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The planning and construction of tall buildings is often controversial, polarizing the public debate on architecture and urban life. In many cases the emotional discourse focuses on aesthetics and view corridors, more than city planning or economics. This paper introduces a framework that analyzes the visual impact a developing skyline has on a city and its surrounding region, using Rotterdam as a case study. By studying the height and completion year, identifying the tall building cluster as it is perceived visually and conducting a GISc-based visibility analysis, the framework provides context to tall building designs. The results make the assessment of individual projects more scientific and balanced, removing many of the emotional elements that often enter into the discussions.

Introduction

Research on the visual impact of tall buildings has the potential to make or break a tall building proposal. In the UK, debates over the appropriateness of projects in London and Liverpool are primarily focused on view corridors, with UNESCO threatening to remove world heritage designations from historic complexes if the new developments damage their aesthetic impact (see Debating Tall, page 5).

Concerns about the appropriateness of tall buildings in the urban environment, the quality of the architecture and the impact on local real estate markets is increasingly reflected in municipal and metropolitan policymaking. Prominent cities with a longstanding tradition of urban management, building regulations and zoning plans often feel the need for additional instruments to control the development of what is described by McNeill as "an extremely complex spatial phenomenon" (McNeill, 2005). Scientific

Figure 1. Rotterdam as a prominent west European tall building city

literature, however, often neglects the substantial impact skyscrapers and their visual footprint can have on urban life. "The significance of these buildings – in terms of height, levels of human occupancy, aesthetic impact and popular representation and use – is in need of careful geographical interpretation." (McNeill 2005)

In 2007 the Netherlands Institute for Spatial Research (Lörzing et al. 2007) published an investigation on the visibility of the proposed Belle van Zuylen tower. At 262 meters the Belle van Zuylen tower would become Holland's tallest residential building and the centerpiece of Leidsche Rijn, the new city district, west of Utrecht. But the Netherlands Institute for Spatial Research analysis showed that the Belle van Zuylen could be seen from most of the "Green Heart," the semi-rural region enclosed by the cities of Rotterdam, Amsterdam, The Hague and Utrecht. The report was the last blow for the proposed development – construction was cancelled soon after the release of the report (Lörzing 2011).

The Belle van Zuylen case is a fine example of using research for tactical purposes through the selective presentation of findings. The study did not present the Belle van Zuylen in its true context. The joint visual impact of all the tall buildings in the region on the Green Heart was not considered, nor how much that impact would change as a result of the construction of the Belle van Zuylen. If the study had included these elements, it may not have caused such stir. In fact, a nearby television tower, the 367-meter Gerbrandytoren tower, built 42 years earlier, dominates the visual impact of the area.

A framework that helps to picture the context of a proposed tall building can potentially neutralize public and political debates that so often lead to polarization. This framework is based on three key elements:

Rotterdam's Tall Building Development

Rotterdam is one of the prominent European tall building cities with a mature tall building policy in place (see Figure 1). Several databases, including the CTBUH's ***The Skyscraper Center***, make it clear that only four western European cities possess this type of mature skyline: London, Paris, Frankfurt, and Rotterdam.

The leading position of Rotterdam is furthermore underscored by DEGW's report on ***London's Skyline, Views, and High Buildings*** commissioned by the Greater London Authority (DEGW 2002). The London policy document uses the same four European cities to compare established European practices of tall buildings policymaking: London, Paris, Frankfurt, and Rotterdam.

The tall building policy document that emerged in the Netherlands is called *hoogbouwbeleid* or *hoogbouwvisie*. The Dutch policies resemble a number of policy documents recently produced in the United Kingdom and Germany.

Height regulation is a key component of all these tall building policies. Height also translates into visibility.

A modern history

Over the years, the city of Rotterdam has carefully cultivated an image as a "city of architecture." But "historic" architecture is not Rotterdam's strong point. Few buildings were left standing after the bombing and fire of May 1940. The few buildings that survived were relatively modern buildings from the 1920s and 1930s. The city had to rebuild its center from scratch. Planners seized this opportunity to experiment with architecture and urbanism, which is why the Rotterdam city center now contains numerous monuments and icons from the modern and modernist period, sometimes referred to as "reconstruction architecture."

Discussions about the appropriateness of tall buildings surfaced from time to time, but never reached the emotional levels experienced in cities with a historic center. Tall buildings are now generally accepted and most are concentrated in the city center. While Rotterdam as a whole uses modern and modernist architecture to promote itself, tall buildings are an essential ingredient in the profile of the city: the skyline, including the famous Erasmus Bridge, has become the city's iconic image (van Ulzen 2007).

