A Systematic Approach Towards Creative Urban Design

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Abstract The last few decades have witnessed a shift from utopianism towards systematic approaches in urban design thinking. The shift has been faced by challenges emerging from the mutual belonging of architecture to both art and science domains. In addition to the widely held claims that a knowledge-based urban design approach would restrain creativity, systematic approaches have been challenged by the complex nature of cities. A full account of the conflicting and overlapping variables in urban design is seen to be unfeasible due to the linear nature of design process. For that, we present a prioritized structure model of design thinking that builds on the generic function of movement in cities. On this ground, we prioritize spatially-determined variables over other quantitative and qualitative variables. We implement the prioritized structure in designing a hypothetical city. From our experiment, we conclude that a knowledge-based design approach can help defining the parameter constrains for solution space. In this process, a creative design input is seen to be inevitable to further define design features and allocate functional relationships. It is seen, however; that by externalizing this process we make explicit the dialectic of design hermeneutics. This approach can be of high value as it enables users and other parties to engage in determining the course of actions required to reach to desirable design criteria.

Introduction

Design as a practice of human cognition in the reproduction of space and recognition of its partially-dependent components continues to be a fertile ground for speculations and experimentation. The domains that played part in researching this

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subject range from engineering, architecture, computation to cognitive sciences and psychology. Mainly there is a divide between these domains based on research-centered approaches and practice-centered ones. Research-centered approaches present a top-down view of the design process. The focus is often on quantifying design knowledge and creativity by looking at what designers say rather than what designers do. The reason for that is the hardship in providing comprehensive account of the criteria against which design performance can be assessed. This is also due to the nature of design process itself, seeing that designers unlike researchers tend to be selective about the knowledge they incorporate in their design decisions. Designers can have different preferences about the criteria they reason with. While the criteria might be determined partially by the design problem; background knowledge might also play a non-trivial part in shaping the design course of actions. This is in itself is presenting a problem given that for a design to satisfy different criteria it has to involve different types of knowledge in different capacities. Practice-centered approaches would be more focused on the experiential part of design and often are on the skeptical side about the possibility of modeling design process. The skeptical standing is mainly reasoned by the impossibility to account for all the variables that make designs possible seeing that many of such variables are qualitative rather than quantitative. There is also the argument that design in architecture relies mostly on intuition and is largely an irrational process. To verify this claim, there is a need to reflect in action on the boundaries of rationality in design thinking. To start with that, the nature of design problem needs to be scrutinized and an investigation needs to be held on how defined or ill-defined urban design problems are [1]. From there, the process; whether rational or irrational needs to be elucidated to reflect on the concept of 'bounded rationality' in design. As Simon defines this concept, he grounds his theory on the subjectivity of a designer and the cognitive limitations presented by the design situation and the background knowledge [2]. In an approach to tackle this limitation; problem-solution approaches can be classified as to respond to well-defined problems or ill-defined problems. For a well-defined problem, an automated process can be adapted to seek for optimum solutions. For an ill-defined problem, designers could seek solutions that satisfy the solution criteria by means of heuristic methods (trial and error). The implementation of Simon's methods has been mainly limited to solving engineering problems. Due to the uncertain nature of architectural and urban design, the concept of *bounded rationality* has not been fully explored. Namely, the boundaries for rational and irrational reasoning have not been clearly identified. The identification of these boundaries can only be done with extra caution by isolating the logics of a designer, a situation and the external parameters that influence the design. In dialectical theory, the relationship between the former logics is what makes seemingly irrational decisions reasonable [3]. The nature of a designer's actions is limited to 'endogenous logic' and is framed by 'exogenous forces'. The design situation acts as an interface between a designer and the world. The 'exogenous forces' are described to be partially independent parameters that restrain the 'free will' of an actor, or a designer in our case. Mandel identifies the dialectic between the ‘endogenous logic’ and ‘exogenous forces’ as a duality that aligns progress in history. This identification echoes the dialectic between a designer and the world in a given design situation as a form of design hermeneutics. These hermeneutics might be internal in a solo design process or partially externalized in collaborative design. Whether, internalized or externalized, design hermeneutics are habitually practiced in the form of question and answer [4]. In a systematic reading of the duality that is inherent in design hermeneutics we might need to force the isolation between what is endogenous and what is exogenous and observe the instants at which an interaction between the two is inevitable. This is not to break the duality between the subject and the object that makes design possible but to understand the notion of ‘bounded rationality’. In other words, by unwrapping and disbanding this duality we might better understand the boundaries between objective rationality and subjective rationality. With the term ‘subjective rationality’ we identify subjective acts of reasoning to be another level of rationality at which decisions are based on qualitative criteria. To explore the boundaries of rationality in architectural design, a structure of priorities needs to be extracted from urban dynamics to inform design reasoning. In such a structure, preference is given to exogenous forces to frame and better define the design problem and to ensure a functional design outcome. A designer’s endogenous logic interferes at certain stages to direct the course of design and to further shape design solutions.

