Parametric Design as Interpreter of the Urban Compositional Problem

One basic application to city block modeling

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The paper explores parametric design technology from an urban design perspective of development. One possible finalization of technique as informer of urban space subdivision is presented, with an eye on geometry and its energy efficiency implications. The recognition of urban space as a field of complex equilibria, where different claims insist on the subdivision process, helps interpret methodology from a critical stance, at least within the margins of selected studies and a partial, yet indicative experiment.

Keywords: complexity, parametric design, urban simulation, energy efficiency, Grasshopper, optimization

NARRATIVE OUTLINE
Parametric design and the burden of an urban «compositional problem»

As a computational support to modeling, parametric design is credited with engineering form mainly for architectural and product design purposes, areas where geometry reacts to a certain range of generative principles, performance measures and algorithmic formulae (Fraser 2012). The paper explores parametric design technology from an urban design perspective of development, that is, beyond the scales and qualities that are proper to single structures like building façades or novelty items.

The complexity of occupation patterns in urban space is such that form interacts with another level of conditional freedom, sensitive to different and simultaneous constraints (Batty 2007). This up-scaled level requires honest and «down-to-earth» interpretations of algorithmic thinking, for the urban outlook cannot rely (only) on standard procedures and repetitive tasks.

The key concern is experimenting parametric design with abstract massing as interpreter of the compositional problem, i.e. an expedient informing the 3D occupation of a precious resource like available space. Scarcity of space is a classic design issue proper to urban land: as land shrinks and expectation grows, the opportunity cost of each form of development expands comparably. Planning is (should be) an exercise of responsibility, and the eco-social effects of choosing one form instead of another reveal the maximum expression of design struggle. In this paper, we call that burden of design the urban «compositional problem».

At some point, ideas of city need to «congeal» into material, tangible fabrics. Spurring from a range of possible blueprints, relevant eco-social effects of form relate to how we address the compositional
problem from a pure geometry point of view (Alberti 2005). Two basic elements concur in defining form as an object: *shape* and *density*. Shape is of tangible nature and represents a «solid» state of form, while density has the impalpable character of a «gaseous» state. However variable they may seem, blueprints of form are single cases of that «liquid» gradient of solutions we find in the middle of the two extremes, and each stands for one possible way of mating shape and density options to address the compositional problem.

The difficulty of composition is that shape and density do not fulfill any correlation but the one(s) picked with discretionary choice over what Lawson (2006) describes as *design synthesis* process. The lack of correlation between shape and density works both ways: we can express the same density though different shapes, but every shape has a different cumulative impact on density strategies (Pont and Haupt 2010).

In essence, the compositional problem is the challenge of discovering a form of virtue, that is, a space-efficient design working in a context of limited land and no correlation between shape and density. A «form of virtue» is the one that can justify a blueprint of space subdivision, both horizontally and vertically, in respect to given goals of performance and at the end of a costly alternative selection cycle.

Conventional design selects the «winning form» of this process by intuitive summation of shape and density episodes. In this case, the «liquid» of output form flows in non-communicating vessels, ending up with «stagnant» models. On the contrary, parametric design filters form by algorithmic-procedural thinking: as such, it can interpret the compositional problem starting from shape and density as generative seed. In this other case, the approach would split and reconnect the two into a stream of correlations, «exploding» form to the full range of performance that a single definition can support.

**THEMATIZING THE PROBLEM**

*Solar energy and the clash with a shape-density dualism of urban form*

As a (necessary) reduction of complexity, the attempt considers the energy dimension of the compositional problem, focusing on passive solar design. Of course, this is not a complete breakdown of urban form and energy management. Other criteria would be central to a parametric understanding of energy and material flows, such as how traffic, centrality and locational choice relate to a zero-carbon future. Construction standards alone do not represent the whole picture of energy efficiency; there is another layer of analysis, an extrinsic one, related to the urban-spatial organization of buildings, both in their shape and density features. While being a relevant quality character, the solar criterion is an expedient for giving a straightforward idea of what it means to interpret the compositional problem as we defined it. In fact, this design task is highly sensitive to how we combine shape and density at the city block level (Morello et al. 2009).

