

## Research Article

# Integration of Space Syntax into GIS: New Perspectives for Urban Morphology

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### Abstract

Although space syntax has been successfully applied to many urban GIS studies, there is still a need to develop robust algorithms that support the automated derivation of graph representations. These graph structures are needed to apply the computational principles of space syntax and derive the morphological view of an urban structure. So far the application of space syntax principles to the study of urban structures has been a partially empirical and non-deterministic task, mainly due to the fact that an urban structure is modeled as a set of axial lines whose derivation is a non-computable process. This paper proposes an alternative model of space for the application of space syntax principles, based on the concepts of characteristic points defined as the nodes of an urban structure schematised as a graph. This method has several advantages over the axial line representation: it is computable and cognitively meaningful. Our proposal is illustrated by a case study applied to the city of Gävle in Sweden. We will also show that this method has several nice properties that surpass the axial line technique.

## 1 Introduction

Over the past two decades, space syntax has been proposed as a new computational language to describe spatial patterns of modern cities (Hillier and Hanson 1984, Hillier 1996). The notion of syntax, derived from linguistics, refers to relationships between different spaces, or interactions between space and society. These principles support the belief that spatial layout or structure has great impact on human social activities. From its origin in urban research, space syntax proposes a language of space that is of interest for many research and application areas involved in the description and

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analysis of spatial patterns in the city. Through the structural analysis of an urban environment, urban planners can derive a better understanding of the evolution of urban areas, and gain more insights to help with the design of new urban layouts. Using space syntax principles, human displacement patterns in the city can be analyzed, mainly by considering the degree to which urban spaces are integrated and connected. Typical applications of space syntax include pedestrian modelling, criminal mapping, and way-finding processes in complex built environments (Peponis et al. 1990, Hillier 1996, Jiang 1999). All these investigations tend to be based on the assumption that spatial patterns, or structures, have a great impact on human activities and behaviours in urban environments. Many empirical studies have demonstrated the importance of space syntax for the modelling and understanding of urban patterns and structures (Hillier 1997, Holanda 1999).

A collaborative integration of space syntax into GIS offers new perspectives to the development of urban morphology studies. Scientists can access large geographical databases and combine the modelling capabilities of GIS with the potential of morphological analysis (Moudon 1997). However a successful implementation of space syntax principles into GIS implies a preliminary investigation on how the space syntax view of space relates to, or is different from current GIS models of space.

There are also some important recent discussions within the GIS research community on how current spatial models developed within GIS correspond to the way human beings perceive and act in their environment (cf. Hirtle and Frank 1997, Freksa and Mark 1999). These extend the conventional geographical frame of reference to large- and small-scale spaces. Large-scale space is beyond human perception and cannot be perceived from a single vantage point; while small-scale space is presumably larger than the human body, but can be perceived from a single vantage point. In a related work we illustrated how the concepts of large- and small-scale spaces provides some modelling fundamentals for space syntax principles (Jiang et al. 2000). A large-scale urban space can be partitioned into a finite number of small-scale spaces. Using such a partition, the degree to which small-scales are interconnected or integrated can be analysed.

The conventional geographical models and modelling concepts used within GIS need to be extended towards some alternative cognitive-oriented models that support the way humans perceive and act in their environment. In the context of a collaborative integration between GIS and urban morphology, such an analysis is important as some of the modelling concepts used within urban morphology belong to such a class of alternative views of space. In fact urban morphology, as applied through the theories and tools of space syntax, provides a computational representation of an urban space in which a graph decomposition of the so-called free space – the space within which human beings are able to move from one place to another in the city (a cognitive model of space in one sense) – gives a set of parameters that allows scientists to understand the basic functions and properties of an urban structure.

A computational implementation of space syntax within GIS requires at least a re-engineering of the spatial models used within GIS as the notion of free-space is a relatively abstract concept, and is not available as such within GIS. In addition, current applications of the space syntax do not give a precise answer on how such an integration should be made from a computational point of view, apart from some empirical implementations which are program embedded and not clearly documented (Hillier 1997, Holanda 1999).

