THE TAIKOO SHING SUPERBLOCK: ADDRESSING URBAN STRESSES THROUGH SEQUENTIAL EVOLUTIONARY SIMULATIONS

MADISON RANDALL[1], TINA KORDROSTAMI[2] and MOHAMMED MAKKI[3]
[1,2,3] *University of Technology Sydney*
[1,2] *{madison.m.randall|tina.kordrostami-1}@student.uts.edu.au*
[3] *mohamad.makki@uts.edu.au*

Abstract. The multiplicity of networks, connections and relationships that exist in every city - complex and varied - are inherent to the urban fabric. Variation within the built form is integral to ensure adaptability to environmental and climatic conditions imposed on cities over generations. This research aims to highlight the benefits of utilizing sequential evolutionary simulations, to arrive at a more resolved solution-set that addresses urban challenges of the Taiko Shing superblock in Hong Kong.

Keywords. Hong Kong; Urban; Sequential Simulations; Evolution; Computation.

1. Introduction

The utilisation of natural world principles for the design of urban tissues has been put forward as a more robust alternative for conventional approaches to urban planning by multiple authors and researchers throughout the late 20th and 21st centuries (Alexander, 1964; Batty, 2013; Marshall, 2008; Weinstock, 2010). Coupled with the rapid development of computational tools, the digital translation of biological evolutionary principles has allowed designers to approach complex design problems, comprised from multiple conflicting objectives, with a greater focus on localised relationships between the design variables; consequently bypassing the requirement of addressing the problem through a predominantly top-down approach.

Although the utilisation of an evolutionary system allows for the design optimisation of multiple conflicting objectives, the complexity of the design problem dictates the success rate of the evolutionary simulation in converging towards fit solutions, (Makki et al., 2018); at times forcing the simplification of the problem to allow for improved results from the simulation. An alternative to this is to divide the design problem and run multiple simulations, where the results of one simulation 'feeds' into the consequent simulation, allowing for greater efficiency when optimising the design problem.

In this context, the results presented will aim to highlight the benefits of utilizing sequential evolutionary simulations to arrive at a more resolved

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solution-set that addresses urban challenges facing the Taikoo Shing Superblock in Hong Kong.

2. Context and Research

2.1. TAIKOO SHING, HONG KONG

Located within the suburb of Quarry Bay on Hong Kong Island, Taikoo Shing is an existing high-rise residential development comprising of sixty-one near-identical towers housing over thirty-five thousand people (Population Census, 2011). This urban superblock is representative of a heavy-handed top-down planning approach, designed as a solution to accommodate the exponentially increasing population density of Hong Kong. Upon analysis of the existing conditions, key environmental issues can be extracted as imperative to the foundation of an urban tissue in this setting. The projected growth of the population, the lack of sufficient open space for residents, the lack of apartment outlook and poor solar gain to apartments, all highlight areas that can be improved to provide an urban tissue that is more robust to an ever-changing context.

2.2. DENSITY + COMMUNAL OPEN SPACE

As recorded in the 2011 Population Census, the total number of inhabitants for the Taikoo Shing superblock was 37,796 across approximately 18.15 ha of land. This equates to ˜4.8m²/capita. With the total population of Hong Kong estimated to increase from 7.07 million (2011) to 8.22 million people (2043); an increase of 0.4% per annum (Census and Statistics Department, 2017), it is vital that the infrastructure can accommodate this increase in population density. Environmental issues such as access to open space, solar and the outlook of apartments become progressively more apparent as the population continues to inflate. Highlighting that the prioritisation of one issue results in extremely poor outcomes for all other contributing concerns.

Currently, the existing development provides no access to private open space, and minimal access to communal open space. As per recommendations by the World Health Organisation, 9m² open space / inhabitant ratio (Maryanti et. al., 2016) should be provided in an urban context. The present condition provides 2.9m² per capita of communal open space, showcasing the severity of this design problem. As a result of the existing building typology, there is an imbalance between the requirements to accommodate an inflating population whilst maintaining global guidelines for equity in access to open space.

