Programmatic Formation: Practical Applications of Parametric Design

Yehia Madkour, Oliver Neumann, and Halil Erhan

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ABSTRACT

Programmatic Formation explores design as a responsive process. The study we present engages the complexity of the surroundings using parametric and generative design methods. It illustrates that responsiveness of designs can be achieved beyond geometric explorations. The parametric models can combine and respond simultaneously to design and its programmatic factors, such as performance-sensitive design-decisions, and constraints. We demonstrate this through a series of case studies for a housing tower. The studies explore the extent to which non-spatial parameters can be incorporated into spatial parametric dependencies in design. The results apply digital design and modeling, common to the curriculum of architecture schools, to the practical realm of building design and city planning. While practitioners are often slow to include contemporary design and planning methods into their daily work, the research illustrates how the incorporation of skills and knowledge acquired as part of university education can be effectively incorporated into everyday design and planning.

1. Introduction

Design is a responsive process. Architects respond to a broad set of references that place the design in a set of comprehensive conditions. They acknowledge design as part of a complex context that includes environmental conditions, social and cultural considerations, economy, materiality, and technology. The complexity of the surroundings as the conceptual framework of design interventions can be engaged with the aid of computational means such as parametric and generative systems. Responsiveness of design is a direct result of the incorporation of novel design, modeling, and fabrication tools. More than the common need to translate abstract references into specific design features, parametric models, digital output manufacturing, and related methods of assembly provide the designer with the ability to connect and relate those design references through computation as an active part of the design decision-making process.

The increasing use of digital technologies in design and fabrication clearly exhibits the instant and inevitable temptation to develop complex formal solutions. However, the conditions that influence form-making decisions are often too abstract to address specific references. Although parametric modeling holds rich potential for controlling multiple processes and transformations, it is yet a bigger challenge to employ the digital technologies in designs that are responsive to the particular conditions of context, user functions, and program based on a complex set of interrelated natural, social, and economic references.

Programmatic Formation presents case studies for a housing tower in Vancouver that explores the extent to which non-spatial parameters can be incorporated into spatial parametric dependencies. A series of explorations demonstrate parametric modeling's potential to engage and coordinate a complex set of independent relationships and conditions specific to urban housing. The proposed parametric design method aims to dynamically build and control a network of contextual, environmental, and programmatic dependencies. The explorations investigate the design of residential buildings at four scales and illustrate how parametric modeling can be productively integrated into the current design and planning process.

The project's explorations define new grounds where digital techniques not only manipulate form but also function, program, and space. In each phase of the study, dynamic relationships are created between the model and its influencing programmatic factors, where the digital model stores explicit performance-sensitive design decisions and constraints, and responds to them simultaneously. This allows for a complex and cumulative expression, both programmatic and spatial.

This approach constitutes a shift in the digital design process away from the ambiguity of open-endedness and mere form-focused diversity to spatial configurations that reflect a complex array of spatial and

programmatic performance criteria central to the design. The approach is applied to the planning process of residential architecture in an urban context. This study relates sophisticated digital design and modeling common to the curriculum of many design schools to the practical realm of building design and city planning. While design practitioners and city planning departments are often slow to include contemporary design and planning methods into their daily work the research illustrates how the incorporation of skills and knowledge acquired as part of university education can be productively incorporated into everyday design and planning procedures.

2. Conceptual framework and architectural context

The availability of parametric modeling techniques in the design and building process coincides with our conceptualization of the surroundings. This understanding of space is itself an extension of the perception "of the configuration of cultural forms in today's world as fundamentally fractal, that is, as possessing no Euclidean boundaries, structures, or regularities" [1]. It coincides with a conceptual shift from a static assumption of form to architecture as an integral part of dynamic and flexible systems.

As a consequence, "...architecture should perform rather than simply form; structurally, environmentally, economically, programmatically, contextually, or in multiple formal arenas. Formal distortions need to have purpose or cultural relevance..." [2]. Parametric modeling allows engaging with the dynamics of culture and space. As a result "meaning can be constructed locally and relationally" [2].

The use of parametric software has implications for design concepts and the responsiveness of designs to context-specific conditions that include technical features of building components, plan layout, building configuration, and configuration of building ensembles in the city. Increasingly, architecture is understood as a product of a complex set of interrelated factors that negotiate social, cultural, environmental and economic conditions. Similarly, cities can be seen as "field conditions" whose "overall shape and extent are highly fluid and less important than the internal relationship of parts" [3]. Seen as products of networks and flows rather than as results of static formal and spatial parameters they are "defined . . . by intricate local connections." [3] Architecture as part of this urban field of dynamic relationships needs to respond to its context in flux, which is understood not as form but as "information drawn from all resources of science and technology as well as economic and political data: the quantifiable aspects of life" [4].

While engendering explorations and realizations of rich and complex formal possibilities, parametric design can "inject performative potential into the built environment" [5]. Parametric tools that enable

responsiveness during the design process allow direct integration of architectural proposals in their complex cultural context. This context is situated at the intersection of environmental, economic, and social factors and is, consistent with its references, in constant transformation. By incorporating changing parameters of dynamic relationships, parametric tools help position architecture and urban configurations as a result of a formation process.

The case studies for a residential tower in Vancouver presented below integrate parametric design into the generation of urban housing. The parametric design tools used in this research empower the architectural design process to respond to the "complex self-regulating orders (already) present in the city" [6]. These references constitute manifestations of urban culture at a range of scales: they include planning guidelines that govern configurations of the urban fabric and that define protected view corridors; they aim at incorporating desired social configurations that affect apartment layouts; and, are designed to control sun exposure. The case studies illustrate practical translations of the conceptual discourse on parametric systems and indicate the relevance of conceptual design explorations for design and planning of buildings and urban environments.

