Chapter 10
A Rule-Based Generative Analysis Approach for Urban Planning

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Abstract Urban plans are difficult to comprehensively analyze quantitatively because they lack sufficiently detailed information. They tend to emphasize land-use, possibly suggesting general building typologies. Nevertheless, they are generally conceived with respect to objective criteria, such as population targets, plot ratios, gross floor areas, etc. This research suggests a rule-based approach to generate relevant building data that can serve to analyze and assess such urban plans with respect to these and other relevant criteria, requirements and targets. Such generation must necessarily take into account local conditions, building typologies, codes and regulations.

10.1 Introduction

Use of computational support for urban planning and design is mostly limited to modeling. Its use for performance analysis, either to inform the design process or to assess design solutions, though available, is still sparse. Part of the problem may be the absence of, or the difficulty in retrieving, sufficient amounts of data to support performance analysis. Certainly, this issue is dependent on the location; if not site-specific, it will differ at least from country to country. Nevertheless, there is always a limitation to the data that is readily available and any specific design queries may necessitate data that cannot be obtained by regular means. To assist in overcoming this hurdle, we distinguish three complementary approaches: extracting data, synthesizing data and mining data. Extracting data refers to data that can be found online however not in a readily downloadable or applicable format and requires manual processing or the development of dedicated scripts to extract the data from the source. Synthesizing data refers to data that is generated from existing

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(design or analysis) data based on assumptions, heuristics and/or typologies. Mining data refers to the application of data mining techniques in order to understand relationships between data.

Another part of the problem may be the lack of simple and flexible workflows that support performance analyses and can easily be integrated into design and planning processes. Especially when such processes are characterized as dynamic, collaborative and constrained by time, skills and the availability of tools. While various systems exist to support performance analysis within urban planning and design processes, these tend to be neither simple to use, nor flexible in their ways of usage, nor can they be easily integrated with other tools that may serve other parts of the workflow. Modular workflows that can easily be adapted by the user to apply within a particular design context or process are of special interest. Such workflows often rely on various software tools that must be seamlessly connected in order to allow the user to switch back and forth between modeling and analysis.

In this paper, we focus on synthesizing data and demonstrate how data synthesis approaches can be used to support performance analysis at early planning and design stages when urban visions have been defined only conceptually and still need to be elaborated in terms of a plan or model. Specifically, we present a rule-based approach to generate relevant building data that can serve to analyze and assess urban plans with respect to relevant criteria, requirements and targets. Such generation must necessarily take into account local conditions, building typologies, codes and regulations. We also address the integration of data synthesis and performance analysis and identify some obstacles for developing integrative workflows on the fly in response to specific questions that may arise in the planning and design process. We draw upon examples observed and investigated within the context of various studios, addressing urban planning, urban design and architecture, including an international, collaborative design studio (Winter School) involving over 170 students and 30 design tutors, organized by the International Forum on Urbanism (IFoU). Finally, we critically review our endeavors and draw some ideas for developing improved support for urban planning and design.

10.2 Related Work

Various systems for parametric urban design already exist. Beirão et al. [1] present a parametric urban design system that provides automatic feedback on a number of urban indicators and density measures. König [2] presents an open source library for computational analysis and synthesis, denoted CPlan, which supports the optimization of spatial configurations. However, both systems only consider buildings as rectangular blocks and do not support a differentiation in building typologies. Knecht and König [3] present a tool that, given a street network, generates building lots and buildings, the latter in one of four types: row buildings, courtyard buildings, ribbon buildings and free-standing blocks. However, the tool supports only one building type at a time and treats other parameters, such as building depth, similarly. As such, it mainly focuses on small developments.

Esri CityEngine [4] considers a procedural modeling approach for generating 3D city models. Specifically, it adopts a rule-based approach inspired by shape grammars but using procedural rules. While CityEngine is very comprehensive in terms of modeling different building typologies, including their facades, it primarily targets 3D visualization over analysis and assessment. Additionally, much of the work in using CityEngine to generate 3D cityscapes is manual in nature, developing or selecting rules that apply to specific plots in order to generate the relevant buildings. Finally, though CityEngine supports some analysis, this is fairly limited and the data generated within CityEngine cannot easily be exported back into a 2D GIS environment (besides Esri ArcGIS) for detailed analysis and assessment.

