# Space Index

## *A retrieval-system for building-plots*

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**Abstract.** *Increasingly, digital architectural data will become available through information technology. Yet until now, there were no satisfying methods to query this data for architectural purposes. This paper introduces an information retrieval system for parcels that not only allows searching for specific attributes, but also includes properties of shape and context of the building plots. An automatically generated index stores the relevant spatial properties as normalized bitmap images on several layers. When a query is started, only this index has to be queried and not the complete database. The search process can be controlled through a graphical interface that incorporates the user's sketches. The retrieved parcels are presented as a sorted list of vector drawings including their contained buildings. With the simplified access to these case-studies, quality and efficiency of the architectural design process could be increased.*
**Keywords.** *architecture-retrieval; shape matching; indexing; operationalization; urban morphology; case-based reasoning.*

## Introduction

Working with references is part of a daily routine for architects and urban planners. Existing projects form a precious knowledge base: analogies can visualize ideas, provide characteristic values or represent the starting point for further design.

Until now, the collective architectural knowledge is hard to access. In the best case, the architect remembers a possible solution for the actual problem, documented in a floor plan atlas or a similar collection of built architecture. These books represent a very subjective selection of examples. They are organized in fixed categories, and can only be queried through this prescribed structure.

In other domains, search engines successfully help find information stored on computer systems and thus facilitate researching for analogies. For architecture, there is no such retrieval system yet. This has several reasons: the calculation of similarity for shapes is more complicated and computationally expensive than for text. Furthermore, architectural information is usually stored in diverse file formats and is often too detailed for efficient browsing.

With the presented approach, the author seeks to enable search features for architects for the retrieval of architectural case studies. An index-based search engine for building-plots is introduced. The parcels can be queried intuitively through a graphical interface by considering both their shape and their spatial context. In a case study, the parcels of the inner city of Zurich are indexed and successfully queried.

## Background

Why do we need methods for comparing and retrieving building plots? To find existing solutions for new tasks, one strategy could be to look for similar problems, which are already solved. Therefore, a closer look on the nature of architectural problems is helpful.

Common architectural problems often have a similar structure: they can be divided in two parts, the given context and the demanded results. Thus, the task of architects can be simplified as follows: design a house with a predefined function on a given building site.

While the requirements of the building can be described through text and tables (for example the amount of needed space), the description of the building site is more difficult.

Until now, one can choose between three different retrieval-systems for architectural research, none of them particularly suited for this purpose: text-based search engines, shape-matching software and Geographic Information Systems. Each of these three retrieval systems has significant shortcomings. Text-based search fails at formulating spatial queries. Hence the search for architectural case studies is circuitous and disappointing. Common text-based search engines reach their limits. "We have no language for describing configurations, that is, we have no means of saying what it is we know. This problem is particularly salient in buildings and architecture, because both have the effect of imposing spatial and formal configuration on the world on which we live. " (Hillier 1996) Existing shape-matching software is too general to be applied in architectural practice: important spatial qualities cannot be queried. In architecture, not only are the properties of the object itself relevant, but the properties of the surrounding area are important as well. The simple geometric queries offered by Geographic Information Systems are not detailed enough to retrieve similar parcels that could serve as reference cases.

## Approach

As mentioned above, the parcels could be the key for the computer-aided retrieval of case-studies for architectural problems. The following work focuses on the latter point, and introduces a comparison metric for the parcels. This metric is based on visibility and proximity measurements of the parcel. These properties are indexed as normalized 2D analysis maps.
The database for the presented approach can be a map of parcels in vector-format, as it can be provided by a geographic information system. Parcels, buildings and streets are represented by 2D-polygons. The author assumes that in the near future a large amount of digital architectural data will be stored and available. This could happen through commercial GIS Applications or Open Source Platforms.

### More than just the shape: a metric for parcels

The measure of similarity between parcels must be defined out of endless possibilities. The aim is to find the best fitting case studies for a given architectural problem. The following work proposes a metric for parcels based on the transferability of its buildings:

Parcel A is similar to parcel B if the buildings from A could be transferred to B with as little adaptation as possible.

For Hoffmann-Axthelm (1990), parcels comprise the basic units of a city. He emphasizes that their main characteristics beyond their dimensions are their interaction with the surroundings. Thus, the range of possible buildings that can be built on a parcel depend not only on its shape but also on the parcel's context. Basic archetypical needs of architecture such as illumination, view and accessibility must be satisfied. Thus the context must be incorporated into the measure of similarity.

