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The Impact of Supertall Density on City Systems

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WSP

Abstract

This paper discusses several topics associated with the densification caused by supertall buildings and their impact on city systems. The paper covers five key areas where a supertall tower creates a concentration of needs and effects. First, the paper comments on population shifts towards the city and how they affect carbon footprint, utilities infrastructure and transport. The effect of single- and mixed-use towers is discussed in the context of population density. The second section brings the issues of transit, accessibility and master planning into focus. The use and criticality of public transport, cycling and walking is described. Servicing and deliveries using freight consolidation and shared systems is also discussed along with their contribution to the culture of sustainable travel.

In the third section the paper reflects on supertall buildings' below-ground utilities and drainage provision, particularly the challenges faced in established city infrastructures. The utilities issues associated with supertall concentration (in land-use terms) compared to equivalent low-rise distribution is also commented on in the context of surface water runoff. In the fourth section, the topic of supertall sustainability is discussed and how city systems need to respond to create desirable and affordable space for occupiers. The changing need for vertical communities, 'stacked neighbourhoods' and the notion of a micro-city is described. Finally, the paper considers the energy consumption and resilience of supertall buildings in the context of basic geometry, façade design, climate and mixed-use benefits as they impact city systems.

Keywords: Price, Supertall, Tower, Densification, Infrastructure, Urban, Sustainability, Low carbon, TOD, Micro-city

1. Introduction

Before considering the impact of the supertall it is worth discussing city density in a little detail to appreciate the context. More than half the global population now lives and works in an urban rather than a rural setting. This has only occurred recently and it is about underdeveloped – but expanding – regions needing to concentrate and upskill a modern workforce. But it is not just this type of growth. The population of Australia for example is expected to double by 2040 and all the expansion will be focused in three cities.

Over the past 20 years or so, this demand has led to a huge increase in the number of tall buildings which are primarily of a residential nature. Some of these buildings provide offices and a few are truly mixed-use incorporating hotels, restaurants, retail, viewing and transport interchanges. Some also manage to contain social infrastructure and other more diverse uses. It is not difficult to find schools, universities, courts, libraries, police, government, performance and other cultural facilities housed in such buildings.

This rich combination of 'programme' leads to increasing density and extended periods during which the buildings are in use. This, in turn, has major implications for some quite unglamorous requirements, such as servicing, waste disposal, utilities infrastructure, security, acoustic breakout, air quality, neighbourhood relationships and way finding.

In order to address the unglamorous it is essential that the needs of the whole building, the activities within it and the plans for surrounding sites are well understood, with a reliable city plan creating the framework for overall density. Leading cities around the world draw up plans and strategies which respond to these needs. Issued in 2016, the updated plan for London includes sections on high-rise development.

Turning to tall buildings and supertall in particular, it is easy to see how several thousand people need to be 'maintained' while they occupy the space available. On the basis that a 300 m supertall building (e.g. The Shard, London) of reasonable slenderness could provide about 100,000 m^2 of floor space, this will accommodate around 10,000 people assuming a commercial use. Therefore a megatall building of 600 m could contain 20,000 people. This is the equivalent of a small town in which lifts, stairs and escalators form vertical 'streets'.

These people must all travel safely to and from the building, preferably using public transport. In 2007, WSP undertook research relating to energy use and carbon emissions. The study compared a large high-rise office with an 'out of town' business park campus or equivalent area.

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The 'out of town' office generated four times the carbon due to the need for the 3,000 plus population to drive to the location (close to Edinburgh). This easily outweighed the extra energy required in a tall building for lifts, escalators, pumps and other height-related equipment. The study discounted the public transport energy cost but this was considered to be minimal on a per-person basis.

Inside the building people must eat, drink and have the associated waste systems; they must be able to reach different spaces within the building efficiently and enjoy an internal environment that is both comfortable and suitable for the functions taking place.

