# Quantifying intra-urban morphology of the Greater Dublin area with spatial metrics derived from medium resolution remote sensing data


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## Introduction, study area and data

**Spatial metrics** derived from satellite imagery are useful measures to quantify structural characteristics of expanding cities, and may provide indications of functional land use types. In this research, we develop spatial metrics for use on continuous **sealed surface** data produced by sub-pixel classification of **medium resolution imagery**. The spatial metrics are then used as variables in a supervised classification approach to create a map showing **morphological land use** classes.

Our study area is **Dublin, Ireland**. The image data used consists of two Landsat images: a Landsat 5 TM image of June, 13th 1988 and a Landsat 7 ETM+ image of May, 24th 2001.


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http://www.mamud.be
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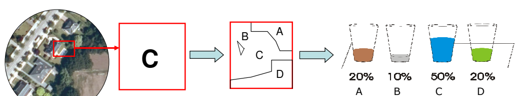
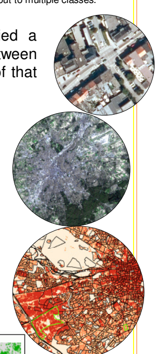
## Deriving continuous sealed surface data

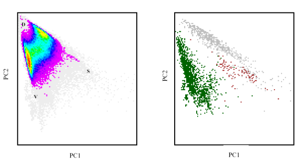
We derived **sealed surface maps** for Dublin with **sub-pixel classification**, a group of techniques that enable optimal information extraction from medium or low resolution imagery by representing pixels covering multiple land cover types as proportions of these types instead of assigning them to a single dominant class.




The red square on the high resolution image represents a hypothetical medium resolution pixel. When this pixel is classified by a traditional, "hard" classifier, it will be assigned to a single class (C in our example), while in reality it is a mixture of four different classes. Sub-pixel or "soft" classification is able to estimate the fractional cover of each of those classes within the pixel, assigning it not to just one, but to multiple classes.

There are several approaches to sub-pixel classification. In this study, we applied a conceptually simple but sufficiently accurate technique: we estimate the relationship between the spectral values of a Landsat pixel and the built-up urban area within the bounds of that pixel with **linear regression analysis**.

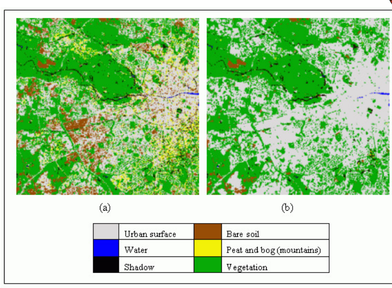




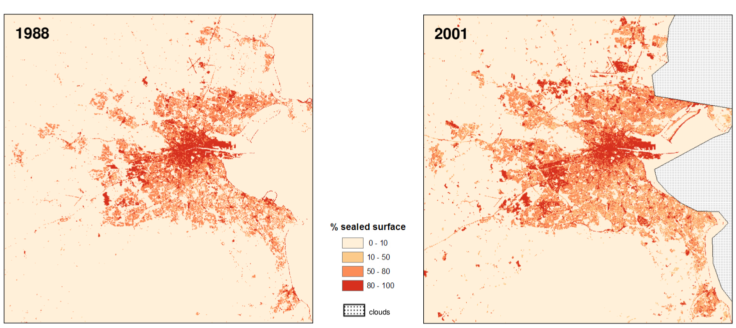

Landsat ETM+ feature space made up by the first and second principal components (left) and position of pure pixels within that feature space (right). Colours on the left graph indicate pixel frequencies ranging from very low densities (grey) to high densities (red and yellow). Colours on the right graph indicate pure pixels vegetation (green), impervious (grey) and bare soil (brown).

Some urban land cover types have similar spectral characteristics as dry bare soils. They therefore also take similar positions in feature space, which makes them impossible to separate with sub-pixel classification. To solve this problem, **urban masks** are developed for indicating pixels that belong to the urban fabric. Only those pixels are subjected to sub-pixel classification.

The urban masks are created by improving an unsupervised classification with **knowledge-based spatial rules** that use area and adjacency thresholds to reclassify pixel clumps.



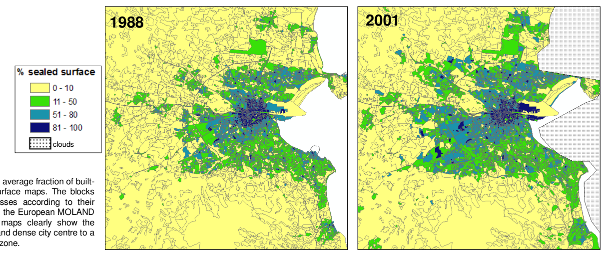

An unsupervised classification based on Kohonen's self-organising-map neural network is first reclassified into meaningful land-cover classes (a). Ambiguous, mixed and spectrally confused classes are then subjected to knowledge-based post-classification rules in several steps to obtain an urban mask (b).



