Generative Improvement of Street Networks Based on Space Syntax

Applied in a case study on an informal settlement in Jeddah

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Abstract. Space syntax is supposed to be an objective method for evaluating spatial configurations. Its contribution to a design process is dependent on the designer’s estimation. The paper describes a generative approach to finding particularly good interventions based on space syntax analyses of axial maps. More precisely, a case study was undertaken through applying such a strategy to improve and connect a segregated street network of an informal settlement to its neighbourhood. Controlling and redirecting movement in slums may cause positive effects. This research is based on and inspired by a consulting project by the company Space Syntax Limited for the Municipality of Jeddah, Saudi Arabia, in which the consulting company designed a regeneration program for declining informal settlements. (Karimi and Parham, 2012)

Keywords. Space syntax; slum upgrading; design computing; urban design.

INTRODUCTION

In numerous case studies, Space Syntax proofed to be an effective method to understand, reconstruct and predict movement in urban layouts. (Hillier, 1987; Hillier et al., 1993) Due to this background, space syntax is not only used for scientific reasons but also to predict, qualify and quantify qualities on design proposals and the impact on their neighbourhoods. Therefore several design projects already incorporate space syntax during the design process stage (Dursun, 2007) by designing and adopting different design alternatives and continuously testing them in order to gain desired results in the space syntax analysis. Designers jump between designing and evaluating and oftentimes layouts demand several iterations. Furthermore, it is not an easy task to figure out the best changes. As space syntax it is used for evaluation, its contribution to a design process is dependent on the designer’s effort and estimation. If the aim of a redesign is to lead to specific results defined by the space syntax theory, designers have to patiently figure out what changes they have to make in order to achieve these requirements. The paper describes a generative approach to finding particularly good interventions based on space syntax analyses of axial maps representing any given urban street network.

Motivation

A space syntax analysis is an automatically processed computation, which resembles usual analyses in other fields as for instance in physics. In recent years, it has gotten increasingly more common to
optimize architectural designs on behalf of physical characteristics, be it because of wind, solar exposure or sound propagation. The intention of these methods is not to make a designers work redundant but to help them to achieve more efficiency in their designs.

There are several cases in which an improved scenario based on Space Syntax analysis might be useful. This paper chooses the topic of improving the urban network of informal settlements. Controlling and redirecting movement in slums may cause positive effects. Combined with other remedial actions, conditions in slums can be sustainably improved. Space Syntax Limited, a spinoff company by University College London (UCL), suggested this new approach. It aims to create a condition to allow informal settlements to self-correct themselves. The method was developed during a commissioned consulting project for the Municipality of Jeddah, which led to a regeneration framework for deteriorating unplanned settlements based on the space syntax theory. It is mainly formulated in Karimi and Parham (2012) and Karimi et al. (2007).

Background
In contrast to the approach described in the previously mentioned papers, where the Space Syntax theory was applied for understanding the whole multi-layered problem of upgrading slums, this research isolates just one aspect that can be easily expressed by an analysis: identifying structural segregation in urban networks. The task is to find efficient interventions that oppose “spatial discrimination”. In detail this means to find efficient solutions for connecting an isolated and fragmented core of an unplanned area to the citywide street grid. The challenge is to find adoptions, which preserve the integrity of physical and spatial structures as much as possible. In the design proposed by Space Syntax Limited, these changes in the spatial structure were drawn by hand, following a space syntax analysis that led to a “deep understanding of the unplanned settlement” and additional other factors resulting from on site investigations. So a new - more or less direct - routing of roads was drawn to link public spaces in the local structure to main roads that were part of to the global network. Constraining for the new road design was the search for minimal interventions on build stock.

The here presented procedure aims to optimize this approach using a computational method, in order to reduce the amount of demolished stock while improving the properties of the network. The described method uses algorithms for axial line analysis. Nevertheless, the methodology is not limited to axial lines and remains valid for any form of segment- or road-centre-lines analysis.

Software used
To achieve a generative application using a Space Syntax analysis, it was necessary to introduce these calculation techniques to an environment that enables parametric manipulation of geometry. Parametric modelling is a technique that enables to draw geometry depending on constraints. A parametric model forms the basis for computational design. Computational Design is a procedural, repeatable, mathematically definable process. It is based on previously defined quantitative sets of rules that can be explored and developed in a framework. Such a framework has to allow variations to be generated and also evaluated.