As said, the two features are required to accommodate a certain degree of compaction: global-scale urbanization and eco-infrastructural costs of soil consumption (Montavon 2010) push to intensive land development. But this has parallel implications for passive solar goals, as concentration of shape and density triggers more obstruction to sunlight access (Nault 2016). The compromise between apparently conflicting goals depends on the intelligent amalgamation of shape and density features. Abstracting shape and density behaviors as *nodes* of a parametric diagram (cf. Woodbury 2010) may be useful to establish correlations between the two, stretching feedback to the high-resolution gradient of outcomes.

This passive energy challenge of form is not new to urban design culture and research (cf. Martin and March 1972). Every project imprints more or less resilient «signs» on land, and bulk subdivisions of space are likely to affect the long-term success of the original scheme. As designers, we can intend complexity as a foremost driver of resilience in parametric urban development; higher complexity of input tends to
widen and diversify the output, even in case of single objectives. Yet, complexity alone is not enough without good instructions: it always requires the «spontaneity» of form-finding (Tedeschi 2014) to build on properly organized grids.

In this sense, the recognition of urban space as a «force field» of complex equilibria, where different demands of occupation intersect various solid-void schemes, helps consider parametrics from a critical stance. Though grounded on a non-exhaustive selection of cases and a partial experiment, the interface between theory and practice leads to recognize some potentials, frictions and development lines of a support system that, borrowed from non-urban domains, is called to embed and simulate the complexity of city forms.

METHODOLOGICAL OUTLINE

Upgrading complexity of emergent patterns to urban design «force field»

The narrative outline assumes the compositional problem as one possible thematization for joining parametric and urban design, where algorithms define a new intelligible link between input shape-density gradients and output patterns of form. Starting from the assembly of generative rules, parametrics would return a transient or blending range of correlations between variable options of shape and density, with direct feedback on consequences for space and energy performance. The importance of feedback does not only stand in real-time simulation: defining the algorithm as «history» of geometry (Tedeschi 2014) means conditioning or injecting propensity to variable standards of performance into the emergence of form itself, based on strategies picked for shape-density gradients and their variation-correlation systems. In brief, the so called «solution space» (Aish 2005) reacts to how the parametric diagram is set.

The examination of three parametric studies, each corresponding to a diagram, would be essential to highlight different variation-correlation strategies deployed in search of performing conditions for dense-and-solar design. The interpretation of case studies is grounded on three lenses that would inspire an up-scaled, urban design-oriented adaptation of parametric modeling: A. Technology, B. Expendability and C. Complexity. The Technology layer (A) corresponds to the level of refinement in associative support and extent of input resolution, details that are supposed to propagate across the system. The Expendability layer (B) considers both elbowroom and sense of controlling the input as key to «elastic» solution spaces, which means more chances to come up with higher energy standards along the gradient of instance models. The Complexity layer (C) centers on realism and representation of output form, in line with aspects of compositional freedom generally found in urban settings, such as variable solid-void schemes and differing layouts for horizontal (width) and vertical (height) occupation of space.

Within this framework of increasing complexity management, Grasshopper® represents a hallmark for its wide-ranging syntax and the expanding nebula of plugins that today focus more and more on the analysis of compound structures and effects (cf. Koltsova et al. 2013).

The intersection between case studies and interpretative layers, namely Technology, Expendability and Complexity, produces some knowledge about both contributions and implications of parametric diagrams as generators of efficient, energy-savvy patterns of urban space. This moment of comparison and interface also inspires a supplementary model, a humble, but due experience of learning, because it paves the way to reflections upon inertial and prospective sides of diagrams in sketching an urban design scenario of development.

