IDENTIFY BUILDING PATTERNS

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ABSTRACT:

This paper presents a method of identifying patterns among buildings and constructing relationships between them. It is envisioned that the pattern objects not only provide operands upon which generalization can be applied, but more importantly, add a new spatial data type with specific semantics in a geospatial database. These new database objects can support spatial analysis and queries that make use of the semantics. In addition, spatial patterns at various scales conform to urban structures and form a natural hierarchy of map objects in a multi-resolution database, which facilitates a streamlined navigation and scalable visualization of cartographic maps. In this research, building patterns are identified based on user specifications which are accommodated by pattern templates. The parametric data model makes it possible to extend the library of pattern templates and to modify specifications to target intended spatial patterns. Map generalization with the knowledge of building patterns will be exemplified as an application of spatial patterns.

1. INTRODUCTION

Automated generalization of urban maps inevitably involves generalizing buildings. There are generally three levels of concerns in building generalization: operations on individual buildings, on groups of buildings, and on constructing database structures to model relationships of buildings at varying representation scales. The focus of this paper is on the methods of identifying patterns among buildings and constructing relationships between them.

1.1 The Needs for Identifying Building Patterns

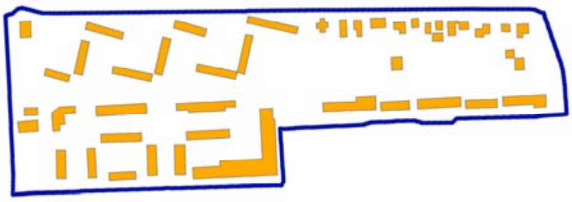
Primary reasons for patterns of buildings being useful include:

- Making significant buildings stand out in maps and databases;

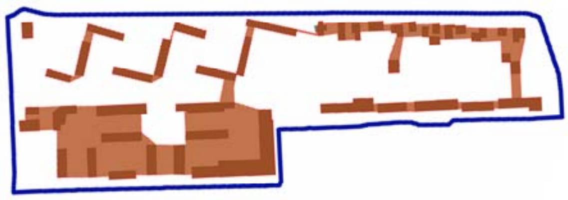
- Making the buildings ready for special treatment (e.g. generalizing); and

- Enriching the database for analysis (e.g. the area is likely not residential since most of the buildings are large and similar to the specified shapes), queries (e.g. where is the nearest highway exit to a sports complex pattern), and integration (e.g. given a dataset with an E-pattern building group, find from the networked databases the datasets, possibly in different scales and formats, that have the same pattern).

The need for building patterns could also be shown by illustrating some of the results of automated generalization operators. Aggregating buildings, for example, is often used for grouping a cluster of buildings within a specified distance. The outline of an aggregation will then be derived as the geometry of a new feature in the output feature class. Without the knowledge of building patterns, context and additional attribute information, buildings pertinent to a distinct spatial region could be marred with other scattered ones, causing the loss of semantic information in the output space. Figure 1 illustrates a block of a map with the application of aggregation. The above figure is the original map where alignment and 'Z' patterns of buildings are perceivable. The figure below shows an aggregated result on top of the original buildings. The aggregation is produced with the improved Aggregate Polygon tool to be released in ArcGIS 9.3. It can be seen that the 'Z' shaped arrangement and alignment styles cannot be treated and enhanced properly to stand out.



'Z'- and alignment patterns perceivable from the buildings in the block.



The patterns are not standing out and cannot be operated individually.

Figure 1. Aggregation without knowledge of patterns

1.2 Existing Research on Building Patterns

Recognition of building patterns has been a research subject for the past decade, starting from investigation of methods of measuring intrinsic properties within and between buildings [Hangouët 1998; Regnauld 1998; Christophe and Ruas 2002], and moving forward to recent calls for viewing maps universally as a collection of patterns such that symbolization can be uniquely applied for emphasis and quality [Mackaness and Edwards 2002]. With the perspective of structures involving buildings, blocks, and towns, Boffet [2001] proposed a method of classifying settlement areas where open spaces constitute an important class of spatial objects.