Exogenous forces can be a makeup of both the physical space and the social set up of society that inhabits space. In a biased reading of the built form and its embedded social structure, we might see the first to be the materialization of the second. To simplify the problem we might consider the spatial structure of the built form and its associated economic activity as the material manifestation of human activities. With this theoretical perspective, we assume that human activities in space conform to certain patterns for which space is their physical imprint. The interactions between the realms of space, society and economy comprise what Jacobs’ terms as the ‘organized complexity of cities’ [5]. Attributing organization to urban complexity might be suggestive of a certain systematic process that governs what appears to be stochastic. While an explanatory model of this systematic process can provide an understanding for the operative mechanisms of urban complexity all at once, an urban design model would need to reconstruct this process. Both an explanatory model and an urban design model should be based on observed scientific evidence for them not to be alien to the urban phenomena. An urban design model however should be able to effectively project the explanatory model on the course of design process to form a comprehensive approach towards problem-solution definition. The projection of urban complexity on a linear design model can only be enabled by prioritizing certain preferences over others.

In this paper, we present a knowledge-based model that aids urban design decisions. We reflect on this model in action to observe where the boundaries exist between evidence-based rationality and designers’ internal logic. The model reflects on a prioritized structure of design thinking. Priority is given to spatial structures to account for movement as the fundamental function of urban form. A generative model is devised to produce different spatial structures. The process of generating street segments is guided by the centrality and extension rules [6]. The structures are then evaluated against properties that are seen to identify the geometric development of cities [7, 8]. After the evaluation, one spatial structure is selected. The configurational properties of the selected spatial structure act as control variables for the parameter space of other partially-dependent form-function variables. This relationship is determined by a parametric model that is extracted from observed relationships between space and form-function parameters in Barcelona and Manhattan. Form parameters include building height and density as well as street width. Functional parameters define the relationship between spatial structure and the overall zoning of the associated areas. Building on a hypothetical sequence of form-function dependencies we can outline several possibilities in which a composite design model operates. We will test the application of both the generative and the parametric models in design and outline events where the model can be fully automated and events where designer input is needed. In doing so, we investigate the role of the composite model in setting the ground for a knowledge-based urban design approach. We also reveal the limited capacity of a purely automated model that is based on spatial criteria in defining the features of design solutions. This limitation does not go against the hypothesis, as we assume that such models are devised to guide designers rather than determine their course of actions.

From an Analytical to a Synthetic Space Syntax

The presence of explanatory theory of cities architecture that reads movement potentials as a function of space is central to any sensible urban design approach. With this contribution, the role of Space Syntax theory in understanding the science of cities cannot be underestimated [9, 10]. Developments on the theory have further supported the theoretical propositions of Space Syntax about a fundamental relationship between space and society. Efforts in this field have often been devoted to further test the theory on different contexts stressing the existence of cross-cultural invariants that govern socio-spatial behavior. Research efforts have also been directed towards modeling invariant correspondences between the spatial structure of cities and their formal and functional attributes [11]. For these correspondences to be devised in design a comprehensive modeling approach needs to be undertaken. Such an approach would necessarily require projecting observed parametric relationships between Space, form and function on design as a sequential course of actions. Aligning this implementation to design would lead to a major change in the functionality of Space Syntax [12]. It would transform it from an analytical model that decodes urban form and contribute to the knowledge about its functioning mechanisms to a synthetic model that encodes this knowledge into design [13]. A synthetic reading of Space Syntax would fulfill early promises by Alexander [14] on a synthetic reading of form. The outcome of the design is an artificial product that, given its reliability on a functioning urban structure; is expected to be less costly in the process of adaptation to natural growth. This is seeing the cities—in spite of human interventions—self organize their spatial structure to enforce global accessibility into planned areas [7]. Along that process, the planned areas subdivide and deform to imitate natural growth. By embedding natural rules in our reproduction of street structures, we aim at minimizing the effort with which cities counter the disruptions made by human interventions to the Parts-whole structural unity. Along the lines of devising scientific models into urban design there is the designer's worry that by erecting designs on an existent reading of space novelty of designs might be limited. There is the argument that such an approach might lead to a pure reproduction of conventional city spaces. On the side of a scientist, there is another worry. The instrumentalization of knowledge into design decisions that are normative in essence might impose risks on the rigor that has been originally ensured by building on a scientific theory. An argument for the first type of concerns could be that despite the emphasis made on knowledge-based reasoning in systematic design, there is enough space for creative connections to be made. In the meanwhile, concerns raised on the side of science claiming that testing knowledge in the ambiguous logic of design might threaten its profound credibility should not stand against the stream that empowers theory by application. In order to elaborate on how and in which capacity creativity might feed into design without risking the rigor that associates a systematic approach, we need to reflect on that by means of design experimentation.