THREE CASE STUDIES

Three strategies for emergent shape and density urban patterns

The case studies may differ in terms of setting and scope, but they all share a parametric control of spatial occupation. Specifically, they predispose shape-density behavior of urban form to energy efficiency,
using the abstraction of parametric diagrams as a way to approach the compositional problem. Recalling the layers used for interpretation and comparison, each case study exemplifies a step toward the ever-higher sophistication of procedural and associative modeling (Technology), in relation to the space left to intuitive thought on one side (Expendability), and to the representation of those concomitant forces that characterize urban settings on the other (Complexity).

Case 1 is a proto-parametric study, developed with additive digital models that emulate associative, procedural rules (Cheng et al. 2006). Case 2 is entirely parametric and developed as a fine-tuning system within Grasshopper® (forward design) (Yunitsyna and Shtepani 2016). Case 3 represents the most integrated diagram, as it consists of an optimization routine fully incubated in Grasshopper (inverse design) (Lobaccaro et al. 2016).

**Case 1. Proto-parametric design (Cheng et al. 2006)**

This study interprets the compositional problem in a proto-parametric manner, that is, informing subdivision of space with manual arrangements of shape and density. A square surface of one hectare represents the ideal «sandbox» of this research. The atopic setting binds the approach to pure design guidance rather than direct urban block modeling. It is a fictitious exercise of *form-finding*, where intuition constrains the procedure of abstraction to a narrow gradient of results. Though correlation is manual, form is not a predefined mass; it is, rather, the end result of switchable shape and density modules that, in the end, prove to be effective in matching solar and compact design.

The process starts from abstracting horizontal (*H*, 2D) and vertical (*V*, 3D) occupation of the surface to variable shape and density options. These insist on distributive layout (shape) and proliferative extent (density) of units. All units have the same square plan. Shape considers two schemes that can affect *H* and *V* occupation in either way: uniformity and randomness. Density expresses *H* and *V* occupation by, respectively, two degrees of site coverage, low (9%) and high (36%), altering the amount (n.) of units, and three plot ratio levels, low (1.4 m$^3$/m$^2$), medium (3.6 m$^3$/m$^2$) and high (7.2 m$^3$/m$^2$), altering the height of units. These options inform generation of models as input data working independently from one another, just as sliders in parametric diagrams. Models representative of this freedom can have low coverage (low n. of units spreading over the *H* plane), high plot ratio (high *V* extent of units), uniform display of units and random heights, as well as the opposite scheme: high coverage, low plot ratio, random unit location and uniform heights.

Of all the possible mixtures between shape and density, layout and extent, only 18 models are selected for solar simulation, assuming variance as a descriptor, but also admitting the flaws of traditional CAD systems (Fig. 1). Aside from modest resolution of input, these imply extra software for evaluation, in this case PPF®, and no reactivity of form. Each of the 18 models is processed, plotting comparative solar ranks for shape-density settings.

**Case 2. Forward parametric design (Yunitsyna and Shtepani 2016)**

This case interprets the compositional problem by even comparison of ideal shapes, testing density-solar implications over the same rule of thumb. Three urban types are examined: single house or tower, row house and perimeter block. The rule in question is a passive principle equating building height to the minimum distance between units. Parametric modeling becomes key to explain form as the ready-made propagation of design concepts. Here, Grasshopper® turns the rule of distance into a dynamic subdivision scheme, where every increase in floor number is a step more to the «rarefaction» of fabrics (Fig. 2). Number of floors is the only slider, ranging from 1 to 10, and informs *V* occupation, while the input governing *H* occupation is the set of curves depicting the three urban types. As the sample site is limited, changing floor number involves several output fea-
Case 3. Inverse parametric design (Lobaccaro et al. 2016)
The last research interprets the compositional problem by solar-led upgrade of housing envelopes to be developed in Trondheim, Norway. This time, the use of parametric design as final incubator of form pays for the real-world location of units, and does not include a procedural definition of the neighborhood scheme, contrary to the previous studies. However, constant envelop refinement, while being relatively influential, has significant effects on achievable volume in respect to sunlight potential. In this sense, it happens to be a source of typological innovation, especially when the basic footprint of development is already set to meet other criteria not necessarily in line with solar. Among these, an appealing and legible pattern for people, where blocks (solid) delimit public space (void) and give the enclosure necessary to pedestrian life. For this reason, the study embraces conventional and parametric approach in a way that the former ensures articulate views along public space, and the latter is expected to optimize envelopes according to every consequent orientation of units.