Timpf [1997] discussed an interesting multi-scale hierarchical spatial model for cartographic data. The cartographic objects, which would be created and accessed as a directed-acyclic graph, are dynamically selected for rendering from individual semantic classes based on the principle of equal information density. The data model is able to support intelligent zooming by drawing cartographic sketches quickly in appropriate scales, at the expenses of storing pre-generalized cartographic objects. The proposal, of accommodating data about 1) links to objects at another level and 2) the representation information necessary for rendering cartographic objects in the tree nodes, is worth further exploration.

Lee and Hardy [2007] highlighted the importance of geographic context and patterns while doing generalization, and explained methods of exploring and expressing some of the patterns using ESRI geoprocessing tools.

1.3 Objectives of this Research

Various simple and complex patterns can be observed with bare eyes while visualizing maps containing buildings at appropriate scales. Our first objective is aimed at providing flexibility for operators to specify conditions with which a pattern of buildings can be identified. The method is to devise a set of parameters to be measured against buildings and associated areas. The parameters, together with the devised methods for the evaluation of them, serve as a pattern template with which building features will be filtered. Pattern templates will be implemented as software objects to be added into an expandable catalog of patterns.

The second objective is to describe the underlying data structures to support a spatial context wherein searches and pattern matching processes are conducted. The issues of persisting the patterns and their associated features will be discussed as a subsequent research objective. Finally, the applications of building patterns will be explored, initially within the context of map generalization.

2. A PARAMETRIC MODEL OF BUILDING PATTERNS

Unlike a supervised pattern recognition method working on imagery data where shape templates are used wholly for training candidates in the output space, the method of identifying building patterns out of vector-based features, described in this paper, uses a set of controlling parameters as a specification to link buildings together forming a pattern. Like a learning process applied in the imagery world where neighborhoods are searched, the proposed method probes an intended pattern from sets of natural neighbors. This section discusses atomic building features and basic controlling parameters used in pattern templates.

2.1 Abstraction of Buildings

For simplicity and convenience, an oriented minimum bounding rectangle (MBR) of a building will be used to encapsulate its micro-level building detail and to characterize its relationship with other buildings. The operations on the MBR involve the indices of its four corners (indexed 0 – 3, clockwise) and four edges (Figure 2), as well as the orientation and area properties.

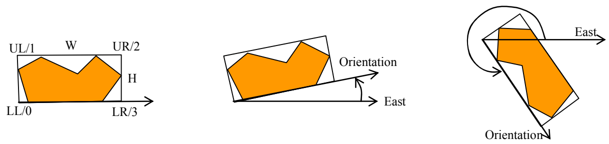


Figure 2. Building, MBR, and defining notation

While identifying patterns, the geometric properties of the MBR and of the enclosed building are used to discriminate buildings that are not "similar" to the ones in a search. Table 1 lists the parameters that are employed during the process. The efficiency of evaluating the parameters matters when processing large number of buildings. The properties revealed from MBRs should primarily be considered.

Parameter	Description
Size $A_{building}$	The actual area of a building.
Size A_{MBR}	The area of MBR
Orientation	For consistency, the orientation of an MBR is designated to be determined by its major axis which is always directed toward the East half of the plane. Orientation is thus measured as the angle starting from the East axis and rotates, counter-clockwise, to the directed major axis.
Elongation	A rough measure of squareness of a building, the ratio of the length of the major axis of MBA over that of the minor axis, W/H.
MBRFullness	A measure of being fulfilledness of a building within the MBR, the ratio of building area over that of the MBR, $A_{building}$ / A_{MBR}.
Complexity (not yet applied in prototyping)	A measure of irregularity of a building, considering its boundary and structure complexities (BC and GC). $C = w * BC + (1\text{-}w) * GC$. [Su et al. 2006]

Table 1. Parameters used to describe the shape of a building

2.2 Structural Parameters for Relating Buildings

The parametric model allows operators to specify "constraints" that the concerned buildings need to satisfy. It is critical to understand the set of parameters designated to control the freedom of the pieces involved in a pattern. In a pattern-match process, a building will be initially probed to be a part of the pattern and a neighborhood search will be conducted to look for the remaining parts to satisfy the specification. The candidate buildings will be filtered through the "similarity", discussed above, and the "structural fitness" criteria shown in the table below. The graphic illustrations of the structural parameters are shown in Figure 3.