In this paper, we target the semi-automatic generation of information that is explicitly relevant for the analysis and assessment of an urban plan. For example, the identification of the number of floors and service cores may lead to a measure of useable floor space that can serve to calculate approximate returns on investments. Other than the 3D building shape, it is possible to export such data for further analysis into a 2D GIS environment. We also emphasize workflows that simplify or (semi-)automate the process of rule selection and support the integration of data synthesis and performance analysis.

10.3 Background

This work was initially developed for an international, collaborative design studio and, subsequently, further developed alongside an M.A. Urban Design studio and a Master of Urban Planning studio.

10.3.1 The IFoU Winter School

The motivation for this work stems from an international, collaborative design studio (Winter School) involving over 170 students and 30 design tutors, organized by the International Forum on Urbanism (IFoU), in which the authors participated as tutors. Participants from all over the world came together to work for 12 days on proposals for Jurong Industrial Estate (JIE), a 5000 ha industrial area in the west of Singapore. The brief was to develop proposals for the transformation of JIE from an almost mono-functional, segregated and fragmented, polluted industrial area into a major catchment area for future population growth that integrates clean(ed) industrial plants with green lungs, attractive housing and vibrant urbanity for one million people.

During the IFoU winter school, students were divided into teams of 8–10 students, who then worked intensively together to develop visions and proposals.

The grouping of the students was organized in such a way so as to ensure that each group included a mix of students from different institutions and regions in the world. While this rich mix of students created great opportunities for cross-cultural interaction and design, it also presented some significant challenges. One of these challenges was the dynamic and at times even chaotic nature of the design process. The design process that emerged from within these groups of students was highly non-linear, and combined sketching and drawing with digital methods and tools. Typically, groups would meet intermittently to discuss overall strategies and goals, and would then break into smaller sub-clusters to work in parallel on specific topics. Often, these sub-clusters would then start exploring completely new ideas, which would later have to be reconciled within the larger group. In many cases, conflicts emerged which then had to be resolved through heated discussion. In general, this reflects the fact that urban planning and design is fundamentally an unstructured or 'wicked' process characterized by (1) multiple actors with differing, legitimate values and opinions; (2) high uncertainty; (3) aspects of irreversibility; (4) no clear solutions; (5) being fraught with contradictions; (6) being persistent and unsolvable [5].

At the start of the winter school, students were provided with extensive data on the existing conditions of JIE. The students were then encouraged to use this data as a starting point for their design process, and to use digital methods and tools to develop proposals. However, this proved difficult due to the fact that the software tools that they tended to use were very diverse. Students had to be able to use the tools they were familiar with and to exchange data in a variety of formats. Although some students had experience in using Geographic Information System (GIS) software, most were only able to use simpler types of tools such as Autodesk AutoCAD and Trimble SketchUp. These issues may seem to be secondary, but in reality they had a significant impact on the types of proposals that were developed and on the arguments made to support those proposals. One key challenge in all groups was the difficulty they had in backing-up claims about their proposals with quantitative data.

Figures 10.1 and 10.2 show two slides from the final presentation from Group 9, the winning group. They highlight two key issues with data synthesis: one relating to the generation of urban proposals and the other to the evaluation of urban proposals.

Figure 10.1 shows one of the waterfront typologies developed by this group that integrates industrial with residential functions. The overall target for the winter school was to create housing and other amenities for one million people, while still maintaining a significant portion of industrial clean-tech industry. The target resulted in some quite well defined requirements of floor areas for different functions. However, models such as those shown in Fig. 10.1 are purely visual and cannot be used to quantify the total floor area that would result. With all groups, it was difficult to understand whether the proposed typologies and urban massing were appropriate for one million people or not. In some cases, the floor areas may have fallen far short. This type of quantification is important since proposals that work well at lower densities may be fundamentally flawed at these higher densities.