3. Design computation and parametric systems

3.1 Categories of tools for design support and parametric systems

Computational design support tools, although initially received with skepticism by many, have enhanced the process of designing and have contributed to the creation of better artifacts. Conventionally grouped in three categories, these tools provide designers with a set of functions to capture and represent design information in different stages of design. The first category of tools is used to structure and model pre-design information for requirements specification and planning purposes. The tools in the second category—more commonly known as CAD systems—help designers to model geometric properties of design solutions as objects to be built. These models can be used to generate multidimensional digital and analogical views of a design at different levels of resolutions. The third category aims to use information captured in geometric-spatial models for generating information on the performance of the design. The challenge for utilizing conventional computational design-support tools has been that design systems handle design information in isolation and, therefore, provide limited support for the responsive and integrative design process.

Recent computational design systems present opportunities for alleviating this challenge. Among these, and the most promising, are design systems enabling parametric and constraint-based modeling. They present

opportunities for supporting the design process more naturally and seamlessly. They are capable of creating, managing, and organizing highly complex (parametric) design models by integrating different types of parameters and rapidly searching for alternative solutions [7], [8], [9]. The "performance-based design" approach presented by Oxman [10] proposes integrating 'environmental performance criteria' within associative and parametric design models for performance optimization. These systems with their generative nature have become a "source of inspiration" for designers in 'form finding' [11] and interactively experimenting with 'what-if'' scenarios [12].

Parametric systems are different from conventional tools: they are adaptable and responsive [11]. Their responsiveness is defined as a reaction to applied changes and updating models in a real-time basis. Similarly, the parameters of a model either trigger change or are modified to follow other changes such that the model is kept coherent by not losing its defined characteristics. It adopts the changes. These systems are more flexible. They can eliminate or reduce the need for reproduction of design models when a change is needed. Once a model is defined, changing parametric values can quickly generate variations in design; and if properly defined, models can respond to changes by propagating change to the associated elements in the design geometry. Using these systems for creating objects with non-Euclidian geometries has become more common in distinct domains such as architecture, aerospace, automotive and industrial design with, for example, aesthetical and functional goals [13].

3.2 Making responsiveness possible: Underlying meta-structure of parametric systems

The power of parametric systems in capturing non-spatial and spatial parameters together stems from the underlying meta-structure for representing designs (Figure 1). A design model is composed of objects defined as 'Features'. In general, a *Feature* refers to a geometric entity in the model that is parametrically defined and can be composed of and associated with other *Features*. Decoupling and strict interfacing policies between Parameters and Features enable declaration of different types of Parameters independent from the geometry. This becomes particularly useful when the geometry (or Features) needs to be defined and generated considering non-spatial parameters, which can correspond to contextual parameters such as 'occupancy load', 'proximity constraints', 'land-use ratio', and 'color range'. Values of parameters can be either assigned by the user or derived from 'Expressions' that are simply implementations of logical or algebraic statements or algorithmic functions. Types of parameters are defined at the Parametric Model level to provide input, again, in determining design geometry. 'Responsiveness' becomes possible when these structural components of a parametric model are brought together strategically.

► Figure 1. A high-level structure of parametric design models (in UML notation).
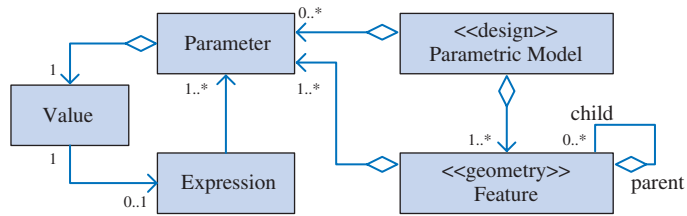
Through case studies, this research explores current capabilities of parametric modeling systems in integrating spatial and non-spatial information at different scales that, taken together, form the most salient input to the design process. In addition, the research explores to what level the 'responsive process of design' can be supported by available parametric tools.

3.3 Tool used: *GenerativeComponents*

The software used for the exploration described in this paper is *GenerativeComponents* by Bentley [15]. Beyond functioning as modeling software, *GenerativeComponents* enables multiple methods for the definition and control of parametric associations between the model elements in a responsive and operable environment. Throughout the design process, the parametric associations allow flexibility through control of design elements. *GenerativeComponents* enables operations on design models more efficiently than computer programming and scripting. The established parametric and logical dependencies are persistent throughout the model and can be maintained during interactive modification. The main user-interface of the software displays geometries with a corresponding symbolic representation of their parametric associations. This symbolic representation plays a crucial role when the focus is not so much on the geometries created, but on the relationships and dependencies that define how the geometries respond to their references.

4. Case studies: Exploration of parametric models

A series of explorations that focus on urban housing demonstrate the potential of parametric modeling to engage and coordinate a complex set of parameters that are used to integrate particular performance criteria into the digital design process at a variety of scales. The incorporation of the dynamically controlled parameters not only has practical implications for the design and building process but also directly affects the quality of the resulting spaces. Particular conditions of program, user functions, and context are used to define the rules that control the proposed parametric design systems. Explicit performance-sensitive design decisions and constraints are integrated into the digital model to enable dynamic modifications and responses.