The decoding of urban dynamics serves as to expose dependencies between variables. Variables that appear to have more control over others can be prioritized in the process of modeling. In doing so, the complexity of urban form and function interdependencies could be partially projected on a hierarchical structure of dependencies and priorities. Such a structure, while reflecting on the dynamic process that directs the functioning of urban form, can better inform the linearity of design process. The nature of design as a process can be read in this course as the set of actions required to reconstruct urban dynamics. The incongruity in setting up a prioritized structure comes from describing a correlation as causal [2]. For that there is a need to distinguish between causal correlations and what is statistically recognized as 'spurious' correlation. Whether a causal correlation means that a variable is fully determined by another variable is also to be questioned. In the theory of 'cities as movement economies' the configurational settings of space are seen to raise movement potentials for certain street segments [11]. This chain is followed by retail activity emerging along routes that have high movement activity. This if described as a causal chain of relationships might lead to the erroneous understanding that space can fully determine movement and its consequent economic activities. Another reading for that is the demand and supply model [15]. In this model, space defines movement potentials. Movement flows while restrained by spatial configurations will then form the demand for certain form-function requirements. The consideration of space-form and space-function relationships in a demand and supply model might structure a directional relationship in which space encourages movement, and movement forms a demand for certain form-function variables to fulfill. A direct relationship between one variable and another should always be taken with caution as to bear in mind the interdependencies between variables, especially those that form the supply for movement. In adapting such models for design support systems, there is a need to rank certain preferences for supply variables. The hierarchical structure that represents space-form-function relationships might be better elucidated as to see space as a control parameter that partially determine natural movement and partially constrain configurational movement.

The preference of a spatial knowledge in constraining design probabilities is not a particularly novel proposition. In fact, Hillier [10] recognized that this knowledge could be built into a design model that prioritizes the 'generic function' of movement and occupation in spatial structures. He defines three design filters that help constraining a design process. The 'generic function' is considered as the first design filter that defines the spatial genotype and characterizes spatial permeability connecting all spaces in a system. By this functionality, it filters design probabilities to define possible solutions. The space of design possibilities can be further filtered by two filters. These filters are to do with the phenotype criteria of design solutions that are determined by individual or communal cultural identity. They constrain design by means of qualitative criteria that is defined by makers or users. The first design filter can be interpreted in a set of 'discursive techniques'. In urban spaces, discursive techniques might be read as the tendency to minimize depth hence conserve on movement from all origins to all destinations. To reflect on urban dynamics we need to examine how patterns of transformations in cities are produced by situated spatio-temporal conditions of the network elements and parts [7, 8]. The key design dimension for this process is to see how the network configurations would shape the urban environment and set the ground for certain economic activities to occupy space. Following this logic, the correlations reported by Space Syntax between space, form and function become instrumental in informing design decisions. An evidence-based design approach that utilizes Space Syntax into design decision making has long been established [16]. The approach has predominantly been applying Space Syntax as an analytical and evaluative tool. For further engagement of Space Syntax in the making of design solutions, the model needs to be adapted to serve in synthesizing designs. The correlations if hypothetically read from one side, can be seen as relationships between control variables and partially dependent parameters. We identify this adaptation of the model as central to the new synthetic functionality of Space Syntax. On this basis, we update the model initiated by Hillier with a prioritized structure of design filters. The ideal implementation of that would be to consider an urban network as a parametric estimator of urban volume and function. We base these parametric relationships on rules extracted from urban regions [17]. With the application of evident rules in design we reconstruct the relationship between space, movement and their economic byproducts. Hence, we entwine the layers of urban complexity by a spatial preference.