Fig. 10.1 Group 9: proposal for waterfront typologies. *Credits* Marco Berger, Geraldine De Neuville, Fei Bo, Goh Jia Li, Meng Jing, Ravish Kumar, Peter Lie, Delon Leonard, Jasmin Mok, Josef Odvarka, Made Perwira, Jaume Pla, Tanzir Taher, Xia Mengjia, Zhao Danyu (tutors: Erik l'Heureux, Patrick Janssen, Eui-Young Chun)

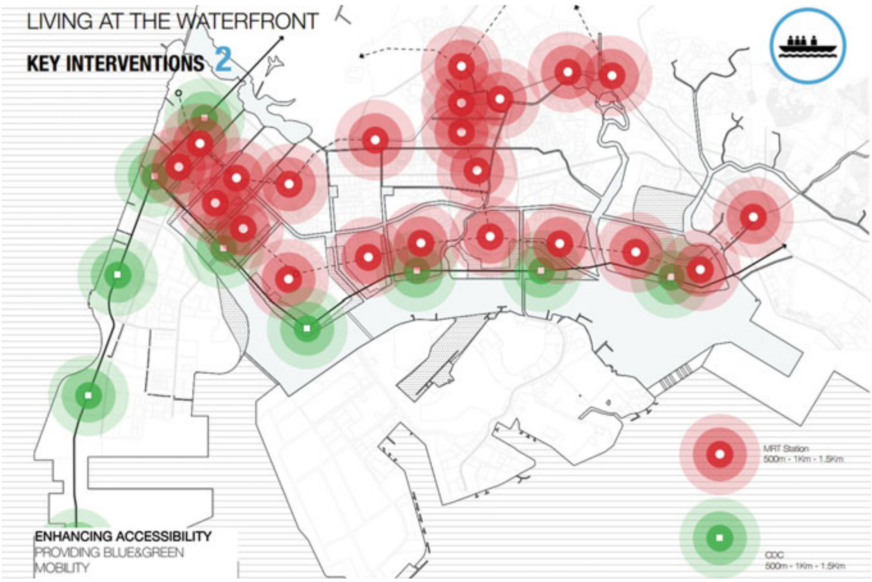

Fig. 10.2 Group 9: enhancing accessibility. *Credits*: idem

Figure 10.2 highlights a different type of data synthesis issue, related to the evaluation of urban proposals. The figure shows how accessibility in JIE would be enhanced by adding various new transport nodes and systems, including additional train stations and interchanges, and also a boat transport system. In this case, the development of the proposals was based on GIS data. However, there was no quantification of actual improvements in accessibility, and as a result it was hard to understand whether the proposed configuration of transport nodes and systems was better than other alternative configurations. GIS systems have tools that could be used to quantify the improvements in accessibility, such as proximity analysis and network analysis. For example, this would allow for the calculation of indicators such as the percentage of people who live within five minutes of a transport node. This would then allow for direct comparison of alternative options. From the point of view of the workflow, the problem however is the disconnect between the 2D GIS model and the 3D urban/building model. The calculation of accessibility requires data on the number of people living and working in each building, which in turn requires floor area data from the 3D model.

10.3.2 Urban Planning Studio

Some of the results of the IFoU Winter School were further developed in an urban planning studio within the Master of Urban Planning program at the Department of Architecture, National University of Singapore. Figures 10.3 and 10.4 show two excerpts from the presentation of the "Ecotopia" project, one of the projects selected from the urban planning studio to demonstrate the data synthesis approach.

Ecotopia stands for a carbon-neutral city amidst lush mid-rise livability. Addressing future resource needs for a projected 2050 Singaporean population increase of over 2 million, the project includes a model of self-sufficiency with respect to five urban metabolism elements: water, energy, food, waste and greenery.

