# 6 Stacking

An important cost generator for a building is the number of floors, or the 'stacking', which is fixed early in the process. The choice of location can itself be determinative for the stacking, but questions of prominence, image and projected character may play an important role for the organization to be accommodated. Stacking is a question to be considered with the first design decisions.

6.1 Quantities and costs.
The chosen stacking affects the surface area utilization and the quantities of structural elements.

6.2 Floor area utilization.
Stacking is a factor in the quantity of circulation area. Model studies provide knowledge about the bandwidth in the gross/useful ratio as a consequence of stacking and size.

6.3 Element quantities.
Besides the surface area of the roof and foundation, the facade surface area also proves to depend strongly on the chosen stacking. Model studies provide knowledge about the extent to which facade surface area depends on the combination of stacking and size.

6.4 Building costs and operating costs.
Differences in quantities and appointment consequent to various stacking decisions cause bandwidths in the building costs and the costs for energy, technical maintenance and cleaning.

## 6.1 Quantities and costs

Stacking

Required space, building form and technical quality level are the cost generators that play a part in cost/quality control in the early phases of the process. The building form is determinative for the quantities of structural elements. An extremely important aspect of building form is the stacking: the choice of the number of floors in which one wishes to realize a building project. Doubling the number of floors for a given schedule of requirements roughly halves the area of roof, ground floor and foundation. However, increasing the number of floors implies a larger area of facade, a larger gross floor area (GFA) and higher costs for lifts. The additional GFA is due to the increased number of staircases and the space occupied by lift shafts. The structural area moreover rises as a consequence of the increased facade length and the quantity of core walls. The cost of the lifts moreover increases because of the greater number of halt positions with their associated facilities, and because there is a higher stress on lift capacity implying larger lifts and/or higher lift speeds.

Location

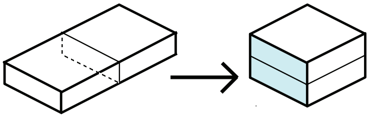
Although the number of floors to be built is decided during the design phase, the choice of location introduces some extremely important conditions for stacking. Local zoning regulations often set a limit on the height, and in some case the height of the building must be adjusted to meet the demands of the adjoining premises. Other factors are the availability of car parking space and the size of the available site, in combination with assumptions as to possible future expansion. The cost of land naturally plays an implicit part in the decision. In extremely high-value locations, people try to use the land as intensively as possible, and this can lead to highly stacked designs. Harmony with the urban surroundings is a design factor that often partly determines the architectural concept. Tall tower blocks act as landmarks, which meet a need in some situations; besides, some building users opt for prominent buildings for promotional reasons.
It can happen, however, that organizational or functional considerations prompt the organization to set requirements for the minimum dimensions per floor, which in turn sets an upper limit for the number of floors.

Useful floor area

To reduce the amount of stair climbing, office buildings usually have toilet groups and cleaners’ cupboards situated on each floor. The number of toilets needed depends on the number of persons present at any given time. A minimum requirement is often specified for one women’s and one men’s toilet per floor. In a highly stacked design this makes it necessary to provide an excessive number of toilets. The same applies to cleaners’ cupboards. The smaller a floor is, the more difficult it is to fit in the required number of rooms. The solution often involves providing more useful floor area than specified in the schedule of requirements.

Minimum option

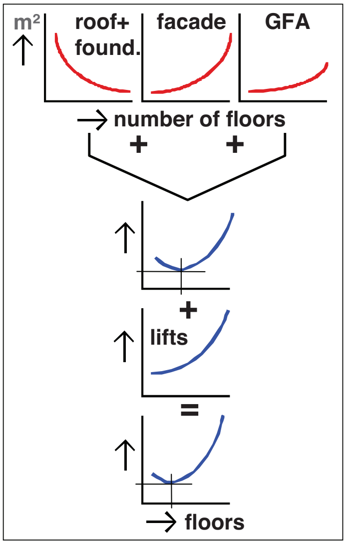
Stacking has simultaneously cost-reducing effects (reduced area of roof, ground floor and foundation) and cost-increasing effects (more GFA and facade surface area, higher lift costs). On balance, there always proves to be one particular stacking option that yields the minimum building costs. This option depends on among other things the comparative unit rates for facade, roof and foundation.



