A Parametric Vernacular: Genetic Algorithms in Urban Formations

As urbanization accelerates across the globe, an increasing number of urban redevelopment projects are initiated to satiate the pressing need for housing. These occur commonly in the form of closed, gated high-rise tower communities that break the urban fabric and become isolated islands in the urban landscape. Often lost in this process are the scale and the spatial continuity of the existing urban fabric, along with the cultural and social framework that it supports.

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The vernacular architecture of a region offers time-tested methods of building formulated over centuries fine-tuned to deal with the specific climatic, spatial, and social conditions of the locale. While these labor-intensive building methods are generally ill-suited for adaptation by the industrial processes of modern construction, the insights that may be gained from analyzing the vernacular opens the possibility for alternatives beyond the adopted default solution that is the gated tower community.

Thus far, the de facto development solution to increasing density in these regions has been the gated tower community. Working off of the early modernist planning tenet of liberating the ground plane and concentrated high-rise living, the tower was seen as a way to elevate living above the pestilence and hubbub of the ground.[1] However, the social and economic context has shifted dramatically since the early 20th century; what was idealistically framed as elevated living and a shared public ground plane has been subverted into walled-off, gated pockets of economic exclusivity that reflect trends of private property development and social segregation.

These tower communities, while ostensibly offering "modern" standards of living and efficiency in structure, create bubbles of space with little to no social interaction within the urban context. This can be seen easily in the urban fabric of Shanghai Old Town (Figure 1), where the traditional lilong neighborhoods coexist side-by-side with newly developed residential towers. While the traditional housing typology allows for a smaller, intimate scale neighborhood with porosity at the ground level, the walls of the tower communities create an unbreakable barrier at the street scale, contributing minimally to the urban fabric.

The inevitability of urban redevelopment in these rapidly growing cities compels us to ask the following questions: Can we densify and modernize our cities without severing the urban fabric? What lessons from the vernacular can we learn


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Figure 1: Shanghai Old Town urban fabric and high-rise communities (Image by author).

and apply to these new developments, as a strategy to preserve the sense of place and city? And how can parametric design methods help us quantify, formulate, and optimize these strategic design frameworks? These issues and the application of genetic algorithms are examined through case studies on both the building scale and the urban formation scale, ultimately proposing parametrically optimized alternatives.

CASE STUDIES

Solar Slabs (Figure 2) is a hypothetical test of a low-rise housing configuration. Set within an overall site boundary of 150 x 90 feet, a simple problem is posed to the Galapagos evolutionary solver: How can three rectangular units (50x80 feet) per floor be arranged in a block 4 stories high, while optimizing for maximum solar exposure in the winter and minimum exposure in the summer? Each unit has 25 possible positions within the slab, leading to thousands of unique configurations per slab. Once the possibilities between different floor configurations are taken into consideration, this results in an exponentially larger design space which becomes very time-consuming (if not practically unfeasible) to evaluate. With the help of the evolutionary solver we are able to automate the evaluation process; the results are shown as fitness values. Configurations with high fitness values were then reinstated as geometry for visual assessment of other factors such as circulation and ground access. This process allows for the performative aspects of the project to have a certain guaranteed level of resolution, while some of the harder-to-quantify characteristics can be evaluated by the designer for suitability.

The Chestnut Grove project (Figure 3) is an example of how the application of such principles may help in a project context. Using a more sophisticated version of the Solar Slabs algorithm, this time taking into account a variety of unit sizes (1-3 bedroom) while favoring for structural overlap and outdoor terraces, the evolutionary process produces solutions that guarantees each unit at least 4 hours of sunlight per day as well as an overall porosity that encourages cross-ventilation to reduce cooling costs. While still arranged around a central circulation and structural core like traditional residential towers, the massing arrangement can accommodate a variety of competing factors that are consciously chosen and balanced while guaranteeing certain performative characteristics. The end result is a residential tower configuration (with a mixed-use commercial/recreational podium) that incorporates a variety of real-world factors into its computational design setup: sunlight, orientation, unit variety, public/private exterior space, structure, and massing porosity. From the developer's perspective this is an adaptable computational framework that can be adjusted to accommodate a range of factors depending on the site's target density and client demographic: unit size composition, square footage, or public facilities ratio. Therefore the result is not a fixed scheme but a resilient solution with a range of adaptability that can be specified, optimized for, and a final incarnation is chosen from a pool of design possibilities that all fit the given criteria.

