Paper presented at the 4th AGILE conference Heraklion Greece april 29-may 1, 2004.

# 3D-GIS And Urban Volume: Applying The Third Dimension In A Morphological Study Of The Amsterdam Urban Landscape

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## SUMMARY

*One of the key-features of intensive urban land use is the use of the third dimension. When space is scarce, cities tend to grow vertically. At present this third dimension is not normally present in urban studies. We propose a new indicator for measuring urban morphology in all its dimensions: urban volume, based on a combination of land use maps and detailed elevation data. The Netherlands are fortunate enough to have high density information on terrain heights. Since natural elevation differences in the western part of the country are almost non-existent, height-data can provide us with information on building heights. The objective of this study is to explore the analytical possibilities for urban studies of this new elevation dataset with (3D-)GIS functionality. As a case study the changes in the urban landscape of Amsterdam in the past 50 years are studied.*

**KEYWORDS:** 3D-GIS, urban development, urban volume, indicator

## INTRODUCTION

The recent changes in the urban landscape have been described extensively. Sub-urbanisation and urban sprawl have altered the classical monocentric city and given rise to new polycentric urban forms that have for example been described as edge-cities (Garreau 1992). Although the decline of the traditional city centre does not nearly resemble the many north-american examples, European cities also show a growing importance of its subcentres (e.g. Gaschet 2002 and Martori i Cañas et al. 2002). The Dutch Randstad area, the constellation of the four biggest cities in the western part of the country, is now generally acknowledged as being an interdependent network-city (VROM 2001) in which the various urban subcentres are functionally related. This changing urban landscape calls for new forms of urban planning that put less emphasis on the original city centres. A thorough understanding of the current urban processes can help formulating new city policies.

New digital geographical data sources and the application of GIS can help urban analysis to come to a clearer conception and better measurement of relevant properties of urban systems such as urban density and diversity (Longley & Mesev 2002, Batty et al in press). A further challenge however is to also include the third dimension in the study of urban features (Batty 2000). New GIS technology now allows for true 3D-modelling. A recent review of 3D-models of urban environments (Shiode 2001) indicates that the traditional GIS-assisted three-dimensional visualisation is slowly being supplemented with spatial analysis and simulation applications. Full analytical applications of the third dimension are scarce however. The present study combines a new elevation dataset with other highly detailed geographical information and (3D-)GIS functionality in a new approach to urban studies.

## METHODOLOGY

Density and diversity are the most commonly used indicators for urban change. The decreasing importance of the urban centre and the increasing sub-urbanisation can be described in terms of a leveling of the classical density and diversity differences of the urban centre and its periphery. This leads to the declining density gradients that were described by Zielinski (1980). The measurement of density is mostly based on population counts in statistical or administrative regios; e.g. census districts. Longley and Mesev (2002) show the benefits of using the more highly detailed individual address point data. Urban diversity indicators frequently rely on land use maps and additional information on for example available services (Maat en Harts 2001).

We propose a new urban morphology indictor here: urban volume, based on the combination of land use and height data. Urban systems are classically mapped according to the their land use. Two dimensional maps show both the urban functions (residential and commercial areas) and the non-urban forms of land use. These maps are normally based on aerial photographs or satellite images from which the heights of building-blocks can not readily be discerned. The lack of this information makes it impossible to distinguish between intensively used high rise buildings and low-rise buildings that accommodate only few residents or employees. Especially in the (new) centres of town, buildings can reach a considerable height when space is scarce. The inclusion of building-height in the analysis of urban systems helps to better incorporate the possible contribution of these specific locations to the urban system. The volume of a building is thus taken as a proxy for its importance in the urban fabric. A further advantage of the use urban volume is that it closely relates to the human perception of urban density (Fisher-Gewirtzman et al. 2003) and therefor can easily be interpreted.