Based on the fact that current computational implementations of space syntax, mainly using the concept of axial lines, are ambiguous and not computable, we propose an alternative modelling representation of an urban structure. Our approach uses characteristic points, namely nodes, parts of the graph representation of an urban structure. This paper will show that our graph representation is at least equivalent to the conventional axial lines approach and that it supports a computable derivation of space syntax parameters. The principles of this modelling approach and its main properties are illustrated through a case study in the city of Gävle in Sweden.

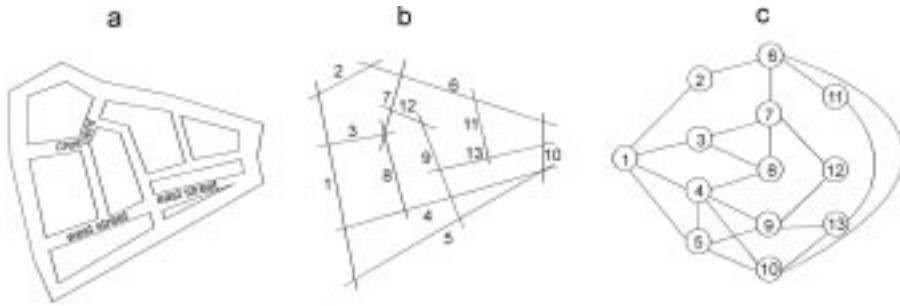
The remainder of this paper is organised as follows. Section 2 briefly introduces the conventional axial line-based approach used in many space syntax studies, and discusses its limitations. Section 3 develops and motivates an alternative and more robust model based on characteristic points. Section 4 proposes a comparative analysis of our characteristic points approach over the axial lines approach through the application of these modelling concepts to a case study. Finally, section 5 draws some conclusions and describes some further work that is now underway.

## 2 Axial line-based space syntax: Principles, potential and limitations

### 2.1 Axial line-based space syntax: Principles

The initial idea of space syntax comes from an attempt to understand evolution and flows within the city: evolution by analyzing the way a built environment has developed as it has, flows by studying some social activities such as people displacements in the city. The axial line-based representation of an urban structure is the earliest approach of the space syntax (Hillier and Hanson 1984). Axial lines are used to represent directions of uninterrupted movement and visibility, so they represent the longest visibility lines in two-dimensional urban spaces. Over the past two decades, this approach has been widely applied to solving various problems in urban systems such as prediction of pedestrian and vehicle flows, crime analysis and human way-finding process (cf. Peponis *et al.* 1990, Hillier 1997, Holanda 1999). A set of axial lines, that mutually intersect and cover a whole free space, is called an axial map. According to Hillier's initial definition, an axial map constitutes the least number of longest axial lines (Hillier and Hanson 1984). We herewith briefly describe the axial line-based space syntax approach, and analyse the potential and limitations for its integration into GIS.

From the point of view of human spatial perception, we consider that an axial line is a vista space that is small enough to be perceived from a single vantage point of view (Jiang *et al.* 2000). Through the representation of a large urban environment by a finite number of vista spaces, and how each vista space is connected or integrated to others, the spatial structure of the urban environment is analyzed. The derivation of an axial map for an urban space mainly relies on prior definition of a convex partition of free space. The "convex map" is said to consist of the least number of largest possible convex spaces needed to cover the entire area (Hillier and Hanson 1984). Thus the derivation is based on human judgement whose formalization is not a straightforward task. The algorithm used can be described as follows: starting from the identification of the longest axial line, actually the longest visibility line, and then the second longest axial line and so on until the whole free space is covered by the intersected axial lines. To illustrate the main principles of this approach, Figure 1a represents a fictional urban



**Figure 1** (a) A fictive urban system, its (b) axial map, and (c) connectivity graph

system. The derivation of its axial map starts from line 1 then 6 then 5 then 4, . . . and finally the resulting axial map consists of 13 axial lines as shown in Figure 1b. It should be noted that the example illustrated is a relatively simple one in which free spaces, i.e. streets, stretch linearly.