SHANGHAI LILONG

The first urban study is located in Shanghai's Old Town, where multiple plots of land have been designated for redevelopment and 99-year leases sold to developers. The vernacular housing formation of the area is the Shanghai Lilong, a small-scale mixed-use housing block with perimeter commercial storefronts and an internal residential circulation system that is accessed through gates. The

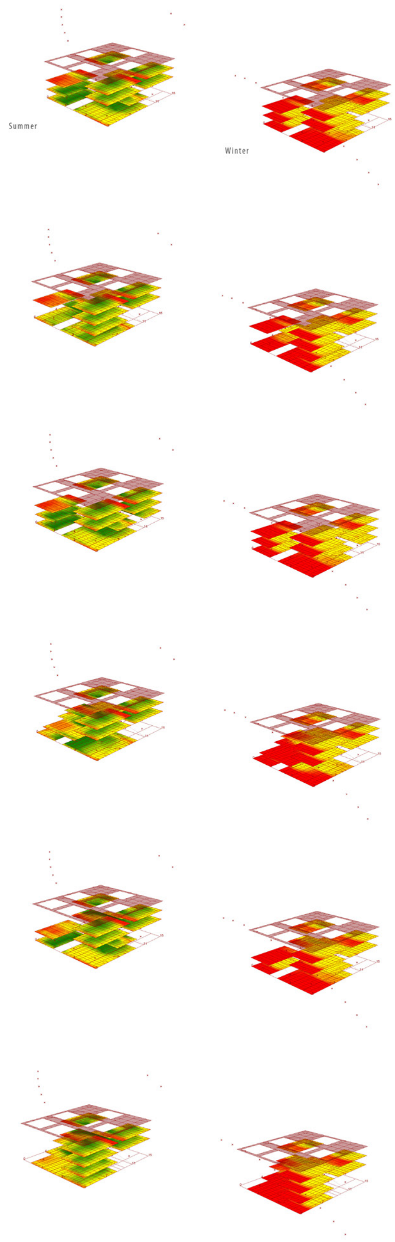

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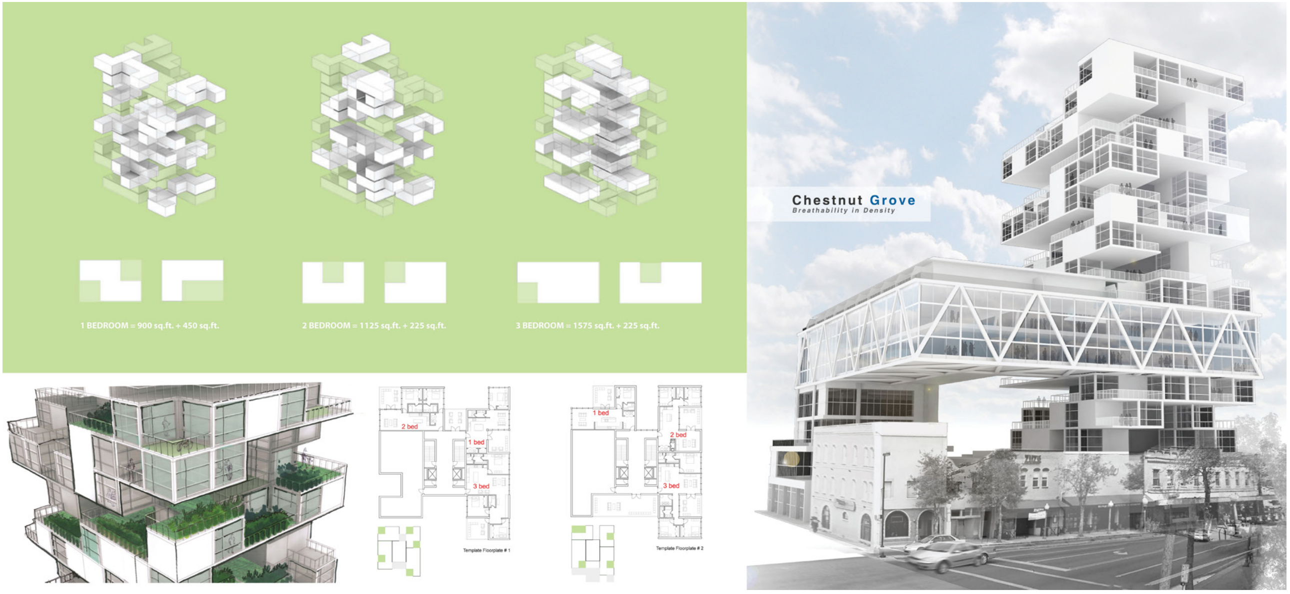
Figure 2: *Solar Slabs* configurations. (Image by author).