Parameter	Description
Distance, D	The distance between two building MBRs. $D = f(\text{MBR1, MBR2}),\ D \in [0, R)$
OrientDiff	The acute or the obtuse angle between orientations of two consecutive MBRs. OrientDiff = orient1 – orient2, where OrientDiff $\in$ [0 .. 180)
GOrientDiff	Global Orientation measures the general sense of an elongated pattern. The Global Orientation Difference measures the change

	of the general sense when a new building is added to the pattern. GOrientDiff = $GOrientDiff_{old}$ - $GOrientDiff_{new}$, where GOrientDiff ∈ [0 .. 180)
SizeRatio	The ratio of larger MBA area over smaller one. SizeRatio = area1/area2, where area1 > area2. SizeRatio ∈ [1 .. R)
ElongationDiff, Δ	The difference between elongations of two MBRs. Δ = w1/h1 – w2/h2, where w1/h1 > w2/h2. Δ ∈ [0 .. R)
FacingRatio, FR	The ratio of projected length, *f*, shared by two Facing Edges, fe1 and fe2, over the longer Facing Edge. FR = *f* / max{ *length(fe1)*, *length(fe2)*} ∈ [0 .. 1]

Table 2. The structural parameters to group buildings

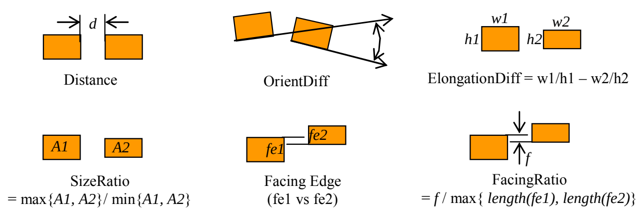
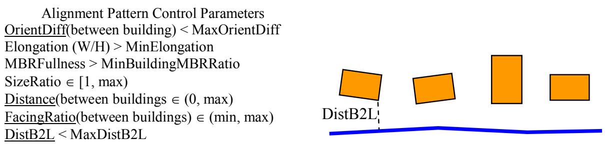


Figure 3. Measures relating one building to another

2.3 Pattern Characteristics

Typical patterns consist of one [1] or more buildings that collectively form a simple stroke or shape. With the structural parameters, the concerns are now about formalizing essential parameters necessary to articulate a pattern. It is important to note that the formalism not only dictates the variables to be defined with a pattern template object, it also reveals the computations to be implemented within such a template object (Figure 4). Of the parameters characterized, the ones underlined are mandatory and the others are optional.

For a given set of data, it is up to an operator to decide whether certain patterns need to be identified for further treatment such as generalizing. The parametric model provides the capabilities of specifying new building patterns and modifying parameter values of existing ones.