2.3. MULTI-SCALAR APPROACH

Within the Taikoo Shing superblock, three fundamental relationships need to be addressed in order to successfully implement a resilient urban tissue. The first aspect of this multi-scalar understanding is the relationship of the Superblock to its surrounding context. This explicitly focuses on connections to existing networks, public facilities, distribution of people, and its reaction to site-specific conditions.

Secondly, within the scale of the Superblock, there is a rich relationship between the block typologies. This level investigates functionality, distribution and scale of the blocks, and the impacts they have on each other.

Finally, the scale of an individual building needs to be assessed in regards to the podiums, the surrounding buildings, and within the tower form itself. Understanding what aspects of the form perform well, and could be maintained throughout the design stage.

Through breaking down these complex urban issues into different scales, it enables one to comprehend a design problem as a compilation of smaller design issues that can be addressed sequentially. Therefore, and in the context of utilising a multi-objective evolutionary algorithm to tackle the design problem, the utilization of sequential simulations allows a multitude of different relationships to be explored in greater detail. Through exploring two dependent, yet sequential evolutionary simulations, the algorithm can more directly explore the solution space for each simulation, thus allowing for a greater chance of convergence towards an optimal solution set.

3. Method

3.1. EVOLUTIONARY STRATEGY

The evolutionary algorithm that will be implemented in this experiment is the *NSGA-2* developed by Deb et. al. (2000). *NSGA-2* is the driving algorithm behind the software *Wallacei*, a free plug-in written for *Grasshopper 3D* developed by Mohammed Makki, Milad Showkatbakhsh and Yutao Song (Makki et. al. 2018).

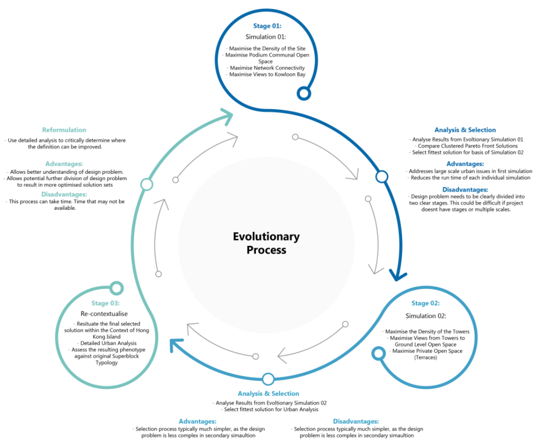


Figure 1. Evolutionary Workflow Diagram.

Through using a multi-objective evolutionary algorithm, in which the design objectives for the design problem have been identified, the experiment presented divides the formulation of the design problem into two simulations, the first and primary simulation addresses issues that are specific to the urban scale, while the secondary simulation focuses on issues within the scale of the block.

This approach of dividing the design problem (and thus the evolutionary simulation) allows greater emphasis to be applied in resolving each stage individually, resulting in a more considered and improved design outcome. The pseudo code for the simulation is presented in Figure 01.

4. Experiment Setup

4.1. PRIMARY SIMULATION

4.1.1. Parametric Definition

The foundation of the experiment is the existing site boundary and the primary/secondary road connections identified from studies of the existing site conditions (Figure 02). These existing conditions define the primary road connections, which in turn define the primary block structures which are consistent across all simulation outcomes. To assist in 'randomising' the location of the building forms, these static primary blocks are populated with rectangular regions ranging from 30.00-40.00m (Rx, Ry). Within each of these regions, a single point is created (Ptx, Pty) which acts as the centre point for the building forms.