To reflect on a prioritized structure of design thinking, we update Hillier's theoretical model of design filters to include four sets. The first set of design filters defines the generative laws of urban space. These laws have been addressed in [6–8]. The laws are extracted from the evolution of urban form. The second set of filters, are inferred from the first set and define parameters that are directly estimated from the temporal state of spatial structure. The third set of design filters are not directly related to space but are determined by other types of quantitative criteria. Examples for that are environmental constrains, construction constrains and emergency planning. The fourth set of design filters are then purely determined by designers or users and encompass all the qualitative criteria that defines the features of a design solution. Qualitative criteria are normally associated with cultural, aesthetic singularities or idiosyncrasies.

Designer and user's involvement in this design filtering process is inevitable for a solution to be defined. Designers are central in making decisions to direct the course of actions and select relevant criteria. They are also involved in making decisions where higher degrees of freedom leave larger space for uncertainty or where overlap and conflict between different variables interrupts design progress. These issues are expected to arise at any stage. In this paper, we aim at presenting a design experiment in the form of a reflective practice [18] where we report the stages at which designer's input is required. We also report difficulties with regards to the automation of certain criteria. We mainly present a design process where we involve the first two filters in determining the universe of design probabilities. We then present creative variations on the outcome of the constrained process. The objective of this tactic is not to claim that a design process can be fully automated but to present a structured approach towards design development and discuss the difficulties that might be encountered in this approach. This is taking into account that by externalizing design thinking we can allow for self-criticism and user participation with the scope to democratize design process. The approach is structured in such a way as to maximize certainty about design decisions at a stage that is considered to be fundamental for a spatial structure and its associated form-function criteria to operate. With the gradual shift towards uncertainty, there is an increasing need for a designer/user creative input to further shape design outcomes. This filtering process is structured to conserve on problem-solving where automation can be an option. It allows for defining decision points where selection and allocation is needed. While the form-function parameters described in [17] appear to be strongly determined by spatial configurations, we expect overlapping and interrelationships between the parameters themselves. More importantly, we expect that these parameters involve internal evolutionary dynamics that link them to their prior states. The sequence in which the form-function parameters operate to shape urban form can be inferred from the process of urbanization itself and can be tested through simulations.

The Dynamic Geometry of Cities

Simulation of growth behavior in cities has been a domain where urban geographers have invested for decades [19, 20]. Models that have been developed to simulate growth were based on combined CA-agent techniques. Structural properties of the street network have not been represented in these simulations. Taking an analytical approach, early Space Syntax experiments [9] have presented a generative pattern of organization on the local scale of an urban area. The approach was further pursued by investigating the emergent structural properties that result from the repetitive process of block alignments. This has led to evidence-based assumptions about the characteristics of local and potentially generative dynamics in organic grid. Hillier [10] recognizes the tendency of longer lines to continue straight and shorter lines to be blocked forming near right angles with other lines. By identifying that process as the "centrality and extension" rule he sets the ground for the assumption that local rules will have an effect on the global pattern of urban structures. Whether, a centrality and extension rule on its own can lead to the generation of cities is something that needs to be questioned, provided an evidence on different orders of urban growth and its stationary effects [8]. In search for generative dynamics that governs cities, a process of preferential attachment has been outlined [7] to operate on the local and global structures given their spatio-temporal conditions. The process seems to also involve the pruning of weakly integrated local structures. The system's integration values are apt to be normally distributed if an organic grid pattern prevails. Stationary patterns that were seen to be conserved by the system throughout growth might be considered as a side effect of this process [8]. The conservative patterns were recognized as the steady state that the system arrives at in a process of reaction-diffusion. In this process, the phenomenon of equally distributed metric patches that resembles dissipative solitons is marked. The patterns emerge as the system is in a continuously updated state of equilibrium where wave like structural change spread from the original core towards the edges and bounce back into the system. Both generative processes and their steady state effects constitute the criteria against which we identify a spatial structure to belong to the class of urban street networks. At this stage it is difficult to rule out the role and sequence in which these laws generate urban structures, we therefore take them as criteria for urban pattern recognition.

