ISEE Reflections

A sustainability point of view on horizontal and vertical urban growth

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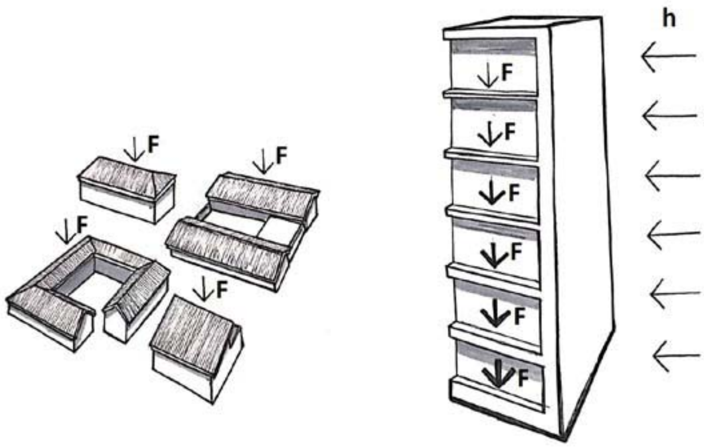
In many regions of the world the urbanisation process is accelerating dramatically. This puts pressure on urban planners but also politics to develop strategies for sustainable city growth. With the rapidly increasing demand for living space in urban areas, cities typically grow vertically. This is largely driven by real estate markets and sometimes also by the desire for status symbols.

Certainly, vertical urban growth makes sense, when horizontal growth destroys important flora and fauna (e.g. in rain forest regions), but in many cases vertical growth is result of real-estate business and expansion limitation due to state or country borders. However, economics and borders are made by humans. They follow human-made rules. Gravity does not. Therefore, from a point of view of sustainable materials and resource use, the trending vertical growth of cities may come under scrutiny.

The following aspects should be considered, when a decision is taken between a new quarter with limited number of storeys or a new skyscraper.

Material demand and technical specifications

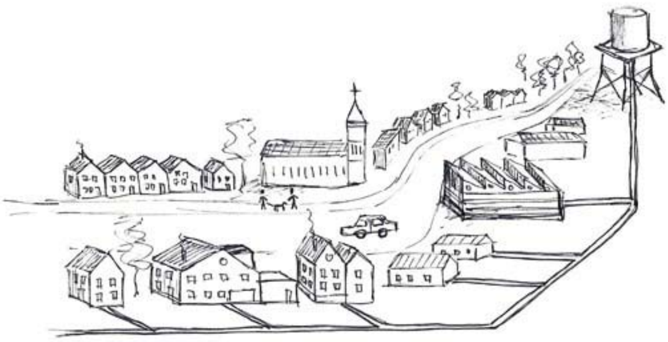


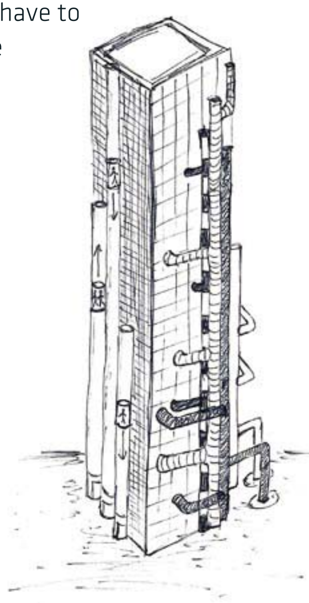
The volume that needs to be surrounded by materials for walls and ceilings or roofs is identical, whether single units are build or units are stacked. Nevertheless, in case of a skyscraper the cumulative loads of each unit have to be considered. In addition, horizontal loads like wind add a severe momentum that is negligible in small buildings but very high in large structures. In total, this demands for either larger cross sections, thus more materials consumption, and materials with higher strength specifications (e.g. higher reinforcement degree and more cement). Hence, vertical city growth automatically demands for more resources.

Infrastructure requirement

Both, vertically or horizontally grown cities demand for infrastructure. Only in vertical structures, this is often not so visible. However, also the top storeys of skyscrapers have to be accessible by elevators, they need to be supplied with water and energy and their waste has to be disposed of.

