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Parametric Modeling for Form-Based Planning in Dense Urban Environments

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Abstract: Parametric instruments are employed broadly across the building industry. The study of applying parametric techniques to sustainable form-based planning, however, remains insufficient. This paper therefore critically assesses parametric techniques for facilitating form-based planning in an urban environment. The analysis is to twofold: Can a parametric technique truly enhance the form-based planning process more effectively than existing planning processes? and By what means can form-based planning layouts derived from parametric techniques be appraised? Methodologies include a case study in Hong Kong, quantitative and qualitative analysis, and experimental modeling on parametric platforms. Results indicate that the urban forms can be visualized in real-time during planning processes with a parametric coding system. Existing planning processes do not benefit from real-time visualization, but these alone do not necessarily result in more rational planning layouts. Parametric techniques produce visual models effectively but are not a planning panacea. Findings include a criticism of parametric techniques and pertinent instruments in urban projects, as well as valuable insights for the study of complex form-based planning in dense urban socio-environments.

Keywords: parametric modeling; form-based planning; simulation; dense urban environment

1. Introduction

Parametric instruments have been applied in the architecture and construction industry for some decades. They enable architectural design cooperation, multi-scenario testing, and three-dimensional modeling. Some scholars argue that parametric architecture has come to its second phase of evolution, called "parametricism 2.0", showing promise in solving intricate socio-environmental issues [1]. A series of parametric urban-scale practices have been adopted by architectural institutes and studios such as Zaha Hadid Architects. Most of these projects focus on parametric representation or design simulation rather than on enhancing planning processes. This paper is not about the performance of a single building or a small group of buildings but large-scale urban planning. Parametric planning does not focus on surface patterns, dynamic facades, or flowing space. It focuses more on controlling parameters of land scale, density, floor area ratio, street width, building heights, etc. It may be appropriate to say that parametric planning and parametric architecture are two separate research fields. Parametric techniques have rarely been applied to urban-scale planning; especially the form-based planning projects. This paper thus assesses parametric techniques for facilitating form-based planning in an urban socio-environment. The research questions whether a parametric technique can improve the form-based planning processes and generate feasible layouts in a complex urban socio-environment.

As its name implies, form-based planning shapes the urban form rather than zoning land uses [2]. Existing form-based planning methods regard an urban environment as a collection of various transects. These transects are mainly described with hand-drawings and manual models. Mapping transect zones depends on existing urban development conditions and the planners' experience. A transect matrix of form-based planning defines a hierarchical development scale from sparse suburban to dense urban cores [3–7]. It includes forms from rural to city [8], including natural, rural, suburban, general urban, urban center, and urban core zones. These transects are aligned as an array from natural to artificial. The natural side of the transect matrix represents areas in which human intervention is comparatively weak and the natural preservation strong. The artificial side indicates where human intervention is relatively strong and natural retention weaker. Duany describes the transect matrix as an approach whereby:

> *" ... it arranges in useful order the elements of urbanism by classifying them from rural to urban. Every urban element finds a place within its continuum. For example, a street is more urban than a road, a curb more urban than a swale, a brick wall more urban than a wooden one, and an alley of trees more urban than a cluster. Even the character of streetlights can be assigned in the transect according to the fabrication from cast iron (most urban), extruded pipe, or wood post (most rural)".* [9]

The theoretical foundation of form-based planning can be traced back to the 19th century when contemporaneous understandings of the natural environment influenced perceptions of the urban environment. Accordingly, researchers applied ecological methods to elaborate on the typology of urban sites. In 1826, Von Thunen created the concentric development ring (CDR) model to describe how natural lands and agricultural costs affected urban-periphery environment development. The CDR model described city area as located at the center of a series of circles. Between city and grazing were horticulture and dairying, forestry, crop rotation, enclosed fields, and three-field land areas from inside to edge [10]. According to the sectional system of CDR, scholars argued that inhabitants' activities, living density, even social development were also sections following natural resource distribution. Patrick Geddes' Valley Section (1909) concluded that natural conditions guided human activities from mining to fishing [11] and this concept shaped the subsequent analysis of both eco- and urban systems. Some naturalists use sections to describe land composition [12]: Land within a specific range is expressed in sectional transformations, including ocean, beach, primary dune, trough, secondary dune, and base dune. This method of dividing the land using section transformations appears in urban environmental analysis. Duany adopted the concept for human settlements and, from about 2000, this idea has permeated the thinking of New Urbanists [13] and form-based planning. Like the sectional transformations of an ecological environment, transects in an urban environment describe the characteristics of the physical surroundings with related human behaviors. Social activities depend on the division of transects and so will correspond to a specific zone. For example, in an urban core zone, people tend to shop, gather, or engage in other public activities. In a suburban zone, people lean toward more private or casual activities, such as home or community life. When people move from a community living area to a public activity area, their routes cross different transect zones. Overlapping moving routes helps to describe the range and activity trends of multiple transect zones.