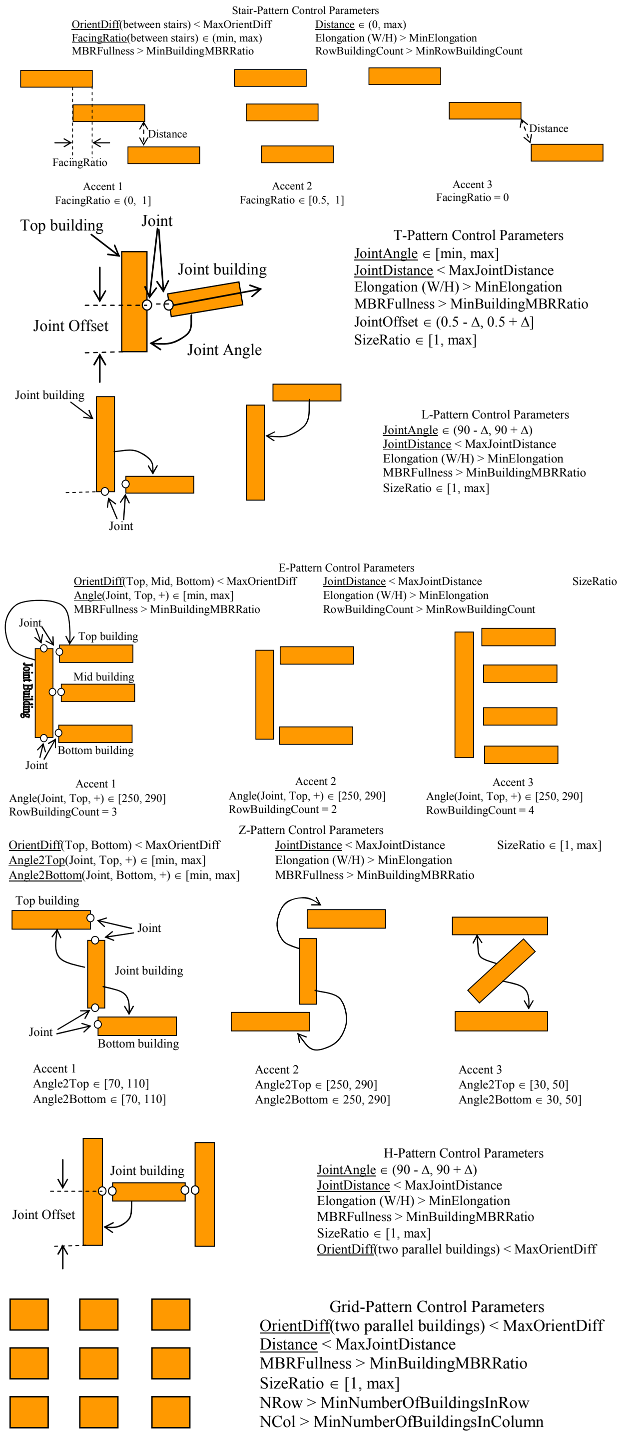


Figure 4. Controlling parameters and their measures

2.4 The Built-up Pattern

In generalizing maps from large to smaller scales, blocks of buildings are often replaced with polygons symbolized as built-up areas, if the density of buildings is higher than a threshold and no special representations for any of the buildings are necessary. It is desirable for the automation of generalizing of built-up areas to consider a non-uniform distribution of buildings within a block, such that open spaces could be identified on the map.

[1] Digitization may have merged buildings of a pattern as one feature. The detection of a single building pattern will not be elaborated in the paper.

The 'Built-up' pattern is designed to satisfy the scenarios. A built-up area, whose boundary is generated by a building aggregation operator, is defined here as a polygon enclosed within a block. An open space is "dual" to a built-up area within a block. A Built-up pattern may consist of at least one built-up area with or without open spaces. The parametric specification of the Built-up pattern is shown in Figure 5.

Note that an open space can only exist when FillingType is NonUniform and when the open space can have an empty inside circle greater than a specified minimum area. The reason of using an empty inside circle is for open spaces to be large and visually significant, instead of being composed of small and narrow areas. It is possible to add an "OpenSpace" pattern so that boundaries of open spaces can be defined and symbolized. The detail how this will be done will not be discussed in this paper. Figure 5 shows a Built-up polygon at the left and two generalized polygons based on an E-pattern and Alignment patterns.

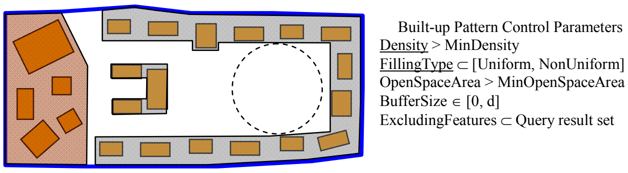


Figure 5. The Built-up pattern specification (manual drawing)

Cartographers would not use a built-up area to cover blocks containing large, special, or high-rise buildings which themselves may form special patterns and be symbolized differently. The ExcludingFeatures parameter is needed to serve the purpose, which requires database queries. The following section explains the implementation of the parameters discussed above.