The difference is the energy demand. Horizontal infrastructures largely only have to overcome frictional forces. Vertical structures have to additionally overcome gravity forces, which can even help to save energy in horizontal infrastructures (e.g. in water supply and sewage management).

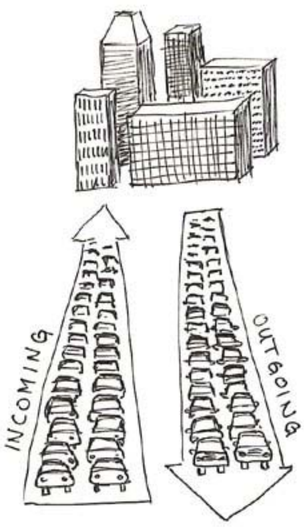




Traffic management

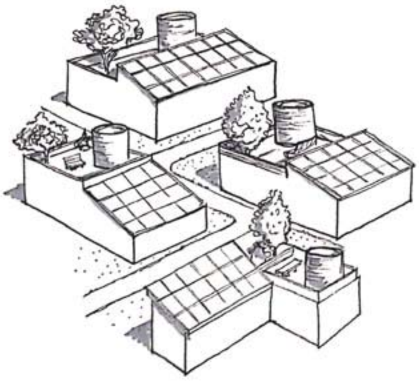
Vertical structures centralise work places. People have to approach and leave their work every morning and evening, respectively. This happens every day and often over long distances, since residential areas and business centres are typically far away. This inevitably causes inefficiencies, since many people waste lots of time stuck in traffic jam, time they could better spend with families. And even a highly efficient public transportation system runs significantly below its capacity outside the peak hours in the morning and the evening. Permanent traffic congestion, that can be observed in cities like Lagos, Douala or Dar es Salaam, causes avoidable hazardous exhausts and carbon emissions, but it also has a social component, as both, daily business and private life have to be synchronised and adjusted permanently with the urban traffic.

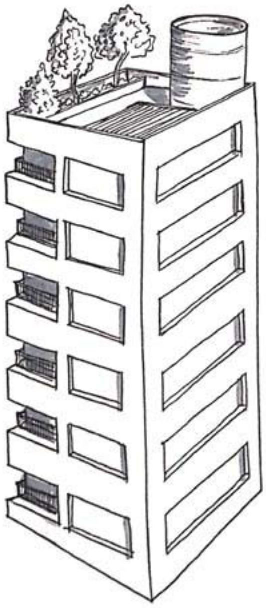
In horizontal structures work places are dispersed. Business and residential areas can be merged, which makes it easier for people to live close to their work place. The traffic can be more diversified, shorter distances are possible, and more people can can opt for means of non-motorised traffic.



Potentials for environmentally friendly technologies

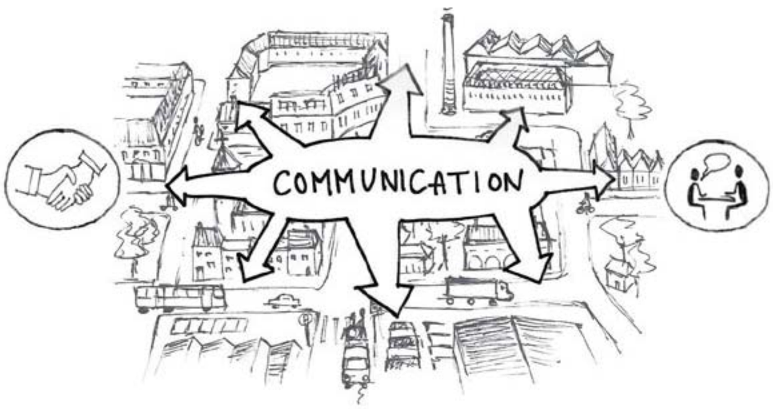
Roofs can be useful spaces for either living or environmentally friendly technologies. Roofs can be covered with solar panels, they can be water supply, or they can bring back some nature into cities with green roofs or urban farming areas. Horizontally grown urban areas provide much more potential and versatility for efficient use of roofs than vertical structures.