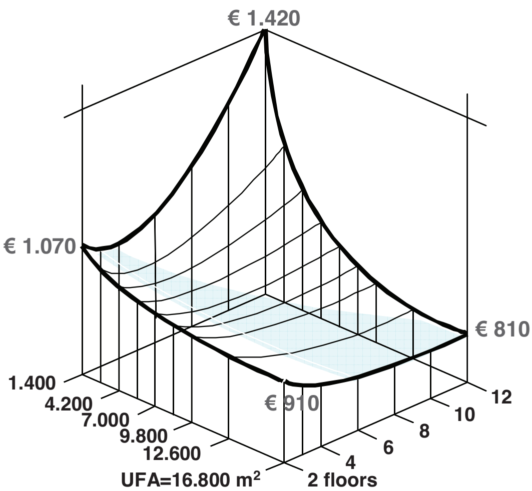
higher stacking means:

-less roof and foundation
-more facades
-more GFA
-expensive lifts

the buildings costs depend on the stacking, and there is one stacking choice that yields a minimum




## the effect of stacking on building costs




The building costs depend on the size and the stacking. A minimum domain exists.

reference date 01.01.1994

## building costs per m² of useful floor area

Literature [2], [12], [16], [24], [51]

# 6.2 Floor area distribution

Model research

The decision on the number of floors to use for realizing a brief has consequences for required space. Higher stacking results in more circulation area, and the amount of structural area also increases. The circulation area increases because more of the total area is occupied by staircases and lifts. The structural area increases because a greater facade length is necessary and the quantities of core walls around staircases, lifts and shafts increases. In a collaborative project of the Government Buildings Agency and TU Delft, a model study was undertaken in 1994 to obtain insight into the magnitude of these effects and their consequences for costs. The study developed building models which differed from one another only in the total size and in the number of floors. The size varied from 1,400 $m^2$ to 16,800 $m^2$ of useful floor area. For each size, stacking factors of 2, 3, 4, 6, 8, 10 and 12 floors were examined. The models were based on a single-corridor structure with facade zones measuring 5.4m in depth and central corridor of 1.8m width. Daylight admission to the rooms takes place through the longitudinal external walls. The same solution was assumed for all models as regards building materials, construction method and air conditioning. The figures show the results of this model study.

Circulation area

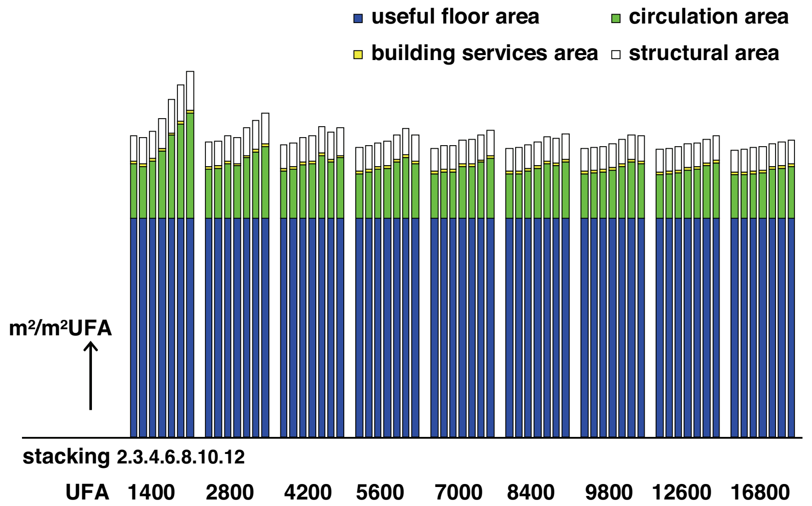
The circulation area increases relatively sharply when the storey size drops below approximately 400 $m^2$ useful floor area. The distance between the staircases in this case becomes less than the permitted maximum of 50m, so that each staircase gives access to less $m^2$ of useful floor area. This also explains the irregularities in the curves of the relation between gross floor area (GFA) and useful floor area (UFA). One combination of size and number of floors results in a lesser separation of staircases/lifts than another, unfavourably affecting the GFA/UFA ratio.