2.5 The XML Model for Pattern Specification

An operator's intention to identify patterns from map data can be conveyed to system through an XML model where pattern names and the associated parameters are specified. An XML model can host multiple patterns as well as named parameters that are commonly concerned in the processing of all patterns. It is envisioned that a plug-in tool could be designed to facilitate the generation of the XML model through a GUI where operators can sketch, visualize, and customize a pattern template. The lists below illustrate the specifications for an Alignment pattern and a Z-pattern. Note that not all parameters are specified for the Alignment pattern, which relaxes the criteria for buildings to be in an alignment group.

```xml
<Template>
    <Name>Alignment</Name>
    <Type>Building</Type>
    <Parameter>
        <Name>Maximum Orientation Difference</Name>
        <Value>30</Value>
        <Unit>Degrees</Unit>
    </Parameter>
    <Parameter>
        <Name>Minimum Facing Ratio</Name>
        <Value>0.5</Value>
    </Parameter>
    <Parameter>
        <Name>Maximum Distance</Name>
        <Value>10</Value>
        <Unit>Meters</Unit>
    </Parameter>
    <Parameter>
        <Name>Size Ratio Tolerance</Name>
        <Value>3</Value>
    </Parameter>
    <Parameter>
        <Name>Maximum Building Line Distance</Name>
        <Value>20</Value>
        <Unit>Meters</Unit>
    </Parameter>
</Template>
```

List 1. The specification of an Alignment pattern

```xml
<Template>
    <Name>ZPattern</Name>
    <Type>Building</Type>
    <Parameter>
        <Name>Accent</Name>
        <Value>1</Value>
    </Parameter>
    <Parameter>
        <Name>Maximum Orientation Difference</Name>
        <Value>10</Value>
        <Unit>Degrees</Unit>
    </Parameter>
    <Parameter>
        <Name>Angle to Top</Name>
        <Value>80, 100</Value>
        <Unit>Degrees</Unit>
    </Parameter>
    <Parameter>
        <Name>Angle to Bottom</Name>
        <Value>80, 100</Value>
        <Unit>Degrees</Unit>
    </Parameter>
    <Parameter>
      <Name>Maximum Joint Distance</Name>
        <Value>5</Value>
        <Unit>Meters</Unit>
    </Parameter>
    <Parameter>
        <Name>Size Ratio Tolerance</Name>
        <Value>2</Value>
    </Parameter>
    <Parameter>
        <Name>Minimum Elongation</Name>
        <Value>3</Value>
    </Parameter>
    <Parameter>
        <Name>Minimum Rectangularity</Name>
        <Value>0.8</Value>
    </Parameter>
</Template>
```

List 2. The specification of an Z-pattern

Within the XML model, the ExcludingFeatures parameter could be implemented as the "Exclude" keyword tag with syntax listed below. The keyword should be placed within the "Template" tag block.

```xml
<Exclude>
    <Name>Large Features</Name>
    <Field>
        <Name>Area</Name>
        <Value>3000</Value>
    </Field>
    <Name>High Rise Features</Name>
    <Field>
        <Name>Height</Name>
        <Value>20</Value>
    </Field>
</Exclude>
```

List 3. XML syntax for an 'Exclude' database query

2.6 Catalog of Patterns

Once communicated with the pattern recognition system, the pattern templates contained in the XML model will be read and the corresponding template objects will be instantiated with the parameters. The object structure of basic patterns using the object-oriented paradigm is illustrated in Figure 6. The abstract Pattern class supports general methods such as IdentifyPatterns, Add, Remove patterns, and GenerateOutline. The implementation of these methods is the responsibility of individual pattern objects.

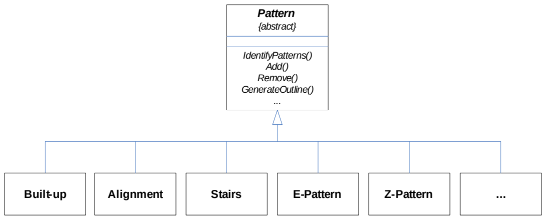


Figure 6. The pattern class and objects.

As new pattern templates could be discovered with various data sources, it is of paramount importance that the catalog of templates is open for additions and that the implementation of a new template object is relatively easy. It is envisioned that the ease of the object design could be met by providing a commonly required context object, to be explained below, and a specification of standard computations associated with each named parameter of the parametric model. The standard procedures evaluating pattern characteristics will not be discussed in this paper.