4.1 Space configurations

A first part of the study incorporates social and environmental references in a parametric system to generate a wide range of spatial configurations and modes of occupation within typical city apartments. Changing social factors such as lifestyle and living scenarios of potential users together with environmental factors such as location, orientation, and views are the design parameters that define the configuration of space. A typical one-bedroom unit layout, which includes a number of interrelated subspaces, was used as a reference for this study. Each space has its unique set of spatial properties. Relationships and accessibility between the subspaces such as living rooms, bedrooms, kitchens, bathrooms, and balconies are identified and set as rules into the parametric system to regulate the configuration change (Figure 2).

input data	value	min/max
> Variable bed_living_In	0.4	0 —●— 0.55
> Variable bed_living_Out	0.4	0 —●— 0.55
> Variable depth_bed1	0.3	0 —●— 0.5
> Variable depth_bed2	0.3	0 —●— 0.5
> Variable h_in	zero	0 ●—— 0.2
> Variable h_out	zero	0 ●—— 0.2
> Variables wall_1	1.0	0 ——● 1.0
> Variables wall_3	1.0	0 ——● 1.0
> Variables wall_4	1.0	0 ——● 1.0
> Variables wall_bath	1.0	0 ——● 1.0
> Variable kitchen	0.2	0 —●— 0.6
> Variable rise_living	zero	-1 ——— 1.0
> Variable stairs_living	4.0	0 ——● 4.0
> Variable rise_bed	zero	-1 —●— 1.0
> Variable stairs_living	3.0	0 ——● 3.0
> Variable terrace_depth	0.2	0 ——● 0.2
> Variable horizontal	0.2	0 —●— 0.5
> Variable vertical	zero	0 ●—— 0.5
> Variable hz_divisions	1.0	1 ●—— 4.0

▲ Figure 2. Base model for Space Configurations.

The parametric model components such as walls, floors, and ceilings define the subspaces. Acknowledging that a residential floor is composed of an array of this base model, the boundary walls of each unit is fixed while the position of interior walls and floors, as well as the glazing surface, are controlled parametrically. Variables are used in the parametric base model to manipulate geometrical and spatial changes in each of the model components. Floors are designed to be either flat, stepped, or ramped. Wall separations are either full height, a percentage of the full height, or non-existing. The exposed side of the unit is covered with a skin system, for which variables are set to adjust the size and ratio of glazing to solid walls. Limits are set for each of the variables to control the possible range of change in each of the geometries.

All design constraints are parametrically embedded into the design model. This allows for constant regulation of the model's behaviour and the visual display of the changing process for the designer. These constraints are also considered rules under which the system's variables control the

interaction between components, thereby affecting the system's performance (Figure 3).
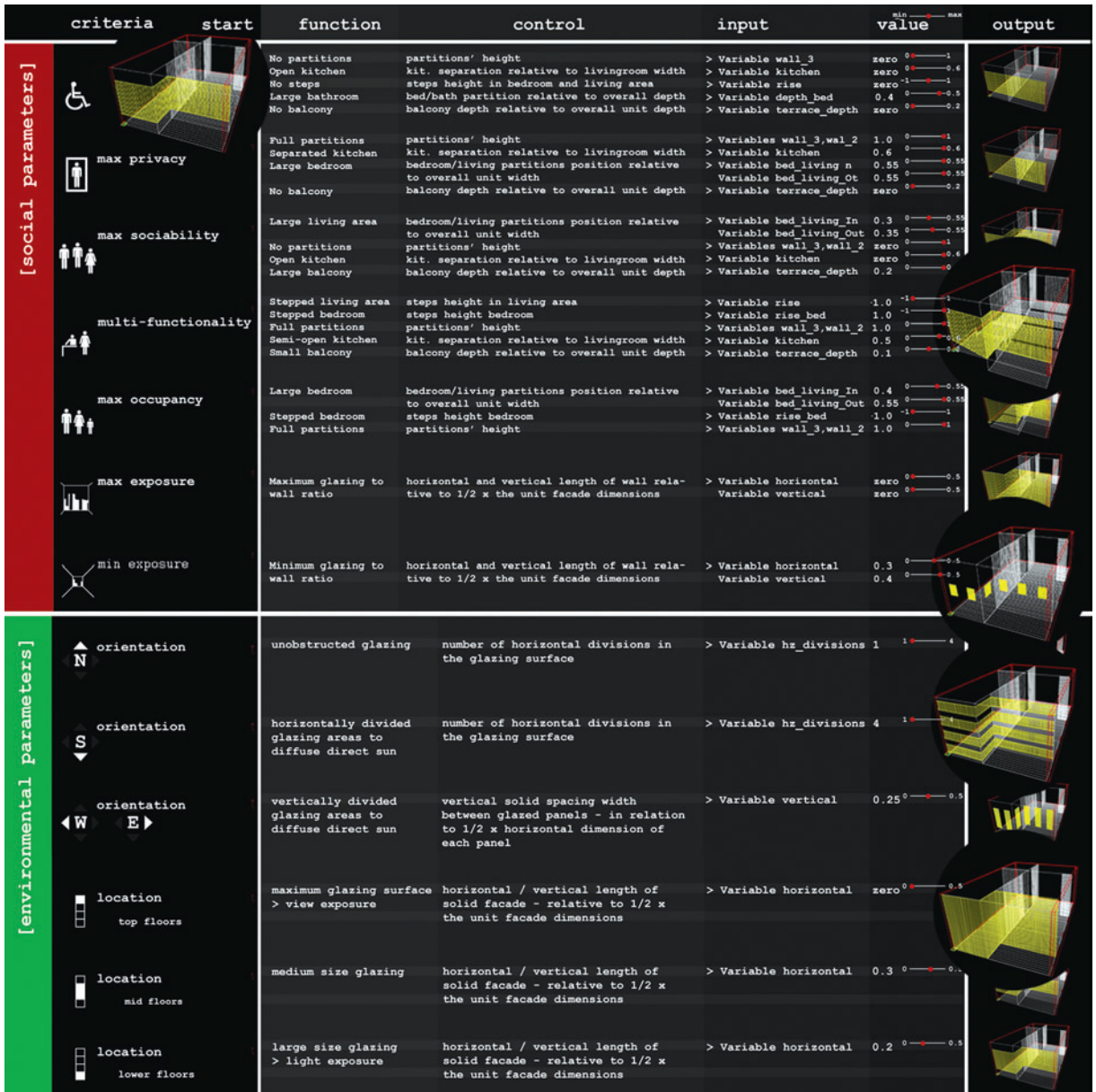
Social references: a range of social criteria that consider issues of accessibility, privacy, sociability, multi-functionality, occupancy, and desired levels of exposure are the basic parameters of the apartment configurations. These references address specific related functions that are controlled by the parametric model's variables, and the related geometries and components. Each of the non-spatial criteria is associated with related values for the component variables of the system to reach best fitting spatial configurations (Figure 3).

