Exploring the Generative Potential of Isovist Fields

The evolutionary generation of urban layouts based on isovist field properties

Sven Schneider[1]*, Reinhard König*[2]
Bauhaus-University Weimar
http:/infar.architektur.uni-weimar.de
[1]*sven.schneider@uni-weimar.de,* [2]*reinhard.koenig@uni-weimar.de*

Abstract. *Isovists and isovist fields can be used to numerically capture the visual properties of spatial configurations (e.g. floor plans or urban layouts). To a certain degree these properties allow one to make statements about how spaces affect people. The question that serves as the starting point of this study is to examine whether spatial configurations ca n generated on the basis of these properties. This question is explored using an experimental approach for the computer-based generation of two-dimensional urban layouts. The spatial arrangements of two-dimensional elements (building-footprints) within a given boundary is optimised in terms of the desired isovist field properties by means of an evolutionary strategy. The paper presents the results of this optimisation and discusses the advantages of this method compared with pattern books as commonly used in architecture.*
Keywords. *Spatial Configuration; Generative Design; Evolutionary Strategy; Isovists; Visibility Based Design.*

INTRODUCTION

People experience space through their senses, and the sense of vision in particular. The properties of a spatial configuration as we see it with our eyes are referred to as visuospatial properties and are mainly influenced by two factors: the surface characteristics (materials, textures and colour) and the arrangement and size of the spatial elements. In this paper we consider only the latter. The arrangement of elements in space is termed the spatial configuration. The elements of a configuration (boundaries such as walls or ceilings) define what you see or don't see from a specific point of view and thereby affect human behaviour (see e.g. Hillier, 1996; Lawson, 2001).

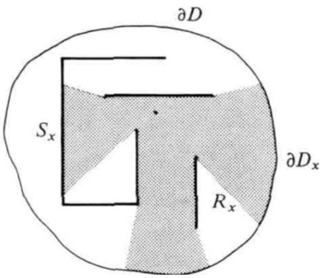
The effect of spatial configurations on the behaviour of people is a crucial factor for creating liveable and thus sustainable environments (Gehl, 1987). To ensure that environments exhibit certain visuospatial qualities, designers often refer to regulations and guidelines such as urban codes or pattern books as they contain specifications for the recommended dimensions and shapes of roads, open spaces, buildings or building details (Alexander et al., 1977; Duany, et al., 2006; Parolek, et al., 2008). While this approach is useful as it ensures a certain standard in the planning of environments, it is also relatively inflexible in its ability to respond to changing contexts. The sheer variety of possible criteria in the real world and their complex interrelationships means that such pattern-collections can only hope to offer a limited number of sample solutions. And because every planning and design problem is in principle unique (Rittel and Webber, 1973), such an approach can only be of limited use in design processes.

In addition, patterns typically provide a geometric solution to achieve a certain spatial effect but it is of course conceivable that different geometric solutions can produce similar spatial effects. A pattern-collection is therefore always a subjective selection of what is possible in principle. From our point of view, instead of offering a few specific patterns that produce certain visuospatial effects, it would be more useful to develop mechanisms that produce a multitude of patterns based on the intended effect. Such an approach would allow one to intelligently look for appropriate solutions for many different contexts. Faucher and Niver (2000) describe this approach as an “inverse design” approach, a term borrowed from inverse simulations in physics and mechanics. In this article we implement an inverse design process using computer-based generative methods for the automatic generation of spatial configurations (layouts). We examine whether specific spatial patterns can be (re-)produced based on specific visuospatial properties which is important in order to be able to support complex design processes where a number of criteria need to be reconciled. Because we are considering only criteria that relate to visibility within spatial configurations, this method can also be referred to as “Visibility Based Design”.