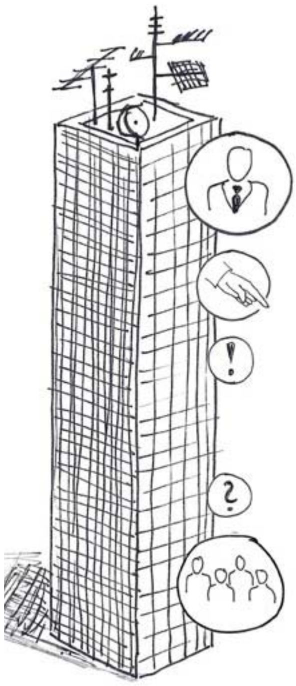


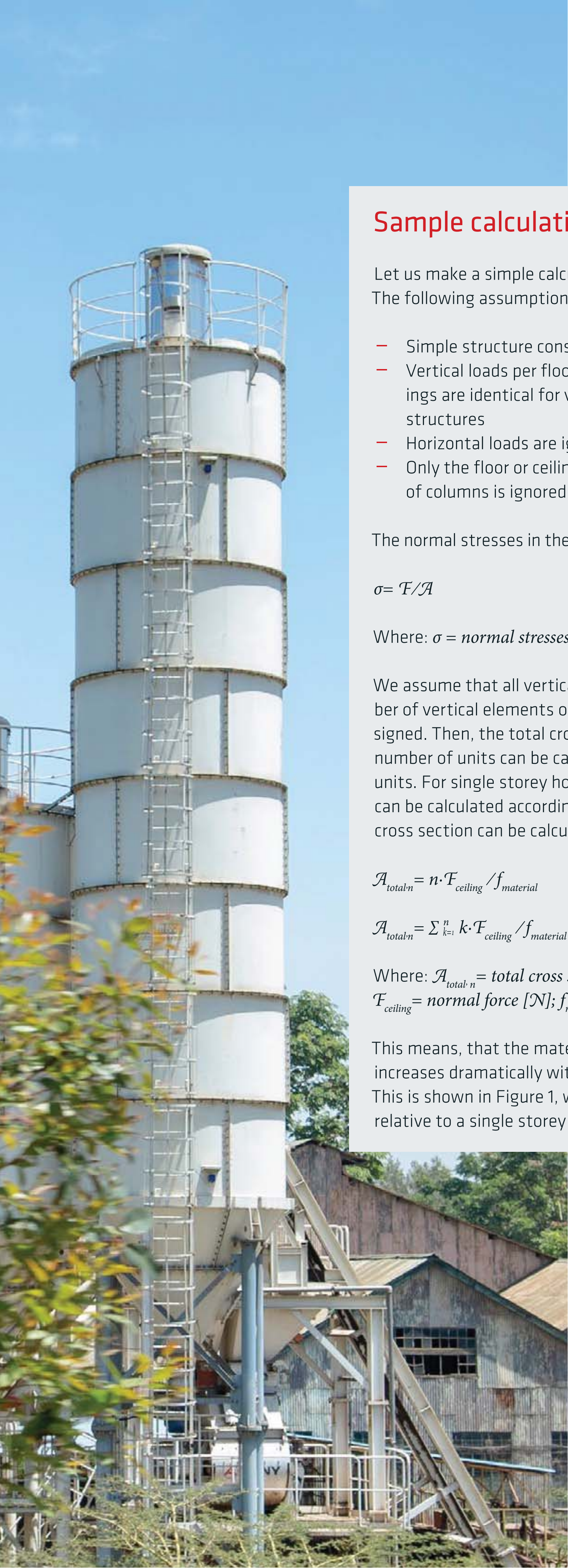


Communication and social cohesion

In vertical structures the major communication direction is also vertical. Not seldomly the storey number correlates with either wealth or power. In horizontal structures the communication options are diverse and at eye level. The multi-lateral communication without symbolic hierarchy and power demonstration can be a spark for local business and public activities that strengthen the social cohesion.