With the rise of form-based planning implementation in recent decades [14], multiple computational-aided techniques aid form-based planning projects. Compared to existing manual planning methods, computational-aided techniques result in relatively efficient planning processes and intensive databases—especially in complex urban situations. For instance, Kim and Clayton used building information modeling (BIM) tools to support form-based planning [15]. They proposed that the capabilities of an application programming interface that supports object-oriented programming results in a powerful environment for expressing planning and design concepts [15]. For the purpose of their study, variables such as road width and building size were defined as modeling parameters. These applied mostly to small-scale single buildings and blocks rather than to large-scale urban morphology. A surfeit of detailed constraints may create a confused database; one difficult to implement in real practice. BIM tools, as a result, seem unsuitable for form-based planning. CityEngine, a modeling tool for urban projects, is also tested in form-based planning [16]. Designers could use only the parameters and modules that are already set in CityEngine's inner system because of the limited editing function provided by the interface. As a result, CityEngine proved too inflexible to control complex urban forms. This paper experimentally employs another parametric tool, Rhinoceros 3D (with its plug-in Grasshopper 3D), to pursue using parametric techniques to support form-based planning. The tool contains a visualized coding interface to create three-dimensional models and has worked on simulating the construction results of building projects for years. In this paper, Rhinoceros 3D and Grasshopper 3D help to examine the parametric techniques on an urban scale.

To evaluate the use of parametric techniques to facilitate complex form-based planning, this paper focuses on a high-density zone of Hong Kong as a study site. Form-based planning itself relates to multiple elements such as urban development strategy, public participation, feasibility assessments of land use, zoning laws, and urban management. A form-based planning project is a comprehensive consequence of various effect factors. This paper limits the study scope to the design process and scenario layouts. Accordingly, the parametric technique is analyzed specifically in the design process and scenario layouts of form-based planning.

2. Methods

The methodology framework consists of two stages (Figure 1). The first stage comprises data integration and transect zoning. Methods include field study, quantitative analysis, and parametric modeling. These work to answer the research sub-question 1: Can the parametric technique improve the form-based planning process? The second stage examines travel behavior and routes. The methods include parametric field lining and qualitative comparison. They contribute to answering the research sub-question 2: If the parametric technique can improve the form-based planning process, can the parametric planning process generate feasible layouts in a complex urban socio-environment?

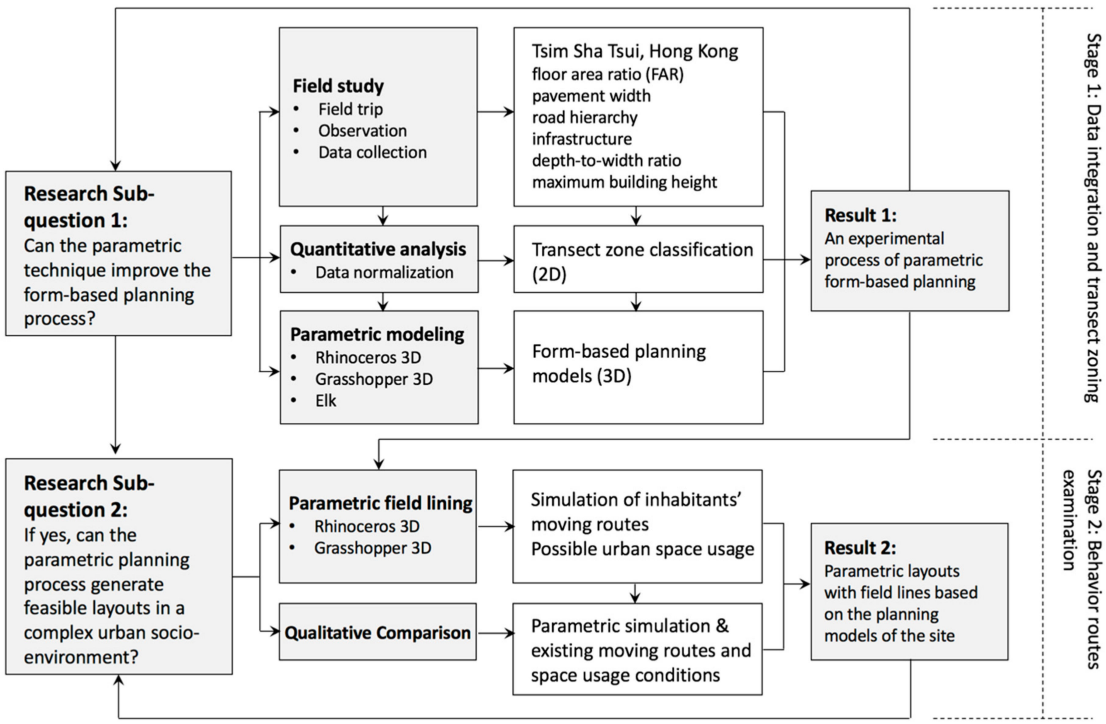


Figure 1. Method framework.

At the first stage, Tsim Sha Tsui of Hong Kong—a typical dense urban core zone—is the field study site. A series of form-related data is collected through the field investigation and data in differing scales and measurements are normalized for directly numerical classification with the statistical method. The classified data helps to define transect zones during the planning process. A parametric model of form-based planning is created through the interface of Rhinoceros 3D when the classified data is imported into Grasshopper 3D and the relationships between the pre-set parameters edited. This stage targets the question of whether parametric techniques can improve form-based planning processes.

At stage two, the model provides a foundation for visualizing the scenario layouts of form-based planning with parametric techniques, and the field line method is used to analyze the layouts. Attraction areas, such as shopping malls and open spaces and interference areas such as mountains and water systems, are defined as constraint points to create the field lines based on the model. Integrating filed lines enables a rough indication of potential routes that move between the different transect zones of form-based planning. The simulations of inhabitants' travel between zones and use of urban space are compared with the existing conditions of Tsim Sha Tsui to assess whether the parametric planning process can generate feasible layouts in a complex urban socio-environment.