Form-Function Parameters

In our suggested model for a prioritized structure of design thinking, we have referred to the second set of filters as those that are determined by the geometric configurations of the street network. Analytical approaches that looked for correlations between spatial structure and urban form and function have occupied the validation front of Space Syntax theory. An attempt to go beyond the validation to modeling has been made by Banister et al. [15]. As explained earlier, the demand and supply model they propose interprets the state of the urban street structure as the demand and interprets the supply to be the corresponding street width and landuses. The demand can be determined by the functionality of the street network topology as a regulator for movement flows. The supply can be read as in how the parameters of street width and landuses would respond to estimated movement rates that are provoked by the network properties. Research has followed this approach to outline a comprehensive model [17] that brings together all the associations between form-function properties and space. This model updates the deriving point where space is considered to be the demand by accounting for its topo-geometric properties. The associations between the demand and the supply are further translated into parametric constrains. Following that an evidence-based parametric model is outlined. In this model, space acts as a proxy indicator for urban volume and its overall zoning functionality. To extract the parameters, an intermediate layer, the *pixelmapper* is devised to translate the values of the spatial structure and the data points of the form-function maps into a certain resolution. The resolution is defined by the length of the polygons' edges in this layer. In order to test the parametric model, we take it to be the second set of design filters. The solution space defined by such filter is to be further refined by a designer's selection of third and fourth order of filters.

Generative Variations and the Geometric Filter

In this section we evolve a number of growth iterations for hypothetical urban patterns using Hillier's centrality and extension rules with a margin of randomness. For that longer lines are encouraged to continue in the system and intersect with other lines forming semi-continuous patterns. Shorter lines are more likely to stop at the first line they intersect with forming near-right angles where possible. The structures produced present varying syntactic properties and patterns. In order to recognize structural patterns that match those of cities we assess these iterations by looking for properties that identify the generative processes outlined earlier. We particularly resort to the property of normally distributed integration values and steady state metric patches as criteria for urban pattern recognition. The question is whether differentiation and self-organization that mark these generative and steady-state patterns can be a natural product of a local generative rule. The experiment's first objective is to verify by means of simulation whether this process of centrality and extension can on its own generate urban structures that match the configurations of cities geometry. The second objective is to look at this process from a design perspective and identify stages at which a designer's input is needed.

By running Choice SLW (segment length weighted) analysis, we can extract a structure that has the highest 10 % values and evaluate its continuity. The

∑TD/NC	15726.2	11366.29	7747.37
∑ SL	51730.92	46011.49	39664.84

Fig. 1 The first row represents growth iterations using the centrality and extension rule. The second row displays segment choice SLW analysis

Fig. 2 Rendering metric mean depth values within different radii for the three growth iterations

evaluation can be made by measuring its normalized cumulative total depth values and cumulative segment length. Choice as a measure of 'shortest putative journey' and integration as a measure of depth in the system are angular-based graph properties of the street network [21]. Steady state patterns can be recognized by running metric mean depth analysis (MMD). The measure simply represents average physical distance from each street segment to all neighboring segments in a network [22]. Integration values are expected to be normally distributed in a grid that presents a differentiated structure. The normal distribution can be evaluated through measuring the goodness of fit KSL test. The evaluation measures of choice indicate that iteration 3 performs better than iterations 1 and 2, Fig. 1.

Calculating MMD for different radii does not identify clear patchwork patterns in the background network of any of the three variations, Fig. 2. We might need to run this measure on a larger scale to verify this, but for the scope of this analysis we could report that a local rule on its own is incapable of producing steady state

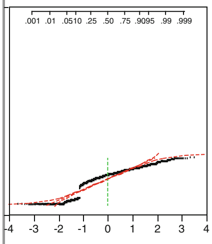
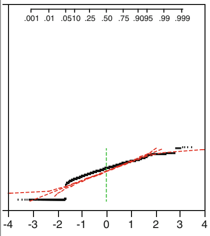
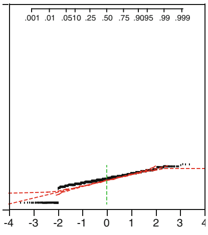
	Iteration1	Iteration2	Iteration3
Intelligibility R^2	0.126	0.139	0.179
Distribution of Integration Rn values			
—— Normal	(653.1,265.102)	(750.239,242.664)	(586.137,117.541)
Goodness-of- Fit KSL Test Prob>D 0.0100 >	 D 0.149932	 D 0.095711	 D 0.03652

Fig. 3 Testing the distribution of integration values for different iterations of growth

patchwork patterns. The patterns we target are identified as equally distributed patches that are byproducts of a self-replication process, a property of reaction-diffusion systems [8]. We believe that the absence of clearly defined patchworks is due to the fact that the directional mechanism of the current model not accounting for reinforcing feedback. Judging on KSL test we find that Iteration 3 fits best with normal distribution, Fig. 3. Given the findings we have, iteration 3 prevails as it presents an optimum path in the foreground structure that conserves physical distance and angular turn costs. It also presents a structural differentiation that match better urban form. We therefore choose it and proceed by applying the parametric model to define design features.