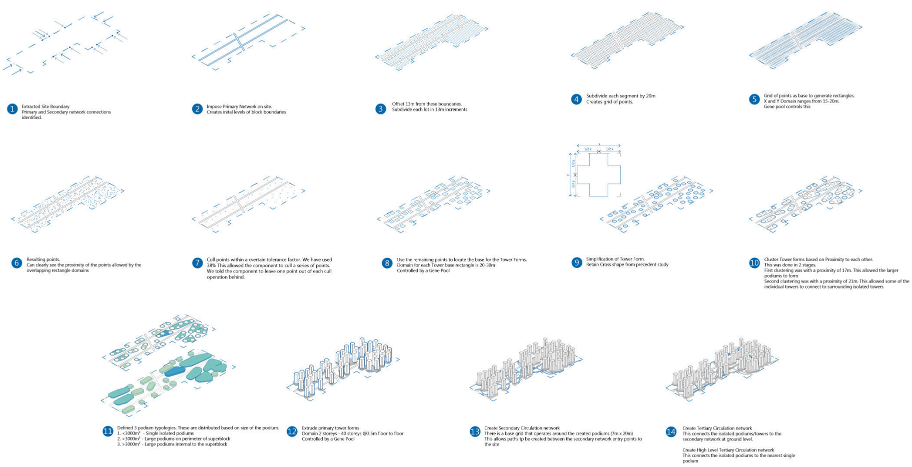


Figure 2. Construction of the Primary Parametric Definition.

To ensure there is a separation between the building forms, a culling operation has been introduced. This culls points within a tolerance of each other (38% for this experiment) leaving one point behind. The remaining network of points serves as the centre points for the preliminary building forms. The rectangular base size of the building forms is then generated using a gene pool (Bx, By) These building base plates are then clustered based on proximity to each other, resulting in podium forms that can range from a single isolated building to larger clusters of 5-6 buildings. These podiums are then sorted into three categories based on size (<3000m² - Single isolated podiums, >3000m² - Large podiums on the perimeter of the superblock, >3000m² - Large podiums internal to the superblock) These podium typologies are all extruded to a uniform height (3 storeys) as defined by studies of existing podiums.

The final stage of the primary simulation extrudes the tower footprints to various heights (H) whilst generating the secondary Networks based on a grid that goes around the created podiums and towers. This includes the tertiary street network which connects the isolated podiums to the secondary road network.

4.1.2. Fitness Objectives and Genes

Table 01 highlights the fitness objectives that the evolutionary simulation optimised for, as well as the variables (genes) modified by the evolutionary simulation which defined the superblock's morphology.

Table 1. Fitness objectives and genes for the primary simulation.

Fitness Objectives			
#	Abbreviation	Objective	Definition
1	V	Maximise Views from the Buildings to Kowloon Bay	This objective has been calculated by using a static curve representing the location of Kowloon Bay in relation to the site (for simplicity of the algorithm, the curve was divided into seven points, which serve as the points of interest) in which buildings were evaluated according to visibility to the bay.
2	D	Maximise Population Density across Taikoo Shing	From studies of the existing Taikoo Shing development, it has been calculated that the average apartment size is approximately $70m^2$, housing 3-4 people. This statistic was then applied to the calculated Gross Floor Area of the site to estimate the population density of the superblock.
3	N	Maximise the Secondary and Tertiary Road Networks	This objective is calculated by measuring the accumulated length of all of the secondary and tertiary networks generated between secondary entry points to the site (Figure 03)
4	SG^P	Maximise Solar Gain to Communal Podiums	The solar analysis conducted in the experiments utilise three primary vectors, representing the sun's position in the morning, midday and afternoon. Each point on the podium's surface is calculated to either receive 100%, 66%, 33% or 0% of sunlight.

Genes			
#	Abbreviation	Definition	Domain
1	R^x	X length of the region in which the centre point for the building forms will be located	30.00m to 40.00m
2	R^y	Y length of the region in which the centre point for the building forms will be located	30.00m to 40.00m
3	Pt^x	X coordinate of building from centre point	0.00 to 1.00
4	Pt^y	Y coordinate of building from centre point	0.00 to 1.00
5	B^x	Building width	20.00 to 30.00
6	B^y	Building depth	20.00 to 30.00
7	H	Extruded height of buildings	0 to 40 storeys

4.2. SECONDARY SIMULATION

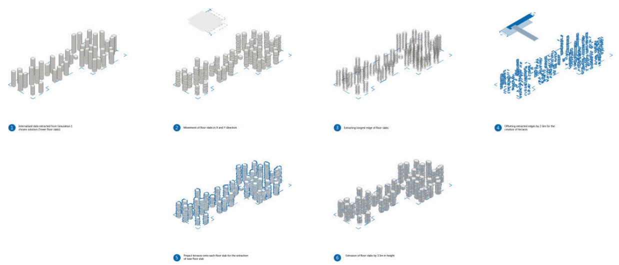


Figure 3. Construction of Secondary Parametric Definition.