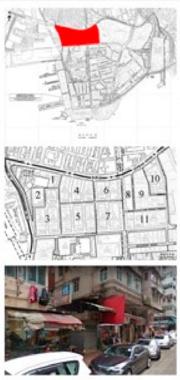
2.1. Stage 1: Data Integration and Transect Zoning

2.1.1. Field Study

The Tsim Sha Tsui area of Hong Kong is characteristic of a dense environment developed along the seaside. The site contains a series of blocks developed in accordance with existing streets and road networks. Victoria Harbor is the source of much marine transportation and trade with Tsim Sha Tsui. It is historically a commercial area, consisting of small-scale streets with traditional shops and large-scale financial centers built during urban renewal. Public green spaces such as Kowloon Park are interspersed between high-density buildings.

Given the scale of the study site and the density of the urban environment, this paper chooses six form-related data types to generally describe the existing form conditions of Tsim Sha Tsui. These are: floor area ratio (FAR), pavement width, road hierarchy, infrastructure, depth-to-width ratio, and maximum building height. During the field investigation, a table recording the values of each data type was compiled for each block in Tsim Sha Tsui, as indicated by Figure 2. The site comprises sixty blocks; twenty are included here as examples.

Jordan Road Area						
Block No.	FAR	Pavement width	Road hierarchy	Infrastructure	Depth-to-width ratio	Maximum height
1	8.15	3	6	4	2.13	80
2	5.2	1.5	3	2	1.86	80
3	11.10	1	3	2	2.40	80
4	9.71	1.5	3	2	4.25	80
5	9.72	1.5	3	2	4.25	80
6	7.53	2	6	4	1.78	100
7	7.10	1.5	6	4	1.78	100
8	11.75	2	6	4	2.59	100
9	7.55	1	4	3	3.55	80
10	8.67	1.5	4	3	4.40	80
11	7.84	1.5	6	4	1.86	80



Hong Kong Observation Area						
Block No.	FAR	Pavement width	Road hierarchy	Infrastructure	Depth-to-width ratio	Maximum height
12	7.60	1	3	1	3.82	80
13	7.33	1	2	1	3.09	80
14	3.73	1	2	3	8.00	80
15	6.54	1	2	1	3.27	80
16	7.12	2	4	2	4.20	80
17	7.04	2	4	2	4.20	90
18	11.80	3	6	4	3.13	80
19	10.31	1.5	3	2	4	80
20	8.26	1.5	3	2	4	80

Figure 2. Examples of data collection in Jordan Road area and Hong Kong Observation area.

The transect matrix is the basis of form-based planning, in which values of form-related data reflect the transect zones. For example, if a block has a high FAR value, it may belong to a transect zone with more artificial than natural features. Comprehensively analyzing and classifying the values of the form-related data enables designers to achieve a form-based zoning map with multiple transect zones. The map at this phase is two dimensional. It appears as colored blocks on the site—just as existing planning maps do. Color-blocks on form-based zoning maps represent different form-based zone types; on existing planning maps they represent different land-use types.

2.1.2. Quantitative Analysis

Quantitative analysis methods work to organize and classify the collected data of the sixty blocks. Data normalization aims to ensure a relational data integration based on normal forms. Dependencies are enforced by integrity constraints. After reducing the dependency and redundancy, the original data can be grouped and classified directly—despite being recorded with different measurements and ranges. As Formula (1) indicates, the normalization process fits collected data into a closed interval [0,1].

$$\text{Normalized (ei)} = \frac{ei - Emin}{Emax - Emin}, \tag{1}$$

where ei =the original data that to be normalized. $Emin$ = the minimum value of E. $Emax$ = the maximum value of E. If $Emax$ is equal to $Emin$ then Normalized ei is 0.5.

At this point, each block has a specific table recording the normalized results of the form-related data type. When the tables are combined, each data column contains a series of normalized data that represent specific blocks. To define the transect zone of each block, the paper uses Formula (2) to achieve normalized data summation and then mean value:

$$\text{X} = \frac{\sum_{k=1}^{n} Xk}{n}, \tag{2}$$

where X = mean value of normalized data. Xk = X1. n = the number of the parameters.

The value of X represents the degree of artificiality in a block of the transect matrix. A higher X value means the block is closer to the artificial point in the transect matrix and vice versa. Although various elements affect determining the degree of artificiality, this paper limits the elements to the form-related variables collected in the field investigation. X values of all blocks are demonstrated in Figure 3. If one block's X value is relatively high, it means the urban form of this block has more artificial characteristics, such as high FAR, wide pavement width, or high building heights. If low, this indicates an urban form with more natural components, like narrow pavements or low building heights.