The space around the building also needs to be attractive and accommodate the transport systems and utilities needed to facilitate the people who work, rest and play there. But how can this density be sustainably addressed through transit, utilities and energy infrastructure? And what of the catering for day-to-day business needs such as the servicing and deliveries necessary for a supertall tower?

2. Transit and Masterplan Implications

Achieving a direct and positive relationship between increased building height and increased sustainable travel is only possible through balanced land-use planning and the continued promotion of Transit Oriented Development (TOD) in urban areas. This should be complemented by the introduction and enforcement of planning policies that promote a culture of sustainable travel and which impact on the way buildings are designed to function and operate.

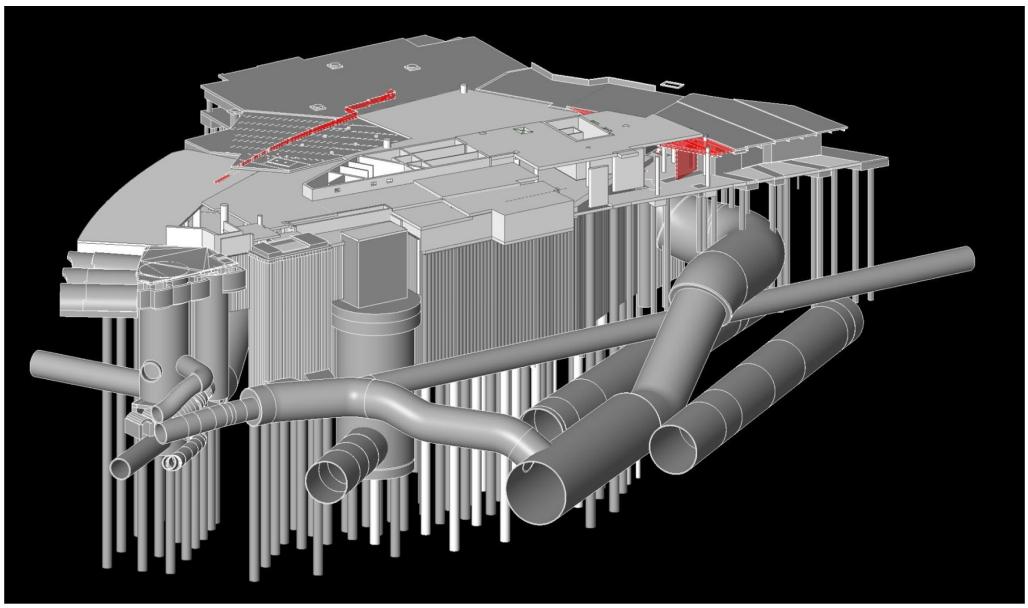
In creating a vertical 'town' accommodating mixed uses, supertall buildings may, to some extent, reduce the need for the horizontal transportation of people and goods. But how many people would actually want to live and work in the same building? It is likely that the vast majority of people living or working in such buildings will still need to travel to and from them each day and in so doing, rely on conventional transport networks.

Constructing ever-higher buildings to accommodate more and more people increases population density (densification) and puts additional pressure on urban transport systems. It also pressurises cycling/walking networks as the increased congestion on the roads combined with the high cost of constructing large basement car parks beneath supertall buildings makes private car use impractical. The budding electric vehicle revolution together with the arrival of autonomous vehicles will transform the way we travel by car and remove the need for much of the existing urban parking provision that is currently needed. However, urban road networks will continue to have a finite capacity and therefore non-car modes will continue to dominate urban transport. The continued improvement and increased capacity of urban public transport services and walking/cycling facilities is therefore necessary to support the successful increase in urban population density.

Investing in infrastructure to promote non-car modes in urban areas is therefore essential in supporting the transport demands generated by high-rise development. In London, Transport for London (TfL), which controls the development of much of the transport infrastructure and services across the majority of the city, has invested heavily in public transport, cycling and pedestrian networks in recent years. This has included the introduction of new, air-conditioned trains with increased capacity and new signalling systems to enhance service frequency on a number of underground lines. In addition, there are new cycle 'superhighways' radiating out from the city centre and improved pedestrian crossing facilities with countdown information to create a safer walking environment. These, combined with a policy of reducing highway capacity and parking provision in new developments across the city (including on the outskirts of the city), is allowing for ever-denser development to come forward while still ensuring the transport network can function at peak times.