Environmental references: The environmental set of references includes the orientation of the unit and its floor configuration and controls of glazing surfaces. Variables that control the glazing divide and extend in both horizontal and vertical directions to respond to lighting and privacy requirements. Rules are set to control the system's response to orientation and location. Horizontal glazing divisions are used on south facing facades to reduce heat gain, while vertical divisions are used on east and west facades. Lower floors in high-rise buildings are less exposed to direct and diffused light and, therefore, need larger glazing areas while upper levels are set to have unobstructed glazing surfaces (Figure 3).

Living scenarios: A user interface based on the social and environmental factors allows potential occupants to choose appropriate layouts. The system's variables are manipulated accordingly to find the best configuration for the selected combination of references. In addition to the base model's initial configuration, Figure 4 describes potential spatial configurations defined by changing living scenarios inside the unit space. The design system responds to the change in influences simultaneously and dynamically reconfigures its components to find a non-linear accumulation of spatial alterations. While each of the influencing references contributes to a specific configuration of spaces by manipulating specific components of the parametric system, the resulting space configurations constitute an account of all the independent references and their effect on each other. They cannot be described as a linear sum (Figure 4).

4.2 Tower formation

The tower formation study explores the effect of the physical and environmental context on the formation of a residential tower located in downtown Vancouver (Figure 5). The goal is to create a dynamic responsive system (model) able to interact with the building's immediate environment. Forces that may influence a building's overall form are identified and translated into relationships between the components of the tower's parametric model. These outside forces address a number of factors including views, sun exposure, cordial orientation and context. Rules that control the tower design's response to each of the parameters are designed and set inside the parametric model. A model of downtown Vancouver

criteria	start	function	control	input	value min—max	output
(accessibility)		No partitions	partitions' height	> Variable wall_3	zero	
		Open kitchen	kit. separation relative to livingroom width	> Variable kitchen	zero	
		No steps	steps height in bedroom and living area	> Variable rise	zero	
		Large bathroom	bed/bath partition relative to overall depth	> Variable depth_bed	0.4	
		No balcony	balcony depth relative to overall unit depth	> Variable terrace_depth	zero	
max privacy		Full partitions	partitions' height	> Variables wall_3,wal_2	1.0	
		Separated kitchen	kit. separation relative to livingroom width	> Variable kitchen	0.6	
		Large bedroom	bedroom/living partitions position relative to overall unit width	> Variable bed_living n	0.55	
				Variable bed_living_Ot	0.55	
		No balcony	balcony depth relative to overall unit depth	> Variable terrace_depth	zero	
max sociability		Large living area	bedroom/living partitions position relative to overall unit width	> Variable bed_living_In	0.3	
				Variable bed_living_Out	0.35	
		No partitions	partitions' height	> Variables wall_3,wall_2	zero	
		Open kitchen	kit. separation relative to livingroom width	> Variable kitchen	zero	
		Large balcony	balcony depth relative to overall unit depth	> Variable terrace_depth	0.2	
multi-functionality		Stepped living area	steps height in living area	> Variable rise	-1.0	
		Stepped bedroom	steps height bedroom	> Variable rise_bed	1.0	
		Full partitions	partitions' height	> Variables wall_3,wall_2	1.0	
		Semi-open kitchen	kit. separation relative to livingroom width	> Variable kitchen	0.5	
		Small balcony	balcony depth relative to overall unit depth	> Variable terrace_depth	0.1	
max occupancy		Large bedroom	bedroom/living partitions position relative to overall unit width	> Variable bed_living_In	0.4	
				Variable bed_living_Out	0.55	
		Stepped bedroom	steps height bedroom	> Variable rise_bed	-1.0	
		Full partitions	partitions' height	> Variables wall_3,wall_2	1.0	
max exposure		Maximum glazing to wall ratio	horizontal and vertical length of wall relative to 1/2 x the unit facade dimensions	> Variable horizontal	zero	
				Variable vertical	zero	
min exposure		Minimum glazing to wall ratio	horizontal and vertical length of wall relative to 1/2 x the unit facade dimensions	> Variable horizontal	0.3	
				Variable vertical	0.4	
orientation N		unobstructed glazing	number of horizontal divisions in the glazing surface	> Variable hz_divisions	1	
orientation S		horizontally divided glazing areas to diffuse direct sun	number of horizontal divisions in the glazing surface	> Variable hz_divisions	4	
orientation W E		vertically divided glazing areas to diffuse direct sun	vertical solid spacing width between glazed panels - in relation to 1/2 x horizontal dimension of each panel	> Variable vertical	0.25	
location top floors		maximum glazing surface > view exposure	horizontal / vertical length of solid facade - relative to 1/2 x the unit facade dimensions	> Variable horizontal	zero	
location mid floors		medium size glazing	horizontal / vertical length of solid facade - relative to 1/2 x the unit facade dimensions	> Variable horizontal	0.3	
location lower floors		large size glazing > light exposure	horizontal / vertical length of solid facade - relative to 1/2 x the unit facade dimensions	> Variable horizontal	0.2	