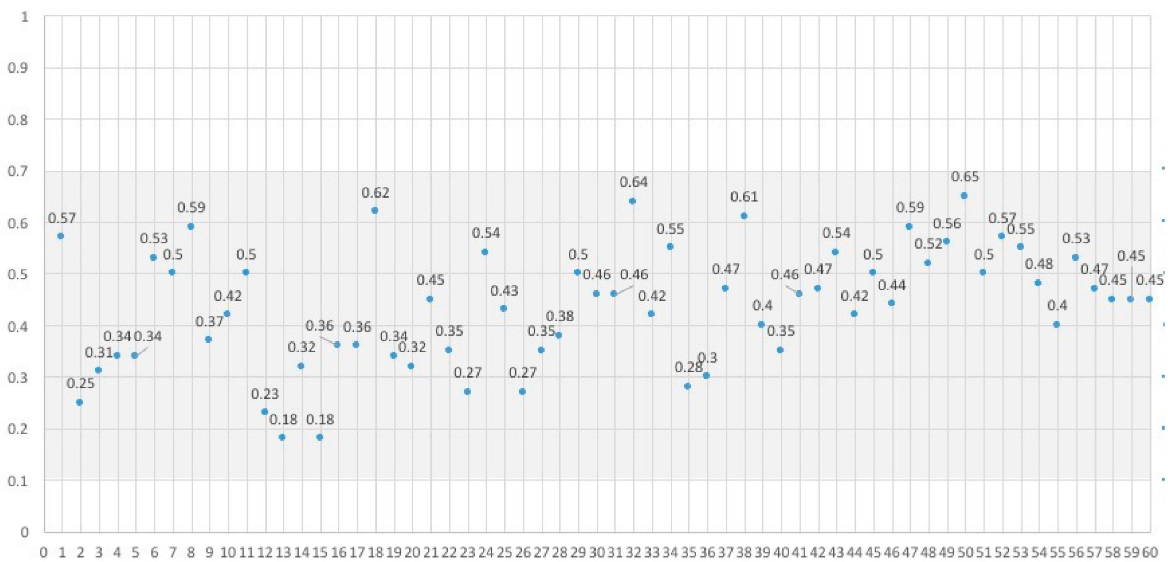


Figure 3. The value of X of each block in Tsim Sha Tsui.

According to Duang, the zones of a standard transect matrix are named from Transect1 (T1) to Transect6 (T6)—from natural to artificial. The higher the number value, the greater the artificial nature of a transect zone. T6, the urban core zone, represents the most artificial areas of a standard transect matrix. As a typical dense area, Tsim Sha Tsui belongs largely to T6. Inside the Tsim Sha Tsui area, more detailed transect zones are required. Accordingly, X values of all blocks are grouped with a certain tolerance. Considering the in-depth planning of the site, this paper sets the group tolerance as 0.1. Therefore, each X value belonging to the closed interval [0,1] is grouped within a certain range. For example, the X value of block No. 2 is 0.25 and block No. 12 is 0.23. They both belong to the range 0.2–0.3 so are grouped as one transect zone. This transect zone is named as T6-2. The name contains two parts. T6 indicates the study site generally has urban core zone features. The dash alongside a specific number indicates the zone is a subtype of T6. The number after the dash is named according to the first decimal number after the digit. Figure 4 demonstrates that all X values are calculated by Formula (2). The values cluster within the range 0.1–0.7. With a tolerance of 0.1, all X values are grouped into six equal value intervals. Arranging X by numerical values, each block belongs to one specific transect zone in the transect matrix of Tsim Sha Tsui. As Figure 4 illustrates, the transect zone of blocks 13 and 15 is T6-1 and the transect zone of blocks 2, 12, 23, 26, and 35 is T6-2. Blocks 3, 4, 5, 9, 14, 16, 17, 19, 20, 22, 27, 28, 36, and 40 are transect zone T6-3. Blocks 10, 21, 25, 30, 31, 33, 37, 39, 41, 42, 44, 46, 54,55, 57, 58, 59, and 60 are transect zone T6-4. The transect zone of blocks 1, 6, 7, 8, 11, 24, 29, 34, 43, 45, 47, 48, 49, 51, 52, 53, and 56 is T6-5. Those of blocks 18, 32, 38, 50 are T6-6. The artificial level of urban form generally becomes higher from T6-1 to T6-6.

zone / block	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
T6-0																														
T6-1													0.18		0.18															
T6-2		0.25										0.23											0.27			0.27				
T6-3			0.31	0.34	0.34				0.37					0.32		0.36	0.36		0.34	0.32		0.35					0.35	0.38		
T6-4										0.42											0.45				0.43					0.46
T6-5	0.57					0.53	0.50	0.59			0.5													0.54					0.50	
T6-6																		0.62												
T6-7																														
T6-8																														
T6-9																														
T6-10																														

zone / block	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
T6-0																														
T6-1																														
T6-2					0.28																									
T6-3						0.30				0.35																				
T6-4	0.46		0.42				0.47		0.40		0.46	0.47		0.42		0.44								0.48	0.40		0.47	0.45	0.45	0.45
T6-5				0.55									0.54		0.50		0.59	0.52	0.56		0.50	0.57	0.55			0.53				
T6-6		0.64						0.61												0.65										
T6-7																														
T6-8																														
T6-9																														
T6-10																														

Figure 4. Transect zones of blocks in Tsim Sha Tsui.

2.1.3. Parametric Modeling

Transect zoning is a core component of the form-based planning process. The elements of transect zoning include software Rhinoceros 3D and Grasshopper 3D and the related geographical site information, encompassing scripts, and planning models. Rhinoceros 3D and Grasshopper 3D have functionality to combine transect zoning with the parametric modeling platform. The transect zoning structure is outlined in Figure 5. Transect zones based on data collection and normalization have been prepared in the former analysis.

Rhinoceros 3D is a tool for building parametric models by means of an algorithmic program. Grasshopper 3D is a visual programming environment which runs as a plug-in on top of Rhinoceros 3D modeling software [17]. By dragging the components or nodes onto the screen canvas and mapping the flow of parameter relations, a user-defined layout is achieved with geometries and materials [18]. Grasshopper 3D requires no knowledge of programming or scripting but still allows designers to build form generators from the simple to the awe-inspiring [17]. It is better for multi-scenario testing than non-algorithmic modeling software. Changing parameters propagates changes across all functions and redraws the geometry [19].