Reducing harmful carbon emissions caused by travel can be achieved in three basic ways:

- Reducing the need to travel (e.g. working from home, video conferencing etc);
- Reducing the distance of travel (e.g. through sensible land-use planning and ensuring employment centres/entertainment destinations/civic facilities etc. are as accessible as possible), and
- Switching the mode of travel to more sustainable op-



tions (e.g. public transport, walking and cycling instead of private car use).

Supertall buildings can contribute to all three of the above if designed carefully and when combined with appropriate planning policy. Currently under construction in the City of London, 22 Bishopsgate is a 62-storey landmark tower that has been designed as a vertical community; it will offer tenants a huge variety of services that will reduce their need to travel. For example, the building will offer health and wellbeing facilities (including a gym), restaurants/bars, a communal food hall, an innovation hub for start-up businesses, Wi-Fi throughout and the largest bike-parking facility in Central London. This mix of amenities, combined with limited on-site car parking, a comprehensive suite of sustainable transport initiatives and the highly accessible location of the building in the very centre of the city and close to 10 stations, means that people based in the building will have less need to travel outside the building, less distance to travel to reach the building, and will be able (and encouraged) to use non-car modes when travelling to and from the building. At 278 m tall, 22 Bishopsgate is just shy of 'supertall' status. However, the design approach taken here is becoming increasingly common in high-rise buildings as people demand more from the buildings they work in.

An increase in population density brought about by high-rise development will also require goods deliveries to be managed more efficiently through the promotion of more sustainable transport practices. This is already happening in London through implementation of the London Freight Plan and the Freight Operator Recognition Scheme (FORS), which encourages freight operators to take up green fleet management and other measures to improve the sustainability of London's freight distribution. Delivery and Servicing Plans (DSPs) are used to increase a building's operational efficiency by reducing premises' delivery and servicing impacts, specifically with regards to reducing CO_2 emissions, congestion and the risk of collisions involving servicing vehicles. DSPs aim to reduce delivery trips (particularly during peak periods for the transport



network) and increase the availability and use of safe and legal loading facilities. They utilise a range of approaches including consolidation and collaborative delivery arrangements to help reduce the impact of commercial goods and servicing vehicle activity generated by developments. This will become increasingly important given the higher volumes of goods arriving at, and waste being taken away from, ever bigger buildings.

In summary, taller buildings can be a catalyst for promoting a culture of more sustainable travel in cities simply by making car journeys unfeasible due to the limitations of urban highway and parking infrastructure where population density is high. The buildings can also be designed in such a way as to promote non-car modes, such as through the provision of adequate on-site cycle parking and good quality showers and changing facilities. Such facilities need to be combined with enhanced infrastructure for non-car modes, including public transport, cycling and walking facilities in the surrounding areas to ensure that a high level of accessibility is achieved. The responsibility for this therefore lies with both the developers, the building designers and the local planning authorities.

3. Utilities Infrastructure

A supertall tower will house an increased population at a single point, compared to an equivalent amount of lower density housing or office buildings which will tend to spread the population over a wider geographical area. A key challenge is the availability of sufficient utilities and drainage infrastructure in the immediate vicinity of the site, together with city or area-wide implications for the transmission of these utilities to and from site relative to the point of generation and discharge. Often in such situations the capacity of the infrastructure network will need to be upgraded to meet future demands and resilience.

When considered in isolation, the need for increased power generation facilities, communications networks and increased wastewater treatment facilities for supertall developments do not have an overall increased quantum of demand compared to a similar population spread across lower density sites. However it is the concentration of higher density developments in a smaller area that needs to be considered differently. The approach to new and existing development districts will vary to accommodate and coordinate the complex of often congested utilities transmission ducts, sewer networks and access chambers for service entry points and drainage infrastructure.