In terms of how each line intersects other lines, various morphological parameters can be derived for the analysis of an urban structure. These parameters include the *connectivity*, *control value*, *local* and *global integration*. The *Connectivity* of an axial line measures the number of lines that directly intersect that given axial line. It also denotes the number of immediate neighbourhoods of an axial line. The *control value* of an axial line is given by the sum of the inverse *connectivity* values of the immediate neighborhoods of this axial line. Literately the *control value* shows the degree to which each axial line “controls” its immediate neighbours. In order to introduce the notion of integration, let us first define the notion of *depth*. The *depth* of an axial line is defined by the number of lines distant from a given number of steps to that axial line. While connectivity considers immediate neighbours, depth considers k neighbours.

In order to introduce the calculation principles of *depth* and *connectivity*, let us assume some variables in the connectivity graph (Figure 1c). The connectivity graph is the dual graph of an axial map, and it is derived by representing axial lines and line intersections from an axial map as nodes and links, respectively (Figure 1c). For any particular node in the connectivity graph, the shortest distance (or steps) far from the node is denoted by  $s$  ( $s$  is an integer), the number of nodes with the shortest distance  $s$  is denoted by  $N_s$ , the maximum shortest distance is denoted by  $l$ . Using the expression,  $\sum_{s=1}^m s \times N_s$  space syntax parameters are calculated as follows:

$$\sum_{s=1}^m s \times N_s = \begin{cases} \text{connectivity} & \text{iff } m = 1 \\ \text{local depth} & \text{iff } m = k \\ \text{global depth} & \text{iff } m = l \end{cases} \quad (1)$$

where  $1 < k < l$ , usually we adopt three steps for the calculation of *local depth*, i.e.  $k$  is equal to 3 (this means that we consider those lines within three steps from an axial line). We can also note that *connectivity* is equivalent to *local depth* if  $k = 1$ .

Let us take the example of the axial line identified as number one (equivalent to node one in the dual graph) in Figure 1. This line intersects four lines, so the connectivity of the axial line one is 4. The immediate neighbourhood of line one are lines 2, 3, 4, and 5, their respective *connectivity* values are 2, 3, 5, and 4. So the *control*

value of the axial line one is equal to  $\frac{1}{2} + \frac{1}{3} + \frac{1}{5} + \frac{1}{4}$ . Overall this axial line number one has four neighbourhoods one step away, five neighbourhoods two steps away, and three neighbourhoods three steps away (herein the concept of steps is equivalent to that of shortest distances). So *global depth* is equal to  $4 \times 1 + 5 \times 2 + 3 \times 3$  if  $m = 3$ . If  $m = 2$ , then local depth with two steps away is equal to  $4 \times 1 + 5 \times 2$ .

Another notion related to local and global integration is the basic properties of symmetry and asymmetry. Mathematically, the relationship of two nodes *a* and *b* are said to be symmetric if the relationship of *a* to *b* is the same as the relation of *b* to *a*. For example, the relation of *a* and *b* to *c* in Figure 2a is symmetric. In contrast, the relation of *a* to *b* with respect to *c* in Figure 2b is not symmetric, because the relation of *a* to *b* with respect to *c* is not the same as the relation of *b* to *a*, and from *a* one must pass through *b* to *c*, but not vice versa.

The integration value is actually a measure for relational asymmetry and it is measured with either *Relative Asymmetry* (RA) or *Real Relative Asymmetry* (RRA). These two variables are calculated as follows:

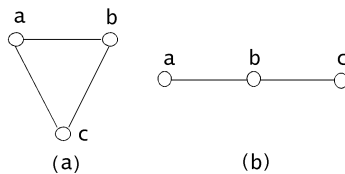
$$RA_i = \frac{2(MD - 1)}{(n - 2)} \quad \text{and} \quad RRA_i = \frac{RA_i}{D_n} \tag{2}$$

where *n* is the number of axial lines of an urban system,

$$D_n = \frac{2\{n[\log_2((n + 2)/3) - 1] + 1\}}{(n - 1)(n - 2)}$$

and this D-value gives the standardized value for the integration value from mean depth (MD) (Kruger 1989). The mean depth is given by the global depth (see Equation 1) divided by  $n - 1$ . In the following case study as well as in space syntax software like Axman and Axwoman, integration is a reciprocal function of RRA. This relationship means that the bigger the integration value the more integrated the axial line is. Axman is a space syntax program based on the Macintosh computer (see <http://www.spacesyntaxlaboratory.org/software/index.htm> for more details), and Axwoman is a freeware space syntax program implemented as an extension of the ArcView GIS (see <http://www.hig.se/~bjg/Axwoman.htm> for more details and downloading instructions).