ISOVISTS AND ISOVIST FIELDS

One method for measuring visual properties associated with a particular arrangement of boundaries (spatial configuration) is to use isovists. An isovist (as shown in figure 1, left) describes the part of an environment that can be seen from a single observation point (Benedikt, 1979). Various parameters can be derived from an isovist, such as the *area*, the *perimeter*, *compactness* and *occlusivity*. The *area* of an isovist describes how much one can see from a certain vantage point. The *compactness* describes the relationship between *area* and *perimeter* compared to that of a perfect circle and indicates how complex or compact the field of view is. *Occlusivity* indicates the amount of open edges. An open edge denotes an edge line of the visual field which is not bounded by a physical boundary (e.g. a wall). *Occlusivity* is small in locations that offer few or no views into other parts of that configuration. For example a viewpoint within a completely closed, convex space has an *Occlusivity* of 0.

To evaluate an entire spatial configuration it is necessary to look at a configuration from more than just one viewpoint. To this end Benedikt proposes the creation of isovist fields. The computer-aided calculation of isovist fields is described by Batty (2001). A regular grid is generated and an isovist is calculated for each point in this grid. The properties of these multiple isovists can then be represented by giving the grid-points different colours. Dark points refer to low, light points refer to high values (see Fig. 1, right).



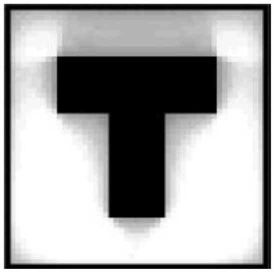


Figure 1
Left: An isovist from a vantage point inside a spatial configuration (figure taken from Benedikt, 1979); right: An isovist field for a T-shape, mapping the isovist area onto the single gridpoints (figure taken from Batty, 2001).

One way to evaluate a configuration based on isovist fields globally is to use average, minimum and maximum values, as well as the standard deviation of the frequency distribution of the individual isovist properties. These characteristics can, for example, be used to describe the public spaces within an urban layout. In Figure 2, this is demonstrated by an example: the public space of two different building patterns (perimeter block and terraced row development) has been analyzed by determining the isovist properties *Area* and *Compactness*. One can see clearly that both structures differ markedly in their isovist field characteristics. For example, the average isovist area of the terraced row structure is three times larger than that of the perimeter block, although the built-over floor area is similar in both cases. For the value of compactness we can see that the isovists in the perimeter block are generally more compact than those in the row structure. At the same time the latter reveals a lower standard deviation than the perimeter block, which means that the isovists in the row structure are evenly non-compact, while in the perimeter block development, there are many compact (i.e. the backyards) as well as non-compact isovist fields (i.e. the streets).

The extent to which isovist properties help us make statements about how spaces affect humans is still not fully understood. However, empirical studies have shown that various correlations exist between those properties and the actually perceived spatial experience. Franz and Wiener (2008) used VR experiments to show that area, compactness and occlusivity correlate highly with how test persons rated the perceived beauty, complexity and spaciousness of a configuration. Furthermore, they showed that the subjects were able to find points in a configuration with the largest and smallest field of view. Conroy-Dalton (2001) and Wiener et al. (2011) found that isovists capture information that is relevant to wayfinding behaviour, especially when it comes to deciding where to go next.

If we assume that, as described above, it is possible to make statements about the experiential qualities of a configuration, it should in turn be possible to derive a configuration for an intended spatial experience. In the following, we have drawn on an idea put forward by Benedikt (1979) to generate spatial configurations on the basis of isovists. Benedikt formulates this concept at the end of his original article about isovists in architecture as follows: *"One might*