## Datasets

A crucial component of our approach consists of the newly developed Dutch national elevation dataset (*Actueel Hoogtebestand Nederland*) which has become available in 2003. This highly detailed dataset was collected over the past seven years under the supervision of the Survey department and is based on laseraltimetric measurements. It has a height precision of about 15 cm standard deviation per point and an average point density of 1 point per 16 $m^2$ or better (Oude Elberink et al. 2003). Huising and Gomes Pareira (1998) offer a full discussion of the intricate problems that occur and that are dealt with in the pre-distribution phase of laser-height data, but these do not strongly affect the general, high-quality of the data. The elevation data thus has enough spatial detail to distinguish individual houses and gives a detailed account of their heights. Since the natural terrainheights in our study area are close to the Dutch national datum level (0 m or mean sealevel) the heights of the original dataset can directly be used to describe the building heights. For this study we use a rasterised version of the original point-dataset with a 5x5 m pixel resolution that provides an average value of all height points within the gridcell. For the rare cases that a gridcell is lacking information (e.g. in the case of a missing overlap in the original data strips) a combination of mathematical techniques is used to fill in the gaps (Vosselman & Maas 2001). Only the larger waterbodies completely lack height information because of their reflecting characteristics. These do not pose a problem in our analysis because we are focussing on the built-up areas.

To select only the heights of buildings an overlay is made with a thematic layer that contains information on land use. A detailed topographical map (top10vector, see TDN 1998) that distinguishes various buildingtypes is used for this purpose. This procedure makes sure that non-urban elevated objects such as trees and infrastructure are not included in our analysis of urban volume.

The original height dataset has one serious shortcoming for our study of the urban environment. This is related to the fact that the main purpose of the data is to provide natural terrain heights for the provinces, local water boards and the ministry of public transport and water management that ordered its collection. Various filtering techniques are applied to specifically extract the ground surface heights and large buildings are deliberately extracted from the dataset during this process. Especially the bigger buildings that protrude considerably from their environment (individual high rises) are affected by this algorithm, leading to the fact that heights over 40 m are non-existent. To compensate for the missing high buildings additional information was obtained from a specialised website (skyscrapers.com) which is operated by the Emporis corporation. This commercial platform gives a short description of all tall buildings (over approximately 40 m) in many metropolitan areas worldwide and lists amongst others: year of construction and maximum height. The height information was manually added to the buildings data layer.

## Data treatment

The selection of the building heights out of the original height grid is done in several stages. A first step is to create a binary raster layer out of the topographical vector-map that allows for the discrimination between built-up and other gridcells. The top10vector data provides detailed polygon information on the outer extremes of both residential, commercial and industrial building types. Building shapes are not always provided correctly however. The inner (or island) courtyards of many residential buildings for example are not properly described– i.e. many buildings are 'hollow' but are not shown as such. Thus leading to an overestimation of the built-up surface. A method to compensate for this bias is to add an additional query for values above 5m. This selection process provides us with a subset of the height values within building structures that are greater than 5m. The gridcell values are then multiplied by their surface area (25 $m^2$) in order to represent a volume-per-pixel of buildings only. A flow diagram of the applied methodology is provided in ***Figure 1***.

In order to allow for a comparison of the present situation with the past we have created an outline of the urban area around 1950. This historic urban limit is based on a detailed dataset that includes the year of construction of all present buildings in the municipality of Amsterdam. After selecting all individual buildings that were built before 1951 we can create a binary raster layer that describes for every 50 m grid-cell whether buildings were present at that time or not. This reconstructed historic urban area map allows for the extraction of those gridcells in the building heights dataset that were supposedly built-up in 1950. For this selection the tall buildings that were constructed after 1950 were excluded. This rough approach has of course some limitations. Old buildings for example may have been replaced by newer ones in the past 50 years. These locations will erroneously be left out of the 1950 analysis thus introducing an underestimation of its urban volume. The opposite may also be true: the heights of recently added buildings in the immediate surroundings of a formerly isolated old building may unintentionally be included. Another limitation is related to the fact that buildings are actually represented by a single co-ordinate for every individual address, which in the case of large (industrial) buildings may lead to an underestimation of their total surface area. Visual inspection of the historic urban area map however shows the old parts of town as a more or less continuous surfaces, indicating that the described limitations only affect isolated locations. Since our analysis is mainly meant to explore the possible use of the urban volume indicator we do not consider these drawbacks to be serious constraints to our analysis.

## CASE STUDY

The newly proposed urban volume indicator will be applied to the greater Amsterdam area. The capital of the Netherlands provides an especially interesting case study area because its urban landscape has changed significantly in the past 50 years. From 1950 onwards the extensive garden villages were added to the western and southern limits of town, following the 1935 general extension plan (van der Cammen et al. 1988). After the failure to develop the central riverfront (IJ-oevers) in the 1980's several high rise areas have sprung up around the relatively young ringroad. Concentrations of office building with maximum heights of up to 150 m have been constructed at the western, southern and south-eastern edges of town and around the more centrally located Amstel railway-station. Amsterdam can now be described as a polynuclear or edge-city. Our study aims at visualising and quantifying these urban changes by comparing the urban volumes of 1950 and 2000.