Depending on the *depth* used, that is, local versus global, the matching *integration* value is called *local* versus *global integration*. *Local integration* considers both immediate and non-immediate neighbourhoods: that is, lines that intersect each immediate neighborhood and so on recursively up to a few steps away. *Global integration* considers both immediate and non-immediate neighbourhoods up to *k* (all) steps away. Both *connectivity* (or *control value*) and *local integration* are local



**Figure 2** Relational symmetry and asymmetry (Hillier and Hanson 1984)

parameters, as they only consider immediate neighbouring lines or lines within a few steps. In contrast, global integration considers all other lines and is a global parameter.

## *2.2 Limitations of the axial line-based space syntax*

One limitation of the axial line-based space syntax comes from the fact that axial lines do not exist in reality: it is a concept used to represent small-scale spaces. Thus these axial lines are not directly represented as modelling units within existing urban GIS (i.e. the way urban networks are segmented within an urban GIS does not directly match axial line units). Additionally their derivation is not computable, i.e. no automatic methods to draw an axial map exist. More critically assigning morphological properties to one line is relatively illogical: a line is too large to constitute a basic morphological unit. In other words there is no reason to assume for example that an axial line has a unique accessibility. The limitations of the space syntax therefore take two forms: there are practical limitations in terms of GIS database implementation and cognitive limitations from a spatial modelling point of view.

From the principles of the space syntax approach presented above, we can remark that the complexity of the derivation of an axial map is high from a computational point of view. This is because, according to the sequential rule of deriving and drawing the axial lines, the derivation starts from the identification of the longest axial line, and then the second longest axial line, and so forth. Overall, the axial map provides the least number of axial lines. Based on human judgement, it seems possible to complete the axial map of an urban system, but the process is very time consuming for a large city. Furthermore, no one can guarantee that axial maps created at different times are precisely consistent, not to mention maps created by different people. The requirement that an axial map consists of the least number of axial lines is hard to satisfy. In other words, there is no way to ensure that the axial maps created are made of the least number of axial lines.

On the other hand, a valid application of the space syntax approach has to be based on an axial map effectively composed of the least number of lines. Otherwise, the analysis is less meaningful, because the overall number of lines will not be representative of the urban structure. So far the derivation of an axial map still relies on human judgement to draw individual lines, so no automatic solution has been identified, particularly for large cities, within the space syntax research community (cf. Peponis et al. 1998).

In many urban GIS databases, a street is often partitioned according to logical constraints or some physical properties and not with the vista properties of the space syntax approach. One street modelling unit may also be partitioned into several lines in the corresponding axial map if the street is curved (e.g. the crescent was partitioned into two axial lines in Figure 1). Or alternatively several streets may be represented as one axial line (e.g. both west street and east street together represent an axial line in Figure 1). More complicated cases may occur in sparse urban areas where axial lines have no such simple corresponding relationships at all. Thus space syntax analysis results cannot be easily assigned to streets in GIS databases. In dense urban areas where streets stretch linearly as illustrated in Figure 1, one can check how axial lines are related to corresponding streets, possibly through a complete breakdown of the streets by intersections, and set up such a correspondence for comparative purposes. Certainly this is not a satisfactory solution, in particular when dealing with the modelling of a

large city where there are many sparse areas. Indeed, morphological properties obtained through space syntax are assigned to axial lines, and not to the street object as a whole within the GIS database. Therefore, these incompatibilities lead to some critical constraints and uncertainties as the morphological properties of the axial lines are based on a non-deterministic process.

From a cognitive perspective, an axial line actually gives a representation of a small-scale space that can be perceived from a single vantage point view. A typical example of a small-scale space is a straight street segment. However, the visual field observed from one end of a line is different from that observed from the other end of a line. More precisely, the visual fields from any individual standing points along an axial line are different. Thus, it is not logical to assign the same morphological properties to an axial line, and it helps to justify our point-based approach.