GFA/UFA

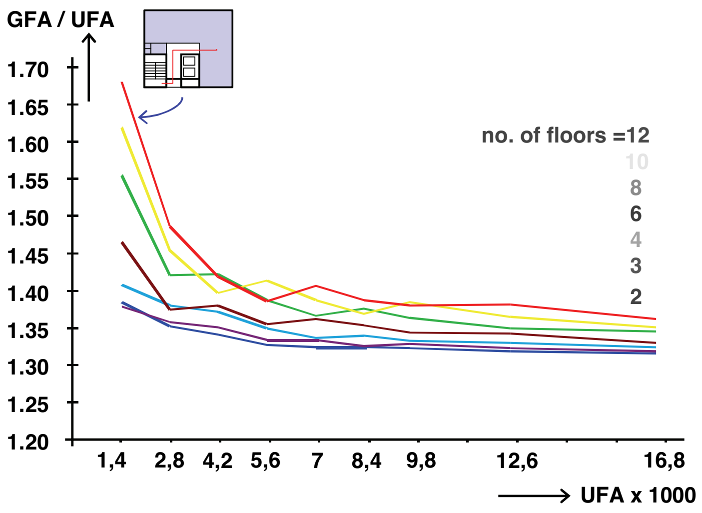
The bandwidth of the GFA/UFA ratio is huge. For the 16,800 $m^2$ UFA programme, its value ranges from 1.32 at 2 floors to 1.37 at 12 floors. For the 1,400 $m^2$ UFA programme, the GFA/UFA ratio is 1.38 for 2 floors and 1.68 for 12 floors. The fire authority generally stipulates that occupants must be able to evacuate the building in two directions. This means there must be at least two staircases on each floor. For very short volumes, such as that of the 1,400 $m^2$ building in 12 floors, the fire authority often grants exemption and allows the use of a single staircase on the condition that the access to this staircase is from outside the building. This situation is assumed in the model study. If the fire authority insists on the use of two staircases, the GFA/UFA ratio increases to up to 2.0.

Indices

Indices are used for comparing variants of different sizes. These indices are often expressed per $m^2$ GFA. However, indices per $m^2$ GFA fail to take surface efficiency into account. Since stacking alternatives often differ considerably in the generation of $m^2$ GFA, it is better to use indices per $m^2$ UFA for analysis purposes.




stacking and required floor area




the gross/useful ratio depends on total UFA and stacking

Literature [2], [12], [16]

## 6.3 Element quantities

**Model study**

The higher the stacking chosen for a specific programme, the smaller the surface area of roof, ground floor and foundation, and the greater the area of facade needed to enclose the building. When the stacking results in more facade area, less internal walling is needed to provide access to the rooms. In the Government Buildings Agency/TU Delft model study of the effect of stacking decisions, the consequences of stacking for structural quantities was considered.

**Roof and foundation**

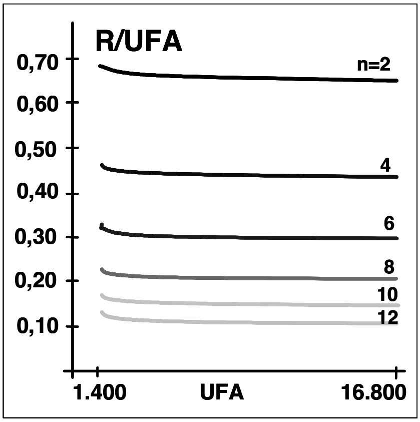
For comparison of the variants, indices per m² useful floor area (UFA) were used. Since small buildings have less favourable GFA/UFA ratios than large buildings, the R/UFA index varies. Small buildings have a relatively large area of roof at a given stacking compared to large buildings at the same stacking.

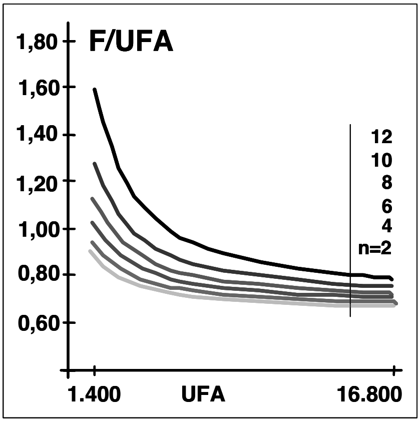
**Facade and internal walls**

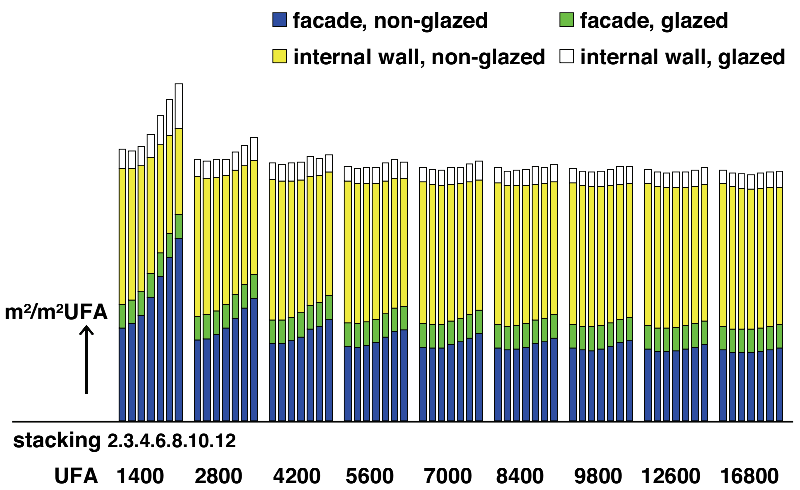
Higher stacking produces a lager area of end wall for the single-corridor structure assumed in the model study. The quantity of longitudinal external wall also increases owing to the greater number of spaces adjoining the outer wall for staircases and halts for the lifts. In the building models, it is assumed that office spaces have windows in the longitudinal external walls only. The quantity of facade glazing per m² UFA is hence the same for all models. The diagram makes it clear that for higher stacking, the increased quantity of facade takes over some of the function of the internal walls, making less internal walling necessary.