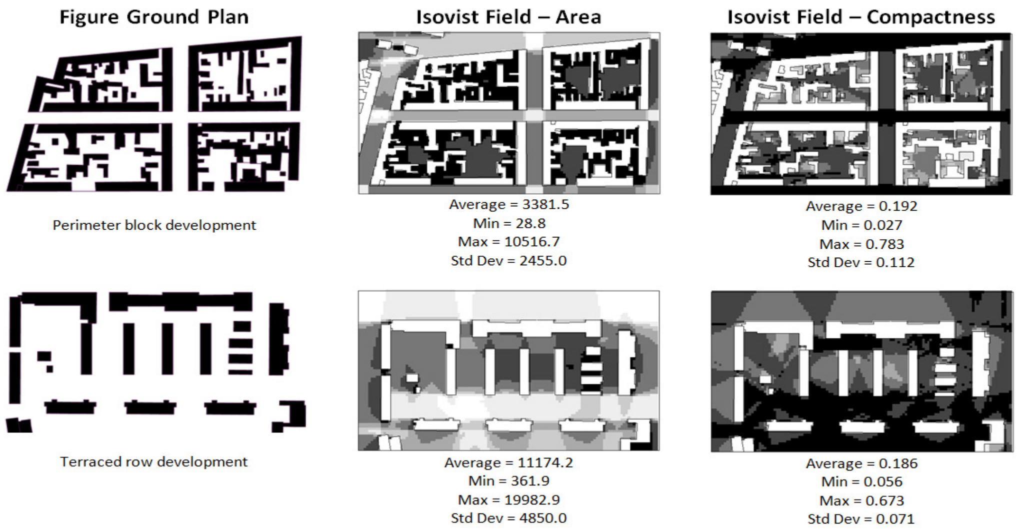


Figure 2
Analytic comparison of the isovist fields of two different urban structures (undertaken with UCL-Depthmap).

well ask: when is it possible, given one or more isovist fields (…) to (re)generate E [the spatial configuration] as a whole? (…) a direction seems clear: to design environments not by the initial specification of real surfaces but by specification of the desired (potential) experience in space (…)." This question is examined in the next section using an experimental approach for the generation of urban patterns.

GENERATIVE APPROACH: AN EVOLUTIONARY STRATEGY

For the generation of spatial configurations, we use an optimisation method based on evolutionary algorithms (EA). Evolutionary algorithms are well suited to our purposes for two reasons: they are flexible and can easily be adapted to changing problems, and they require no a-priori patterns for guiding the search process (Rechenberg, 1994). This is particularly important because we want to investigate the influence certain parameters have on a solution. For this it is important to exclude confounding factors, such as a conscious change of solutions.

The two essential components of a generative system based on EA are the generative mechanism (GM) and the evaluation mechanism (EM). The GM serves to generate variants. This mechanism is based on a model that represents the particular problem in an appropriate manner. In our case, this model must be able to generate geometric representations of two-dimensional layouts. Ideally, one would use a model from which any geometric layout variant can be generated, but, due to the immense number of possible solutions, this would increase the computing time to an impractical level. Rules must therefore be defined that permit a wide range of potential solutions while keeping the search space as small as possible.

The EM of an EA is used to evaluate the variants produced by the GM. The way these variants are evaluated is described by a so-called fitness function. This function defines the qualities that the desired solution should have. In the context of this article, these qualities are described by certain isovist properties.

In a previous study we had shown that isovist properties are in principle well suited as objective criteria for the optimisation of layouts using EA (Schneider and König, 2011). Here the properties of single isovists were used to position walls in a way that ensured specific visual relationships between different points of view. The GM used a grid of lines in which single lines could be switched on and off to optimise the configuration. The fitness function of the EM consisted of the target values for each Area and Compactness of the single isovists and the target values for the area of overlap between the different isovists. Based on these target values, different configurations of floor plans with three rooms were generated. The three rooms have a similarly large area, a high degree of compactness and simple topological relationships (room 1 is connected to room 2 and 3, but room 2 is not connected with room 3). Figure 3 shows an example of the results of a test scenario.