The process works on sample envelop forms. These behave according to the three roof vertices of a standard section that, once extruded and rotated as correspondent units, is supposed to reproduce thickness and orientation of housing within the masterplan. Input resides in the $H$ and $V$ coordinates controlling each roof vertex of the section (shape); coordinates propagate to volume and exposure of the corresponding envelop (density and sunlight-related features).

The masterplan shows alignments to public space defining three orientations: N-S, E-W and 30° S-W. This implies repeating solar optimization of the sample per orientation to gather higher and higher amounts of sunlight on roof while conceding the

tures: the amount of units generated, built density, site coverage and solar gain, with trends depending on the building type selected.

Similar to case 1, the area size is one hectare and emergent patterns have no neighborhood, so results of this study can only give general urban design suggestions. Yet, this time the surface assumes two alternative shapes, rectangle and circle, which are meant to challenge form generation more than the basic square of the previous study. Though types do not mix on the same surface, examining three instead of one is a way to unfold and equalize the impact of different pure models in space.

A central aspect is that explaining form by parametric diagram makes it possible to govern the output as a transparent result of input. Algorithms are unambiguous and deterministic systems: propagation is such that every input change produces the only possible output for that condition. That means associations between floor number, building curve and scale of performance become traceable all along the gradient, and as we set a new input, we discover lower and higher-rating mixtures between layers of shape, density and solar radiation.
canyon-like pattern of units in the masterplan. To a certain extent, density also rises, because the fitness is such that radiation is relativized to compactness. Being this a surface-to-volume measure for heat dispersal, the process leads to growing solar capture and volume at the least expense of material surface. At the end of the cycle, the algorithm selects three optimal pairs of coordinates, corresponding to three roof sections, each able to maximize radiation over compactness for that orientation (Fig. 3). Once the masterplan adapts manually to new sections, further solar analysis applied to the whole neighborhood shows parametric balance of shape-density-radiation to portray a Zero-Energy design for thermal.

The conventional-parametric liaison is not banal: it brings the issue of dealing with distortions characteristic of a humanly, other than ecologically sensitive place, which is central to our concept of urban space as a «force field». Then, our supplementary model will parameterize what here is preset as conventional modeling. Shape-density freedom will define the overall blueprint to address coincident sides of the compositional problem, meeting demands of space that, while claiming parallel qualities, are supposed to interfere with a solar-and-dense ideal.

**ONE BASIC APPLICATION**

**Modeling a parametric pattern of city block and its responsive evolution**

The exercise assumes the increments in complexity suggested by the three studies, crossing the three lenses of interpretation considered, and setting the ground for reflection upon advanced urban pattern strategies. Technology highlights the importance of Grasshopper in sustaining form-data association and high input resolution for wider gradients. This is what differentiates purely parametric cases 2 and 3 from the proto-parametric case 1. Expendability leads to keep both shape and density as independent and fully trackable inputs, so as to appreciate freedom of cross-combination and human responsibility observed in case 1. While balancing human-machine control of form and simulation, our model inherits the fitness proposed in case 3, i.e. radiation-to-compactness, in compliance with the problem of a solar-and-dense design. Case 3 is also the most inspiring one in terms of realism, for both diversity and articulation of solid and void, but prearranging subdivision of land leaves no room for parametric control of the neighborhood as a whole. Therefore, Complexity emphasizes the importance of abstraction in addressing conflictual occupation, the essence of urban space, drawing value from specific quality (Steinø 2010), divergent criteria and distortion factors that, in turn, claim satisfaction of concurrent properties.
«Specific quality» of the model resides in opening (abstracting) the gradient to diversified behavior of units; each can assume a form independently from the others, thus multiple solid-void layouts can coexist on the same plot, leaving room for multiple sides of performance.