Rotterdam's semi-official tall building history portrays a 100-year prelude from the late 19th century, with the completion of the 42-meter Witte Huis, built in 1898, to the so-called "first wave" of high buildings in the mid-1980s. Prominent city planners suggest that the city at the turn of the century was on the verge of a "second wave" of tall buildings, which would feature supertall buildings (Maandag 2001). However, this tale cannot be underpinned with facts. Neither the height nor the location of the high buildings dating from this early period relate to the municipal policy on high-rises. It was only in the 1970s that the current tall building area in the middle of the city center began to emerge.

Essential data on tall buildings can be easily presented by means of a scatter plot. In the case of Rotterdam, the building height and the year of completion were plotted, including the primary use of such buildings. The beauty of Rotterdam's scatter plot lies in the clear patterns that emerge. In her book ***Form Follows Finance,*** Carol Willis explains that the end of a tall building wave is typically marked by the construction of the "tallest building so far." If we would consider these "tallest buildings so far" as anomalies and disregard them, the development of the Rotterdam tall building cluster is characterized by a remarkable continuity. However, if Carol Willis' insights are applicable to Rotterdam, then the year in which the tallest building so far was completed could be used as the breaking points between tall building waves. Three such buildings stand out in Rotterdam: the Faculty of Medicine of the Erasmus University, also known as Hoboken (1969, 112 meters), the Delftse Poort (1991, 93 and 151 meters) and the Maastoren (2009, 165 meters). If the tall building history of Rotterdam is indeed characterized by waves, then these buildings are indicative of three such waves, as represented in the scatter plot (see Figure 2). The end of the wave is determined by the latest and tallest building in a development cycle.

A first wave of tall building construction began in Rotterdam in the early 1970s and a second wave followed in the late 1980s and early 1990s. This second wave is not only defined by architectural height. The

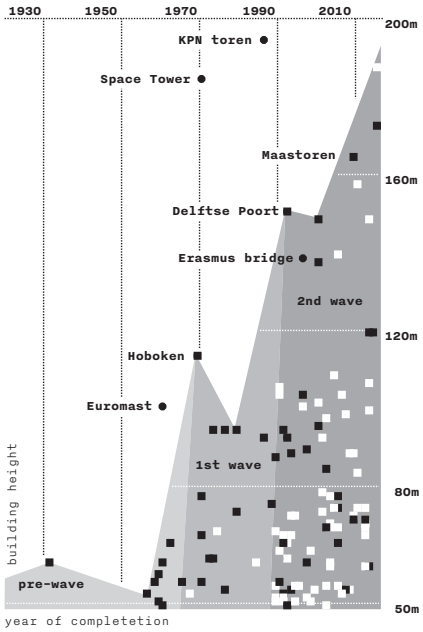

Figure 2. Scatter plots of the architectural height and the year of completion of Rotterdam's tall buildings, without and with so-called tall building waves

Figure 3. Rotterdam, Weena Boulevard. The architecture dominated by the use of mirrored glass façade. The Delftse Poort (1991) is on the left

periods before and after 1989–1992 display many qualitative differences relating to tall building policy, architectural design, internationalization and the functional use of tall buildings.

In 1993, the Rotterdam Municipal Council launched its first tall buildings policy (Hoogbouwbeleid) in a structured attempt to steer the development of tall buildings in the city (Dienst Stedenbouw + Volkshuisvesting 2000). The architectural quality of tall buildings from the era between 1969 and 1991 was dominated by the use of mirrored glass façades (see Figure 3). Some examples of brutalism were built as well during this time. The Delftse Poort (1992, 93 and 151 meters) was the last design with mirrored glass façades. These styles disappeared, and the building designs became more diverse. The most prominent example of brutalism, the PTT Telecom building, a 51-meter tall tower built in 1970, was demolished in 2007, removing it from the skyline altogether.

In a parallel development, foreign architects and internationally-operating Dutch architects became more involved in the design of tall buildings in Rotterdam. Until the mid-1990s, tall buildings were predominantly designed by local architects, with the exception of SOM and its three identical 95-meter tall Europoint towers built between 1975 and 1978. Since then, international architects have played a major role in tall building design in Rotterdam. The buildings designed by international architects include Murphy Jahn's Fortis Bank (1996, 104 meters), Renzo Piano's Toren op Zuid (2000, 96 meters), WZMH's Millennium Tower (2000, 149 meters), Norman Foster's World Port Centre (2001, 138 meters), Mecanoo's Montevideo (2005, 152 meters), KCAP's Red Apple (2009: 128 meters), Alvaro Siza's New Orleans (2010; 158 meters), OMA's De Rotterdam (2013, 149 meters) and the list is growing. The presence of these international architects is particularly felt in the design and construction of the tallest and most prominent buildings in the tall building cluster.