The plugin ‘SpiderWeb’ enables the use of graphs in Grasshopper 3D, a parametric modelling tool for Rhinoceros 3D, a 3-D modelling software, developed by Robert McNeel & Associates. Richard Schaffranek is developing ‘SpiederWeb’ at the Vienna University of Technology. This research project also contributed to its development. To run Space Syntax analysis one needs both elements: On the one hand the ‘SpiderWeb’ needs to be installed with Grasshopper 3D. On the other hand the definition calculating the Space Syntax analysis are needed. The author published them as clusters to be imported in Grasshopper. From this setup, many different generative applications using Space Syntax can be approached.
**METHOD**

The axial map of the settlement is extended by several kilometres to its surroundings, in order to identify the citywide street network. This network can be straightaway spotted when applying an integration analysis at global radii. In the same analysis one can also identify very separated areas that happen to be the problematic informal settlements. Then again, these spots show high walkability within their direct surroundings, what is indicated by high integration values obtained from integration calculations at local radii. This has been shown and explained by Karimi and Parham (2012) and forms the starting point of the generative approach. In this paper two subsidiary methods for intervening the street network are proposed and split in two scenarios.

**Scenario 1**

In the first scenario creates new connections between existing axial lines are created. This means that the total amount of streets within the system increases. In praxis, the consequence of a new street means the removal of existing buildings within the road’s new area. Theoretically there are infinite possibilities for new line generations, so one has to limit the amount of generations to a manageable amount: In a first step, 10% of the most integrated axial lines determined by the analysis with a local radius within the area of the informal settlement are selected. In a second step, 10% of the most integrated axial lines, obtained by the global integration analysis and located within the target area or surrounding its boarders are selected. Both sets of axial lines are stored for further processing.

An external parameter named ‘block size’ is introduced, which divides the previously selected axial lines into segments of a certain size. For this case study, the block size of 50 meter was chosen. It defines that every 50 meters along an axial line, a starting point (resp. an ending point) of a newly generated line is located. These points were taken to draw new axial lines between the two sets, unless they fit in the domain between the minimal axial length of 50 meters and maximal axial line length of 350 m.

For every single axial line that is generated, an individual Space Syntax integration analysis at a global radius is calculated. Due to the complexity and extent of the calculation, the calculation time amounts on average 356 seconds. After every calculation the following values are extracted and saved for later processing. Only values for axial lines within or directly neighboring the area of the informal settlement are considered:

- Generation ID, to identify the axial line
- Line length
- Intelligibility, a value defined by space syntax theory
- Integration sum, sum of all integration values in the system
- Integration min, smallest integration value within the system
- Integration max, largest integration value within the system
- 0,25 quantile of all integration values
- 0,5 quantile of all integration values
- 0,75 quantile of all integration values

These values are put into a table to enable their comparison and evaluation. The table is sorted in descending order by size, once for each of these values: intelligibility, integration sum, integration min, integration max, 0,25 quantile, 0,5 quantile and 0,75 quantile. For each sorting, the adequate generation IDs for the highest one percent of all values is stored in a separate list. Based on this new list the accumulation of generation IDs is extracted. This brings out what axial lines have the biggest effect on the largest amount of measurements.

**Scenario 2**

The second Scenario proposes an extension of existing axial lines within the target area. This method is quite different to the first one, as it keeps the amount of axial lines constant. Every single axial line within the target area is extended by 150 meter. There are 449 axial lines within the border of the informal settlement. This means that for each line, two possibilities are calculated: one for an extension in every direction. Scenario 2 enables 898 generations
in total. Likewise described in the first scenario, the same values are calculated and stored for the same evaluation.

**RESULTS**

**Scenario 1**
Figure 1 highlights the most efficient 1% of all generated new axial lines, which improve the overall integration within the informal settlement measured at global radii. It shows new connections one would not easily think of. Many new axial lines connect to streets of the global grid, but some even propose changes within the internal organization of the quarter. One has to keep in mind that these are the best improvements due to the rules of generation and its predefined parameters: maximal- and minimal axial line length and block size.