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Lilong houses themselves can be categorized into five major types, each with its own unique spatial and neighborhood characteristics.[2] The strong social neighborhood aspects of the typology are well documented, with the inner circulation lanes being appropriated for other uses where “residents had transformed this thoroughfare into an everyday ‘community corridor,’ utilizing these lanes as space for almost everything from hanging out to chat and for community meetings, to cooking, washing clothes and selling stuff to gambling and so on.”[3] The success of the lilong typology led to widespread adoption and it became the predominant housing typology within Shanghai’s urban fabric within a century. While many of the current existing lilong neighborhoods are in varying states of disrepair, many of its residents are waiting for government-initiated urban renewal to “modernize” their living spaces with apartment towers. However, the vibrancy, the social dynamic, and the sense of community that the lilong provides is almost invariably lost in the new developments that create their individualistic utopias within their own walls. It has been argued that while the lilong is no longer the most appropriate form of housing for Shanghai given modern living standards, some form of “low-/medium-rise high-density, multi-functional, community-oriented urban housing that will preserve the unique nature of individual vibrant neighborhoods” is a viable alternative.[4]

A parametric framework was set up in CATIA to emulate the dimensional structure of the lilong formations, and the multi-objective optimization software modeFrontier was used to iterate and optimize for often competing factors. Most of the plots in Shanghai Old Town are very irregular, so simply rotating the grid orientation of the Lilong units provides efficiencies depending on the shape of the overall plot outline, as well as progressively narrowing secondary circulation lanes as they serve less units. This creates staggering of the units, which in turn improves the efficiency of space usage. Applied to a non-orthogonal plot, the algorithm iterates to accommodate different unit sizes, circulation/public space to private space ratio, and small unusable leftover spaces allocated for greenery. However, due to the interface results are output as data points on plot charts making interpretation of the outcome fairly unintuitive, as is the process for reinstating specific configurations for further visual evaluation. Additionally, the scheme was applied and tested as a mat typology without considering the

Figure 3: *Chestnut Grove Project* Witters Competition 2012 1st Place (Image courtesy of Tim Beecken, Darryl Ditzel, Max Gooding, Jenna Lychako, Brittany Ross, Azhar Ahmed Khan).

possibilities for upwards expansion, therefore while relatively successful in maintaining the vernacular spatial structure the overall gains in efficiency and density are very limited. As such, the lilong typology is already a very dense and efficient framework for low-rise housing; further study into strategies for vertical growth and layering are required.

DUBAI BASTAKIYYA

The second urban study is situated in the Bastakiyya district of Dubai, a historical district with multi-generational Persian-inspired vernacular dwellings. Of particular interest is the strategic arrangement of buildings, facade openings, and courtyards that help deal with the harsh climate, as well as the windtower, a passive cooling mechanism that is embedded within the dwellings and operates off of the prevailing coastal winds.

HOUSING DEVELOPMENT STRATEGIES

Contemporary housing developments in Dubai serve as a study in contrasts in the overall planning approach to urbanism. As can be seen in developments like the Palm Jumeirah, these are conceived as distant, autonomous, and exclusive neighborhoods for the wealthy elite with little to no services for its residents as well as no accessible public spaces for the general populace. Located in the western end of Dubai just southwest of the Palm, the Jumeirah Islands (developed by the same developer Nakheel Properties) are literally clusters of villas situated on artificial islands within an artificial lake. These gated communities are not only isolated islands in terms of the overall urban fabric but also literally islands within man-made lakes, contributing to the segregation and fragmentation of the city.