[social parameters]

[environmental parameters]

▲ Figure 3. Social and environmental references for Space Configurations.

serves as context for the tower study. The initial tower model is a rectilinear extrusion that subsequently responds to site boundaries, setbacks, and the maximum allowable height.

Five primary references controlling the formation of the tower are described below and shown in Figure 6:

1. The proposed tower model reacts to the preserved view corridor that is crossing its site, not only by adjusting its height, but also by engaging the tower's form. The points that define each of the tower's

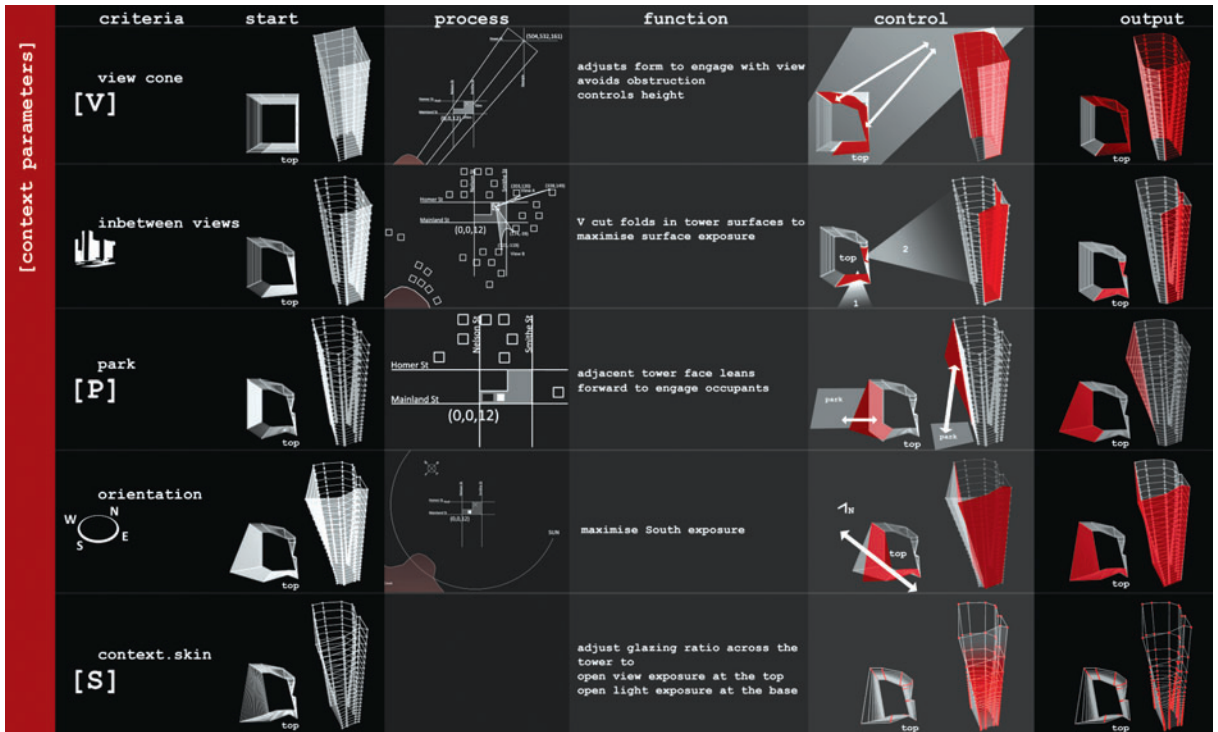► Figure 4. Living scenarios for Space Configurations.
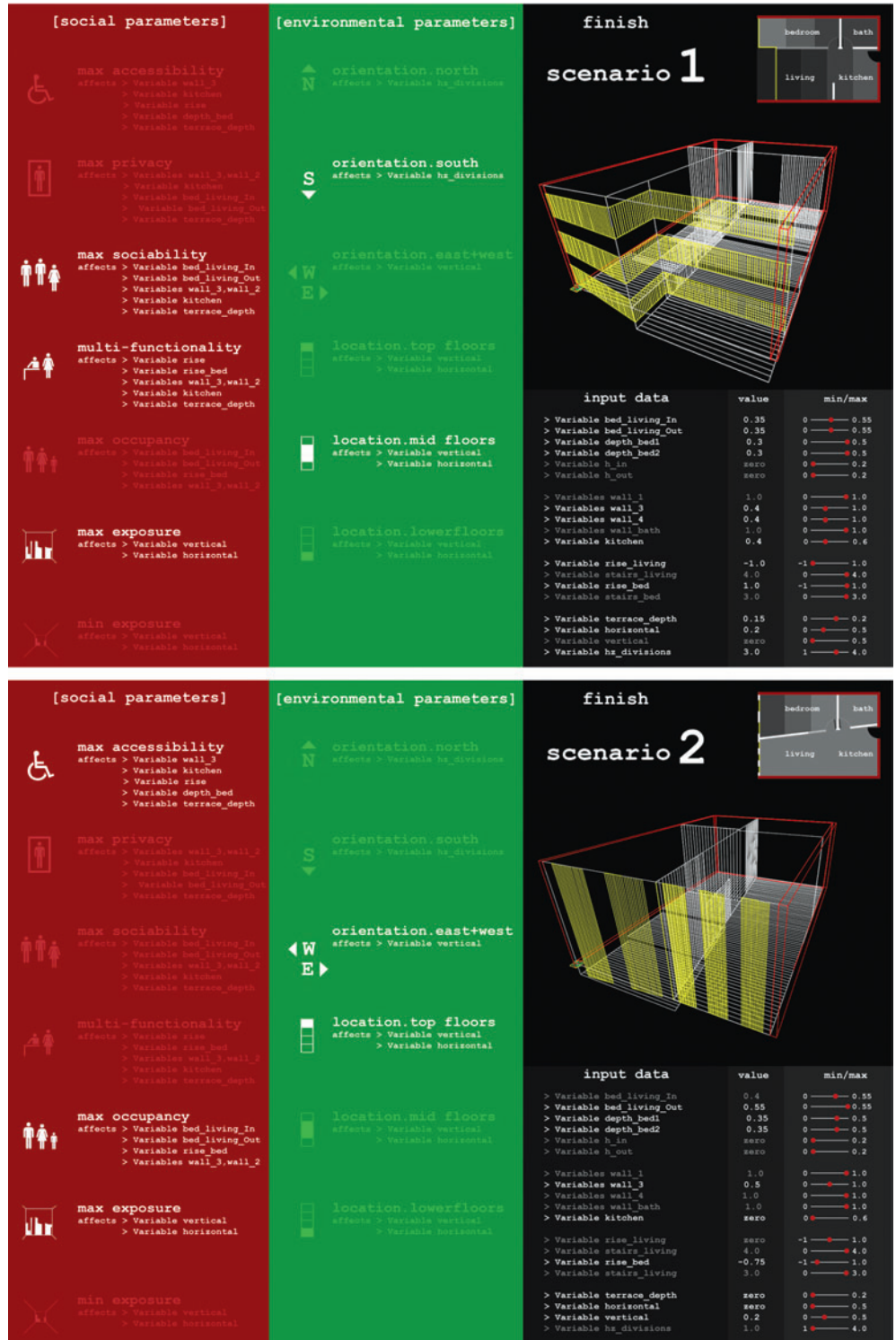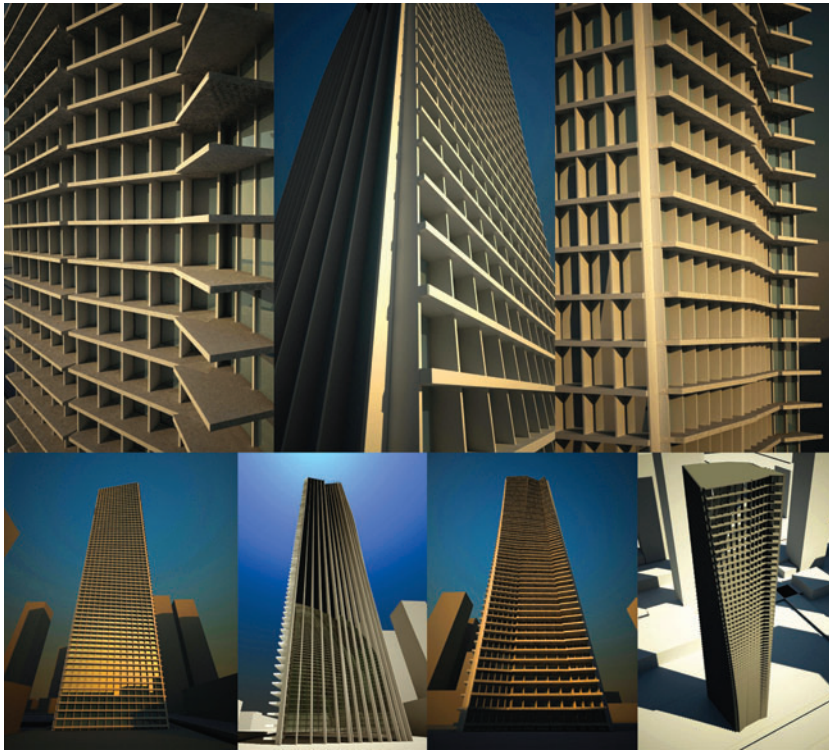
faces are set to move in the direction that provides greater exposure to the view target defined in the view corridor.

2. In order to engage the tower with views between surrounding buildings, folds in the building's volume are created to provide more surface exposure towards the available openings between adjacent buildings. The size and location of folds respond to the tower´s distances to the surrounding buildings.

3. An adjacent park influences the tower's formation by maximizing the visual connection with the units that are facing the park. One side of the tower leans forward to engage the park.

4. For maximum passive solar heating, the parametric system is designed to increase the tower's southern exposure. Cardinal directions are modeled in the parametric system and linked to the tower's edges that dynamically change to increase the tower surfaces exposed to the sun following the southern exposure rule.