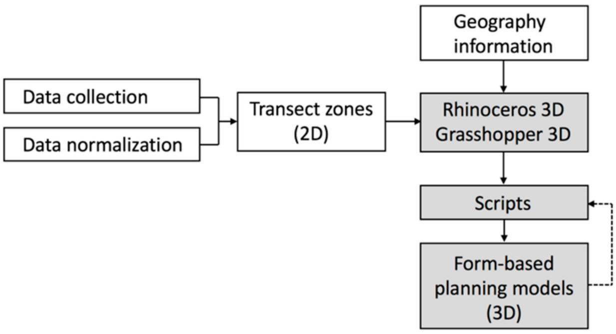


Figure 5. The process of transect zoning.

The geographical information of Tsim Sha Tsui is obtained from Open Street Map (OSM) format map (Figure 6). OSM map can input data directly into Rhinoceros 3D and Grasshopper 3D. The primary purpose of OSM is to create an editable map of transportation infrastructure (streets, paths, railways, or rivers). OSM data, however, also include a multitude of points of interest, buildings, natural features, and land-use information, as well as coastlines and administrative boundaries [20]. A physical environment is composed of various elements; buildings, road systems, and infrastructure, for example. While in a large-scale community such as Tsim Sha Tsui, buildings are the predominant visualized elements affecting people's perception of the urban form. This paper therefore uses building models to represent the urban form on a modeling platform. Grabbing building information from OSM, Elk™ (a plug-in of Grasshopper 3D) translates the data into coordinate points. The physical information of Tsim Sha Tsui is thus prepared for the modeling platform.

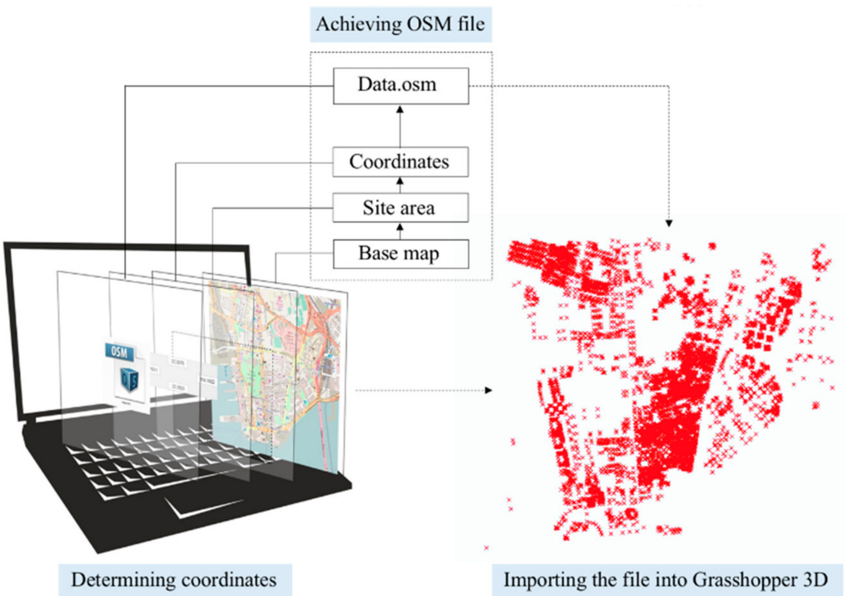


Figure 6. The workflow of importing OSM data into Grasshopper 3D. Building information is obtained from OSM Online by setting site areas on the base map. Writing scripts in Grasshopper 3D, the building information is translated into parametric coordinates. These coordinate points work to process the parametric modeling in Grasshopper 3D.

Building models are generated according to the transect zones in Grasshopper 3D. Each model group corresponds to a specific script (an example script is presented in Figure 7). A script consists of five parts. Parts A and B control the maximum and minimum building height. Because of the high-density environment, higher buildings may create natural light deficiencies, and lower buildings may reduce the efficiency of land use. It is thus necessary to control the maximum and minimum building heights to balance density and land usage. Part C controls building lot coverage; part D the number of building floors. Part E combines the building units into a specific transect group. The scripts help to reflect real-time building models during the planning process. In Figure 8, the yellow block areas represent a specific transect zone and a set of scripts connect with each of them. For example, models of transect zone T6-6 concentrates mainly on high-quality commercial–residential neighborhoods in the north and the large-scale mansions in the middle of Tsim Sha Tsui. When parameters and constraint rules are changed in scripts, Rhinoceros 3D presents real-time changed scenarios. The process of form-based planning becomes flexible and visualized by using parameters to control three-dimensional models.

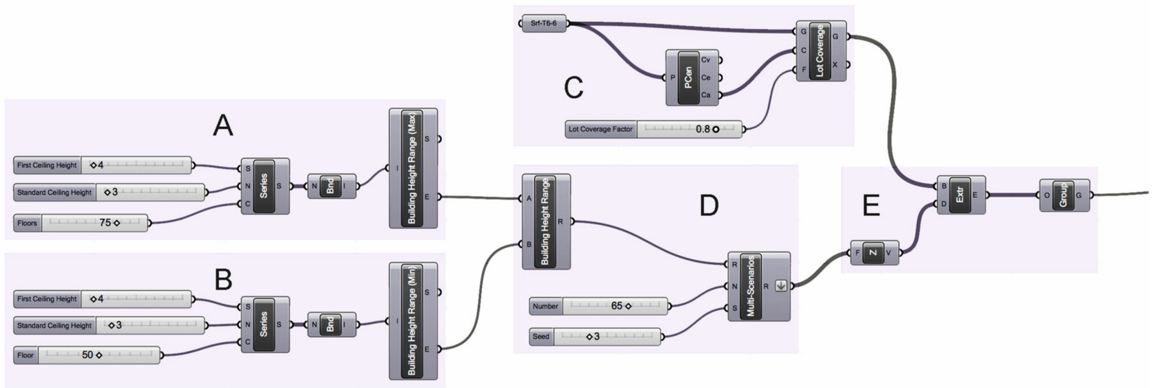


Figure 7. An example script of parametric modeling in Grasshopper 3D for one transect type.

