenon includes suburbia where green garden area is replaced by hard driveways, hard front areas and terraces.

Approximately 1.5 % of the global GHG is related to spill water. The Danish water sector represents app. 2.4% of the national electricity consumption (Andersen, 2008) - marginal figures in the big perspective. But the increasing flooding of cities and regions is not a marginal problem nor represent sustainable urban conditions. Flooding may be avoided if rain water is held back by or infiltrated through green urban elements.

Urban greenery and urban ecology. State of the art.

Cities normally represent a massive reduction in vegetated area thus altering the ecology of cities compared to ’natural’ ecosystems or agricultural land. Four major ecological effects have been identified (Whitford et al, 2001): First, urbanization affects climate; cities tend to be hotter than the surrounding countryside and create what is known as an urban heat island. Second, urbanization affects hydrology; cities shed more water as run-off into their streams, rivers and sewer systems. Third, cities are net producers of carbon dioxide and have lower amounts of stored carbon. Forth, cities are widely regarded as having lower biodiversity.

In order to supply simple, operational tools for urban planners Whitford et al have derived performance indicators to quantify the four major ecological effects of urbanization. Secondly they have tested the indicators on four UK Merseyside sites which demonstrate different degrees of urbanization:

One effect of urbanization on climate is that heat produced by buildings and cars warms up the environment. Energy uptake is promoted during summer days by buildings and roads having a high thermal storage and low albedo (the fraction of solar energy reflected back into space). More heat is therefore stored through the day and reradiated during the night. Also, energy loss due to evaporation is lowered because of the reduced vegetation. The result is a ‘summer heat island’, which makes life uncomfortable and increases the need for air conditioning. The final input parameters in the calculation of these effects are the relative areas of three surface cover types: Built environment, bare soil and green space.

The major effects of urbanization on hydrology are caused by the replacement of vegetation by more impermeable structure like buildings and roads. Interception of rain before it reaches the soil is reduced because there is less vegetation to be wetted. Also, evaporation of water from vegetation is reduced. Third, infiltration of rain into the soil is reduced due to less permeable area. Consequently, more of the rain is diverted into sewers and streams. Rain water run-off into catchments depends on soil type, catchment wetness and the percentage of impervious surface. This last variable has been shown to be crucial in determining the run-off coefficients of urban catchments.

A third major effect of urbanization is raised carbon emissions, from the use of energy for household and transport. Trees can shelter buildings in the winter and cool them in the summer by shading and evaporation, an effect which is though very difficult to calculate. The storage and sequestration rate of carbon in urban trees is much more amenable to study and the Chigaco-studies of Rowntree and Nowak (1991) including considerations on the mixture of young and old, broadleved and conifer trees have identified the percentage of tree covered urban areas as the key parameter: The carbon sequestration = (8275 x % tree covered area) kilo per ha per year. Considering the fourth effect, biodiversity, according to Forman (1995) the area, density and boundary length of and connections between green areas have been proved important.

The four calculation tools (Whitfort et al, 2001) then tested on four residential areas of Merseyside: The greenest settlements, Sherdley Park and Claughton, showed better results in all four categories. The maximum surface temperatures of Sherdley Park were 7°C lower than in Wavertree (respectively 52 and 12% green space). These calculations are very similar to actual measurements made by Pauleit and Duhme (2000) showing differences of 6°C between areas with respectively 50 and 15% green space. Sherdley Park had a water run-off coefficient of 51% while Wavertree had 86%. Claughton stored 17 tonnes carbon per ha per year, while Scotland Road stored O.2 tonnes. Also the biodiversity of Sherdley Park and Claughton were better.

Urban greenery. Discussion.

Maximum temperature differences of 6-7°C between green and less green cities indicates that there are very huge potential energy savings related to cooling cities and buildings in the summer by implementing greenery and trees as part of the city. This will also cause better treatment and conduction of rainwater. It is discussable whether absorption of carbon dioxide should necessarily take place in the city and not outside, and from a strict anthropocentric angle we may discuss whether animals and plants should necessarily live in the city. But still, from a purely physical/sustainable point of view there seems to be strong arguments for implementing greenery in the city. In this perspective a city should not be denser than it allows green elements to be marked parts of the townscape and its architectural appearance.

BUILDING ENERGY USE

The concentration of activities and people in cities can have an environmental advantage through the sharing of resources. Most obviously sharing of infrastructure – energy and water supply, drainage, roads, buildings and public transport – which reduces the energy per capita associated with its construction (and possibly maintenance) and also allows for the use of combined heat and power production through a district heating distribution network.

However, when one considers the implications of high density on the demand side of building energy use and on building integrated renewable energy production (such as PV), does the balance begin to tip in favor of lower densities?

The building energy use will be influenced by different factors arising from increased urban density:

More compact construction will lead to a smaller envelope to volume ratio, which will decrease the need for heating and cooling, but might increase the need for artificial lightning and mechanical ventilation.