Fig. 10.3 Ecotopia: land use master plan. The site is divided into three different mixed-use belts, from *top* to *bottom* mainly residential, mainly industrial and mainly commercial. *Credits* Andrea Meinarti Rachmat, Tey Hui Ping Serene, Delon Leonard, Wu Xin Peng, Loh Sze Sian (tutor: Oscar Carracedo)

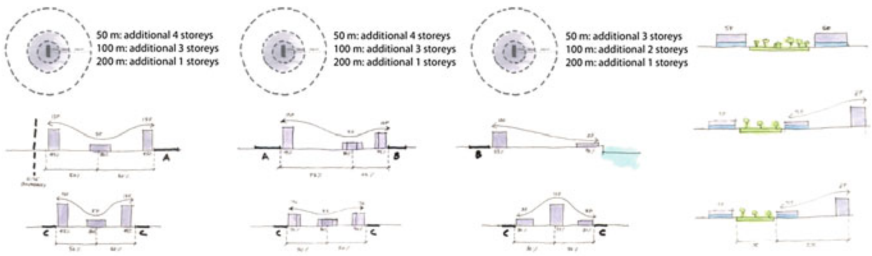

Fig. 10.4 Ecotopia sketched rules for building coverage, distribution and height, in relationship to roads (classes A, B and C), parks and other boundaries, from *left* to *right* within the residential belt, within the industrial belt, within the commercial belt, and with respect to parks. *Credits* idem

The overall site is divided into three different, horizontal, mixed-use belts: mainly residential in the North, mainly industrial in the middle, and mainly commercial around the waterfront. Each belt is divided into a number of eco-cells, such that three different mixed-use cells make up a self-sustainable eco-strip. Each eco-strip joins together industrial clusters around each of the metabolism elements of waste, energy, food and water, in a closed loop to ensure self-sufficiency. Using projected numbers of future demands on resources, a 'per person area requirement' is calculated, which is taken into consideration in calculating the maximum possible population.

Figure 10.4 presents the Ecotopia sketched rules for building coverage, distribution and height, for the different mixed-use belts and in relationship to roads (classes A, B and C), parks and other boundaries. These sketched rules formed the basis for the data synthesis approach.

10.4 Synthesizing Data

Prior to the start of the winter school, a semi-automated data synthesis method was developed to generate building models based on a set of simple rules. As the main purpose of these building models is to quantify the overall massing and floor areas that can be achieved, these building models only needed to consist of simple massing with floor plates and did not need to be highly detailed in their visual appearance. In order to support fast iterative generation of large-scale urban models, a parametric modeling method was conceived that generates building models based on parameter fields encoded as images. This method consists of three main stages. First, the proposed urban typologies need to be encoded as parametric models with a small number of general parameters, such as maximum building height, site coverage, plot ratio, and ratio of functions (e.g., residential, commercial and industrial). Second, for each parameter, a grey scale image is overlaid over the site and used to create a parameter field. Figure 10.5 shows an example of four images applying to five parameter fields. These images can either be created by hand in an

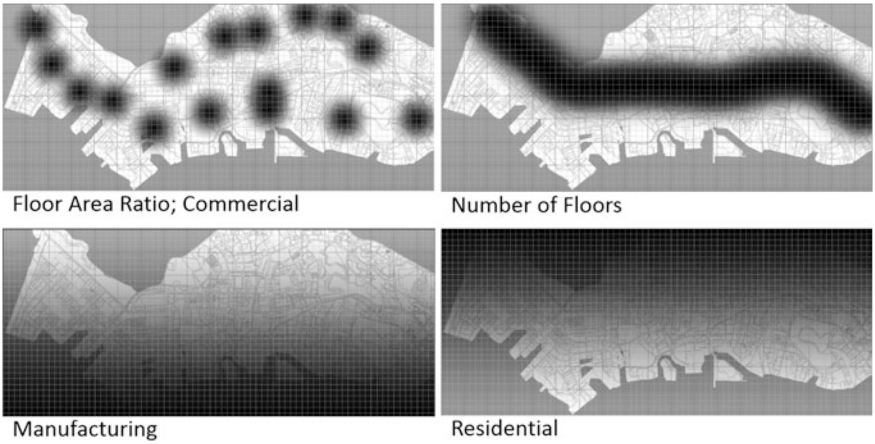

Fig. 10.5 Four grey scale images defining five parameter fields overlaid over the site. *Credits* Ibrahim Nazim