4.2.1. Parametric Definition

This secondary simulation uses the extracted phenotype from the first simulation as the starting point (the selection process is described in the following sections). The tower floor plates from the selected outcome of the Primary Simulation are inputted as base phenotype for the secondary simulation. Each floor plate moves in the X and Y direction (Mx, My). While this process influences the outcomes for all objectives being optimised in this simulation (SGT, S and SGB) it has the most profound effect on (S) as the further the floor plate deviates from the original centre point of the building, the weaker or 'less fit' the solution becomes. This is countered by the requirement to optimise for (SGT) where the fitter solutions would have the most floor plate movement (Mx, My) contributing to more extensive private terraces. The final stage of this simulation is the further offset of the building form to create the terraces (T). This gene has the most substantial impact on (SGT) as it significantly increases the area of the terraces, enabling greater solar gain to be achieved (Figure 05).

4.2.2. Fitness Objectives and Genes

Table 02 highlights the fitness objectives that the evolutionary simulation optimised for, as well as the variables (genes) modified by the evolutionary simulation which defined the superblock's morphology.

Table 2. Fitness objectives and genes for the secondary simulation.

Fitness Objectives			
#	Abbreviation	Objective	Definition
1	SG^T	Maximise Solar Gain to Private Terraces	The solar analysis conducted in the experiments utilise three primary vectors, representing the sun's position in the morning, midday and afternoon. Each point on the podium's surface is calculated to either receive 100%, 66%, 33% or 0% of sunlight.
2	S	Maximise Structural Integrity of Buildings	This objective optimises the centre of gravity of each tower by minimising the distance between the centre of each floor plate to the centre of the building's bounding box.
3	SG^B	Maximise Solar Gain to Building Facades	The solar analysis conducted in the experiments utilise three primary vectors, representing the sun's position in the morning, midday and afternoon. Each point on the podium's surface is calculated to either receive 100%, 66%, 33% or 0% of sunlight.

Genes			
#	Abbreviation	Definition	Domain
1	M^x	Move floor plate in the X-Direction	-2.00m to 2.00m
2	M^y	Move floor plate in the Y-Direction	-2.00m to 2.00m
3	T	Terrace Depth	2.00m to 6.00m

4.2.3. Algorithmic Setup

The following settings (Table 03) have been applied within the *Wallacei* plugin for the *NSGA-2* evolutionary algorithm. The simulation was run on a consumer-grade PC, i7-8700 3.20GHz processor with 32.0 GB of RAM.

Table 3. Algorithm settings for both simulations.

Algorithm Settings	Simulation 1	Simulation 2
Generation Size	50	50
Generation Count	100	100
Population Size	5000	5000
Crossover Probability	0.9	0.9
Crossover Distribution Index	20	20
Mutation Distribution Index	20	20
Simulation Runtime	9hr 0min 40sec	7hr 10min 20sec

5. Experiment Results & Selection Process

5.1. PRIMARY SIMULATION

5.1.1. Results

Through reviewing the charts generated in Wallacei (Figure 04) it demonstrates that there are both successful and less successful aspects of this primary simulation. When analysing the Standard Deviation graph (SDG) in conjunction with the Standard Deviation Trendline (SDT), it illustrates that for the first three objectives (D, N, SGP), variation either stabilised or increased throughout the majority of the simulation's runtime, however, convergence is observed across these three objectives in the final generations, indicating the algorithm localising towards an optima towards the end of the simulation.