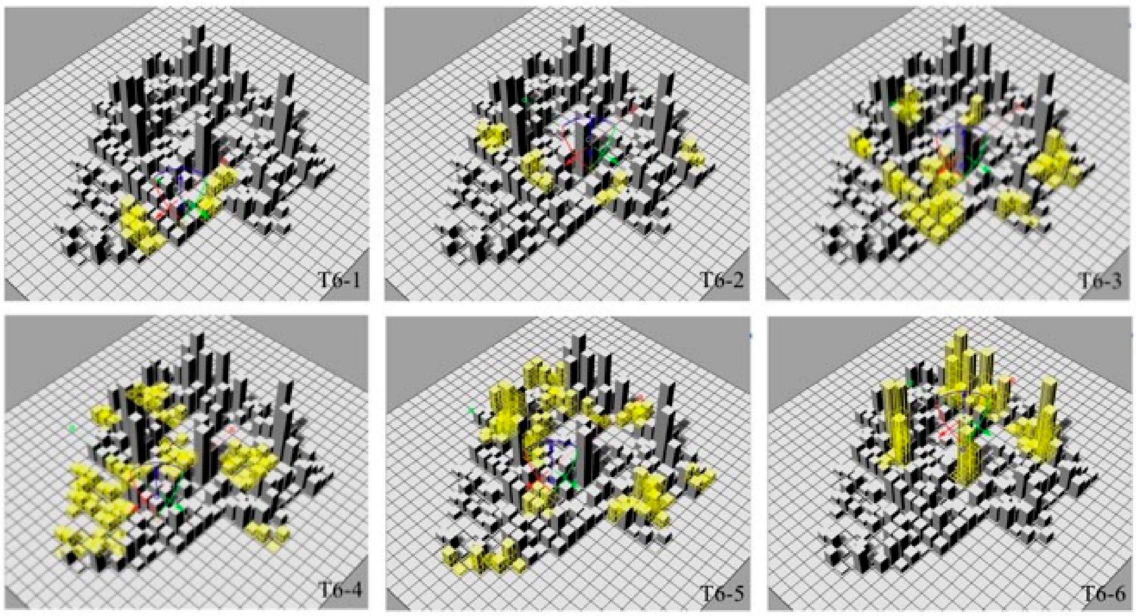


Figure 8. Parametric models of Tsim Sha Tsui. Each model group represents one specific transect type.

2.2. Behavior Route Examination

2.2.1. Parametric Field Lining

The complexity and dynamic nature of a dense urban zone make it difficult to examine a form-based planning layout—not only to evaluate the urban form but also to consider whether inhabitants can make full use of the planning for a more convenient daily life. In dense cities, form-based planning remains an open problem in terms of shaping urban form and people's behavior in specific transects. People use urban space in various ways, but their moving routes for different targets, such as social, commercial, or working, are also an essential use of space. More walkable routes may lead to more environmental and social safety, pleasing aesthetics, natural features, pedestrian amenities, land-use diversity, and a superior social milieu rating [21].

Based on the three-dimensional models generated in last stage, the parametric field lining method is employed to analyze people's travel behavior and the behavior routes they take. The parametric platform of Grasshopper 3D enables a computer to calculate the field lines to simulate routes. Field is originally a physical term. It defines groups of lines used to describe a field's strength and direction. Kohler, an American psychologist, borrowed the physical concept of field, including force, boundary, and vector, to explain human behavior in the living environment in 1936. He argued that the living environment influenced people's behavior as they unconsciously created a psychological field to connect to the physical environment. Koffka, too, defined the relationships between individual activity and the physical environment from the field perspective. He argued that people's perception of reality was a psychological field, and the reality to be perceived the physical field [22]. It is psychological and physical fields together that form the environmental field. Accordingly, in an urban socio-environment, the built space is a field with boundaries and forces that shape inhabitants' movement. A strong force starts at places of attraction where people tend to cluster, such as shopping malls, public parks, or office buildings. The weak force starts at interference areas such as mountains or water. By defining a start point, the field lines flow along the vector to a specific iteration limit and step size [23].

In this phase, the essential settings are attraction interference coordinate points. Traditional commercial blocks around Jordan Road and newly developed financial centers in Tsim Sha Tsui East are set as the attraction points; Signal Mountain the interference point. Figure 9 shows the script generation process in Grasshopper 3D. When running the script, the computer can automatically identify the field lines based on the settings of attraction and interference points. The behavior routes examination script contains six parts (Figure 9). Part A sets the coordinate points of attraction areas. These areas belong to the zones of "more urban" in the transect matrix. They work as moving destinations that attract people to a cluster. Part B sets the coordinate points of interference areas. They are located predominantly at Signal Mountain and belong to the "more natural" zones of the transect matrix. The height of the natural reserve prevents people from walking or driving across the interference areas. It resists the moving flow. Part C defines the vector direction of the field. Part D runs the scripts to generate field lines. Part F colors the field lines for easy-to-read results.