Figure 2 compares values obtained by an integration analysis of the system with and without the calculated intervention. It clearly shows the significant improvement of integration, which is equally distributed throughout the entire spectrum. That implies, that the upgrading effect measured by integration effects most settlers without privileging certain locations. The values of each axial line within the informal settlement and in its direct neighborhood are displayed in ascending order for their integration value.

**Scenario 2**
Figure 3 highlights the most efficient 1% of all generated extensions that improve the overall integration within the informal settlement measured at global radii. As in scenario I, one has to keep in mind that these are the best improvements due to the rules of generation and its predefined parameters. Again it unveils several good and seemingly useful possibilities of axial line extensions throughout the entire network. This result also stresses the necessity of connecting the informal settlement to the northern neighbourhood.

Figure 4 shows a graph comparing integration values of the urban network with and without the applied interventions. Again, it clearly shows the significant improvement of integration, which is equal-
ly distributed throughout the entire spectrum. The values of each axial line within the informal settlement and in its direct neighborhood are displayed in ascending order for their integration value.

**DISCUSSION**

The results, in particular found in the first scenario, show several similar suggested axial lines. There is the possibility to tidy up overlapping axial lines by

![Graph comparing integration values of the system before and after the intervention.](image1)

![Map showing efficient extensions of existing axial lines aiming to improve the overall integration within the informal settlement.](image2)
computation. There wouldn't be any benefit in doing so, as the presented information should not be understood as the final stage of a design. It represents a catalogue for more efficient pursuing design work, respecting other needs and factors on site that were ignored prior to that stage.

Several proposed axial lines also concentrate on the northeast part of the informal settlement. There they bridge two highways, what causes high integration values. However, new connections will not bring desired improvements there. This issue is pointed out by space syntax researchers in several papers and lectures: a street with a high integration and choice value needs to provide enough space and attractive design for both, pedestrian- and car movement, to enable desired urban qualities. This is for instance a factor that needs to be respected in pursuing designs.

**Observations**
Further analysis of the partial results led to the unlikely interesting observation of an interrelation between values of intelligibility and integration sum. The graph in Figure 5 shows values of integration in y-axis ranked by decreasing order of intelligibility values in x-axis. For some reason it appears that while intelligibility is decreasing the integration sum is increasing.

**Calculation times**
The fact of long calculation times is the reason for cutting down the amount of generated lines to a reasonable size by filtering only integrated and segregated starting points for new lines generations. Actually, it would be possible to increase either the percentage of chosen starting points or simply allow every location within the working area to generate lines. When doing so, the amount of generations in the case study rises up to 300,000 lines and more. This increases the calculation time to several years. The structure of the algorithm however allows splitting up calculations between several computers.

**Heuristic search**
The initial intention of this research was to look for the best combination of several generated axial lines at once and not to analyse them one by one. Due to the large number of combination possibilities, search heuristics were used, but while working on this project, it turned out that there was no
need for using them. Several computational tests and detailed analysis of this issue proved that the best combination always consists of the axial lines ranked highest in individual calculations.

When using a genetic algorithm for finding optimized results for individual line generations, there would be the need of defining another method for generating new axial lines. However, it remains questionable whether a relaxation of the fitness landscape can be achieved.

Further research
The implementation of heuristic search strategies is a field that requires further research and will certainly lead to the development of other methods for generating axial lines.

Furthermore, information as for instance land use, building height or FAR (floor area ratio) could provide a basis for producing more refined results. Additionally, the assessment of generated variants could also consider information like building height, value of conservation or demolition effort. Introducing more data may enable a more detailed parametric design model, allowing to suit more requirements – for example a specified amount of FAR could define a benchmark.

The concept of the approach based on axial lines described in this thesis is easily applicable to other models, as for example, segment- or road center lines. First tests were successful but required significantly longer calculation times due to the bigger amount and complexity of the algorithms. Even more costly calculations would require adapting a generative approach based on VGA Analysis.

CONCLUSION
The approach described in this thesis does not deliver results that should be seen as the final stage of a design. It attempts to find possibilities to improve street networks based on the space syntax theory that uses graph mathematics to describe spatial quality. The results obtained through this method solely consider the mathematical properties of the axial line map and ignore various factors that cannot be put in relation or cannot be described mathematically. It represents a guideline for further design work and provides a catalogue of options that cause highly effective impacts. Some of these options could not be spotted easily by using conventional space syntax tools.
REFERENCES