Solar availability especially during the winter period will decrease due to shadowing from neighboring buildings. This will increase the need for heating and artificial lighting. It will also have an impact on the potential for exploitation of renewable energy (PV, solar thermal, earth coupling).

A higher urban density will change the microclimate around the building and lead to increasing temperature levels (the heat island effect) due to higher solar absorption and lower water evaporation rates in dense urban areas than in rural settings as well as heat supply from buildings. This will decrease the need for heating and increase the need for cooling of buildings.

In a dense city environment air pollution and noise levels are increased, which might prevent the use of passive technologies like natural ventilation and passive cooling and require mechanical solutions, which often have a much higher energy use.

The impact of the above mentioned factors is likely to depend on the building type. Domestic buildings are dominated by energy use for space heating and both the more compact construction and the possibility of greater solar access and passive solar designs will have a large potential to reduce space heating demand and thus the overall energy use in housing. In office buildings the energy need for heating, cooling, ventilation and lighting are approximately of the same size and access to day lighting, natural ventilation and passive cooling will be important as well.

Building energy use. State-of-the-art.

The impact of urban density on availability of passive solar radiation and its impact on heating energy in domestic buildings have been investigated theoretically by the LT-method for UK (London) climatic conditions and building construction (Steemers, 2003). For domestic buildings the heat saving comparing detached housing with apartments (increased compactness) is reduced as the solar obstruction angle is increased and for an obstruction angle above about 30^{o} the balance will begin to swing against densification (Steemers, 2003), corresponding to a plot ratio of up to 250%. For non domestic buildings it is shown that the total energy use actually increases (about $20\%/m^2$ for air-conditioned and $100\%/m^2$ for naturally ventilated) with increased building depth from 12m to 24m due to increased energy use for lighting and ventilation and that the energy use also increases with increasing solar obstruction angle (20-45% going from a 0^{o} obstruction angle to a 30^{o}) due to less daylight availability (Steemers and Ratti, 1999). The LT-method has also been used to analyze the energy demand in relation to urban form for larger urban areas, typically 400m x 400m (Ratti and Richens, 1999). The results showed for a density range of plot ratios from 125% to 500% that for a doubling of the density the energy use increases in the order of 25%.

A study on the relation between urban density and solar availability has been conducted by using the computer model 'SustArc' (Capeluto and Shaviv, 2001). Here a 'Solar Volume' is defined as a volume containing all the building heights that allow solar access to each surrounding building, and at the same time are not shaded by the neighboring buildings, during a given period of the year. They show for the location of Israel (32^{o} north latitude) and a street width of 12 m that a requirement of solar access on a south facing facade between hours 10 – 14 will result in a maximum urban density is about 160% with a maximum building height of about 6 stories.

Several authors have investigated the heat island effect of high urban densities and the impact on building energy use. Measured temperatures in the London area was used as inputs to a building simulation program to assess the heating and cooling loads of a typical air conditioned office building positioned in 24 different locations (Koloktroni et al, 2007). It was found that the urban cooling load was up to 25% higher that the rural load over a year, while the annual heating load was reduced up to 22%. Similar results have been found for the city of Athens (Santamouris et al, 2001).

Building energy use. Discussion.

It is evident from the previous studies that urban density has a considerable impact on the building energy use and that a balance exist where energy saving advantages of increased building compactness is outweighed by less availability to passive solar heating and daylight, smaller suitable surface areas for renewable energy integration and increased use of mechanical solutions due to increased noise and air pollution.

Although investigations does not exist for Scandinavian conditions and the exact results cannot be transferred directly the general conclusions are valid. For residential buildings it is beneficial to move from detached houses to more compact building types in a dense urban context. For office buildings a higher building depth than 12 m will lead to increased energy use and compared to a rural setting an urban location will always increase the energy use. Heat island effects in very dense urban development decrease heating energy use and increases cooling energy use but do not change the overall energy use very much. Anyway it still might have a considerable impact as primary energy factors for heating often are much smaller than for cooling.

CONCLUSION

How dense must a sustainable settlement be? Concerning urban mobility the Newman and Kennworthy-survey showed that with only 20-30 dwellers per hectare car use increases exponentially. Taking 40 dwellers as a minimum each occupying 60 m2 will result in a plot ratio of 48% if dwellings cover half of the urban area. 48% resembles dense row house building or open three storey apartment buildings. Concerning building energy use different investigations speak of tipping points (where energy use starts to increase) at plot ratios of 250%, 125% and 160%. The 160% concerning solar access is for Israeli locations - in Northern Europe this figure will of course be smaller. Reduced building depths allowing natural ventilation and daylight also point towards plot ratios in the lower end of the scale. The same goes for the inclusion of urban greenery. A very rough estimate of the density of sustainable settlements points to plot ratios between 50 and 150%. Not Hong Kong nor widespread Houston but plot ratios in the European urban tradition.

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