For cities steeped in history such as London, with multiple generations of utilities infrastructure within the existing street network, the installation of new utilities infrastructure can be exceptionally challenging. Circumstances often require the diversion of existing live infrastructure to create space for and facilitate the construction of new utilities. The design of this new infrastructure, which is usually in the immediate vicinity of the site and contained within high quality public realm spaces, needs to be discrete and easily accessible and maintainable, without affecting access to the building or its amenities. Where possible, provision of multi-utilities conduits or tunnels should be considered, especially when within an area where tall or supertall developments are clustered together within a business district and there is the opportunity for tunnels to be constructed as headings (short tunnels) with discrete surface access chambers.

Similarly, new or enhanced foul- and surface-water sewer infrastructure, which is often quite deep, may need to be constructed using tunnelling or heading technologies to minimise disruption at street level. The availability of adequately-sized sewers for surface water and significantly increased foul flows is a key challenge with supertall development. Foul water discharge generated by the population (i.e. any water that has the potential to be contained such as WC flushes, water used for cleaning etc) that is concentrated at a single point within the sewer system, is likely to require an increase in the size of the local sewer systems. However, this is potentially offset by the removal of the need for a much larger sewerage system to serve the equivalent population over a wider geographic area. This clearly has a beneficial effect on the reduction in the use of new construction materials, carbon emissions for construction and any impact on existing green space.

A similar impact can be observed through the effects on surface water runoff. As the overall plan area is smaller



than the equivalent population contained in traditional housing or lower density office developments, it follows that there is an equivalent reduction in impermeable area that otherwise might contribute to greater surface water runoff and ultimately lead to a higher risk of flooding.

It should be noted that with very high buildings the vertical side of the building may have to be taken into consideration as a contributing catchment area, which can offset some of the savings gained. However, as planning policy tends to restrict all surface water runoff to or towards equivalent rates to address climate change, the actual impact on the receiving sewer or watercourse system will be minimal, regardless of the size of the building and development. This reduction in flow rate is achieved through the use of Sustainable Drainage Systems (SDS) which provide an opportunity to increase the biodiversity of the building's immediate environment, coupling an engineering solution with a benefit to the wider environment.

4. Sustainability

Vertical urbanism is the key to sustainable living within the constraints of finite land resources. Supertall buildings might well play a part in addressing the needs of the ever increasing urban population.

Technology and innovation continues to help us solve issues such as efficient use of materials, energy and water. While building supertall creates technical challenges for construction and operation, the continuous development of super-strength and energy generating materials, innovative ways of constructing LEGO-style and 3D printing and generally a much better collaboration between the design disciplines aided by BIM seems to break down the barriers for super-efficient vertical cities. As infrastructure now extends to urban greening and even food production in the form of 'farmscrapers' the vision of self-sufficient supertall buildings slowly but surely becomes reality.

However the real challenge of the future of supertall buildings is to create inspiring, comfortable, affordable and inclusive 'liveable' spaces in a primarily vertical arrangement.

Current socio-economic trends suggest that an increase of loneliness and a lack of physical activity are a real threat to our mental and physical wellbeing. To function sustainably, supertall buildings must address our most basic needs: human interaction, spaces for everyone that inspire and get us moving but at the same time provide respite from the city routine.

Key challenges for tall buildings are often the loss of community spirit due to physical separation. It is the separation through floor plates and a focus on rapid vertical transport in and out of the building that often hinders the social interaction of building occupants and users. Zooming down an elevator is just not the same as strolling along a neighborhood street. Therefore one of the key aims in addition to low environmental-impact construction and operation is to work towards creating a 'micro city' – a vertical community that provides a high concentration of varying activities and enables an urban identity.