This relates to input and correlation system. Surrounded by a dummy context, the block is composed of building units emerging from related parcels, which follows typical morpho-layers of the urban scene. Parameters of shape inform the $H$ occupation of units over their own parcels, and consist in local $uv$ coordinates. $Uv$ pairs establish the covered surface of each unit. In this case, specific quality does not apply to $V$ occupation, because a single parameter of density, volume over plot area, splits evenly across units. Nonetheless, some diversity in extrusion is achieved according to the extent of each covered surface, so heights depend on both shape and density. Other specific quality principles not present in the previous studies are aggregation and elision of units. Aggregation occurs by solid union when lateral faces of one or more units overlap along borders, producing complex types. Elision happens by cull pattern when the covered surface of one or more units is zero; this expands open space reallocating volume equally across remaining units.

The two divergent criteria of appraisal are: a) average compactness of units ($m^2$ of envelop to $m^3$ of volume), and b) average solar energy density on envelop ($kWh\ h \ per \ m^2 \ per \ year$, simulated with DIVA for Grasshopper®). The fitness used for optimizing the block is such that the latter measure is relativized to the former. The objective is maximizing the $\beta/\alpha$ ratio, searching for those parameters of shape and density (respectively, $uv$ coordinates and building potential) suitable to reduce heat loss tendency in favor of both volume and solar gain.

Distortion factors are further distinction elements of the model, mainly for their role in composition. These are urban form measures standing for some of the complex «forces» representative of urban space. Working as proxies of place making, they inform additional tuning so that the optimal
outcome stretches to cover other relevant quality aspects. As such, distortion factors entail meeting demands of \( H, V \) or \( H&V \) occupation that might interfere with sunlight-compaction harmony. Parametric design proves to be helpful when real-time checking is important. The complementary factors are: \( \gamma \) natural surveillance \((H)\), expressed as linear coverage of built fronts over plot length (Porta and Renne 2005); \( \delta \) visual variety \((V)\), expressed as variation coefficient of heights; \( \epsilon \) spaciousness \((H&V)\), expressed as \( m^2 \) of open space over built volume (Pont and Haupt 2010), here adapted to \( m^2 \) of equivalent floor area.

Our block is ready for interpreting the compositional problem. The test follows three steps. First, it starts from a uniform arrangement of buildings; each parcel has a unit, and units are equal horizontally and vertically. Second, it runs optimization for solar energy density and compactness (30 Galapagos cycles, 20 generations each). Third, it considers fine-tuning the solar-driven block tentatively and cumulatively, with an eye on impacts for fitness and distortion factors. Assumptions lead to results that suggest the ability of parametrics in «unpacking» the compositional problem. Propagation of inverse and forward design choices ends up with the improvement of both solar and built density, dampening the loss in street surveillance while also supporting a certain degree of height diversity. No significant expense for the original spaciousness (Fig. 4).

LEARNING FROM THE EXPERIENCE
Notes on mastering complex abstraction in the urban design perspective

Drawing from abstraction of shape and density, the model is an example of using parametric design as interpreter of the compositional problem, i.e. as a tool that informs subdivision of space on a finite plot of land to address the solar-and-dense challenge of urban form. Specific schemes and distortion factors, i.e. demands of \( H-V \) occupation, are also involved, in a way upgrading the algorithm with (few) complexity elements integral to the urban «force field».

Reflecting upon what abstraction of form implies at higher complexity is essential, because our model is rudimentary for various reasons; as such, it is far from the ideal concept of «parametric urban design». Similar to cases 1 and 2, the setting is fictitious, and emulation of edge effects for solar is approximate and homogenous along the plot. However, resolution of input and propagation to output explodes subdivision of land in a way that case 3 leaves unexpressed and restricted to conventional modeling. Still, aside from key rules of aggregation and elision, we do not observe any further innovation able to expand the «solution space» and interpret the compositional problem.