In comparison, the Karama district, which was developed in the pre-boom 1970-80s provides residents with a park, a shopping mall, restaurants, grocery stores, two mosques and many retail stores. Considered one of the densest residential neighborhoods in Dubai, Karama also maintains a close proximity to Dubai Creek and older parts of the city. The district is easily walkable and scaled for pedestrians, leading to a much more lively and robust atmosphere possessing the “four generators of diversity” (mixed use, short blocks, buildings of differing ages, and density) as outlined by Jane Jacobs in her critique of modernist planning principles.[5] The Bastakiyya district also shares many of these traits, albeit scaled and tailored to a way of life that fit the socioeconomic norms of the late 1800s.

DUBAI VERNACULAR

Dubai’s vernacular architecture is perhaps the only remaining expression of the city’s culture and also the only source of authentic architecture left. The area of Bastakiyya is home to the surviving vernacular coral-stone houses (many demolished in the 1970s and 1980s)[6], which have now been renovated to support art galleries, museums and cafes. There is the perception that “no practical lessons can be gleaned from vernacular traditions for the architecture of the present”[7] and the notion of equating ‘poverty with the past.’[8] Islamic tradition emphasizes the importance of the family unit and its relation to the larger community. The urban form is such that it generates a “high degree of active social interaction and strong neighborly relationships.”[9] Thus the religion favors urbanization[10], houses in close proximity to each other with opportunities for greeting and meeting others. To maintain a sense of social cohesion, communities were usually only big enough such that all members were within walking distance from one another.[11]

The courtyard house form is the most common housing typology in the Bastakiyya area. Generally, the courtyard serves as private outdoor space for the family and encompassed with three 'tiers' of parallel spaces: verandas, inner rooms, and outer rooms.[12] The courtyard serves as an organizing element for each home as main summer living spaces are generally placed on the south of the courtyard, winter living to the north, and multi-purpose spaces to the east and west.[13] Climatically the courtyard can also assist in air circulation of the surrounding rooms, specifically the windtower rooms. Air circulation around the rooms can be adjusted via doors and windows that open onto the courtyard.[14]

The windtower is a passive-cooling structure that rises above the roof of a house at between 12-15 meters above ground level.[15] The purpose of the windtower is to harness breezes and direct them down into the room or basement below and offers a method of passive-cooling in a region where temperatures are generally high all year round. Windtowers in Dubai are generally oriented to the North-South direction. This particular orientation allows for optimum exposure to the cool afternoon sea breezes that arrive from the Northwest.[16] In this orientation, the vanes within the tower are parallel to the prevailing winds and this allows for the maximum volume of air to be directed down into the room below. A windtower is only effective when it optimizes its exposure to incoming breezes; any breezes that experience turbulence from contact with other towers and structures will not be as effective for subsequent towers. Thus towers need to maintain a certain distance from other towers such that they receive unobstructed air and that they do not obstruct other towers in their vicinity.

DENSIFY DUBAI

Given the above observations, the premise of the project is two-fold: 1. To challenge existing housing typologies by introducing a new typology that is derived from the Dubai vernacular, thus accounting for cultural and environmental constraints. In order to achieve this the courtyard house as a basic flexible unit is adapted to a multi-storey scenario. 2. Reinterpret the vernacular form and role of the classic windtower that traditionally has solely affected interior volumes. To expand their role in the urban environment windtowers will be utilized as a passive cooling strategy for both interior and exterior spaces allowing for streets and plazas to be cooled as well.

A target density for the project was established by surveying current population data of districts near Dubai creek, showing a range varying from 40 persons/hectare to 180 persons/hectare. This led to the establishment of 130 persons/hectare as the target population density. As a test site, a vacant lot was chosen that is adjacent to the Dubai creek, the historic Bastakiyya district and high-density mid-rise housing. With a scale that can accommodate several blocks, its adjacency to the historic district and mid-rise housing allows for comparison of results with existing context. The site is open to the creek therefore a steady flow of fresh air from the Northwest can be assumed; it is also divided into five smaller 'blocks' by streets that will establish connections across the site.

ESTABLISHING THE STREET GRID

Aside from geographic constraints, wind plays an important part in the form of the Bastakiyya grid. Streets(particularly those that run North-South) are oriented so as to maximize their exposure to incoming cool afternoon breezes from the Northwest. The wind passes through streets and plazas to help create comfortable outdoor environments.