## Operationalization of space

Besides the similarity of the parcel shape, the author proposes three properties as indicators for the transferability: visibility, distribution of neighboring buildings, and orientation and position of the street. The following section describes how these properties are measured.

Indicating the visibility and the proximities of the parcel in one single numeric value for each plot would be an oversimplification because these properties may highly vary inside the parcel. Their distribution in space is an important characteristic of the parcel, and must be measured and saved in the index. Two algorithms are presented: one to analyze the visibility and one for the distances to regions of interest. Their pixel-based approach is easy to implement and fast enough in the desired precision.

The visibility of a point can be measured as the surface area of the polygon that can be seen from this position. In our case, the maximum view-range is limited to a length r. This limitation is a compromise between accuracy and performance. We assume that the relevant view-range-profile for the parcels stays within these limitations. The maximum visibility would therefore be the surface area of a circle with radius r. The implemented algorithm for calculating the visibility is based on Bresenham's line algorithm (1965), which can be used for approximating the view-axes quickly.

Another algorithm is implemented for the distance-analysis to certain regions. This algorithm can be used to quantify the open space between the neighboring buildings and the orientation of the parcel towards the street. If one allows for a small deviation, this can also be done using a raster-based method. The raster offers an efficient modification of the Dijkstra's shortest-path-algorithm by a sweep-line strategy (Dijkstra, 1959). For every position of the grid, the implemented algorithm calculates the distance to the region of interest.

## The parcel index: multilayered normalized bitmaps

The previous section discussed the algorithms to analyze the relevant properties. In the following, the author presents methods to index the results of the measurements, so they can be scanned and compared effectively. The presented search engine only extracts information it deems relevant. Several layers of information can be included in the parcel index. In case of a query, not all the data has to be browsed but only this index.

To achieve a fast comparability, the results of the analyses are normalized. Every parcel is covered with a grid, which always consists of the same amount n of vertical columns and horizontal rows.

For every point of the grid that lies inside the boundary of the parcel, the qualities are calculated, as described in the previous section. The obtained

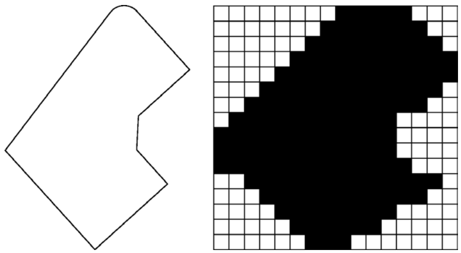

*Figure 1*
*Parcel and normalized shape index.*

*Figure 2*
*Parcel and radius of influence*

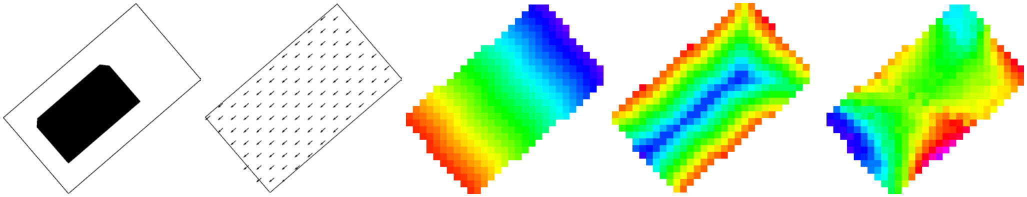

*Figure 3*
*Parcel and its index-maps:orientation to street, distance to street, distance to surrounding buildings and visibility*

information can be displayed as a grayscale image with a fixed width and height of N-pixels, with the brightness mapped to the evaluated value. These images are henceforth referred to as dimensionless maps.
To measure the distance between two of these maps, the differences of the single pixel values are summated. The sequence of the values is saved into the index. Together with the dimensions of the bounding-box and the simple geometric properties, they offer an accurate key for the retrieval of the parcel.

### Vector-map
Not only the distance but also the orientation of the parcel can be a relevant value. For the query, the orientation towards the street is more important than the absolute distance (We can assume every parcel being directly accessed by streets). To index this orientation, a two-dimensional vector-map based on the normalized bitmaps mentioned above is introduced. For every point of the grid, the direction of the shortest distance to the street is saved. These vectors can be compared through their Euclidean distance. As an option, the angle of this vector could also be saved into the bitmap-index, and the distance would be the minimal angle in between.

### Graphical interface and adjustable relevance ranking
Architectural queries can hardly be formulated using text without losing relevant information. To overcome this limitation, the author proposes a graphical user-interface where the search can be specified by drawings. This allows spatial configurations to be described more intuitively. Not only can the architect query for similar parcels by drawing the parcel as a polygon, but he can sketch surrounding buildings and define the connected street.