Current ideas about sustainable high rise are based on a form and layout that encourage people to make use of spaces within the building and that provide access for leisure and mingling. With the help from smart building technology and wearables, walking across floor plates and in-between floor plates is prioritised and encouraged, creating a sense of 'neighbourhood' that also keeps people fit and connected. At the same time, elaborate and well-placed landscaped spaces allow resting and relaxation within the building envelope.

But even though the ideal vertical city provides everything its inhabitants need under one common roof, its success relies on people moving in and out of it. Connectivity to public transport hubs and good wayfinding for pedestrians and cyclists ensures that tall buildings do not unnecessarily contribute to local traffic congestion and increased transport-related energy use and emissions.

5. Energy Use, Resilience and Building Physics

Supertall construction presents a number of unique environmental and energy design challenges not normally found on lower-rise developments. Increasing land values and decreasing amounts of new developable land in our cities, combined with natural population densification and ever more advanced engineering capabilities means that supertall buildings will only ever become more prevalent; as designers we must find ways to maximise the advantages that this can bring. However with challenge, comes opportunity.

Perhaps the key differentiator with supertall is simply one of geometry. First, supertall buildings have a much smaller ratio of roof-to-floor area than lower rise buildings. From an engineering point of view this introduces a natural limiting factor – less space is available for building services plant (usually heat rejection) and critically from an energy standpoint, renewable energy technologies such as PV.

To attain the highest levels of energy performance – for example net zero energy – on-site generation is required.



Buildings which have achieved this standard to date, particularly in urban or semi-urban environments normally rely on PV to offset residual emissions associated with lights, small power or ancillary building equipment. This can be most easily achieved where large amounts of roof area are available relative to floor area, as this maximises the amount of PV which can be installed. In supertall buildings, this on-site 'offset' is not available, so other solutions must be sought to achieve the same effect, with varying degrees of success. In London for example (although by no means supertall), the Strata tower was designed with three 19 kW wind turbines integrated into the roof structure; while Heron Plaza uses PV panels integrated into the glass façade of the lift shafts on the southern façade.

Similarly, supertall buildings can be often more slender than lower rise structures. This makes the performance of the façade much more important in terms of both the environmental and energy performance of the building. The impact of this is naturally dependent on internal use and climate – in a supertall office building in London for example, the performance of the façade has much less of an impact on overall energy use than in a residential tower in Stockholm or Dubai. Close attention must be paid to the design detail though. A supertall building almost always necessitates a curtain wall solution which is rarely able to perform as well as a traditional built-up wall and infill glazing solution.

Furthermore, the taller a building gets the more resilient its systems must be to overcome the challenges of height. A taller building creates higher pressures in pipework necessitating the use of more robust pipes, larger pumps and possibly intermediate plant rooms. While there is nothing which cannot be overcome through design, greater economic reliance is placed on the net area or cost plan to include one or both of these solutions.

As previously stated, with challenge comes opportunity. So, from an energy standpoint, where is the opportunity with supertall?

First, it is worth considering the frame of reference when measuring a building's performance. Typically we would measure a building's energy use or carbon emissions in absolute (KWh or Kg CO_2) terms relatively, based on floor area (KWh/m^2 or Kg CO_2/m^2). Using those metrics, a supertall building may or may not perform as well as a low-rise building but if we equate the same to developable land area, our supertall solution will perform much better. Similarly we often find that supertall buildings are more densely populated than low-rise schemes, therefore a 'per person' metric (KWh/person or Kg CO_2/m^2) may yield similar results.



Nevertheless, what about other opportunities? Would a supertall office building ever perform better than a lower-rise office building? Perhaps not. But many of the newest supertall buildings around the world are not single-use buildings. The Shard combines office, retail, residential and hotel space, as does the Burj Khalifa and Jeddah Tower. This mix of uses in a single building and within a relatively compact area creates ample opportunity for load and energy sharing between uses. Heat rejection from office spaces can, for example, be used to generate hot water for the office components. With good design to maximise the potential for this, the overall energy footprint for a supertall building can be substantially reduced.