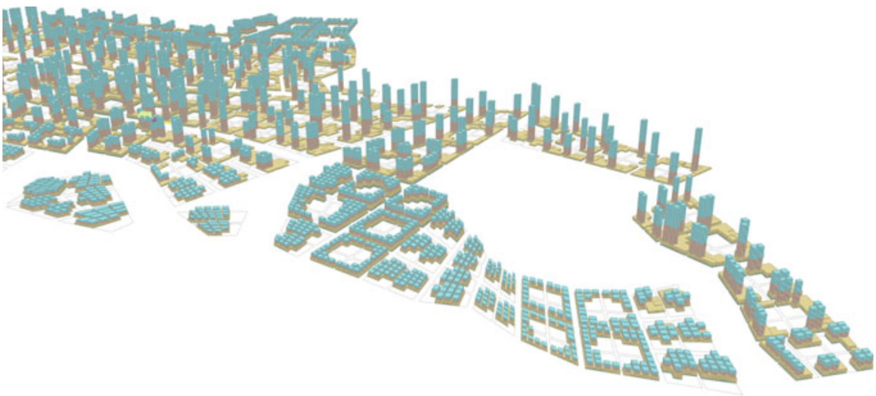

Fig. 10.6 Resulting model generated from the parameter fields shown in Fig. 10.5. *Credits* idem

image-editing tool, or in a GIS system based on certain proximity rules. By default, dark areas of the image correspond to high parameter values, light areas to low parameter values.

Third, large parcels on the site are subdivided into smaller plots according to various subdivision rules, and the parametric models are then used to generate varying building models for each plot, reducing the need to manually detail the road network and plot distribution. The resulting model generated from the images in Fig. 10.5 is shown in Fig. 10.6. This model includes floor plates for each floor, which makes it straightforward to calculate floor areas, such as the total floor area for each function.

SideFX Houdini was used to implement the data synthesis method. The parametric models that serve to generate the building models were actually encoded as procedural rules taking as input the respective values from the different parameter fields. Additionally, a number of workflows were developed to support both generating and evaluating urban models. Exporting the Houdini model to Unity Technologies Unity allowed for advanced visualization. Transferring the data within Houdini from the 3D building model on each plot back to the base polygon for that plot, these base polygons with the attribute data attached could then be exported as a Shape file and imported back into a GIS system.

However, having developed these workflows, it quickly became apparent during the winter school that there was not enough time for groups to apply these types of workflows. Despite having overcome various hurdles, the workflow still proved too challenging for use in the timeframe of the winter school. This was mainly due to the fact that the students had limited knowledge of both GIS and parametric modeling, and learning these methods in such a short timeframe was not feasible. Hence, after the winter school was completed, the workflow was adapted and used to further develop a number of proposals from the urban planning studio to demonstrate the applicability of the method in the context of a design studio. Specifically, rather than relying on parameter field images, the rules were adapted to consider proximity to roads of different categories, MRT lines, parks, waterfront and, possibly, other boundaries, all elements that would have been previously identified in the 2D model. Additionally, the workflows were further relaxed to allow the import of the 2D model as a drawing (e.g., from AutoCAD).

Figure 10.4 illustrates the "Ecotopia" sketched rules for building coverage, distribution and height in relationship to roads, parks, waterfront and other boundaries, for the different mixed-use belts. These sketched rules were disambiguated and encoded as procedural rules. Figure 10.7 shows the model resulting from the data synthesis method. The model was developed in collaboration with one of the students responsible for the "Ecotopia" project in order to ensure a proper interpretation of the project specifics (including the sketched rules) and in order to assess the applicability to the design studio context. The data synthesis results of this and one other project were also presented in an exhibition "Rethinking Urban Practices For Jurong Vision 2050" held at the National Library Building and at the URA (Urban Redevelopment Authority) Centre in Singapore.