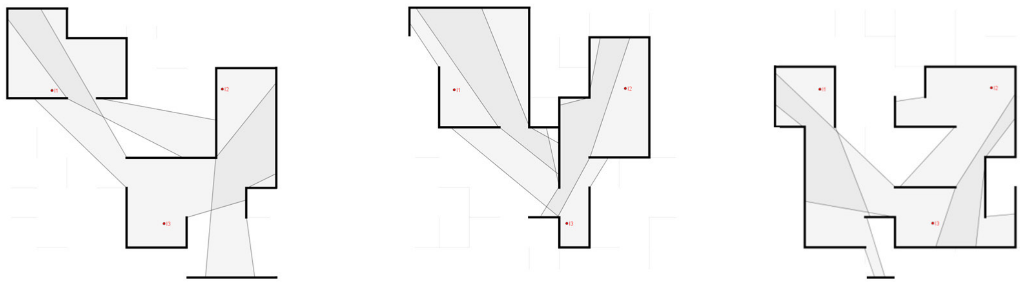


Figure 3
Variants of a configuration defined by 3 viewpoints P1(top left), P2 (top right), P3 (bottom centre) in which the isovists of P1 and P2 shall not overlap.

GENERATING URBAN LAYOUTS FROM ISOVIST FIELDS PROPERTIES

In the following we demonstrate how urban layouts can be generated according to specifically defined isovist field properties. We begin by describing the technical aspect of the generative system (GM, EM) before showing and discussing the results this system produces for a simple test scenario.

Generative Mechanism (GM)

Using the GM, variants – or so-called individuals – are generated. An individual represents an urban layout. It consists of a fixed number of buildings located on a plot of land. The buildings as well as the plot are represented as rectangles. The operations of the GM include the random positioning and scaling of the rectangles (buildings). The rectangles should firstly not overlap and secondly stay within the given boundary. These two criteria are checked after the random placement of a building and if necessary the coordinates are adjusted through specific movements. In order to avoid non-feasible solutions, such as buildings with a width of 3 m, minimum and maximum widths (minWidth, maxWidth) and surface areas (minSurfaceArea maxSurfaceArea) are defined for the rectangles as well as the minimum and maximum coverage (minCoverage, maxCoverage) of the plot. The properties of the building (position, length, width) can only be changed within the range defined by these constraining values.

Evaluation Mechanism (EM)

The evaluation of the individuals is undertaken using the isovist field properties. For each individual an isovist field must be calculated. Since the calculation of isovist fields is computationally intensive and time-consuming, we use an approach introduced by Schneider and König (2012) which uses the graphical processing unit (GPU) for carrying out this calculation. Compared with conventional CPU calculation the calculation speed is increased many times over. This reduces the duration of the optimisation process to an acceptable level: the evaluation of an individual in the test scenario takes approximately 0.15s, while the population of the EA consists of 15 individuals. The average, maximum and minimum values as well as the standard deviation of various isovist properties can be derived from the isovist field. These values are used as fitness criteria for defining the objective function. The objective function describes the deviation of an isovist field-property from a corresponding target value. In general terms, the fitness function can be specified as follows:

$$f(x) = abs(IFValue - targetValue) \quad (1)$$

where IFValue refers to an isovist field property (such as *Average Area*) and *targetValue* to the value this property should have in the final solution.

Results

The generative system presented above was evaluated using a test scenario. The goal of this test is to find out if and which spatial patterns can be generated on the basis of isovist field properties. The test scenario examines the positioning and scaling of five buildings within a square boundary (*MinWidth* of the building = 7 m, *MaxWidth* = 30 m). The isovist properties that are used for optimisation are *Area* and *Compactness*. To better understand the influence of the various properties on the resulting spatial configurations, we minimised and maximised the individual criteria:

$$f(x) = IFValue \rightarrow \min, \max \quad (2)$$

The distribution of the two isovist properties *Area* and *Compactness* in the isovist field can be characterised by four values: average, minimum, maximum and standard deviation. These can be either minimised or maximised. As a result, 16 objective functions can be defined for the 8 *IFValues* (*Average Area, Min Area, Max Area, StdDev Area, Average Compactness, Min Compactness, Max Compactness, StdDev*

Compactness). Several test series were performed for each of these objective functions. For each series one representative result was chosen and shown in Figure 4 and 5. In the following the results are explained in more detail.

The minimisation or maximisation of *Average Area* means that the area that a person sees inside a configuration should on average be either as small or as large as possible. In Figure 4 (top row, first image from left) it can be seen that by minimising the average area, a solution is generated in which several small open spaces between buildings occur. The maximisation of the same value results in the generation of an L-shaped building pushed to the edge of the plot resulting in one large open space (Figure 4, bottom row, first image from left).