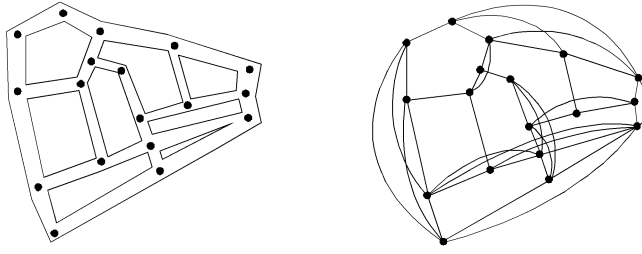
### 3 A new approach: The point-based space syntax

Based on these practical and cognitive limitations of the axial line space syntax, we hereby advocate a spatial modelling alternative in order to provide a computable process for the derivation of space syntax parameters. Our approach is based on the flexible concept of characteristic points derived from urban street maps (e.g. central line street networks). These points are representative of the network structure in the sense that, within an urban environment, *people make a navigation decision* on where to head next when they reach these characteristic points. For example, if one comes to a crossroad, one would have three choices to make: to go left, right, or ahead. These points include road junctions and turning points (i.e. a turning point is defined as the peak of a curve). From a morphological point of view, all those directly visible points from a characteristic point determine the *visual connectivity* of the point. Similarly the number of steps required to reach every other characteristic point determines the *integration value* of this point.

To illustrate this approach, let us take the urban system presented in the previous section. The first step of this approach is to identify these characteristic points (Figure 3a). This procedure is relatively easy compared to the derivation of the axial lines, and computable (see Algorithm I in the Appendix). The next step is to determine how each characteristic point is visible to others, thus connectivity values are derived (Algorithm II) and a visibility graph is generated as shown in Figure 3b. The visibility graph is also represented as an adjacency list format for further computation of the *integration value* (Algorithm III).

In order to describe the method of deriving characteristic points, let us introduce some concepts often used in GIS graphic representation. *Arcs* represent linear features, for example a street network. Each arc is assigned an ID and its coordinates are defined as a series of x, y coordinates. *Nodes* represent endpoints and the locations where linear features connect. A *vertex* is denoted as a pseudo node, as a vertex is not considered as a “real” node where linear features connect.

Given a street network dataset, characteristic points constitute a superset of nodes in the street network. It includes all the nodes and a few vertex points whose distance to the straight line linking the two ending points of the arc is greater than a given threshold. In practice, it is relatively easy to choose a suitable value for this threshold depending on the curvature of the streets: the larger the curvature of the streets, the



**Figure 3** Characteristic points and visibility graph

bigger value of the threshold. The first algorithm reproduced in the Appendix can be used for deriving characteristic points.

Once the derivation of the characteristic points has been accomplished, the next step is to determine how each point is visible to others. Without loss of generality let us assume that the city represented is flat; that is, there is no variation in elevation. Thus one point is visible from another point if the line linking the two points does not intersect with any building polygons (see Algorithm II in the Appendix for further details).

The computations in Algorithm II lead to a graph of inter-visibility as shown in Figure 3. It should be noted that this graph is an unweighted graph with a value of 1 as the distance between two adjacent nodes. Then a variety of space syntax parameters can be calculated from the visibility graph. For instance, each point is given an *integration value* that defines how it is integrated to other points. In graph theory, the *integration value* has another name, the status (Harary 1959, Buckley and Harary 1990), which shows the positional status of a node within a graph. This value can be calculated with the third algorithm reproduced in the Appendix.

Our approach provides several advantages over the axial line based space syntax approach. Firstly, the semantics of point-based values is relatively precise, so the automation is completely possible compared to that of the axial map. The first algorithm reproduced in the Appendix provides a method for automatically deriving characteristic points from a street network dataset. Secondly, the point-based value is more appropriate as it supports the derivation of continuous changes in the space syntax values between two connected nodes. This reflects the spatial distribution of the accessibility as shown in the following case study. On the contrary, in the axial line based approach, assigning a morphological value to a straight street segment is relatively illogical, because accessibility along a long straight street should not be the same value. Thirdly, the data structure used by this approach is compatible with the node-edge graph models often used in GIS. In particular, several GIS surface analysis functions can be used to create morphological distributions based on the analysis of discrete point values.