10.5 Localization

The data synthesis method firstly developed for the winter school only considered a podium and towers typology for mixed-use functionalities (industrial and commercial in the podium and office and residential in the towers). The variation in the resulting model in Fig. 10.6 is due to an automatic division of plots into smaller entities, such that the podium does not have to fill the entire plot but may be concentrated near the roadside. In the Ecotopia model, the building typologies were

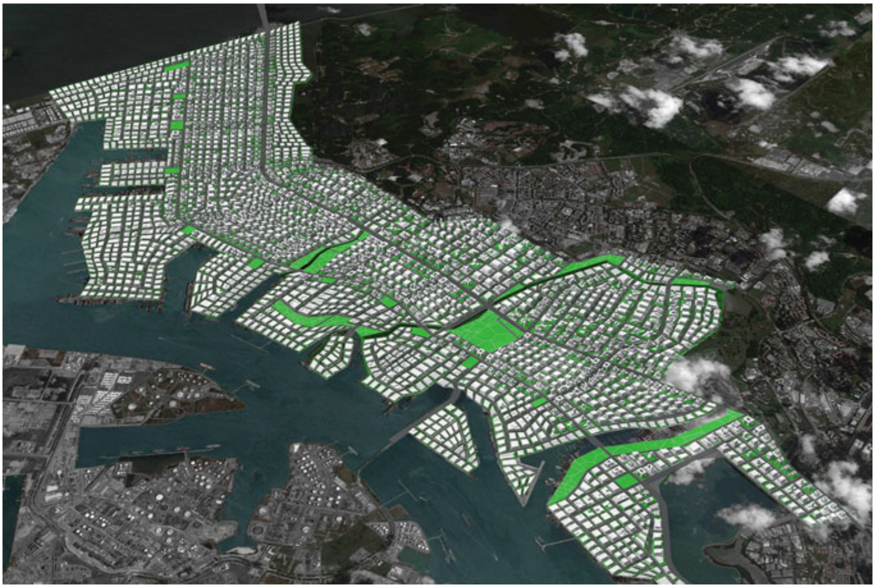

Fig. 10.7 Generated model of Ecotopia, corresponding the rules shown in Fig. 10.4 and the building typologies as considered in the "Ecotopia" project. *Credits* Lin Xiong and Andrea Meinarti Rachmat

adapted from the project specifics and consider, among others, also an elevated platform with a central light well supported by four corner towers. While urban planners and designers might specify and develop their own typologies, for the purpose of using the data synthesis method and workflows in a design studio setting, taking into accounts constraints of time and effort, it would be important to provide a number of predefined typologies that, while offering sufficient variability, also reflect on the geographical and cultural context of the project. For example, public housing developments in Singapore consider a limited number of apartment types as prescribed by the Housing Development Board (HDB) and arrange these apartments mostly in a point block configuration of either 4 or 6 apartments. Also, JTC Corporation, as the main developer of industrial and business parks in Singapore, considers a number of standard building typologies, such as *flatted factories*, which are high-rise, multi-tenanted developments with common facilities such as passenger and cargo lifts, loading/unloading bays and car parks. JTC's flatted factories are designed for clean and light businesses that require functionality, production flexibility and space utility. The development of such typologies for the data synthesis method is the topic of future research. Other localized information to be taken into account are building codes and regulations, including setbacks from roads, maximal building heights, etc.

10.6 Conclusion and Future Work

We presented a rule-based approach to generate relevant building data from 2D urban plans that can serve to analyze and assess such urban plans with respect to different criteria, requirements and targets, and can be applied within a design studio context. We have emphasized the need for such generation to take into account local conditions and building typologies.

Future research will explore both computational methods and interactive workflows. The former investigation will include a grammar-based data synthesis approach. This approach will require the conception of a relevant representational and description model for the generation and analysis of building information from urban plans. The model will draw on existing research and development on shape grammars, description grammars, *sortal* grammars and structures [6], and GIS, and be driven by relevant analysis requirements. The model will be assessed in the exploration and development of an exemplary grammar within the Singaporean context and its application to one or more urban plans. This will include an investigation of the encoding of some relevant building typologies and, possibly, of relevant building codes and regulations.

The research into interactive workflows will include the development of methods and tools that make these approaches more accessible to urban planners and designers. The current ecosystem of GIS and modeling systems are overly complex and therefore make these approaches very challenging. As a result, most students (and many practitioners) simply revert to guesswork and rules-of-thumb. The new methods and tools need to be intuitive and enjoyable to use while at the same time enabling design options to be systematically explored with respect to specific constrains and performance criteria.

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