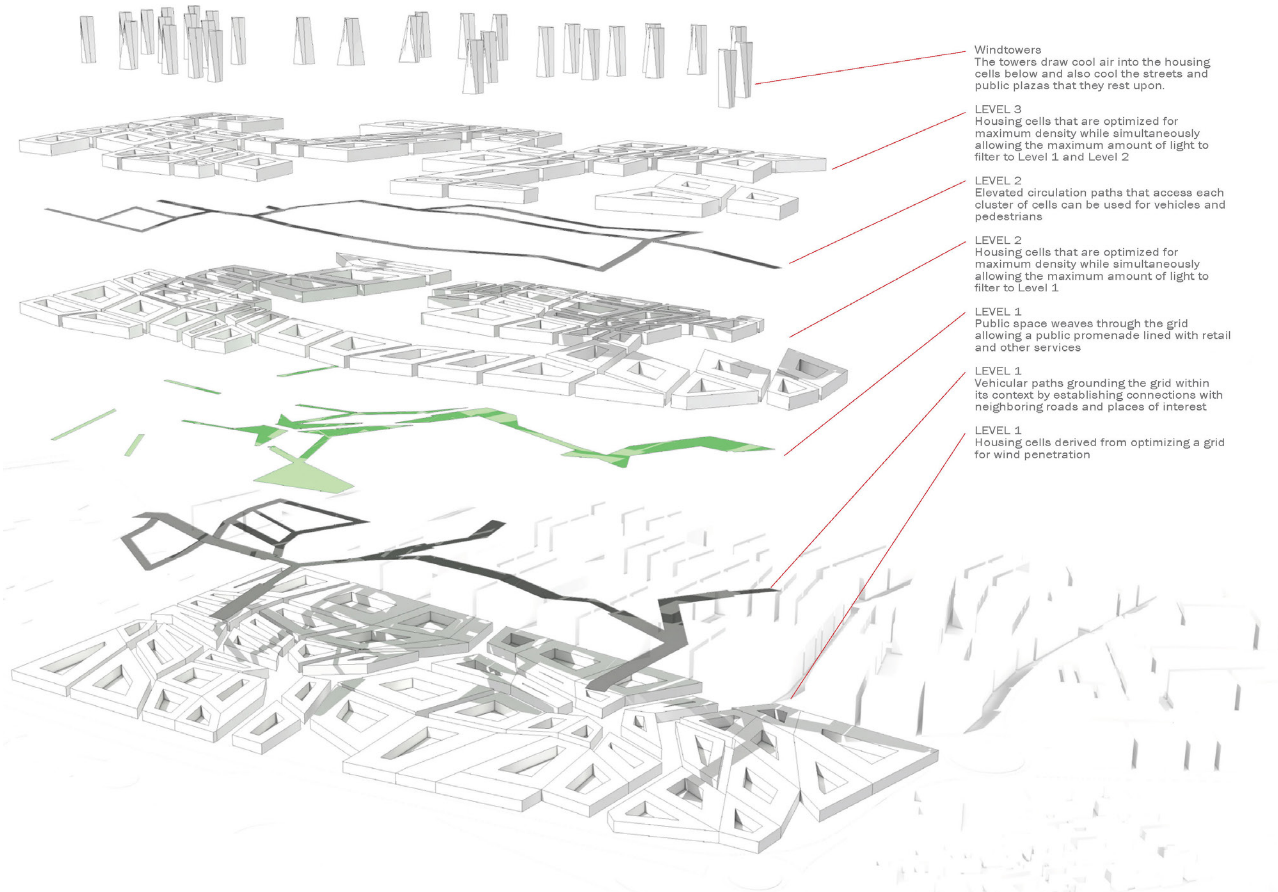
For the setup of the parametric model, an orthogonal grid is distorted by a number of attractor points. In order for the grid to relate to the vernacular it will be optimized for wind and shortest paths across the site, with streets that begin aligned to the surrounding context. For each configuration, the angle between the outer boundary streets and the direction of the wind is calculated, as well as the length of the paths that run across the site. After the resultant subdivision, cells with areas below a minimum value and those with a North-South orientation are removed and designated as public space. The top 16 solutions were reinstated and analyzed, adding into consideration the following subjective factors: availability of public space, diversity in cell areas, location and nature of oblong and oddly shaped cells, vehicular road access from blocks, linear trajectory of roads, and shifting of residential streets to limit sight lines. One particular grid configuration that showed the most potential for all of these factors was selected as the base lower level plan, determining major vehicular avenues, public spaces, and courtyards. CFD analysis of the block layout was also carried out to verify the efficacy of the street configuration at ventilating public spaces. It is important to note that the selected configuration may not be the most optimum computationally but can still satisfy the majority of evaluation factors, while gaining much from a subjective analysis by the designer of desirable traits that are difficult to quantify or evaluate parametrically.