**Balancing**

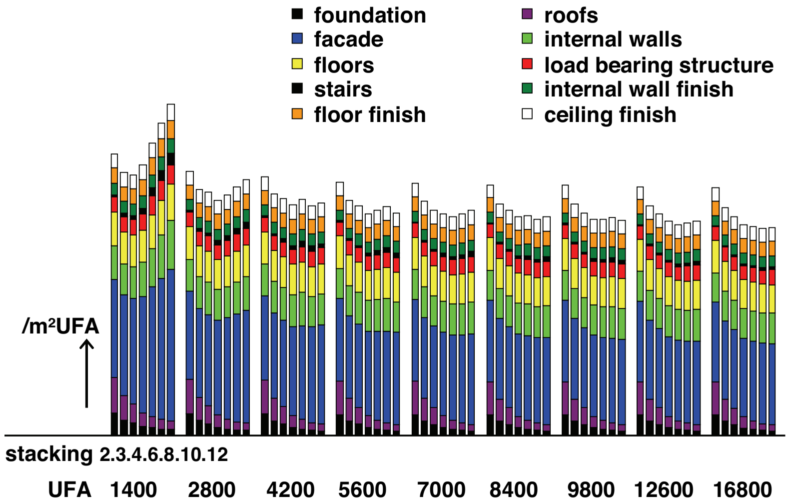
The distribution of costs of structural work reveals the net effect of differences in the quantities of the various elements, which moreover have different unit rates. The combination of roof, foundation and facade sets the trend. In the models up to 4,200 m² UFA, there is a minimum option, an inflection point. For larger buildings, the inflection point is located at a higher stacking. The place of the inflection is determined by the relation of unit rates. A high unit rate for the facades will tend to shift the inflection point towards a lower stacking.






**stacking and the quantities of facade and internal wall**




**stacking and the costs of structural work**

Literature [2], [12], [16], [51]

## 6.4 Building costs and operating costs

**Model study**

The chosen stacking affects the areas of surface area of roof, foundation, facade and internal wall, the number of staircases and the number and capacity of lifts. The gross floor area moreover depends strongly on the chosen stacking, as do the facilities for light, ventilation and heating.
The 1994 Government Buildings Agency/TU Delft model study of the influence of stacking, the consequences of stacking for building costs and operating costs were investigated. The reference data for costs was 1992.

**Building costs**

Higher stacking causes a reduction in the surface area of foundation and roof, and, to a lesser extent, of internal walls. Other elements experience an increase, with the facade having the greatest influence. The combination of decreasing and increasing costs results in a stacking option with minimum cost. This trend is predominantly set by the influence of roof area, foundation and facade. The costs of mechanical and electrical systems follow the trend of gross floor area.
The cost of special plant, including lifts and facade cleaning systems, shows a strong increase with rising stacking. The bandwidth is large. For the programme of 16,800 $m^2$ UFA in 2 floors, these costs are €6 per $m^2$ UFA; for the programme of 1,400 $m^2$ UFA in 12 floors, the corresponding costs are €215 per $m^2$ UFA.

**Operating costs**

The quantities of roof and facade are a factor to be considered when considering stacking. The additional facade area at a higher stacking value consists of end walls, which in the study are treated as windowless walls. Relatively little maintenance is required for an external wall of this kind. The roof does need maintenance, however. The roof and facades form part of the envelope of the building, and hence play a part in transmission losses, which ultimately affect the energy consumption. Central heating systems naturally have a relation to the envelope, and the costs of water systems can increase for higher stacking factors owing to the number of toilets required. In the study, the costs of technical maintenance, cleaning and energy consumption were calculated for the different building models.