3. IDENTIFYING PATTERNS

Described in this section are the procedures required for the pattern matching process. Supportive data structures, commonly needed for all pattern identification, are contained and serviced by a software component named Spatial Context. With the structural support, individual pattern objects are focused on accessing neighboring buildings and evaluating relevant controlling parameters.

3.1 The Spatial Context

A spatial context is referred here as a software component that is responsible for creating and maintaining geometric structures of concerned features as well as any interested contextual information. The main function of the component is to support all required spatial queries about proximity, neighborhood, or well-defined spatial relations. For the application of identifying building patterns, the concerned features are buildings from the same feature class, whilst the contextual information may come from a combination of transportation (roads, rivers) lines, terrain landscape polygons, or landmark points.

Our current experiment involves only roads as the contextual information and the main geometric structure is the Delaunay triangulated TIN, supported by ESRI ArcObjects. With the help of the TIN, the spatial context object generates the partitioned blocks that contain buildings. For each partitioned block, the boundary lines are split at the boundary vertex that anchors an angle greater than a specified parameter value. Then a TIN structure is built over the contained buildings (Figure 7).

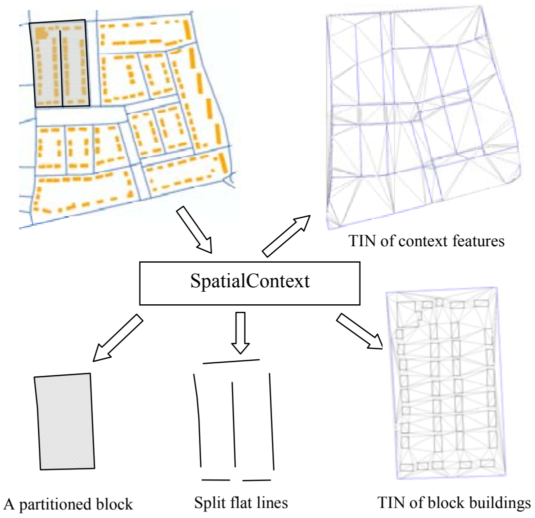


Figure 7. The Spatial context object

The boundary lines are primarily used for identifying the alignment patterns, to be explained later. The process of splitting a block polygon boundary needs a user specifiable angular parameter. The effect of the parameter ensures that a reflection angle of an alignment pattern will not be too small. In addition, the short sharp turns within a generally straight line will be removed by considering the minimum MBR edge of the contained buildings. Sharp turning segments longer than the length of the minimum MBR edge will be split. Note that dangling lines within a block will also be searched and used for aligning.

The TIN of contained buildings is used for neighborhood queries during pattern recognition process.

3.2 The Matching Process

Using the list of partitioned blocks, the pattern-matching goes from block to block. When a Built-up pattern is desired and FillingType is Uniform, there is no need to match other patterns as the block will be filled entirely if density is higher than specified. A non-uniform Built-up pattern will then be processed after all other patterns are identified. If an Alignment pattern is specified, buildings aligned to split lines will be grouped first. A lateral relationship between a line and buildings is sought. This is done by projecting the building MBR to lines and sorting the projections with respect to the start of a line (Figure 8). Where there are multiple projections onto the same section of a line, the building closer to the line will be picked. Corner buildings are projected onto adjacent lines. Their association to only one line is determined by factors such as the distances to lines and similarities to the adjacent groups.

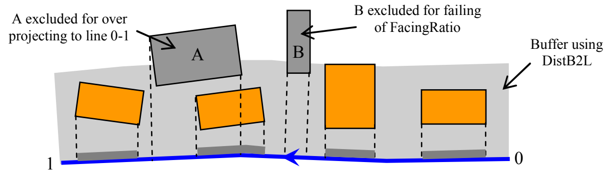


Figure 8. Aligning by projecting

Candidate buildings from the projection are further screened by the constraining parameters. As is shown in the diagram, building B will be eliminated for not satisfying FacingRatio.