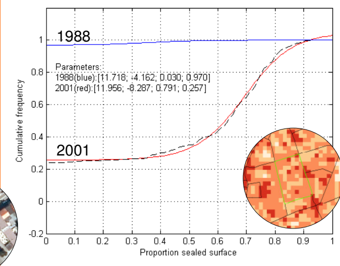

The images above show sealed surface fractions of the Dublin study area in 1988 and 2001 derived by the sub-pixel classification. Both maps clearly show the westward expansion of Dublin, which is indeed where most urban growth takes place given the presence of the ocean to the east and the Wicklow Mountains to the south. The densification and expansion of industrial estates (Broomhill, Ballymount, Park West) near the M50 motorway in West Dublin is clearly visible. Also, the rapid expansion of residential areas in Clonsilla, Hartstown and the new developments in Tyrrelstown to the northwest of the urban area draws attention.

## Characterising urban structure with spatial metrics

Spatial metrics are calculated within the bounds of a geographic area. This area is called the **spatial domain**, a relatively homogeneous spatial entity that represents a basic landscape element. For the Dublin study area, we use regions or **blocks** as the elementary spatial units. These blocks were created by intersecting **road network data** with the European MOLAND **land-use map** of 2000, which provides regions that are relatively homogeneous in terms of land use.




For each block, we calculate the average fraction of built-up surfaces from the sealed surface maps. The blocks are then divided into four classes according to their degree of soil sealing, based on the European MOLAND scheme. The built-up density maps clearly show the urban gradient from a compact and dense city centre to a low density, sprawled suburban zone.



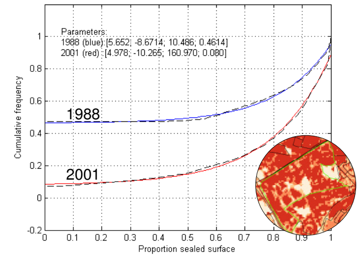

To characterise the blocks in terms of their **morphological properties**, we develop spatial metrics that are based on the composition of each block with respect to sealed surfaces. The **cumulative frequency distribution** of the sub-pixel sealed surface fractions lies at the basis of that because its shape provides an indication of the land-use type the block belongs to.

Low or medium dense residential areas are typically composed of mixed built/vegetation pixels because the spatial scale of single family housing is small compared to the resolution of the image pixels. This results in a sigmoidal distribution function (left, dashed black line). The change of the graph between 1988 and 2001 indicates land use change from pasture to residential development.

To capture the shape characteristics of the distribution curves quantitatively, a **transformed logistic function** was fitted to them with nonlinear least-squares regression. The **parameters** of this fitted function can be related to the morphology of the blocks, and are used as variables in a supervised classification.

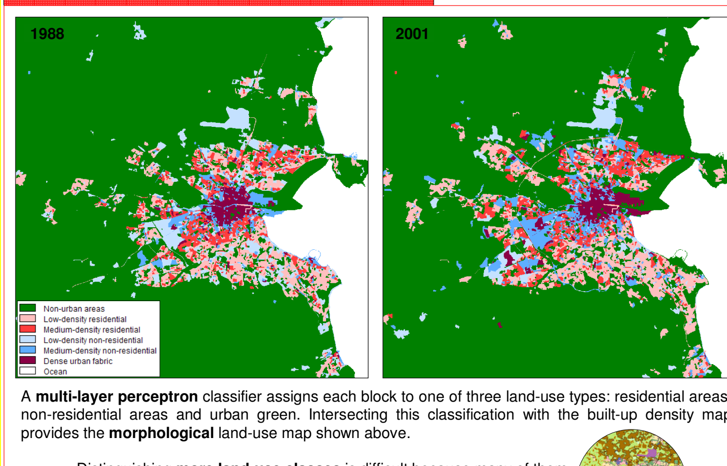
$$P_i(f) = \frac{1}{1+e^{-f}}$$

$$P_i(f) = \gamma \frac{1}{1+e^{-(\alpha f+\beta)}} + \delta$$



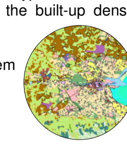

Industrial areas contain little vegetation cover and higher sealed surface fractions, which is reflected by a more "exponential" distribution shape (above, dashed black line). The drop in the curve between 1988 and 2001 indicates increasing sealed surface cover within the block.

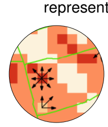
## Deriving a morphological land use map with spatial metrics




A **multi-layer perceptron** classifier assigns each block to one of three land-use types: residential areas, non-residential areas and urban green. Intersecting this classification with the built-up density map provides the **morphological** land-use map shown above.

Distinguishing **more land-use classes** is difficult because many of them represent **function**, which is not always reflected by **morphology.**





Classification results may be (slightly) improved by including **spatially explicit** metrics.