Let us finally note that the derivation of space syntax values often practised within urban morphological studies should be considered as a valuable part of the derived GIS database. This should also include the visual perspectives given by the space syntax view of an urban structure as illustrated in the next section. In fact, such a view of the city should be also considered as an alternative representation of the city and as a part of the GIS database, since the space syntax analysis is often presented visually through the distribution of some morphological parameters across an urban space.



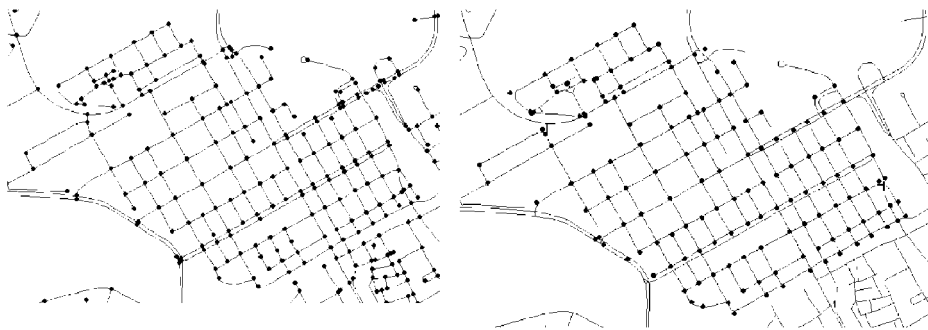
#### 4 Case study

In order to examine how feasible the proposed point-based approach is for modelling an urban space, and how the point-based analysis results conform to that of line-based analysis, we conducted a case study. We chose the mid-sized Swedish town of Gävle located to the north of Stockholm. Plate 2 (see plate section) shows maps of Gävle and the study area.

The case study served three purposes: (1) to automatically derive characteristic points from a streets network using Algorithm I; (2) to calculate and visualise all space syntax parameters which are assigned to characteristic points; and (3) to compare the analysis results obtained with the axial line-based and point-based approaches visually and statistically. Using the algorithm presented earlier, the characteristic points were automatically derived from the street network dataset, as shown in Figure 4a. The basic assumption for the case study is that the morphological structure of an urban system analysed from the point-based approach should be conformable to that of an axial line-based approach. For this purpose, characteristic points are derived from the axial map (Figure 4b), i.e. rather than directly from the street network. However, one can observe that these characteristic points are very similar to the ones that would be derived from a street network.

Based on Algorithms II and III, and taking into account the building polygons shown in Figure 5, space syntax parameters are calculated and saved into an attribute table for each individual node. The results are visualised using 3D scenes in which space syntax values are presented using the third spatial dimension for presentation purposes (Plate 3, see plate section). For the purpose of visual comparison, we used the same colour legend for the 3D scenes, namely an elevation colour legend. One can realise that white or grey represents the most connected or integrated locations, while green represents the most segregated locations. Through the visual comparison of Plates 3a and 3c, or Plates 3b and 3d, we can remark that the point-based analysis results are very similar to that of axial line-based analysis. A comparison of these results with the centre of Gävle characteristics illustrated that the white locations shown in Plates 3a and 3b do correspond to areas of commercial activities, similar to the type of correlation usually identified by axial line-based space syntax analysis.

In order to investigate how the point-based approach conforms to the axial line-based approach, we conducted the following statistical comparison. We derived point-based values such as *connectivity*, *control value*, *local integration* and *global*



**Figure 4** Characteristic points derived from (a) the street network versus (b) the axial map



**Figure 5** Buildings layer used to determine visibility of characteristic points

*integration* and made a sum of these values for all the points along each axial line. Then we examined how those values were correlated with line-based values. Figure 6 shows scatter plots with the x and y axes representing the line-based value and the sum of point-based values along each line, respectively. We can observe that there is a significant correlation between the line-based and point-based values. Detailed statistical analysis shows that  $R^2$  values for connectivity, control value, global and local integration are respectively 0.9563, 0.7175, 0.8373 and 0.9480. This means that the point-based approach does conform to the line-based approach in illustrating an urban structure.