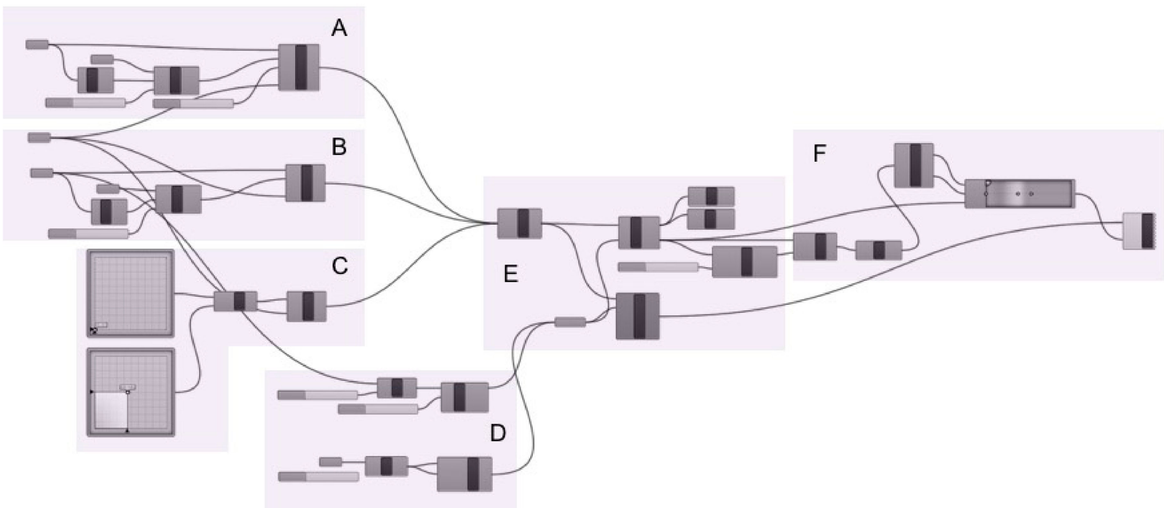


Figure 9. Script for moving route simulation. It contains parametric components offered by Grasshopper 3D. The running result is a bunch of field lines in the Tsim Sha Tsui model representing people's routes of movement for form-based planning.

2.2.2. Qualitative Analysis

Field line performance methodologies see urban planners give computers instructions and constraints. The computer runs the examination process. Modeling platforms use an algorithm to present performance feedback. According to Rogers (1987), an algorithm is expressed within a finite amount of space and time and in a well-defined formal language for calculating a function in mathematics and computer science [24]. The algorithm starts from an initial state and initial input and describes a computation that, when executed, proceeds through a finite number of well-defined successive states, eventually producing "output", and terminating at a final ending state [25]. Parametric instruments enable the expression of parameters and rules that, together, define, encode, and clarify the relationship between design intent and design response [26,27]. By using algorithmic theory as a foundation, the modeling system combines the field line study of phycology and physics and with form-based planning to predict individuals' moving routes in Grasshopper 3D. Field lines are presented in Grasshopper 3D accordingly (Figure 10) and partly reflect urban space usage regulated by form-based planning. The areas with more field lines may attract more people to cluster. The field lines help urban planners to consider the arrangement of the physical environment and improve the feasibility of planning schemes. For example, in the middle part of the site, colored red is where large-scale commercial buildings may best be constructed as there is a high possibility of crowding. A commercial zone is, therefore, an appropriate land-use feature of this area.

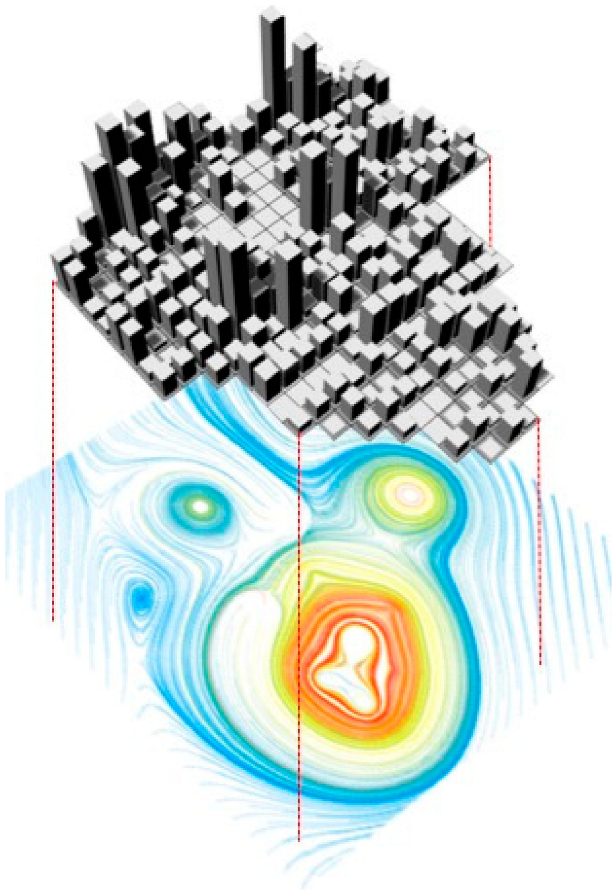


Figure 10. An example of inhabitants' moving routes using the field components in Grasshopper 3D.

3. Results and Discussion

3.1. An Experimental Process of Parametric Form-Based Planning

This paper critically analyzed parametric techniques for facilitating form-based planning. Parametric instruments provide an alternative approach to form-based planning, especially in a complex urban socio-environment. Existing urban planning relies heavily on manual methods, such as hand-drawing and manual three-dimensional modeling, to process planning designs. The experimental process of parametric form-based planning in Tsim Sha Tsui developed by the methodology framework indicates that parametric techniques have the capability to improve the process of form-based planning. Parametric instruments automize the planning process in terms of visualizing design schemes, performing draft resolutions, and presenting possible planning consequences.