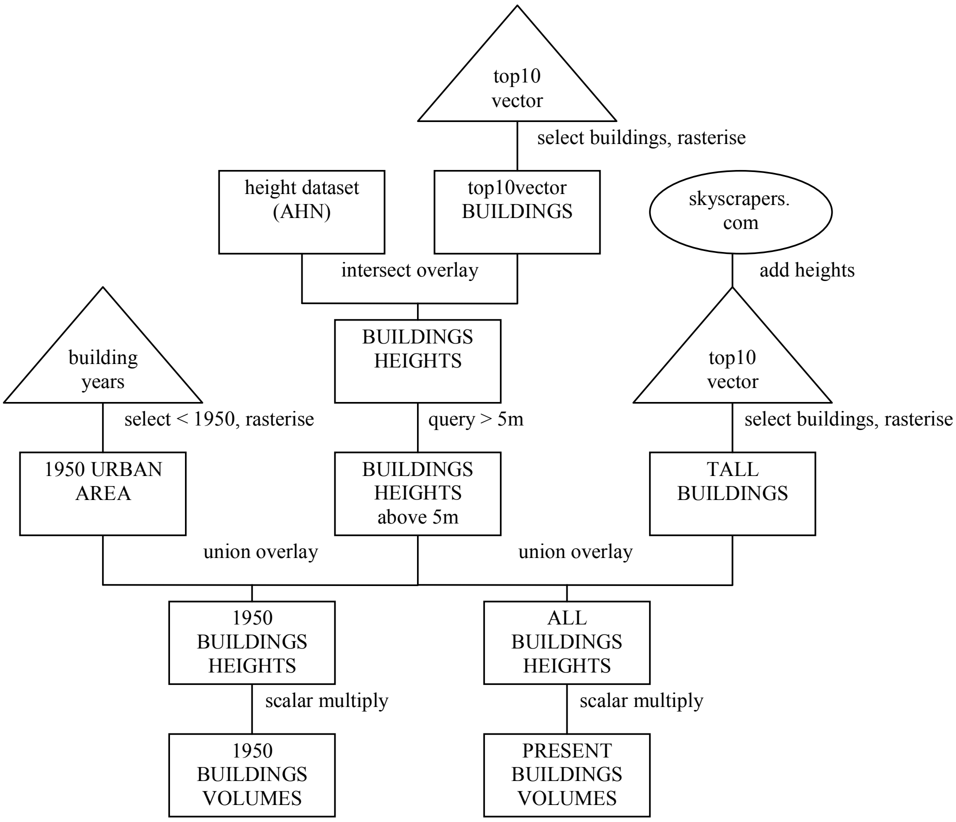


*Figure 1* Cartographic model for the creation of the urban volume indicator for the reconstructed 1950 and present situation

## Data exploration

Before actually looking at the urban volume, we will first explore the nature of the data at hand. By initially analysing the building heights we familiarise ourselves with the characteristics of the study area. A first step is to plot the heights of the gridcells against their total surface area. The graph (***Figure 2***) can be viewed upon as a stylised cross-section of the town and provides a condensed overview of the absolute importance of various building heights in the greater Amsterdam area both in the 1950 and present situation. This three-dimensional fingerprint clearly shows that the highest buildings at present are around 150 m and it moreover indicates that only a limited area is covered by constructions of over 40 m. Due to their small number the distribution of high buildings is partially counter-intuitive: a few of the 40-80 m heights occur less frequently then some of the over 80 m heights. This could also indicate that we are still missing out on a number of the over 40 m heights. By far the largest area is covered by buildings of intermediate heights (10-20 m). The 1950 situation is characterised by maximum heights of around 40 m and a strong dominance of the 15-30 m range. The lower ranges (5-15 m) are in fact scarcer than the 15 m heights indicating that the city at that time consisted of more 3 story apartment blocks than low-rise single family homes. This method of creating a consistent graphical depiction of the three dimensional properties of urban areas can be used to easily compare cities in different environments and times. Future research will focus on actually applying this method on different Dutch cities and time periods and will explore the use of further derivatives such as integral and differential statistics.