Based on this drawing, similarity of the parcels is calculated in real-time as the weighted sum of the similarities between the different properties, such as the shape-similarity, the visibility, the distance to the surrounding buildings and the orientation towards the street. To specify the importance of the different search criteria, the user can adjust the relative weights. Thus the relevance-ranking of the search result is changed.

In response to the query, all resulting parcels are sorted and displayed by their similarity or proximity to the question, and displayed in this order.

## Case study

The presented indexing method allows empirical research about the morphology of the examined parcels. Using the example of the map of the inner city of Zurich (Figure 4), more than 10000 parcels are indexed. Several test queries and their results are shown.

The introduced search engine successfully retrieves usable case studies out of the database. Each query is answered in less than two seconds, the results are displayed almost in real-time. It turned out that the inclusion of the context as search criteria, and the adjustable similarity function are important instruments for retrieving useful references.

### Sample query
The sample query demonstrates a possible

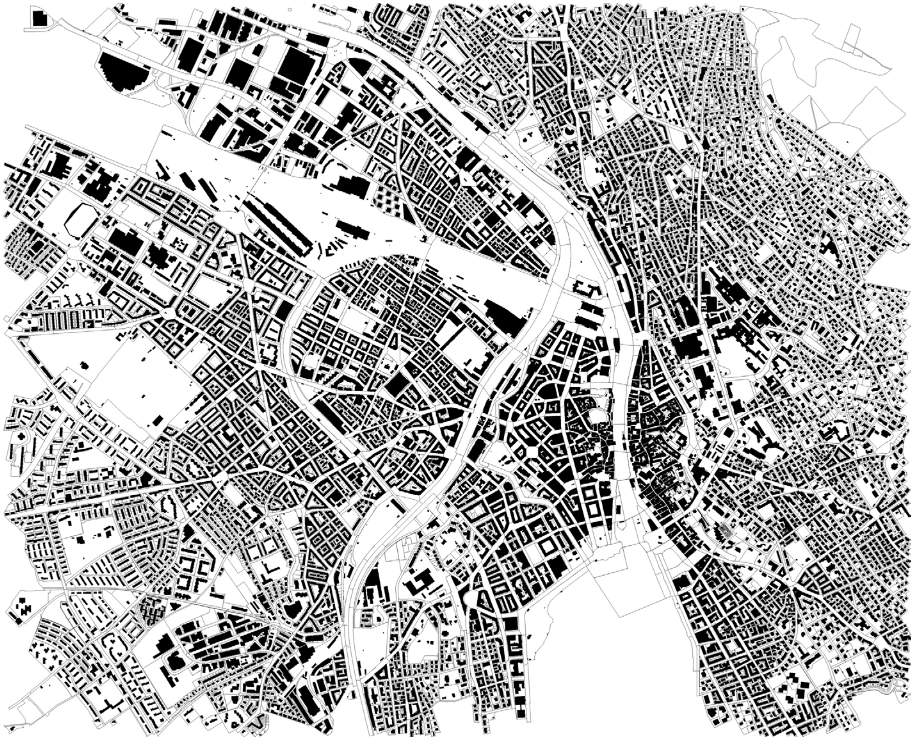

*Figure 4*
*The parcel map of the inner city of Zurich as test case.*

application of the presented approach. An Architect receives a new commission: He has to design a new building on the parcel. In our case it is a corner-parcel surrounded by neighbor-buildings on two sides and by streets on the other two sides.

Now the architect is looking for references for his own planning. If he finds parcels similar to his parcel, he can obtain some information about how they are covered with buildings. He defines his query by drawing the outline of the parcel in scale and marking the existing streets. Additionally, he sketches the surrounding area. As an alternative, he may also directly select the relevant parcel out of the city map as illustrated in figure 5.

When the query is started, the computer delivers similar building-plots in seconds. They are displayed in list as drawings, and sorted by their similarity. If user is not satisfied with the results, he can adjust the relevance-ranking through sliders. He can decrease the importance of the surrounding buildings, and amplify the importance of the orientation to the streets, for example.

If he finds compatible results, he can access more detailed information about these parcels. It is highly likely that the exemplary buildings are compatible with the given parcel. With these references, he can estimate the complexity of his task, predict the costs, and use the solution as starting point for his design.

In an ideal case, the result would contain additional information such as economic values or even construction drawings related to them. He could find out how the old buildings are organized, where the staircases are located and how many apartments they contain.