Finally, there has been a marked difference in the use of tall buildings. Before 1990, the tallest buildings were office or university buildings. Many new tall buildings and proposals are now planned for residential uses (Klerks 2005). Figure 2 illustrates this clearly.

Looking at the scatter plot, there is an interesting lack of buildings between the 110- and 120-meter mark, and a slight drop between 80 and 85 meters. Based on this observation we have identified in earlier research three distinctive height categories in Rotterdam (van der Hoeven 2004):

a. above 120 meters;
b. between 80 and 120 meters;
c. below 80 meters.

Visibility of Rotterdam's tall building cluster

The visual appearance of the city's skyline is determined by the size and the shape of the area where a cluster of tall buildings is developing. To determine the grouping a simple outline can be drawn that links the outer buildings considered part of the cluster (see Figure 4 and 5). If a new building is erected within the outline it will not change the width of the city's skyline, regardless of the angle from which it is viewed. Any building erected outside the outline extends the skyline, as seen from a specific angle.

In the case of most buildings it is clear whether or not they belong to the cluster due to their proximity to the other buildings. The current Rotterdam tall building policy assumes that tall buildings in the Central District, the Centre, the Nieuwe Werk and the Kop van Zuid are part of one continuous area. The question remains if the tall buildings west of this area, Park and Europoint, belong to the area that makes up the visual skyline. From some angles these buildings west of the center are visually part of the cluster and from other angles they are obviously not.

A simple technique can be applied to visualize this. The area from which a building appears to be part of the cluster is determined by drawing two lines that connect the building in question with the two buildings that mark the borders of the cluster. If the angle between the two lines is larger than 90 degrees, then the area in which the building appears as part of the cluster dominates over the area in which it is visually separated from the cluster.

Based on this method, it appears that the buildings in the park area should be considered as part of the cluster: Hoboken (1969, 112 meters) and the Euromast (1970, 185 meters). The three Europoint buildings are clearly not part of the Rotterdam tall building cluster. Adjacent to the clusters of buildings above 120 meters, and between 80 and 120 meters, a large number of buildings were built with heights ranging between 50 and 80 meters. All these buildings were reviewed to assess whether they are part of the cluster. A third outline is the result of this action. All three outlines are displayed in the overall map.

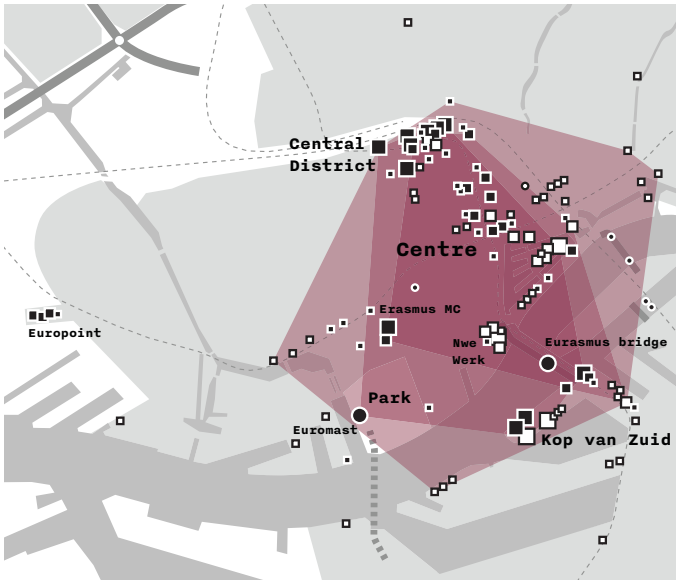

Figure 4. The 2015 multi-layered Rotterdam tall building cluster

Figure 5. Map of the "official" Rotterdam tall building zones 2000–2010

True, the current tall building development within the overall cluster is driven by strategic projects such as the Rotterdam Central Station area development and the Kop van Zuid development. Standing within the cluster these two areas may appear as important sub-clusters. Looking from the outside however, it is almost impossible to visually separate them from the rest of the tall buildings, as illustrated by Figure 4.