Sample calculation

Let us make a simple calculation on a very simplified system.
The following assumptions have to be made:

- Simple structure consisting of only ceiling or roof slabs and vertical columns
- Vertical loads per floor including traffic loads and structural loads from ceilings are identical for vertically stacked structures and horizontally dispersed structures
- Horizontal loads are ignored
- Only the floor or ceiling structure contributes to vertical loads, the own weight of columns is ignored

The normal stresses in the columns are calculated according to the simple equation 1.

$$\sigma = F/A \tag{1}$$

Where: σ = *normal stresses [MPa]*; F = *normal force [N]*; A = *cross section [mm²]*

We assume that all vertical elements consist of the same material, and the number of vertical elements or the dimensions of the cross sections are not overdesigned. Then, the total cross section for vertical elements depending upon the number of units can be calculated for horizontally dispersed and vertically stacked units. For single storey horizontally dispersed buildings, the sum of cross sections can be calculated according to equation 2. For vertically stacked units, the total cross section can be calculated after equation 3.

$$A_{total \cdot n} = n \cdot F_{ceiling} / f_{material} \tag{2}$$

$$A_{total \cdot n} = \sum_{k=1}^{n} k \cdot F_{ceiling} / f_{material} = (1+2+3+4+\ldots+n) F_{ceiling} / f_{material} \tag{3}$$

Where: $A_{total \cdot n}$ = *total cross section for vertical elements [mm²]*; n = *number of units*; $F_{ceiling}$ = *normal force [N]*; $f_{material}$ = *Material's compressive strength [MPa]*

This means, that the material requirement for the structural vertical elements increases dramatically with every stacked storey compared to single storey units. This is shown in Figure 1, which is independent of the material, as it is expressed relative to a single storey unit.

Since for cement, within certain limits, the strength of concrete also depends on the cement content, the same picture would apply in case the cross sections are kept identical but higher strength concrete is used for the lower storeys. Without the simplifying assumptions the difference would become even more dramatic.

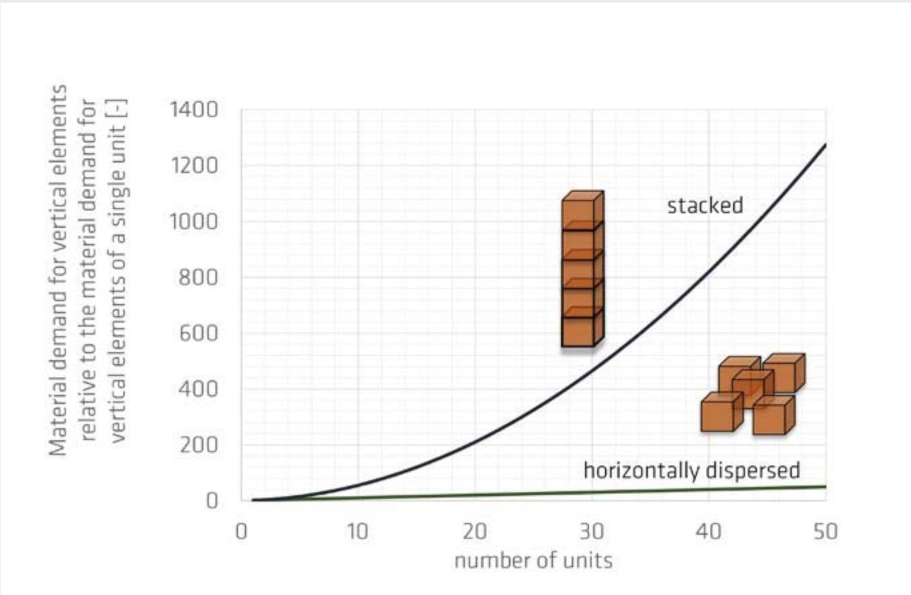


Figure 1: Cement demand for vertical elements of stacked units compared to horizontally dispersed units depending upon the number of units

For a ten storey building, thus, the carbon emissions for vertical elements are 5.5 times as high as for the same number of units horizontally dispersed. For a thirty storey building, it would be already 15.5. times as high. While these number sound dramatic, it has to be considered that the vertical elements often only make out 5% – 10% of the total material volume. However, for a ten storey building this still means 22.5% – 45% and for a thirty storey building 72.5% – 145% higher carbon emissions in comparison to the same number of units, horizontally dispersed.