VERTICAL GROWTH

To create enough density within the limited plot area, a strategy for stacking vertically must be explored; the biggest disadvantage of stacked living areas is loss of light. Light penetration diminishes as we add layers on top of one another; therefore the goal is to find an optimum configuration of cells that balances the density of cells against enough porosity for light to the layers underneath. Since the first layer has been already determined, the second and third layers build upon the first level configuration by creating the courtyard typology block from the center points of cells of the lower layer.

The upper two levels are configured such that at least three cells are grouped together and no one cell is isolated (i.e., every cell has at least two neighbors). The goal is to maximize the number of cells while also maximizing the amount of light that passes through to the lower levels. Applying the same solar radiation evaluation method utilized in the previous projects, the evolutionary solver populates and removes cells based on the above criteria, searching for configurations that balance overall solar radiation while populating as many cells as possible. The top four 'fittest' configurations were critiqued for additional subjective factors: level of porosity over public spaces, ensuring that no level 3 cells lacked level 2 cells to support them resulting in 'hovering' masses, and possibilities for vehicular and pedestrian circulation paths on levels 2 and 3.

Once the 3-dimensional configuration has been determined, the plan is examined to specify vehicular and pedestrian circulation. Since the circulation can only be created if the cells give up some area on the periphery, it is desirable to minimize the amount of circulation so as to maximize the livable square footage and thus the overall density. Vehicular loops are created that allow access to every cluster of cells; the remainder of the streets are used for narrower pedestrian circulation. These circulation designations determine the distance each cell side needs to be offset to provide the required street width. It is important that pedestrian streets only cover the voids partially and allow light to filter through to lower levels; when possible streets are placed along the Northern facades of buildings so as to shade them for pedestrian use.



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CELL SUBDIVISION

Each cell is subdivided into smaller living units by observing some simple rules. A typical cell rests upon four cells from the grid immediately underneath its own level; part of these cells sit within the boundary of the courtyard and the rest outside. The parts that are inside turn into terraces, while the parts that are outside serve as paths to the unit entry, ensuring that each living unit has access to an outdoor space. Each cell can typically be subdivided into 2 to 8 living units depending on its size; each division is unique and the resulting volumes offer a diverse range of living conditions to accommodate various demographics. The facades are also programmed according to annual solar insolation values gained from simulations; drawing cues from the vernacular it is generally more opaque towards the bottom and porous towards the top. Localized variation is determined by the solar insolation map and a privacy map determined by internal programmatic functions.

WINDTOWERS

Within the scheme, the windtowers have been enlarged and straddle the street grid while bridging between cells. Now integrated as a part of the public infrastructure as opposed to being discretized within the housing block, they are tasked with the following functions: cool interior spaces, cool exterior public spaces, support cantilevered cells, and support circulation paths. Additionally they provide opportunities for public space and spatial orientation.

Figure 4: *Densify Dubai* Exploded axonometric of urban layers (Image by author).

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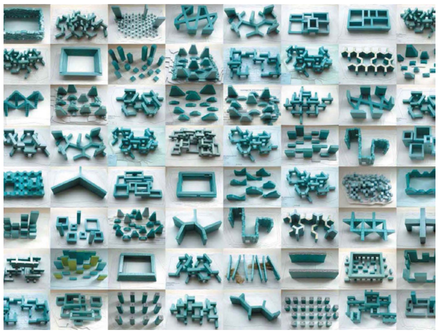

Each tower has a unique form; at the base, the form is determined by the arrangement of structural ducts that follow the optimized grid. At the top of the tower, the triangular form orients itself to the wind. Since the windtowers are now placed over spaces that are between buildings, they are able to cool interior spaces as well as the public spaces directly below them. The placement of windtowers is critical to the ventilation performance, therefore possible windtower locations at the cell nodes were mapped and 'the turbulent cone' that is formed as air passes through the tower simulated. Taking into account the prevailing wind direction(Northwest) the evolutionary solver was tasked with finding an optimal configuration that maximizes the number of windtowers while minimizing any potential interference between towers.