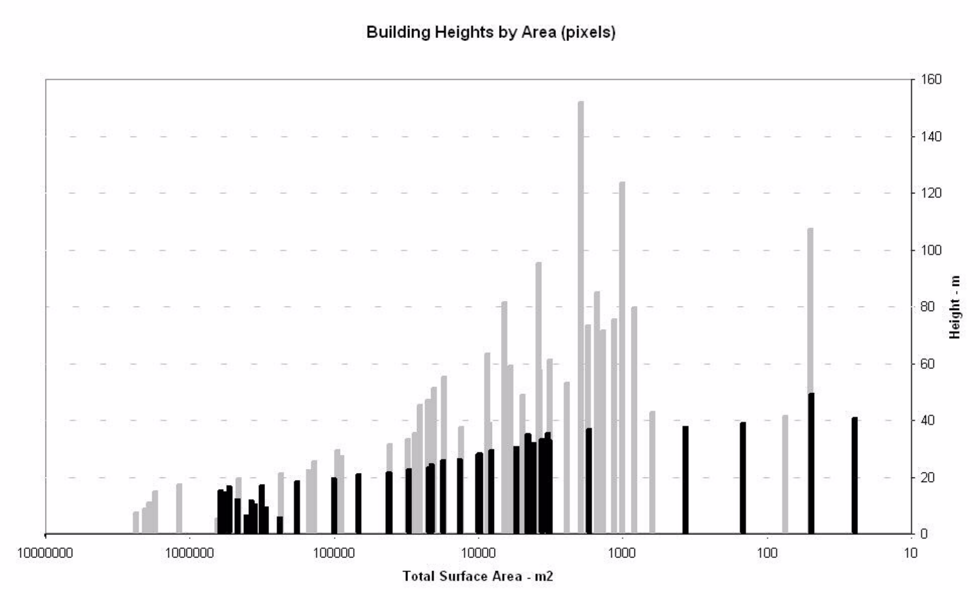


*Figure 2* Overview of the gridcells-heights and their total surface area (logarithmic) for 1950 (black) and present (grey) situation.

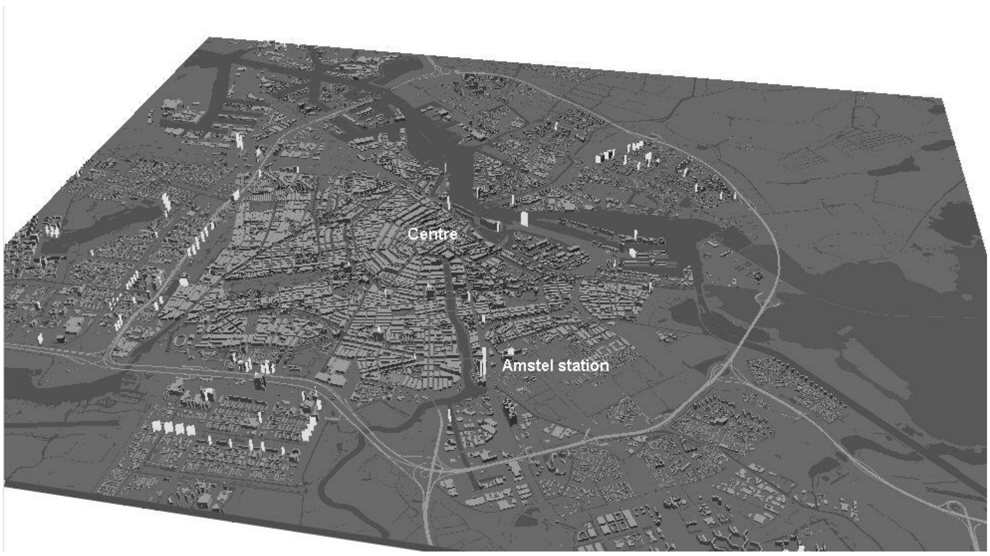


*Figure 3* 3D-visualisation of the study area looking north-west. Higher elevations shown in lighter colours, scale changes in this perspective.

A second approach to more closely inspect the spatial dimension of the data is to visualise the city in three dimensions, see ***Figure 3***. This 3D-visualisation shows a large concentration of medium-heights in the city-centre and scattered small high-rise areas mainly along the western and southern ringroad and around the Amstel train-station. The western and southern post-war neighbourhoods have a more open appearance reflecting the spacious garden-village layout. A few open, green areas can be recognised along the Amstel-river (in the south) and to the north-east.