The minimisation of Min Area means that there is a point in the layout from which one can see only a very small open area. This creates areas which can are like small inner courtyards, narrow alleys or niches. In Figure 4 (top row, second image from left) a niche is marked with a red dot. If Min area is maximised these viewpoints with a small visible area disappear (Figure 4, bottom row, second image from left).

The optimisation of *Max Area* produces similar configurations as it does for *Average Area*. For minimum *Max Area* several small yards are created, for maximum *Max Area* one large yard. In contrast to *Area Average*, not all points in space must have a large or a small isovist area. It is sufficient that there is one viewpoint that meets this criterion.

Through a systematic optimisation of the standard deviation values of the area one can control how strong the differences of the different area values are. Minimising this value creates layouts in which one can see the same area from most of the points. This results in spaces of a similar size (Figure 4, top row, last image). However, if the standard deviation is maximised (many varying area values), then one large and several small spaces occur (Figure 4, bottom row, last image).

In another test series, the different values of *Compactness* were used as objective criteria. The results show that, much like the optimisation of the *Area* values, a typical spatial pattern arises (Figure 5). By maximising the *Average Compactness*, an L-shaped building is generated, which forms an approximately quadratic open space (Figure 5, bottom row, first image from left), while minimising the same value results in an urban structure with solitaires. The position of the solitaires creates long vistas from many viewpoints.

By minimising the *Min Compactness*, layouts arise in which at least one point in space exists with a very non-compact field of view. In the example layout shown in Figure 5 (top row, second picture from left), the corresponding isovist is shown in red. It can be seen that the minimisation of compactness (very narrow and long isovist) emerges through the proximity of two buildings. If *Min Compactness* is maximised, layouts similar to those produced by maximising the average compactness emerge (contiguous buildings with one or more enclosed spaces).

By minimising the *Max Compactness*, layouts arise where no viewpoints with a compact isovist can be found. Accordingly, solitaires emerge which are only a small distance from the boundary of the test field (Figure 5, top row, third image from left). This ensures that there is no “inside corner” in the whole layout. The maximisation of the same value results in the creation of at least one enclosed square courtyard (Figure 5, bottom row, third image from left).

When minimising the *standard deviation* of the compactness values, layouts arise where the compactness value is similar from most viewpoints. The magnitude of this value is not specified. This can create layouts in which the isovists are very compact at all points (e.g. bottom row, first image from left) or layouts in which the isovists of all points have a rather average compactness (top row, fourth image from left). If the *standard deviation* is maximised, layouts arise in which the open areas have very different compactness values. In Figure 5 (bottom row, last image) one can see that a cascade of different compact spaces is created (from completely closed to open with numerous vistas).

Figure 4
Sample results of the optimisation of different objective criteria for Area after n=40 generations.
Top row: Results achieved through minimising the objective criteria. Bottom row: Results achieved through maximising the objective criteria. The configuration is superimposed on the isovist field.