A parametric Framework for Form-Function Definition

In this part of the experiment, we implement the parameters extracted from space form and function relationships to deduce future states that maximize these correspondences. It must be emphasized that the correspondences between street structure and form-function parameters is highly effective on the street level itself and loses its significance when it comes to higher and lower street levels. An exception for that is the building height parameter, which for construction convenience might not exhibit huge variations. To extract the parameters from existing urban cases, we mainly used an intermediate layer that we called the *pixelmapper* to translate the spatial information into a certain resolution. The future states are then defined within that resolution level and might be interpreted as the target space for a maximized association between spatial configurations and form-function attributes. The realization of this association will raise the effectiveness in which the physical domain of urban space responds towards form-function. We outline target spaces separately for each form-function variable and discuss the conflicts and overlaps in-between them. We then present some variations on the target space determined by these parameters.

Parametric constrains explained in [17] can be summarized as follows;

- Segments marked by highest 10 % values of choice SLW are more likely to be wider than others.
- Higher aggregate values of connectivity within a *pixelmapper* unit mark a proxy indicator of higher block density.
- Higher buildings are more likely to be on an intersection point between high choice SLW elements, the likelihood is enhanced by a proximity to dense patches within walkable distance (R1000meters).
- High integration values Rn is a proxy indicator for commercial zones.
- Islands defined by highest 10 % values of choice SLW that have high metric mean depth R3000 are more likely to be zoned as industrial.

Plotting the target space for these parameters from the measures defined by the spatial structure we can highlight the target space for each parameter on its own (see Fig. 4a). The parameters can be fully automated given the spatial measures, with the exception of industrial zones and high-rise buildings. These two parameters are based on the metrically-defined patchwork patterns that seem to render outliers in the analysis. These outliers need to be excluded from the calculation for the patches to be recognized by an automated process. It might be perceivable, looking at the target spaces that the parameters overlap leaving more space for hypothetical assumptions about the interrelationships between these parameters. At this stage, a designer or user input is needed to make decisions and define the relationship between these parameters. The relationship can be defined by furthering the investigation on the association between the variables and real urban scenarios to extract second order parametric rules. Taking that into account, we list several assumptions regarding dependencies between form-function variables as follows;

1. Street width is predominantly determined by high choice SLW values, however continuities are more likely to preserve consistent street width.
2. Block density is predominantly determined by local structures but is more likely to be concentrated around commercially active centres.

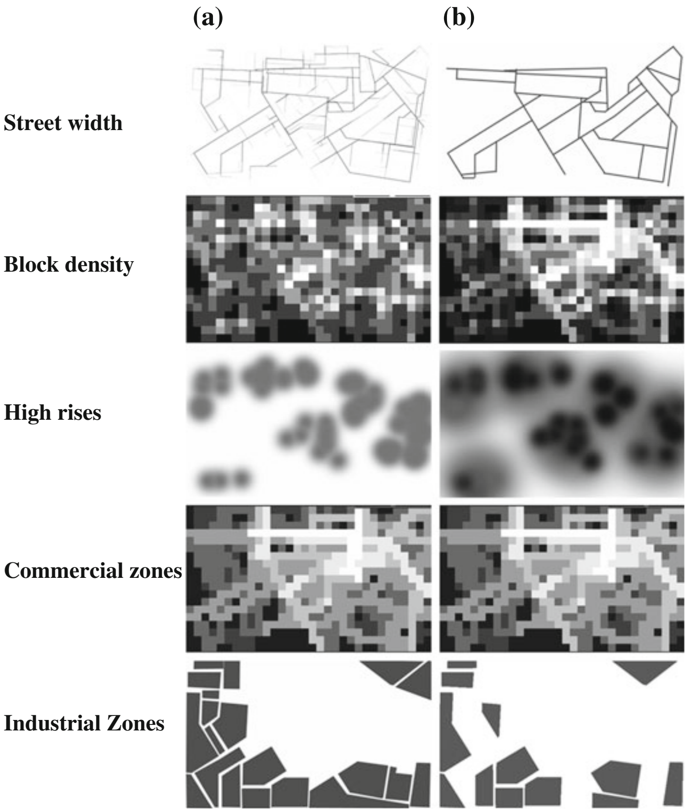


Fig. 4 Measures of spatial structure as proxies for form-function parameters. Spatial structures analyzed using UCL Depthmap [23]: **a** target spaces for form-function parameters based on spatial configurations; **b** target spaces considering interrelationships between form-function variables

3. High-rise buildings are determined by the configurational structure. Buildings are more likely to be higher in commercially active zones. Buildings are assumed to be lower close to industrial zones.
4. Industrial zones have second priority when overlapping with commercially active zones. An overlap with dense areas reduces that effect.