In summary, this case study shows a basic procedure that illustrates how the point-based approach can be utilized to analyse an urban structure. Since this structural analysis is based on individual point values, many external socio-economic data, which are mostly point-based, can be also used for further analysis.

## 5 Conclusions

Although space syntax has been widely and successfully utilized by urban planners, the integration of its modelling capabilities and potential within GIS is still an ongoing problem from a computational point of view. We believe that such integration will facilitate the application and diffusion of space syntax capabilities and benefits towards any urban studies in which the structure and the function of the city is a component.

This paper proposes a brief introduction to the principles and benefits of the space syntax and develops an alternative and robust computational implementation that should facilitate its integration with GIS models. Our approach is based on characteristic points, defined as the nodes of a graph that represent the structure of an urban network. The properties and benefits of our proposal are discussed and validated by a case study applied to the city of Gävle in Sweden.

We plan to implement the proposed algorithms as an extension of the Axwoman prototype software. Instructions for downloading this free software can be obtained from <http://www.hig.se/~bjg/Axwoman.htm>. Further work concerned with the

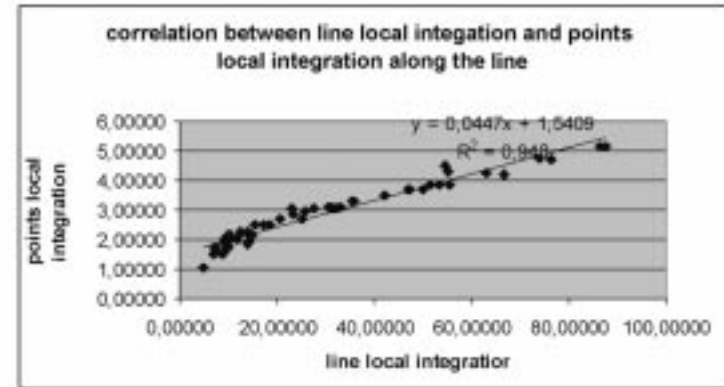
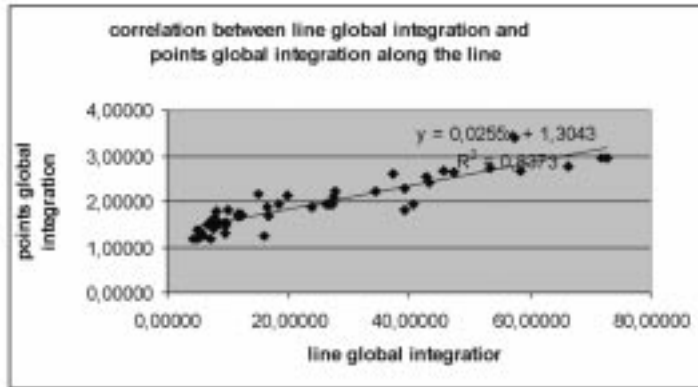
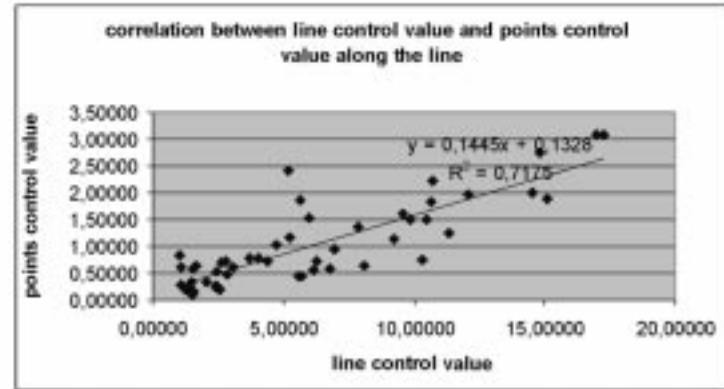
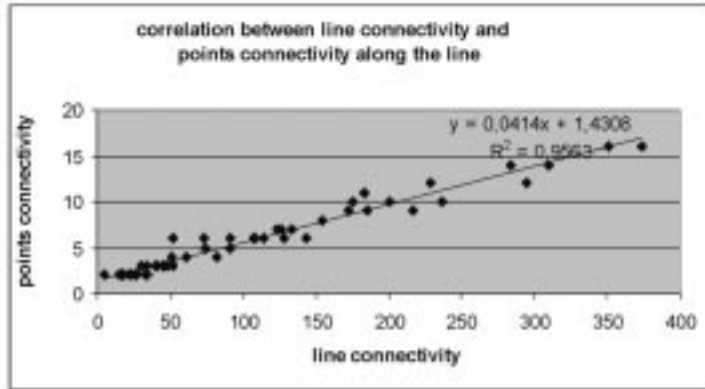