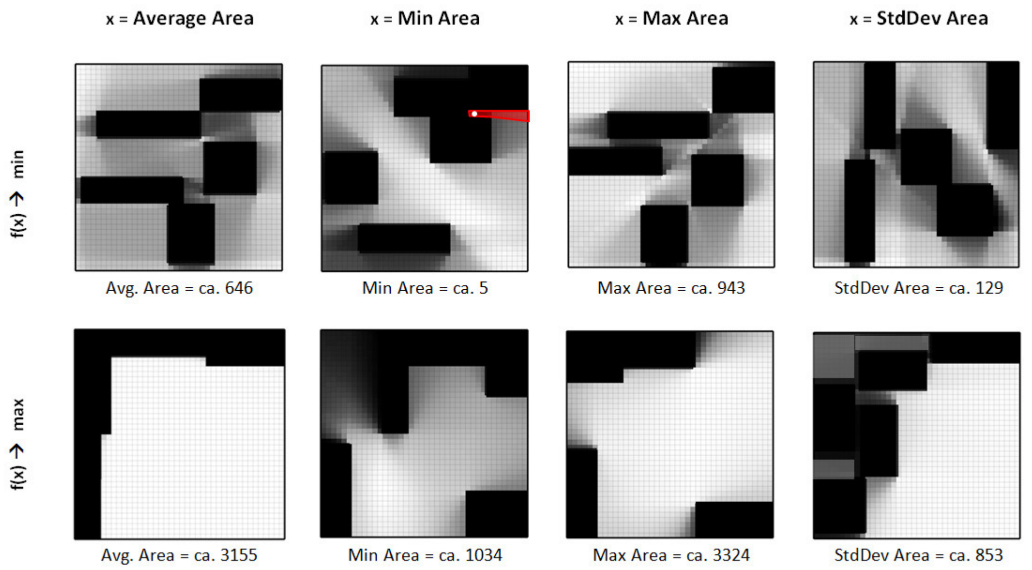
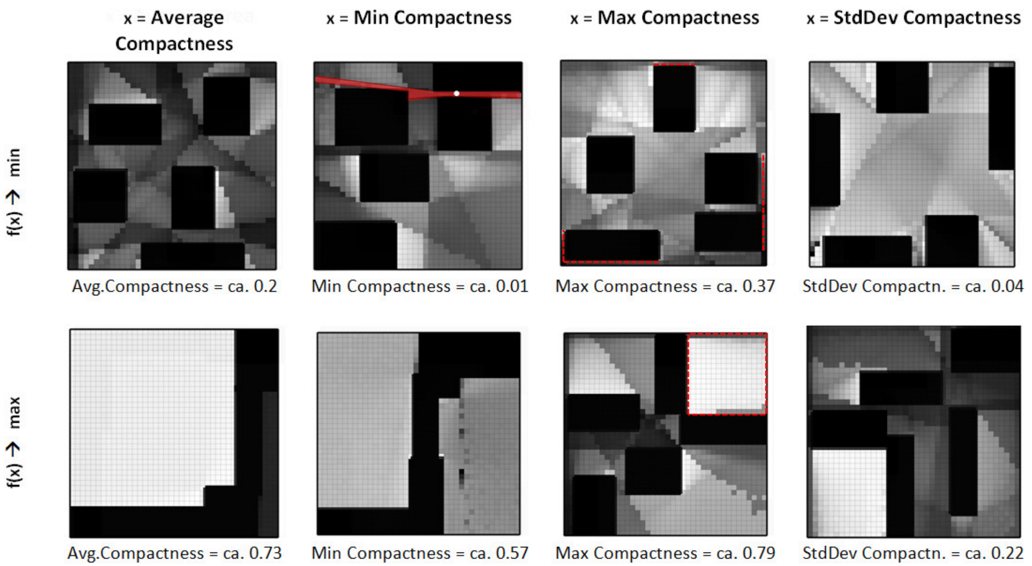


Figure 5
Example results for optimisation of the isovist value Compactness.



DISCUSSION AND OUTLOOK

The arrangement and direction of visuospatial properties is an important aspect in the design of buildings and cities. Conventional methods for supporting this design process usually amount to little more than a collection of exemplary solutions. But a collection of proposed solutions is not able to respond adequately to different contexts with different conditions and their complex interactions. Instead it is necessary to develop methods that can generate a variety of patterns based on certain requirements. In this paper we presented one approach for implementing such a method using a computational system for generating spatial configurations for different objective values of isovist properties on the basis of an evolutionary strategy. The hypothesis that this method can be used to (re-)produce specific spatial qualities was proven using a simple and highly restricted test scenario (location and scale of buildings within a rectangular area).