## Urban volume

The urban volume indicator is initially calculated at the original 5 m grid resolution. This obviously provides an extremely detailed, but also very heterogeneous and dispersed image. In two separate steps we therefor generalise the results to allow for a more easy interpretation of the urban volume indicator. At first the data are aggregated to a 50 m grid in which the average volume of the original 100 cells is retained. The results are then sharpened by applying a maximum-filter in a 150 m neighbourhood. This increases the influence of the high-rise buildings on their surroundings in a way that is similar to their visual domination.

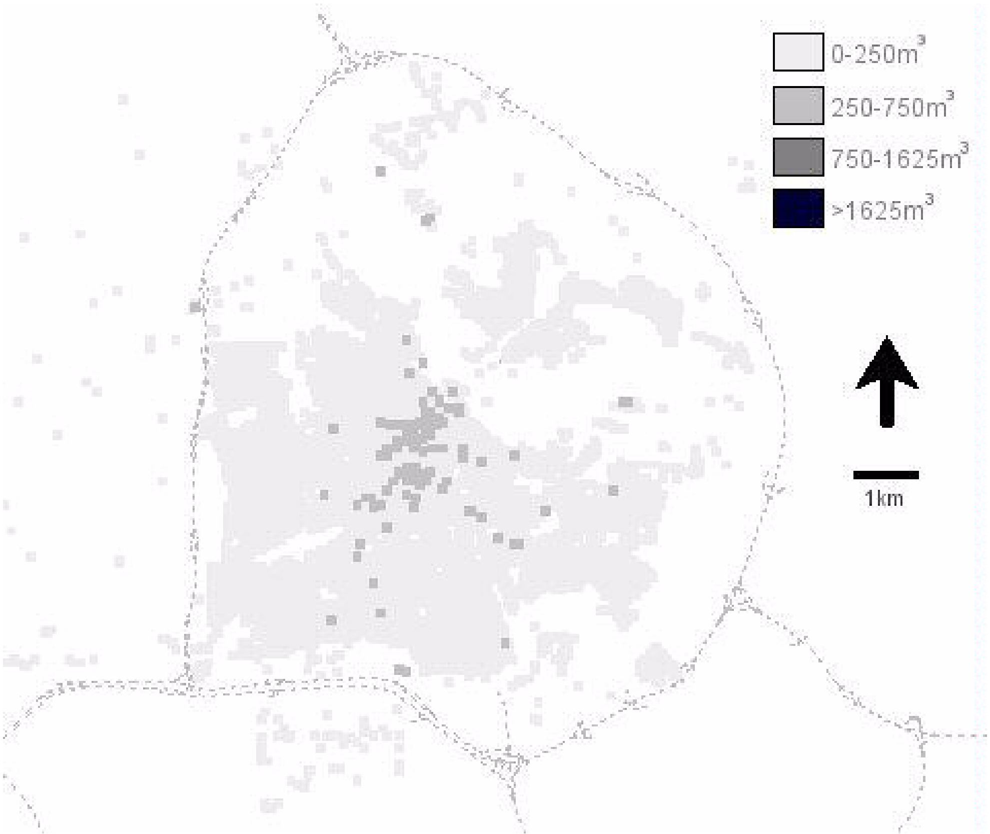


*Figure 4* Urban volume (averaged per 50m gridcell) in Amsterdam, resconstructed 1950 situation.

The reconstructed 1950 urban volume map ***(Figure 4***) clearly shows the prominent position of the historic city centre represented in an abundance of middle range volumes. The suburbs of that time are characterised by low volumes. The city was almost completely confined within the area that is nowadays enclosed by the ringroad. This recently completed infrastructure is added to map for the sake of orientation. The scattered medium-range volumes may partly be caused by the inaccuracy of our approach. As becomes apparent from ***Figure 5*** the medium range volumes in the present situation still have a large concentration in the centre of town. Several other concentrations can now be found in the western (industrial) area of town and around the southern ringroad. These areas also have a few locations with an average volume of over 750 $m^3$ per 50m gridcell. The only two extremely high volumes (over 1625 $m^3$) can be found around the Amstel train-station and just east of the centre. That both of these have a somewhat central location indicates the importance of neighbouring volumes for the calculation of the (average) urban volume. The other high-rise buildings are apparently more isolated and therefor show up less prominently. The figure shows in general that the new high-rise additions to the cityscape have a limited impact on the total volume of the town. The indicator in fact shows that the city-centre in terms of its volume is still an important feature in the urban structure.