Buildings not yet processed, or rejected by a prior pattern-matching, are tested with other intended pattern templates. This is done by taking unprocessed buildings one at a time and sending it, together with the spatial context, to template objects in turn for a match. Within each object, neighboring buildings will be searched and relating parameters computed. Once a complete pattern is determined, all buildings in this pattern are marked processed and will not be processed again.

For patterns involving a small number of buildings, such as Z- and E-patterns, the linking buildings are intentionally probed by querying the other structural parts, like the top and bottom buildings of a Z-pattern. For extended patterns that require the knowledge of neighbors beyond the immediate proximity, a variation of DFS (Depth-first search) or BFS (Breadth-first search) are applied to expand the candidate buildings.

3.3 Hierarchical Geodatabase Structures

At the end of the pattern-matching, the block-pattern-building relationship will be created (Figure 9).

Blocks

OID	BLOCK_ID	SHAPE
1	1	Polygon
2	2	Polygon
...		

Patterns

OID	BLOCK_ID	PATTERN_ID	PATTERN_NAME	SHAPE
1	1	1	Alignment	Polygon
2	1	2	Alignment	Polygon
3	1	3	Built-up	Polygon
4	2	4	Z-pattern	Polygon
5	2	5	Z-pattern	Polygon
6	2	6	Z-pattern	Polygon
7	2	7	Built-up	Polygon
...				

Pattern-Buildings

OID	PATTERN_ID	BUILDING_ID
1	1	4014
2	1	3579
3	1	4374
4	1	396
...		
9	2	4512
10	2	4015
11	2	2270
...		

Figure 9. Block-pattern-building relationship

Assuming building blocks and patterns are generated for a theme of "urban map", the geodatabase would have feature classes and their relationships stored as shown in Figure 10. Note that blocks can be combined to form super blocks which can still have patterns or building directly contained.

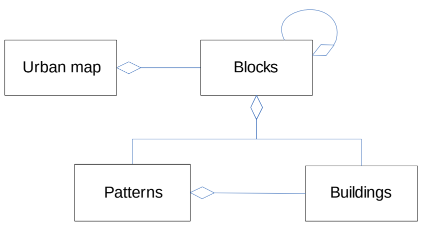


Figure 10. The block-pattern-building relationship

Combining blocks means to eliminate boundaries belonging to other feature classes known to the spatial context object. The boundary semantics (river, road) and classification (highway, local street) would be explicitly needed for the process. More research is needed on merging patterns.

3.4 Map Generalization Using Patterns

One of the generalization treatments on patterns would be to derive an aggregated outline for a pattern object. It would be optional to snap the aggregated outline of a built-up or an alignment pattern to the affiliated lines, as is shown in Figure 11, produced with the on-going research prototype program. Patterns can also help the application of other generalization operators. For example, for a generalization system using an optimizing approach, constraints and actions could be defined at the pattern object level for displacement, typification, enhancement, etc. Possible overlapping of pattern outlines would also be resolved.

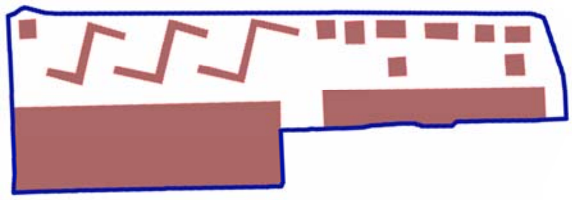


Figure 11. Aggregation considering patterns

4. CONCLUSIONS

The paper draws the following conclusions:

- Building patterns are vital to good generalization
- An automated system for detection of such patterns is feasible
- XML encoding is an efficient and versatile method of defining templates and parameters

Notes:
The author would like to thank Dan Lee of ESRI and Paul Hardy of ESRI Europe for their insightful comments and editing. The idea of the XML parametric model presented in this paper was inspired by a similar approach taken in another research project conducted at ESRI by Jean-Luc Monnot.

The content discussed in this paper involves research prototypes, and should not be interpreted as any commitment by ESRI to provide specific capabilities in future software releases.

Map data used in some of the figures is TOP10NL, courtesy of Netherlands Kadaster.

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