The extent to which isovist properties are useful for describing spatial configurations more comprehensively is an issue that we will consider in further studies. Here we plan to test the method in a realistic case study by generating plans for an urban district within an existing urban environment. In addition to single value optimisation, we plan to optimise different objective criteria simultaneously. Using multi-objective optimisation we want to ascertain whether the patterns resulting from single objective values can be meaningfully combined. It would also be useful to supplement the system with additional evaluation criteria. With regard to visuospatial properties, Visibility Graphs (Turner et al, 2001) are of importance because graph-based measurements of functional criteria allow us to make statements about a spatial configuration (Hillier, 1996). A first promising approach to incorporate the integration value in a generative system can be found in Krämer and Kunze (2005). Furthermore it would be interesting to use 3-dimensional isovists for evaluation. A first useful application of 3-dimensional isovists in architecture is demonstrated in Derix et al. (2008).

The tool we developed for the optimisation and generation of urban patterns can be downloaded from www.decodingspaces.de.

ACKNOWLEDGEMENTS

This study was carried out as part of the research project FOGEB, funded by the Thuringian Ministry for Economics, Labour and Technology and the European Social Funds (ESF).

REFERENCES

Alexander, C, Ishikawa, S, Silverstein, M, Jacobson, M, Fiksdahl-King, I and Angel, S 1977, *A pattern language*, Oxford University Press, New York.

Batty, M 2001, Exploring Isovist Fields: Space and Shape in Architectural and Urban Morphology, *Environment and Planning B Planning and Design*, 28(1), pp. 123-150.

Benedikt, ML 1979, To take hold of space: isovists and isovist fields, *Environment and Planning B Planning and Design*, 6(1), pp. 47-65.

Conroy-Dalton, R 2001, *Spatial Navigation in Immersive Virtual Environments*, PhD Thesis, University College London.

Derix, C, Gamlesæter, A and Miranda, P 2008, 3D Isovists and spatial sensations: two methods and a case study, in S. Haq, C. Hölscher, & S. Torgrude (eds), *Report Series of the Transregional Collaborative Research Center SFB/TR 8 Spatial Cognition*.

Duany, A, Wright, W and Sorlien, S 2006, *Smart Code and Manual*, New Urban Publication, New York.

Faucher, D and Nivet, ML 2000, Playing with design intents: integrating physical and urban constraints in CAD, *Automation in Construction*, 9(1), pp. 93-105.

Gehl, J 1987, *Life Between Buildings: Using Public Space. The City Reader*, van Nostrand Reinhold, New York.

Hillier, B 1996, *Space is the machine: a configurational theory of architecture*, Cambridge University Press, Cambridge.

Lawson, B 2001, *The Language of Space*. Elsevier Architectural Press, Oxford.

Parolek, DG, Parolek, K and Crawford, PC 2008, *Form Based Codes: A Guide for Planners, Urban Designers, Municipalities, and Developers*, John Wiley & Sons Inc. Hoboken, New Yersey.

Rechenberg, I 1994, *Evolutionsstrategie ’94*, frommann-holzboog, Stuttgart.

Rittel, HWJ and Webber, MM 1973, Dilemmas in a General Theory of Planning, *Policy Sciences*, 4, pp. 155-169.

Schneider, S and König, R 2011, Visibility-based Floor Plan Design - The Automatic Generation of Floor Plans based on Isovist Properties, *Proceedings of the International Symposium on Spatial Cognition for Architectural Design (SCAD 2011)*, New York, USA, pp. forthcoming.

Schneider, S and König, R 2012, Real-Time Visibility Analysis, *Proceedings of the 12th Design Descision Support Systems Conference in Architecture and Urban Planning*, Eindhoven, Netherlands, pp. forthcoming.

Turner, A, Doxa, M, O’Sullivan, D and Penn, A 2001, From isovists to visibility graphs: a methodology for the analysis of architectural space, *Environment and Planning B Planning and Design*, 28(1), pp. 103-121.

Wiener, JM, Hölscher, C, Büchner, SJ and Konieczny, L 2011, Gaze Behaviour during Space Perception and Spatial Decision Making. *Psychological Research*, Springer, Berlin/Heidelberg, pp. 1-17.