Figure 6 Scatter plots between line-based and point-based parameters

diffusion and application of the method towards urban studies such as pedestrian modelling, crime mapping and analysis and human way-finding processes, is now underway as well.

## Acknowledgements

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## Appendix: Algorithms used in the paper

Please note that the following algorithms are presented in a detailed format like program segments.

*Algorithm 1: Deriving characteristic points*

**arcList:** stores all arcs of a street network

nodeList: stores all nodes of a street network  
 vertexList: stores all vertex of each arc  
 turningptList: stores all turning points of a street network  
 cpList: stores all characteristic points of a street network

```

For each arc in arcList
  nodeList.Add (arc.ReturnNode)
  vertexList.Add (arc.ReturnVertex)
  if (vertexList.Isnotempty) then
    for each vertex in vertexList
      endPoint = arc.ReturnEnd
      startPoint = arc.ReturnStart
      line = Line.Make (endPoint, startPoint)
      dis = vertex.Distance (line)
      if (dis > threshold) then
        turningptList.Add (vertex)
      end ' end if
    end ' end for vertexList
  end ' end if
end ' end for arcList
cpList = nodeList + turningptList
  
```

*Algorithm II: Deriving the connectivity or visibility of each point*

```

polygonList: building polygons

for each aPoint in cpList
  bIndex = 0
  connectivity = 0
  for each bPoint in cpList
    ab = Line.Make(aPoint, bPoint)
    overlap = 0
    for each aPolygon in polygonList
      if (ab.Intersects(aPolygon)) then
        overlap = overlap + 1
      end
    end
    if ((overlap = 0)AND((aPoint=bPoint).not)) then
      connectivity = connectivity + 1
      adjacencyList.Add(bIndex)
    end
    bIndex = bIndex + 1
  end '' internal for
  _List_of_adjacencyList.Add(adjacencyList)
  connectivityList.add(connectivity)
end '' external for
  
```

*Algorithm III: Deriving local and global integration values*

```

root = SELF.Get(0)
MAXNODES = SELF.Get(1)

status = 0
status_3 = 0
level = 0

CList = List.Make
CList.Add(root)

VList = List.Make
element = 0
while (element < MAXNODES)
  VList.Add(element)
  element = element + 1
end

'' remove {root} from VList and all adjacency lists
VList = VList - {root}
for each adjacencyList in _List_of_adjacencyList
  theIndex = adjacencyList.FindbyValue(root)
  if (theIndex <> -1) then
    adjacencyList = adjacencyList.Remove(theIndex)
  end
end

number_of_localspace = 1
while (CList.Count <> 0)
  level = level + 1
  DDLList = List.Make

  neighbourList = List.Make
  for each element in CList
    neighbourList = neighbourList
      + _List_of_adjacencyList.Get(element)
    neighbourList.RemoveDuplicates
  end

  if (level < 3) Then
    number_of_localspace = number_of_localspace +
      neighbourList.Count
  end

  for each w in neighbourList
    DDLList = DDLList + {w}

```

```

'' remove w from VList and all adjacency lists
VList = VList - {w}
for each adjacencyList in _List_of_adjacencyList
  theIndex = adjacencyList.FindbyValue(w)
  if (theIndex <> -1) then
    adjacencyList = adjacencyList.Remove(theIndex)
  end
end

if (level<3) Then
  status_3 = status_3 + level
end
status = status + level
end

CList = DDList.DeepClone
end '' end of while

statusList = List.Make
statusList.Add(status)
statusList.Add(status_3)
statusList.Add(number_of_localspace)

Return statusList

```