Taking these assumptions into consideration, and given that the parameters were initially extracted from the spatial measures, further refinement might be needed for the parametric model itself. This means that the likelihood for each parameter might need to include positive or negative multiplier effects given an overlap or a conflict with other variables. Parametric constraints on this level of detail cannot be read within clear thresholds. Fuzzy boundaries and Gaussian decay are expected to mark the landscape of the solution space. A preliminary attempt is made in these regards to refine the target space by taking the previously mentioned assumptions into account (Fig. 4b). Given the first assumption, a continuous foreground structure is traced to represent major road network that links the overall structure and thus demand wider street segments. By applying the second assumption, considerable alteration is made to the target space. In this case, a verification of the assumption is needed through an evidence-based approach before considering this assumption as second order parametric rule. With the third assumption, we can further distinguish differentiations on the building height parameter that would help us approximate a target space for that variable. The fourth assumption is found to aid on decision-making regarding the percentage of zones given a preference for commercial activity. Functional constraints are intended to describe an overall property of a zone mainly on the ground level rather than a precise functional type of the identified building blocks. The level at which this functionality is concentrated in certain zones depends on the type of functionality itself and the overall zoning requirements for a city. Commercial and industrial areas normally concentrate in lower levels. Residential and office spaces are more likely to occupy higher storey levels. Regardless of that, the zoning of areas does not determine the programme in which the local functional organisation would operate. It does only imply that there are higher percentages of certain functionalities within an area compared to others.

Ensuing an Exploration into the Universe of Design Possibilities

While we ignore at this stage the third set of design filters given that such a procedure would require multidisciplinary expertise, we aim at presenting design variations after having gone through a knowledge-based design process. The process we identified thus far can be automated given that all the parameters are quantified, validated and generalized to reflect on real case evidence. There are limitations however, in the precise definition of the boundaries at which correlations between space and form-function parameters converge. Before defining convergences there is a need to generalize the correspondences that outline the parametric model itself. This goes beyond our scope for this paper since we consider such model as an aiding tool to frame objective knowledge rather than a model to shape design solutions. To proceed with this experiment, we model design output variations building on the estimated targets (see Fig. 4). We recognize that unless we translate these constraints into a rigid orthogonal design outcome (see Fig. 5a) there is hardly any recognized definite urban form that can be erected on these principles. The exploitation of all degrees of freedom regarding the directions that buildings might align to or the z dimension of the street level in relation to buildings can lead to interesting variations on the design outcome (see Fig. 5b). The model on its own cannot assign specific features to design solutions without designers input. The role of designers in this process is to identify the