5. The parametric system is set to promote open views at the top of the building, and more reserved ones where the tower is immediately adjacent to other buildings. A 'Law Curve' is used to establish dependencies between the number of façade components and their vertical dimensions. It controls the spacing of points along the tower's edges, thereby allowing for varied spacing of facade components across the tower's faces.

criteria	start	process	function	control	output
view cone [V]			adjusts form to engage with view avoids obstruction controls height		
inbetween views			V cut folds in tower surfaces to maximise surface exposure		
park [P]			adjacent tower face leans forward to engage occupants		
orientation			maximise South exposure		
context.skin [S]			adjust glazing ratio across the tower to open view exposure at the top open light exposure at the base		

[context parameters]

▲ Figure 6. Tower Formation references.

   The system uses dynamic responses to control the tower's form while adjusting all its dependent components according to changes in the influencing factors. This approach to design ultimately leads to a building form that results from a formation process sensitive to its surroundings.

4.3 Shade

Shade is an independent responsive sun shading system applied as a component to the tower's surfaces. The parametric shading system calculates its cardinal orientation and controls the appropriate lengths of horizontal and vertical overhangs added to the tower walls as a screen system (Figure 7). The maximum depth of the overhang is dependent on the number of subdivisions and the related subdivision length. The actual length of the overhang depends on its position in relation to the North direction allowing for an automated calculation of best-fitting solar control devices on complex building faces.

4.4 City configurations

The last phase of the exploration engages the tower formation at a larger scale. It defines a responsive approach to city planning and explores a dynamic method of planning and regulating the relationships between buildings in the city to establish a dynamic base that incorporates a complex set of city planning guidelines. The study uses parametric techniques to incorporate
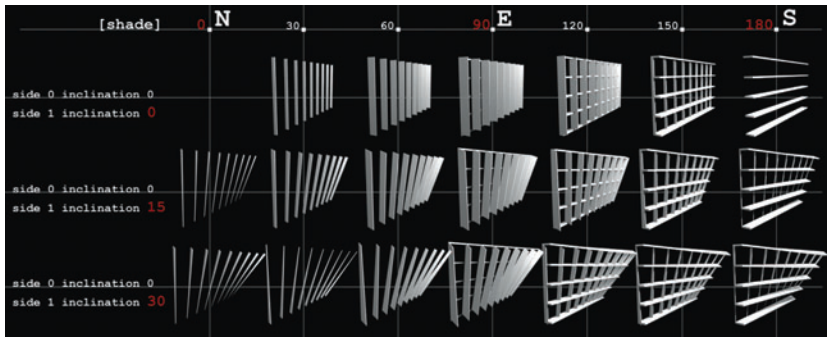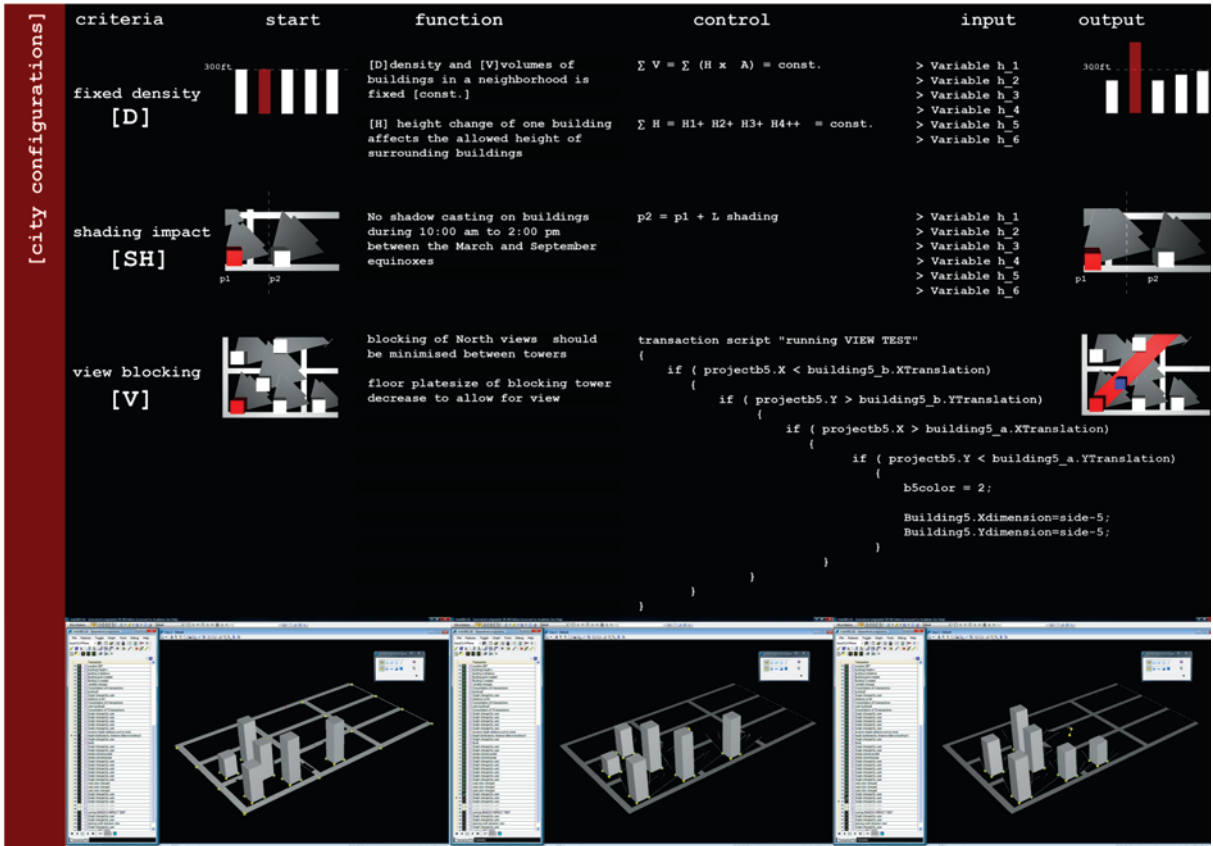
existing planning guidelines. The introduced parameters control the formation of future towers while incorporating the location and dimension of existing towers within the applicable development zone in downtown Vancouver.