The profile differs significantly from the tall building zoning that ruled the development of tall buildings between 2000 and 2010 (see Figure 5). That original tall building zoning was based on traditional urban design concepts such as building alignment, setback principle, boulevard and "visual axis." But using the visibility of the skyline as a means to identify the cluster suggests that the city could allow developments in a much wider area than originally envisioned in the city's guidance on tall buildings.

GISc-based Visibility Analysis

The visual impact of a single tall building was for the first time successfully reviewed (Lörzing et al. 2007; Lörzing 2011) in the case of the 262-meter Belle van Zuylen tower, proposed in 2007 near the Dutch city of Utrecht. The challenge faced in Rotterdam is more complex. In question is the joint visual impact of 130 tall buildings. In order to analyze and represent the visibility of the tall buildings in Rotterdam, a comprehensive GISc-based view shed method was applied (Rød et al. 2009; Nijhuis 2009; Germino et al. 2001; and Nicolai 1971). The accuracy of this analysis depends on the digital landscape model (DLM), and the rule for judging visibility (Fisher 1991, 1993; Riggs and Dean 2007). According to Riggs and Dean (2007), the average level of agreement which can be achieved is up to 85%. These findings suggest that it is better to express the analysis results in terms of probability (Fisher 1995, 1996).

However, to achieve the highest degree of reliability, an accurate barrier model, or digital landscape model, was constructed consisting of a digital elevation model (DEM) in combination with topographic data. The basis is a high-resolution elevation model, the Actueel Hoogtebestand Nederland (AHN-1, 1997–2003), which is precise to about 15 centimeters per square meter. The location, architectural height and year of completion of the tall buildings were derived from the Emporis database (Emporis 2010) and added to the digital topographic map. The resulting digital landscape model was corrected using recent aerial photographs, field visits and street view imagery (Google Earth 2010).

A number of key parameters influenced the result of the GISc-based viewshed analysis. When examining tall buildings, the vertical size – specifically, the area of the façade – and weather conditions play a crucial role in prediction of probable visibility (Nicolai 1971). To put it more precisely, the visual range of objects in the landscape depends on (Duntley 1948; Middleton 1952):

a. the apparent contrast between the object and its background
b. the angles of the object
c. its shape and vertical area
d. the contrast threshold at the level of luminance (type of day)
e. the conditions and technique of observing
f. the eye level and related curvature of the earth (Duntley 1948)

An important factor for determining the maximum visual range of distant objects is the meteorological optical range at different weather conditions. Observations from the Royal Netherlands Meteorological Institute (KNMI) show that the meteorological optical range by full daylight varies from nearly zero up to more than 10 kilometers (KNMI 2010). However, the average ranges of 12 kilometers (50% of the time), 20 kilometers (25%) and 28 kilometers (10%) are typical for Dutch circumstances (Nijhuis 2012; Nicolai 1971). For the analysis we calculated the maximum visual range of the tall buildings under

different meteorological conditions by full daylight and involved vertical area (length-width proportion < 5), vertical shape (rectangular) and contrast value (object-background ≥ 2 %). The cumulative view sheds from the analysis show the probable visibility at a meteorological optical range of 20 kilometers and takes into account the curvature of the earth.

At a distance of 10 to 20 kilometers the human eye has problems observing a group of buildings as separate objects. The buildings tend to blur into one. So far we have not able to adjust the analysis to incorporate this effect.

The GISc-based visibility analysis results show two important aspects of visual information with regards to tall buildings: visual coverage and cumulative visibility (Nijhuis 2009). The output is meant to be descriptive rather than normative. Visual coverage is about where you can see tall buildings in the open landscape; the cumulative visibility is about how many tall buildings you can see. Or, to put it differently, the results represent the intensity, or amount of tall buildings in the skyline of the city.

The visibility analysis of Rotterdam's tall building cluster reveals that their combined visual coverage reaches various places out of town at distances as far as 5 to 20 kilometers. Within the city large bodies of open water, including the river, harbors and lakes, offer similar opportunities to see many tall buildings simultaneously. However, in most of the city the skyline cannot be seen. Discussions on the visual impact of tall buildings should therefore make a careful distinction between the visual impact of the skyline on the cityscape and the very different impact on the landscape.