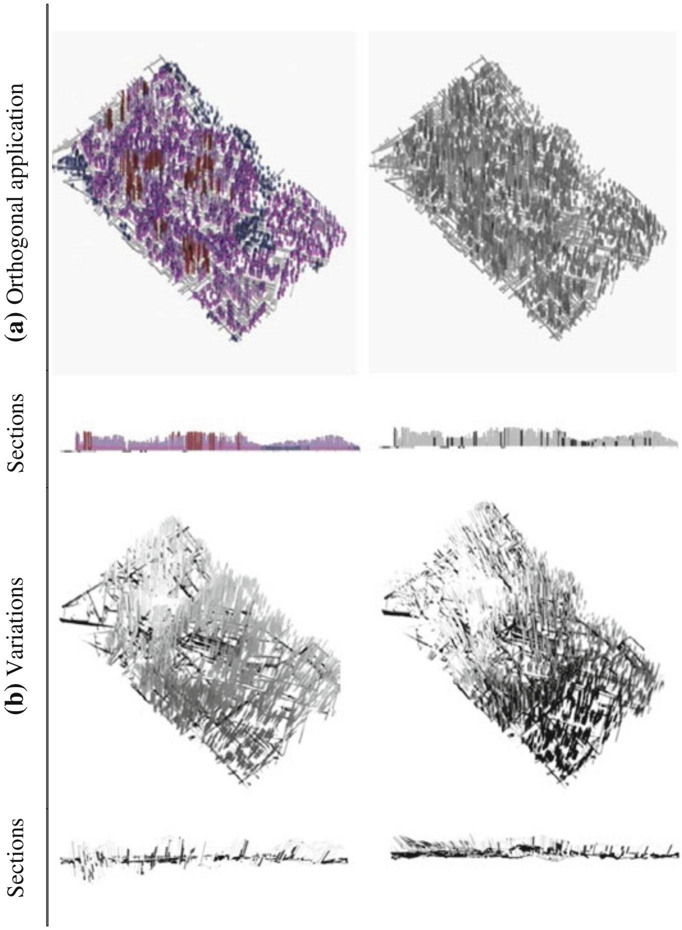


Fig. 5 **a** A direct orthogonal application of the volume-function parameters determined directly by the configurations of the spatial structure; **b** 3D variations on the target estimated volumetric outcome constrained by the first two sets of design filters and further defined by a designer

characteristics of the elementary proportions and shapes of the blocks along with the dimensionality of the street structure to setup the base model for design. Even if we take the second set of design filters to be fixed, high-rise buildings could grow in all directions and cross over presenting multi-dimensional complexities. Taking that to the extreme, blocks could grow horizontally if the infrastructure affords for such an inclination. Street network could also form wave patterns linking to higher and lower levels depending on predefined criteria. Similarly, blocks could exhibit different densities on different levels. Functions could mix accordingly or could be programmed themselves to produce formal variations. Form-function variations could be a product of the third set of design filters or could be arbitrarily defined by designers. The variations presented yield with the idea that, even with the implementation of a partially constrained process, creative design input is not restrained from defining and tuning the features of design outcomes.

Conclusions

This paper presents a theoretical model for a prioritized structure of design thinking and associates the theory with an experimental approach that elucidates the role of a designer in an evidence-based approach. Taking that into account, we review the automated procedures and identify where design input was needed to narrow solution space. With this we outline the boundaries between exogenous forces and endogenous logic in relation to the design problem. We make a distinction between an automated process where objective rationality is fully enrolled and a process where designers are needed to direct the course of actions either by selecting relevant quantitative criteria or by engaging qualitative judgment into design. The objective rationality is yet subject to the constructs of measurement and representation. We emphasize the fact that the attributes discussed in the previous sections will filter designs given a certain resolution of a *pixelmapper* grid unit. The generative process, in which the first set of design filters are applied, is directed to produce a functional network structure that affords for permeable movement all through the system. This process can be fully automated, however further dynamics should be attributed to the algorithm for it to present negative feedback effects hence for the outcome to be recognized as an urban pattern. In the second stage, where form-function parameters define the second filtering process, a designer's input might be needed to determine the influence range for each of the parameters. Yet, the target models can be devised to direct design decisions and to maximize the correspondence between form-function and the network structure of streets. For the third set of design filters, multidisciplinary knowledge needs to be incorporated to reflect on other non-spatially determined quantitative criteria. The final filtering process would be fully overtaken by designers or users who may determine the outlining qualitative features of design solutions.

Following experimentations on the model we have suggested to structure design thinking to take the functionality of an urban structure as a priority condition for urban design solutions. Going from that level of certainty to face uncertainty by applying constraints that further define the solution space we find that creativity is not restrained by our structured and knowledge-based design approach. This comes in response to the claim that scientific approaches in design thinking would hold designs from being creative. For that, we review the determinism of the previously discussed parameters over design. As the parameters aid initial design decisions and ascertain the first steps towards formalizing design solutions, they provide no unique design solution by themselves. The space of design creativity is open for infinite types of variations. The parameters therefore constitute the first two sets of constrains towards narrowing the solution space. Hence, this approach aids design reasoning by prioritizing the knowledge that defines a functional framework. The constraints outlined in this approach react towards the temporal conditions of the parts-whole city structure and partially contribute to the problem definition. For a more correct reflection, the parameters might need to respond to real-time dynamics of the structure and what this implies on the volume and function. Given that such dynamics might be associated with a slower pace dynamics on the level of the form-function parameters, we can ignore the latter dynamics at this stage. Considering these variables as static, more evidence is needed to validate the second order assumptions that speculate about the interrelationship between different form-function parameters. On the computational side, effort should be made on presenting a better definition for the target space and further enable a more responsive modeling approach to visualize the results. With this in mind, developments can be made on this model that may consequently lead to conserve problem solving effort especially when handling complex large scale urban developments. Creative outputs might challenge architectural skepticism about using knowledge-based models in design. This is seeing that through exploring different variations, there are unlimited degrees of freedom in the universe of design possibilities for an architect to innovate and involve personal input into design process.

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