**Technical maintenance**

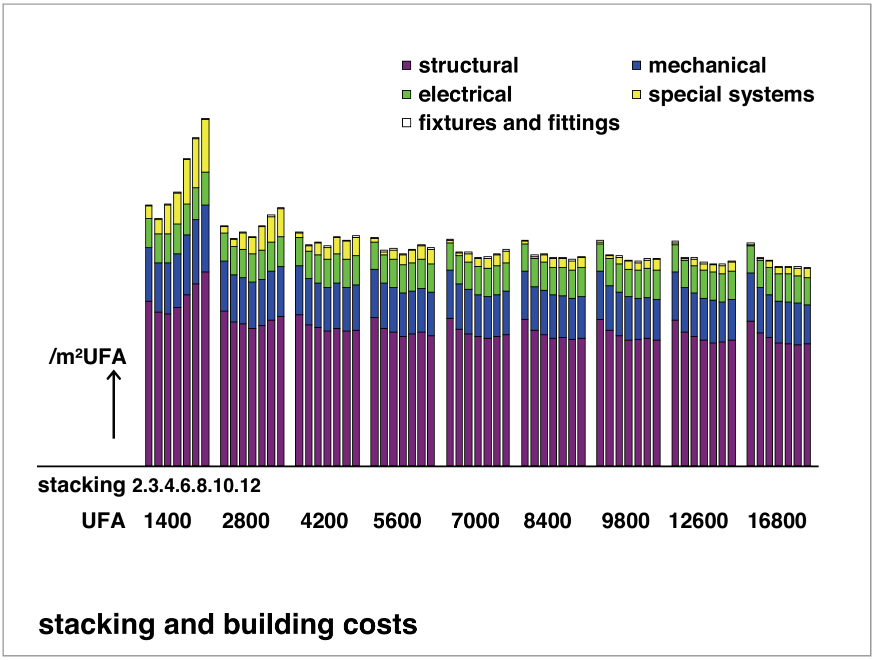
The bandwidth in costs for technical maintenance ranges from €23 per $m^2$ UFA per year for the largest programme in 2 floors, to €45 $m^2$ per $m^2$ UFA per year for the smallest programme in 12 floors. The largest variation turns out to be caused by maintenance of the lift system.

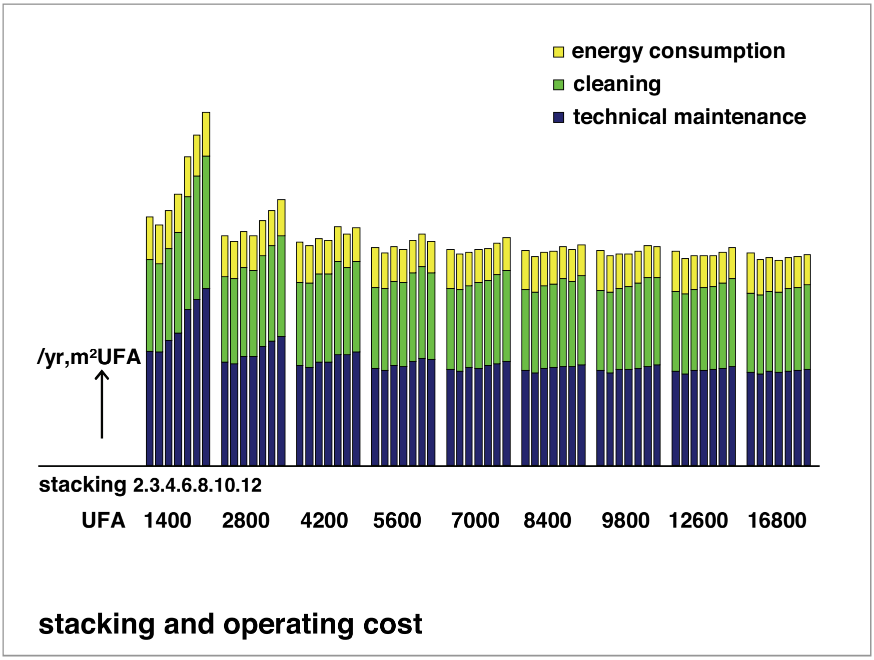
**Cleaning**

The bandwidth in cleaning costs ranges from €20 per $m^2$ UFA per year for the largest programme in 2 floors, to €33 $m^2$ per $m^2$ UFA per year for the smallest programme in 12 floors. The largest variation is in the costs of cleaning the stairs.

**Energy costs**

The differences in energy costs are predominantly due to the HVAC systems. The influence of the envelope is critical, with the result that a stacking of less than four floors performs poorly. Higher stacking factors for small programmes similarly perform poorly, on account of the large facade area. The bandwidth ranges from €5 per $m^2$ UFA per year for the largest programme in 2 floors to €8 per $m^2$ UFA per year for the smallest programme in 12 floors.




Literature [2], [16]