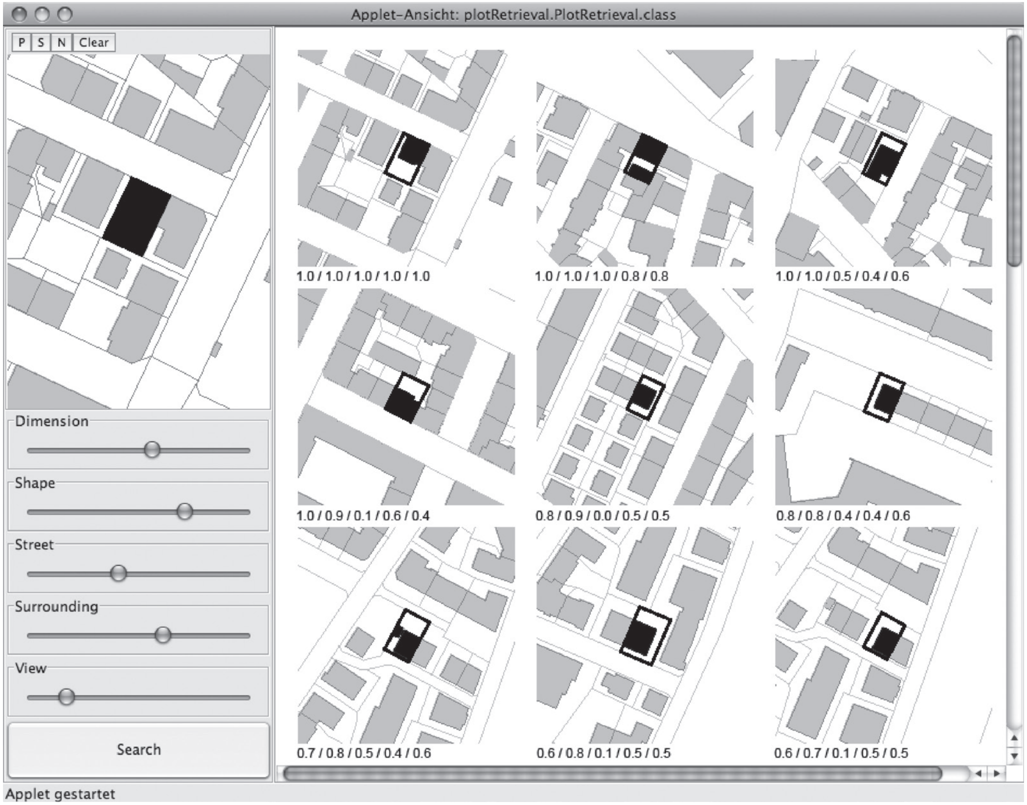


*Figure 5*
*Graphical user-interface of the software prototype, example query and the retrieved search results.*

## Generalization

This work is focused on the indexing of parcels, yet this method could be applied in architecture and urban planning at different scales. The presented index offers an adequate key, everywhere where spatial boundaries can be represented by polygons, and where contextual properties like adjacencies, proximity and orientation are important. Thus plots, parcels, building outlines and even floor plans can be included. The motivation for performing these types of searches is the same: more detailed information could be retrieved using a simple query that formulates abstract shape and context.

The previously mentioned degrees of scale do not lead to significant differences in the complexity of the outlines, so the resolution of the index does not have to be adapted. Only the type of objects to be included in the context has to be modified: On the level of parcels, the orientation towards the street is important; on the level of a floor plan the location of the entrance, the staircase and the windows should be included. The future research of the author will focus on these applications.

An extension of the index to the third dimension would be technically possible, but is not considered as relevant for most of the architectural implementations.

*Figure 6*
*Possible scales for the index: plots, parcels, buildings and floor plans ( floor plans Rossi, 1980)*

## Outlook

What would happen if the computer could propose case studies for a project at the push of a button? If a cad-software would display possible buildings as the architect is drawing the parcel shape, like an auto-complete method?

The presented approach could be used as part of a case based reasoning system. It tackles one of the main problems, the retrieval of well-fitting, similar problems (Schmitt, 1993).

Further research can be made to apply the proposed system to other architectural scales: building shapes and floor plan layouts may also be indexed. Automated methods of adaptation of nearly fitting solutions can be developed. Therefore machine-learning strategies could be implemented.

A digital architecture retrieval system could enhance the speed of the design process of future buildings, and it could optimize their qualities. Mistakes can be avoided, and existing good solutions can be improved.

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