Although parametric instruments can support form-based planning, it may work only at the conceptual stage. As the planning process progresses, various parameters are added to the parametric modeling scripts. This paper uses a small group of criteria to control the parametric model. However, many more factors and parameters impact real form-based planning projects. Accordingly, a parameter database becomes more complex. This may ultimately contradict the original target of using the parametric techniques to simplify the planning process.

Hierarchical form classifications of the urban environment are the basis of parametric form-based planning. Describing urban forms with numerical measurements makes embedding parametric techniques into form-based planning possible. It does not, however, create a panacea to solve all issues of the planning process. For example, the form-based plan uses the collage of transect categories to constitute the evolution of an urban environment. It is one-sided. Form is an essential element of urban development, but not the only element. Overemphasizing urban form may lead to issues such as cultural rejection between communities, land tenure chaos, and loss of urban space heritage. The parametric technique fails to address these matters.

3.2. Parametric Layouts

The result of the form-based parametric layouts indicates that parametric techniques can partially simulate people's movement routes and space usage, but there is no clear evidence proving the accuracy of parametric simulations. Form-based planning shapes people's behavior; people's behavior responds to planning decisions. Traditional analyses of behavior and space usage rely mainly on manual methods. At different times, and in differing conditions, there are considerable differences in the behavior trends. The manual statistics sometimes cannot truly reflect the results of planning until the street blocks are completely built. Parametric techniques work to simulate possible travel routes and use of space at the beginning of the planning process. It helps to avoid wasting resources by automatic calculations that the result in field lines differentiated by a range of colors. The automatic calculations, however, are founded on parametric models—models that are simplified to limit numerical variables. Hence, the parametric simulation of scenario layouts provides a reference for design decision-making rather than a definite valid basis.

Parametric instruments clearly help to predict urban space and land-use development. This does not mean that parametric techniques can provide more rational scenario layouts than traditional planning methods. Field line maps indicate that the higher the density of field lines, the greater the possibility of gathering traffic flow. However, the field lines are determined only by the strength of field force based on the parametric models. Accordingly, urban planners should design a road system to alleviate possible traffic congestion. Commercial centers, trade industries, and entertainment facilities with public attributes are best located at these areas. Conversely, areas with fewer field lines possibly cannot accommodate people and vehicles. In these areas, urban planners can arrange residential communities to create a quiet and safe atmosphere. Real-life conditions, however, are not as same as the analysis by parametric techniques. In the case study of Hong Kong, the zones with fewer field lines are around the Signal Mountain area. There are complex transportation networks around this area and multiple public activities. There are few residential communities but many office buildings and commercial mansions. The parametric technique offers tools to simulate planning layouts but is not always rational in real planning practice.

4. Conclusions

This paper analyzed the form-based planning process and scenario layout examination in a dense urban environment with parametric techniques. Former parametric design practices have been criticized for ignoring sustainable development; however, this paper proposed that parametric form-based planning should take sustainable land use and spatial morphology into consideration at the beginning of the planning process. Parametric instruments provided a three-dimensional modeling platform to support form-based planning. The transects of form-based planning and inhabitants' activities were explored based on the theory of ecological development of a natural environment. Tsim Sha Tsui of Hong Kong was a case study testing the capabilities of parametric techniques. A series of building models were produced on the parametric platform, representing multiple transect zones of form-based planning. Introducing the parametric techniques to form-based planning helped to explore the sustainable urban development of both individual buildings and the wider, large-scale, connected urban fabric.

Human activities both shape and are shaped by transects. In a highly constructed urban core zone particularly, the transects are strongly impacted by social behaviors. This paper uses parametric instruments to visualize inhabitants' commuting behavior and routes. Collating people's commutes helps to inform the use and development of urban socio-environments. Therefore, analyzing these routes is significant for the decision-making of form-based planning and sustainable urban environment study.

The research results answered the research questions: The parametric technique has the capability to improve the efficiency of form-based planning process, but does not necessarily promote rational planning layouts. Parametric instruments offer real-time, three-dimensional models during the planning process. They help urban planners and designers to visualize the scenarios quickly by editing scripts and adjusting parameters. The scripts and parameters, however, become too complicated to regulate urban form when broadening the form-based planning. The complex database instead makes the planning process inefficient. Besides, parametric techniques can help to visualize the possible behavior routes as field lines on a modeling platform. Field lines can partly reflect behavioral trends and the urban space usage, but they do lack accuracy. People's perception of urban space is ever-changing and encompasses complex social conditions and urban development situations.

Parametric modeling studies for form-based planning are a small part of parametric techniques in the architectural industry. Parametric design works as a style rooted in digital animation techniques, its latest refinements based on advanced parametric design systems and scripting methods [28]. Although there are some attempts in the US, Singapore, Hong Kong, etc., parametric form-based planning has no mature practice until now. This paper proposed that computational platforms could provide efficient process to form-based planning. It did not mean parametric form-based planning could bring better design process in real practice. A comprehensive parametric system should include more aspects, such as scheme generation, visioning, assembling, and subsequent implementation. Changing the context to less dense conditions makes the parametric form-based planning face different problems such as land sprawl, urban center recession, and environmental degradation. The application of parametric technology in urban planning has the potential to be much more deeply explored.

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