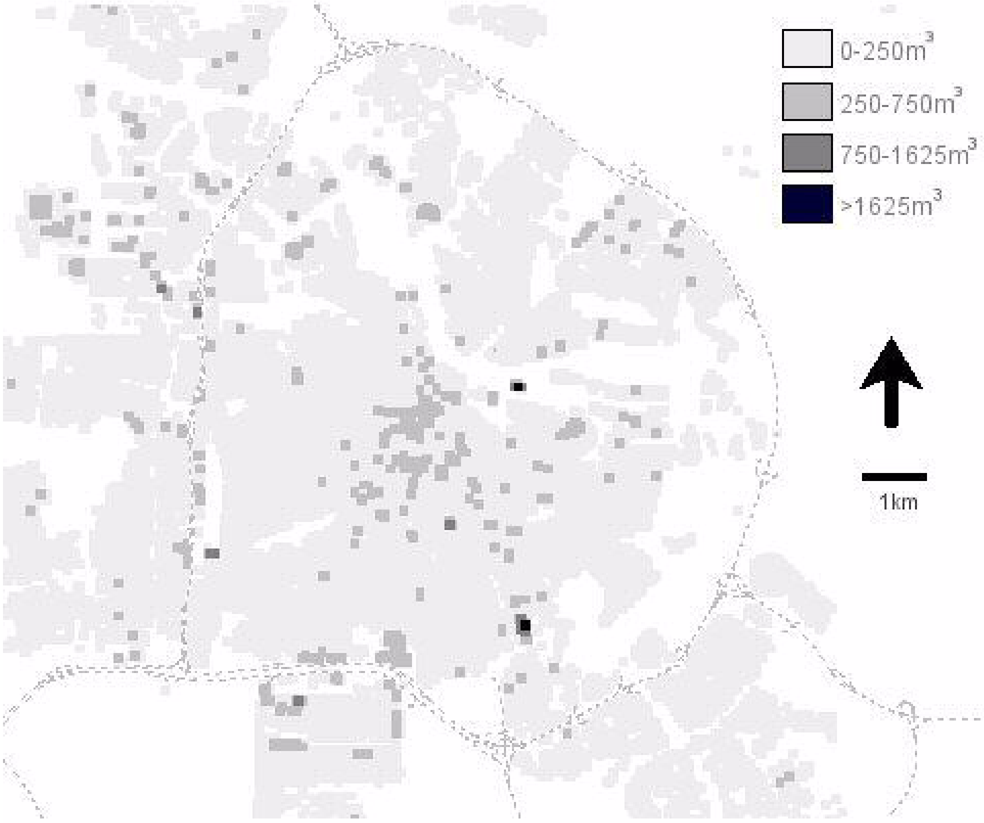


*Figure 5* Urban volume (averaged per 50m gridcell) in Amsterdam, present situation.

## DISCUSSION

The urban volume indicator clearly captures the changes that have occurred in the greater Amsterdam area in the past 50 years. The development of several new high density centres is readily apparent, while the old centre remains an important feature of the town. The proposed indicator provides a concise overview of urban density and pinpoints at the most intensively built-up areas. In doing so it and quantitatively describes the essence of the actual appearance of the city. As opposed to more appealing 3D-visualisations the proposed methodology gives an unambiguous, reproducible statistic of the urban exterior. One might argue however that the visual dominance of the most prominent landmarks (notably the new office-buildings of over 100 m) is not strongly incorporated, leading to a deviation from the human perception of the cityscape. This can be accounted for in an adjusted version of the indicator by for example adding more weight to the individual high-rises.

Some methodological issues are important for a successful application of the proposed indicator to other areas. For cities outside the low-lying western parts of the Netherlands a reconstructed natural surface layer will be necessary to correctly distinguish the building heights from natural elevation differences. The original pre-processed elevation data still contains the building-heights of over 40 m and should in principle be more suited for the analysis of urban volume. By using this dataset the laborious adding of additional height information becomes superfluous, reducing both manual labour and the chance of introducing extra inaccuracy. This however also involves dealing with the original data-gaps and errors and would certainly need the co-operation of the Dutch Survey department that manages the national elevation dataset.

## ACKNOWLEDGEMENTS

This research was commissioned by the Netherlands institute for spatial planning. The geographical datasets for this research were kindly supplied by the survey department of the Dutch ministry of Transport and Water management, the Netherlands institute for spatial planning and the spatial planning department of the city of Amsterdam. We thank these institutes for their kind co-operation.

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