Shape Grammars for Intersections in Urban Network Design

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1 Extended Abstract

1.1 Background and aim

When looking at various technical handbooks for network design, no common suggestion can be found for network layouts. E.g. the street layout standard in Switzerland [1] recommends a strongly hierarchical street type scheme. The standard contrasts with the adaptive hierarchical design, e.g. proposed in Germany. In the USA after 1950, a transition took place from gridded layouts to increasingly more dendritic networks, as recommended by the authority. Despite the considerable impact of network design on economics and overall welfare, the investigated handbooks and standards lack of a fundamental research basis, as they do not specify the trade-off between e.g. VMT and network form.

The literature on transport network design can be subdivided in network optimization and network design. Network optimization deals with existing networks which are improved with respect to e.g. the benefit-cost ratio of the alternatives, often applying a bi-level network optimization approach. A major proportion of their contributions are based on operational research methods. The construction of new networks is normally following different methods, compared to the optimization of existing networks, e.g. [2, 3]. Especially urban planning and design aspects as well as interactions between transportation and land use issues are crucial when designing new networks.

This paper applies the idea of shape grammars, which can be formulated for network design recommendations, handbooks, and standards. In network design, shape grammars describe in the form of rules how different types of network elements are added to each other, e.g. if a major arterial road can be crossed by an access road or if local roads can be joined with larger intersections of high capacities. Suggestions on adjacent building types can additionally incorporate land use aspects [4]. However, this study focusses on the influence of different shape grammars on road network design, and street and intersection types.

Shape grammars originate from different fields in science. A comprehensive list of urban patterns and rules is provided by Alexander, Ishikawa and Silverstein [5], covering architectural, urban and transport issues. Stiny, e.g. [6], a pioneer in shape grammars, contributed on shape grammars for geometry, architecture and urban design. They exerted influence on major subsequent work in their fields.

A key advantage of shape grammars is their ease of application in planning processes. Practitioners prefer robust and reliable methods. Shape grammars satisfy these requirements but are at the same time adaptive to different scenarios and are able to incorporate spatial planning rules, which makes them even more applicable in interdisciplinary field of urban simulation. Moreover, the application of shape grammars needs very low computational requirements and can be implemented in interactive planning tools. Disadvantages are the unknown impact of shape grammars on urban systems and the lack of a fundamental evidence base on their impact.

1.2 Applied methodology

In this work, the evaluation of shape grammars takes place using a specific network design method to account for transport network and shape grammars characteristics. The design method integrates and benefits from both the advantages of a genetic algorithm (GA) and an ant colony optimization (ACO). Similar to a GA, the design method is based on a population of individuals. Each individual is a candidate network, which improves over time using a recombination method. Similar to an ACO, a learning ability is implemented in the design method. As a standard ACO, the design method employs the results from all previous populations and stores this information, which is later available for further network recombination.

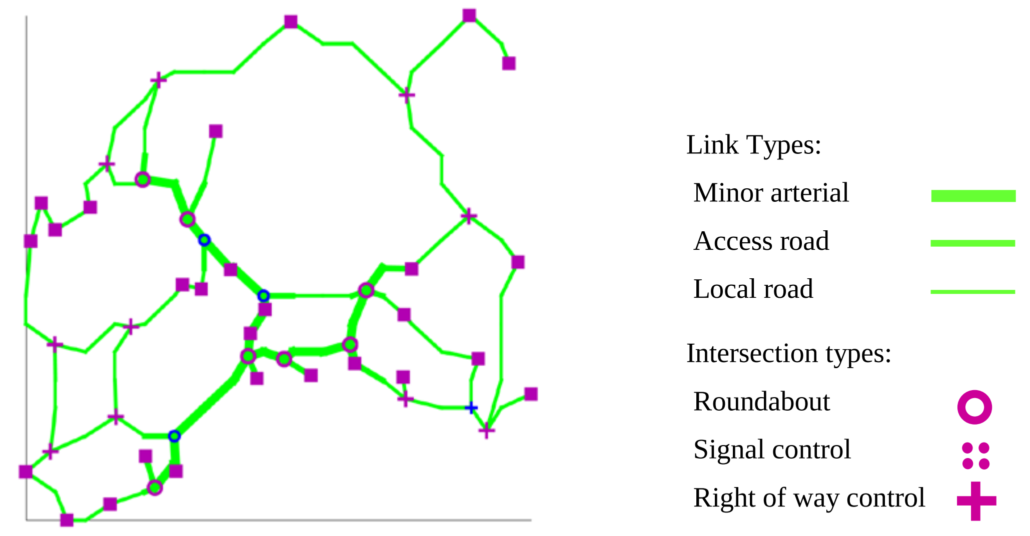
The ability to cope with network characteristics is the major strength of the algorithm. The algorithm addresses shape grammars, redundancies, topography, and can include capacity optimization. The objective function includes the utility of the overall network, and currently comprises the major components of the transport cost-benefit analyses, like travel time and costs as well as infrastructure costs. Calculation time scales with search space size. E.g. the design of a network with 225 candidate nodes, 812 candidate links and a search space of 10^{244} potential solutions takes 3h on a 2.4 GHz computer with 40 parallel threads.

The network roads and intersections are subdivided in different types. Different road and intersection types are matched according to grammar rules, similar to standards in network design handbooks. Intersection types are added to different road types to improve network performance the most, depending to performance, number of arms and costs.

1.3 Impact of Shape Grammars in Transport Network Design

Different networks connect arbitrarily distributed travel demand generating nodes, or centroids, on featureless planes. Evaluations on featureless planes do not bias the outcome due to historical development and political decisions, as when relying on case studies. An example of a network design is given in Figure 1, using the design algorithm mentioned above.

Figure 1 Road and intersection types of a proposed network.



The results are twofold. The first part of the results provides information about the design algorithm and its convergence behavior, and performance. Due to the heuristic nature of the algorithm, accuracy and search space size are opposed to each other in our attempt to gain insights in the convergence behavior. The second part includes different rules on how to align intersection types in space and adjacent to what road type. As the results show, intersection types are a major factor in transport network performance. The impact of intersection types is found out to be significant, and larger compared to different road type distributions. This is remarkable, since research in network design contributes more on road alignment than on intersection alignment. A set of rules is suggested for intersection type alignment in urban transport networks. Additionally, different rules are examined regarding intersections. E.g. the number of arms for each intersection remains low in most networks. Most intersections have only 3 arms, and are element of loops of different sizes. This is a first quantitative confirmation of the suggestion for urban layouts of Alexander, Ishikawa and Silverstein [5].

Further work is going to additionally include land use aspects, especially travel demand – land use interferences as well as growth aspects. Moreover, the transferability of the transport network design method to other networks, like communication, power or water supply makes the network design algorithm very attractive also for other fields.

References

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