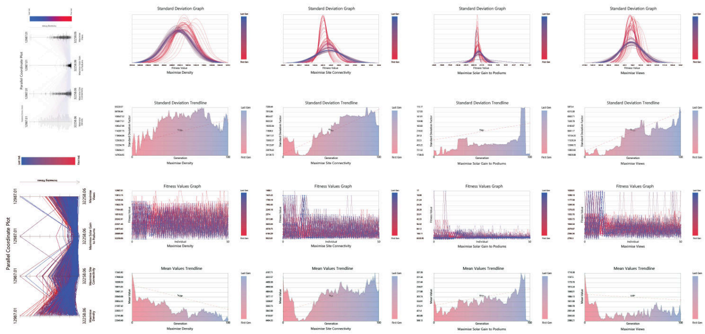


Figure 4. Primary Simulation Results (From top to bottom: Parallel Coordinate Plot, SDG, SDT, FVG and MVT).

Examining the Fitness Value Graph (FVG) concurrently with the Mean Values Trendline (MVT); an increase in fitness values indicates individual solutions that are fitter than previous generations. This pattern can be observed across objectives (V and D) where the MVT reflects fitter generations as the simulation progressed. However, with regard to objectives (N and SGP), and similar to the observations made in the SDT, the mean values across generations became less fit throughout the simulation, however, the mean value increased in fitness at the same stage where the variation across the generation began exhibiting signs of convergence. Through evaluating the outcomes of the charts, it indicates that the simulation optimised for some objectives better than others, while it seems that towards the end of the simulation's run, the 'weaker' objectives exhibited better signs of convergence and fitness. This aspect of the design problem's complexity highlights the applicability of EA's, emphasizing that even through 5000 iterations of the design problem, there is observed a range of fit and less fit solutions. Most importantly, analysing the solution set across the entirety of the population is imperative as it exhibits patterns to the algorithmic run that are non-uniform throughout the simulation. Therefore, the process of selecting the fittest of these solutions then becomes imperative.

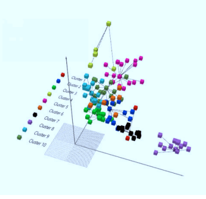
5.1.2. Selection Process

The selection process of the results from simulation 01 is fundamental to the success of the second simulation. Through the *Wallacei* plugin, a K-means clustering algorithm was applied to the Pareto front (the set of non-dominated or "optimal" solutions) of the population with a K-value of 10, in which the Pareto front was grouped into 10 clusters, and the centre of each cluster (i.e. the cluster's best representative solution) was selected.

In order to determine which of the cluster centres was the fittest phenotype, a set of additional urban analytic criteria was conducted on each solution. The table below outlines the numerical urban data extracted from each phenotype (Table 04).

Table 4. Urban Analysis Table and K-means clustering of Pareto Solutions (Simulation 01).

		Cluster 1 Gen. 48 Ind. 6	Cluster 2 Gen. 99 Ind. 39	Cluster 3 Gen. 80 Ind. 40	Cluster 4 Gen. 90 Ind. 37	Cluster 5 Gen. 43 Ind. 48	Cluster 6 Gen. 91 Ind.35	Cluster 7 Gen. 95 Ind. 38	Cluster 8 Gen. 80 Ind. 31	Cluster 9 Gen. 99 Ind. 41	Cluster 10 Gen. 96 Ind. 19
Solar Gain (Podium)	6hrs (%)	10.8	13.3	17.3	11	11	16.6	20.3	19.9	16.4	20.7
	3hrs (%)	17.1	14.6	23.8	24	21.7	21.6	18.9	25.7	18.5	27.3
	0-3 hrs (%)	35.1	30.6	31.6	30.8	34.5	35.2	38.8	30.2	30.2	29.7
	0hrs (%)	37	41.5	27.3	34.2	32.8	26.6	25	24.2	34.9	22.3
Solar Gain (Tower)	6hrs (%)	7.8	8.1	7.1	6.2	7.8	6.1	8.2	8	7.3	10
	3hrs (%)	19.4	17.6	18.4	20.4	18.4	21.5	18.7	21.6	19.3	23.2
	0-3 hrs (%)	27	30.6	29.2	26.8	30.4	29.5	29.9	27.8	31.4	23.7
	0hrs (%)	45.8	43.7	45.3	46.6	34.4	42.9	43.2	42.6	42	43.1
Density and Programme	Residential (m^2)	731,453	702,212	726,865	762,728	680,090	664,144	621,391	551,794	714,847	413,737
	Commercial (m^2)	191,410	109,156	125,852	207,767	134,858	165,925	139,612	143,205	163,263	130,033
	Total (m^2)	**922,863**	**811,368**	**852,717**	**970,495**	**814,948**	**830,069**	**761,003**	**694,999**	**878,110**	**543,770**
	Population	28,594	27,451	28,414	29,816	26,586	25,962	24,291	21,571	27,944	16,175
Access to Views	4 or more POI	9.2	10.4	8.6	8.5	10.6	9.9	9.8	9.7	8.7	10.6
	2-3 POI	22.8	23.2	24.8	16.5	23.9	24.6	24.6	24.1	24.6	25.9
	0-1 POI	68	66.4	66.6	75	65.5	65.5	65.4	66.2	66.7	63.5
Road Network Connectivity	No. Connection Pts	146	190	300	100	138	152	420	336	246	345