The final project example (Figure 4) shows a three-tier (60 feet) configuration that can easily be modified for more or less levels. The configurations can also adapt to sites of varying forms and scales as well. The strategies utilized in the project are all derived from the vernacular architecture of the region and thus bind the contemporary intervention to local roots.

CONTEMPORARY HOUSING PROJECT

A recent example of stacked massing placement via manual iteration is The Interlace housing project designed by OMA in Singapore, completed in 2013. Comprised of a series of alternating stacked horizontal housing blocks arranged in a hexagonal pattern in plan, the scheme provides medium to high density residential housing with larger scale shaded public spaces. The massing was arrived at through many manual iterations and physical studies with blue foam models (Figure 5). The facades of the housing blocks were also computationally analyzed for sun exposure values, which in turn determined facade porosity as well as shading elements. However the scheme does not adjust massing proportions or orientations to reflect possible optimizations in the overall configuration, which sticks to a rigid hexagonal grid. Since the hexagonal grid is easily described as a mathematical construct, it would not be very difficult to set up a framework to simultaneously explore massing options that warp the grid while varying housing block height and depth (length is constrained to the hex grid points). As a framework this could be applied to a large number of sites, with specific criteria of fulfilling a target density and environmental performance leading to the choice of a most suitable configuration for detailed design development.

INTUITION VS COMPUTATION

Throughout the design process architects often work off of assumptions gleaned from experience: precedents, standards, conventional wisdom, and sometimes intuition. While intuitive processes can sometimes yield very finely-honed results, when faced with projects possessing complex intermingled factors determining an optimal course of action can be very hit-or-miss, relying heavily on highly repetitive manual iteration and evaluation. In the book Algorithmic Architecture Terzidis calls for "a complementing and harmonious mix of both thought processes".[17] If the core characteristics of a project can be distilled and described with a parametric framework, genetic algorithms can be very helpful in iterating, analyzing, and uncovering latent possibilities.

These projects demonstrate that genetic algorithm optimization tools can produce efficient non-intuitive results that, if attempted by conventional means, may not have been possible. These results are obtained only by carefully setting up

Figure 5: *The Interlace* massing model iterations (Image courtesy of OMA).

the problem parameters while taking into account the range and number of variables so as to narrow the range of results and reduce computation times. Rather than aiming for one single ideal final condition, the tools can aid in the "possibility of simulating patterns of proliferation toward the automation of multiplicities, rather than singular, prescribed design outcomes."[18]

It should also be recognized that obtaining an optimized solution is only a checkpoint towards a more comprehensive design solution as it is the intervention of the designer that transforms an otherwise 'optimized computer output' to a viable design strategy. The most optimum result from the algorithm may not always be the best solution for the designer, who must constantly balance efficiency with parameters that are not factored into the optimization process. Simultaneously, these studies expose and clarify the underlying forces at work; ultimately the purpose of the tool is not to supplant the designer but to aid in the process of understanding design issues, and how they can be generative towards formulating a more robust design solution.

ENDNOTES

1. *'Standing in a field you cannot see very far. What's more, the soil is unhealthy, damp, etc...'* Le Corbusier quoted in Benton, Tim, *The Villas of Le Corbusier.* (New Haven and London: Yale University Press, 1987), 195.
2. These are: 1. Old Shi-Ku-Men Lilong 2. New Shi-Ku-Men Lilong 3. New-Type Lilong 4. Garden Lilong 5. Apartment Lilong. Sheng Hua, *Shanghai Lilong Housing* (Chinese Architectural Industry Printing Service, Shanghai, P.R. China, 1987), 11-15.
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9. Anne Coles and Peter Jackson, *Windtower* (London: Stacey International, 2009), 28.
10. Ibid., 29.
11. Ibid., 30.
12. Ibid., 26.
13. Ibid., 39.
14. Ibid., 70.
15. Ibid., 166.
16. Ibid., 167.
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