The major crux of the model is that free control of single units entails multiplying the set of input per parcel, meaning higher constraint load. On the contrary, using one input set for all units would reproduce a pattern of generic quality similar to what we see in case 2, where buildings react to a standard rule the same way. Other than being contingent to our example, the increment in abstraction and specific quality is a systematic issue of the approach. Parametric forms exist only by explicit determinism, and always need a critical mass of constraints to emerge as expected. Explanation of growingly abstract forms, while being condition to address the compositional problem flexibly, implies proportional efforts in instructing form and covering all the degrees of freedom possibly released (Monedero 2000). Alternatives would be accepting the abortion of results, the appearance of non-conforming patterns, or simply a reasonable amount of intuitive thought within the algorithm. The last choice would be both realistic and reductive; that is the cost of increasing variety of solutions and complying with the urban design spectrum of demands. Therefore, major challenges of parametric systems will be governing human interference, sustaining the dualism of complexity and deterministic process, and embodying change rapidly and smoothly.

Sophistication of computing power and intelligence will be an unprecedented resource for urban design and regeneration, concerning both planning...
Product and process. Intensive urban developments would draw the greatest benefit from parametrically empowered masterplans, because the game between shape-density correlation and fractality in those areas is of strategic importance for the various social-ecological dimensions of energy. In this respect, parametric models may inject responsiveness into current coordination of plan, project and simulated performance, testing the choice of indices (density) and design guidelines (shape) along a high-resolution gradient. Translation of specific principles into constraints of a diagram would also embed regulations and incentives, enriching decision-making over the effect of rules and generated forms. Examples can be a maximum built coverage, a range of distances among units, or volume rewards for energy benchmarks. In parallel, customization of toolbars and programming knowledge would play as multipliers of cognition for developers and planning analysts. Using diagrams to engineer multi-dimensional assessment could validate rules against common or experimental indicators, weighting systems and synthetic judgements.

Parametric design may have a role in informing a new generation of masterplans, making them «living» programs where data range from ownership to microclimatic impact. Nonetheless, it is important to admit that the peak of abstraction as a way of managing complexity remains a theoretical maximum, where an all-encompassing algorithm, the «absolute» one, spawns virtually endless subdivision schemes and proves to solve the compositional problem in every facet.

CONCLUSIVE REMARKS
Frictions and future perspectives of a parametric upgrade for urban design
Born from the legacy of selected studies, the exercise considers parametric control of space at city block.

Figure 4
Handling the compositional problem of a city block. Excerpts from the collection of output data for the two divergent criteria and the three distortion factors. Variations refer to the starting condition (source: author).
level, conceiving abstraction of form as interpreter of the compositional problem. Practice presented here, though rudimentary to some extent, glimpses the chance of higher protagonism for planners in prompting development forms with real-time feedback on desirability. Following the complexity ladder, from single blocks to the (re)design of districts, parametric platforms could become essential «junctures» for plans, informing the intersection of quantities and guidelines, embedding regulations and incentive strategies, probing the effectiveness of indicators and multi-objective policies.

Since algorithms are expressions of generative principles, some visionary mind could consider the «upgrade» of planning rules based on mathematical definitions. The problem is that dealing with complex equilibria in urbanism tends to build on exceptions. This means that committing to proportionately complex abstraction of form demands to internalize all exceptions, at least the predictable ones, with strong implications for designers [1]. Development of computation will need to incorporate specific quality, essential for the up-scaled nature of patterns, to address the «limbo» complexity would create between algorithmic and intuitive thought, if the objective is original and context-sensitive design. Perhaps what computation will not achieve is reducing the inherent subjectivity of constraints, which could rather reinforce our responsibility in governing the future of city systems.

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