As a responsive model, this exploration serves as a critique of Vancouver's current fixed planning regulations that do not consider the effect buildings have on the formation of others. *City Configurations* is created as a parametric system based on existing streets and towers in downtown Vancouver. Three design criteria regarding density, shading impact, and views are strategically integrated as rules and relationships that guide the interaction between the system's geometries (Figure 8) and ultimately control the position and size of building interventions.

1. Density: The collective volume of towers is fixed to achieve a constant building density within an existing city district. The manipulation of each building's height directly affects the overall building volume and therefore the density in the district. The maximum allowable height is distributed on all buildings instead of regulating the heights per project.
2. Shading Impact: A parametric shading analysis is modeled to avoid shadow casting on surrounding building faces. A dynamic relationship controls a tower's height, its shading footprint and the allowable separation and positioning of surrounding towers.
3. Views: In order to minimize the blocking of preserved views, the parametric model includes a view validation test that incorporates all the towers in the district. If a future tower location blocks extension lines from other towers, the system reconfigures its allowable floor plate size and building height.

Changes in any of the tower's heights trigger a non-linear configuration adjustment of all other buildings in the model. Heights, areas and positions of future towers adjust to follow the density and shading rules embedded in the parametric model (Figure 8). City Configurations can be used as responsive guidelines for the development of new buildings. By adjusting possible configurations of new buildings according to the dynamic state of

The figure shows a table titled [city configurations] with columns:

criteria	start	function	control	input	output
fixed density [D]	300ft	[D]density and [V]volumes of buildings in a neighborhood is fixed [const.] [H] height change of one building affects the allowed height of surrounding buildings	$\sum V = \sum (H \times A) = const.$ $\sum H = H1 + H2 + H3 + H4++ = const.$	> Variable h_1 > Variable h_2 > Variable h_3 > Variable h_4 > Variable h_5 > Variable h_6	300ft
shading impact [SH]	p1 p2	No shadow casting on buildings during 10:00 am to 2:00 pm between the March and September equinoxes	p2 = p1 + L shading	> Variable h_1 > Variable h_2 > Variable h_3 > Variable h_4 > Variable h_5 > Variable h_6	p1 p2
view blocking [V]		blocking of North views should be minimised between towers floor platesize of blocking tower decrease to allow for view	transaction script "running VIEW TEST"		

```
transaction script "running VIEW TEST"
{
    if ( projectb5.X < building5_b.XTranslation)
    {
        if ( projectb5.Y > building5_b.YTranslation)
        {
            if ( projectb5.X > building5_a.XTranslation)
            {
                if ( projectb5.Y < building5_a.YTranslation)
                {
                    b5color = 2;

                    Building5.Xdimension=side-5;
                    Building5.Ydimension=side-5;
                }
            }
        }
    }
}
```

▲ Figure 8. City Configurations.

the built surroundings, this approach opens the possibility to introduce dynamic development bylaws based on a complex set of parameters. A parametric model can be made available through a public website and can contribute to a transparent development process for planners, designers, and the general public.

5. Conclusion

Parametric modeling tools allow the incorporation of complex references into architectural design processes. Design parameters that reference a design context in flux can be integrated to acknowledge social, economic, material, and spatial conditions. The resulting designs at the scale of detail, building, or urban intervention are products of a formation process that responds to ranges of parameters rather than direct reflections of formal interventions. As such, parametric systems can make a significant contribution to design's responsiveness and integration into the context within which they exist.

A key aspect in the use of parametric design tools in the design process is the selection of rules and the translation of design problems and related references into features, parameters, and dependencies. In principle,

parametric design techniques can address, coordinate, and control various programmatic concerns and references if rules for the design are explicit and the assumptions and constraints are sufficiently defined prior to the beginning of the design process. Parametric tools are characterized by a complex method of storing explicit design rules through the design process. The design explicitness creates a closed parametric system, which is only free to respond to the pre-decided references. Unlike CAD modeling, the investment is not so much in the geometries created, but in the rules, relationships, and dependencies that define how the geometries inside the parametric model interact and respond to their references. Once these are set, parametric methods demonstrate an interactive atmosphere in the design process, and provide potential to address added design complexities. Engaging these complex conditions is not limited to design education and academic discourse but is integral to design and planning practices that need to engage a broad set of cultural conditions in order to make constructive contributions.

Despite the benefits of parametric modeling for practical applications in the design and planning process, however, future studies should acknowledge limitations of architecture's engagement with notions of complexity. Responsiveness of parametric modeling has to be further explored considering the translation of responsive design methods into built proposals where building conventions, building techniques, and available materials govern the application of responsive design concepts to complex conditions. Applications of parametric design tools will have to be measured against the reality of the building culture in which,

"...mere complexity does not equal true indeterminacy. And like the deployment of increasingly fine modularity, the application of exotic software to the task of creating 'other' formalism of continuous differentiation, however 'smoothly' flexible or alien, cannot prevent the results from merely introducing (newly) prescriptive patterns of occupation" [14].

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