Development of the Skyline

The accompanying maps show the visual coverage and effect of the tall buildings that are currently considered part of the cluster at vital moments in the development of the Rotterdam skyline: 1970, 1992, and 2015. Figure 6 shows the visual impact of all 130 current and future buildings over 50 meters. The next graphic illustrates specific selections

Visibility buildings > 50 meters

Full daylight: meteorological optical range 20 km (25% of the time) in relation to vertical size and area of the building

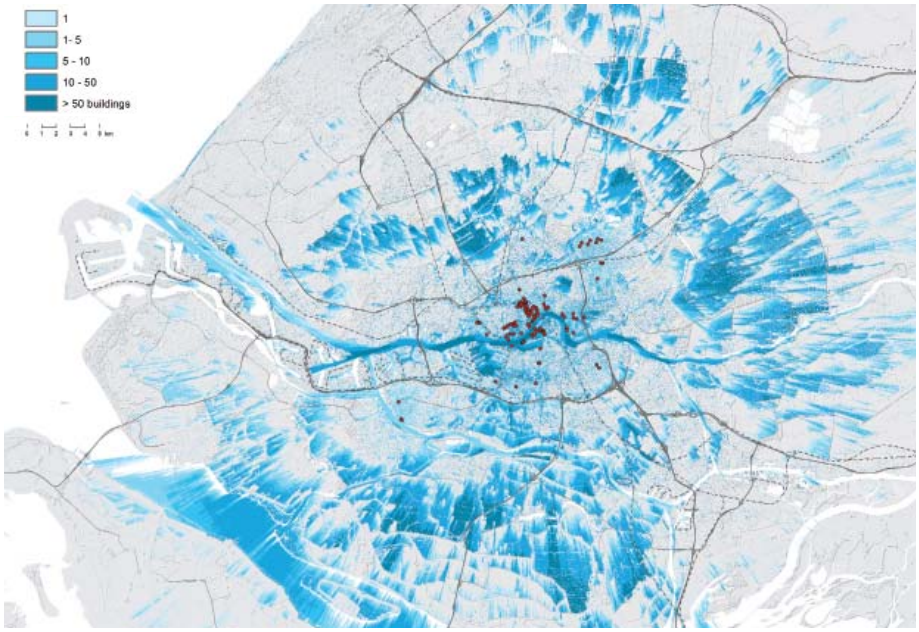

Figure 6. Visibility of all tall buildings in the municipality of Rotterdam

of these tall buildings, based on the outline of the tall building cluster and on the year of construction using 1970, 1992, and 2015 as thresholds (see Figure 8).

The results indicate that the visual coverage of tall buildings outside the city was more or less established in 1970. Extending the Euromast, with the so-called Space Tower, to a height of 185 meters, contributes to this result. The cumulative visibility is getting "thicker" through the years. Tall buildings can be seen from more places inside the city, but outside the city the areas from where tall buildings can be seen does not seem to be growing. This implies that the 1970 skyline of the Rotterdam cluster was dominated by individual and small groups of singular tall buildings. Landmarks are likely to be weak references by themselves. Their recognition requires sustained attention. However, in reality this usually does not happen. Attention is highly influenced by the angles of the building, as well as how far away it is, and how much it merges with the horizon.

A slight increase of visual coverage over the years can be observed, especially north-west and south-west of the Rotterdam agglomeration, up to 1992 and onwards. However, the dominance of the cityscape

Figure 7. The Rotterdam cluster: visibility of the tall buildings built in 1970, 1992 & 2015

dramatically increased over the years and is expressed by the increasing magnitude of cumulative visibility of tall buildings. In recent decades the cluster effect of tall buildings in the skyline became the dominant factor in the visual impact. Starting north and south from Rotterdam in 1970 the visual accumulation of tall buildings in the open landscape developed into a city-embracing pattern in 2015. Although each new tallest building design faces public and political scrutiny, the fact is that the visibility pattern in Rotterdam is already established. Each new development has a decreasing impact as long it is confined to the established tall building cluster.

Conclusions

The context for the development of tall buildings in urban areas can be effectively evaluated by analyzing the historical development in relation to the patterns that emerge from architectural height, year of completion, location in the city, and the functional use of the tall buildings. The framework as presented carries the potential to underpin a city's guidance on tall building development. This framework presents the context of a tall building design, providing a more balanced evaluation of a design proposal compared to studies that focus solely on individual tall buildings.

The mapped Rotterdam tall building cluster differs markedly from Rotterdam's zoning that was in place between 2000 and 2010. This suggests that the city can allow developments in a much wider area than originally envisioned in the city's guidance on tall buildings. The visual coverage of the buildings that make up the current Rotterdam tall building cluster is roughly equal to the coverage of the buildings that were already in place in 1970. The skyline of Rotterdam has clearly become denser as a cityscape as many more buildings can be seen simultaneously in the surrounding territory. As a result each new development has a decreasing impact as long it is confined to the established tall building cluster. ■

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