The selection process inherently has an aspect of subjectivity to it. The urban analysis conducted was ranked from one - six. This was applied as a tool to assist in determining which solution was to carry through to the second simulation. The selected solution (Gen. 95 Ind 38) was only the fittest for the Road Network Connectivity, however, it still showed strong results across the other analysis criteria. When reviewing the analysis, it was decided that a solution was not to be selected if it was severely detrimental to other analysis criteria. For this reasoning, Cluster 10 (Gen. 96 Ind. 19) was excluded from consideration, while it performed well for the Solar Access and access to view, it was at a severe cost to the density.

5.2. SECONDARY SIMULATION

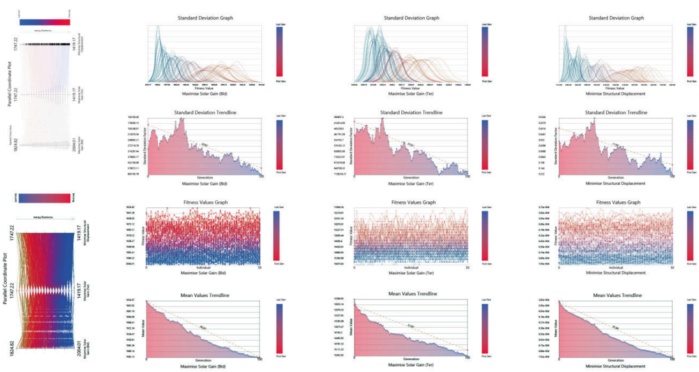


Figure 5. Secondary Simulation Results (From top to bottom: Parallel Coordinate Plot, SDG, SDT, FVG and MVT).

5.2.1. Results

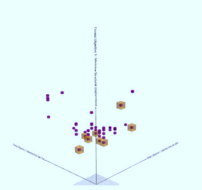
Through reviewing the charts generated in *Wallacei* (Figure 05) it demonstrates that this secondary simulation was more successful than the primary simulation. This is due to the reduced complexity of the design problem being addressed within this simulation. Reviewing the (SDG) alongside the (SDT) clearly illustrates convergence across all objectives. The fitness values significantly increased throughout the course of the simulation, whilst simultaneously reducing variation in comparison to the earlier generations. The (FVG) and (MDT) charts also re-iterate the above statements, reflecting a significant improvement of the fitness values as the simulation progressed.

5.2.2. Selection Process

The selection process for this simulation required a different approach than the first. There were only eight Pareto front solutions across the entire population set, each being located in the final generation. Instead of clustering the Pareto front, each of the Pareto solutions was extracted. Having all Pareto solutions located in the final generation is a further indication of convergence, also suggesting that there is very little variation between each of these solutions. When prioritising the objectives, weighting was applied to the size of the private terraces as it was the main objective for this simulation. Gen.99 Ind. 5 was selected as the fittest solution from the population set, as it had the largest m² of terraces. The terrace solar gain was comparable to Pareto Solution 3 which had the fittest values for that criteria. Similarly, with the building solar gain values, they were extremely close to the fittest values of Pareto Solution 4 (Table 05).

Table 5. Urban Analysis Table and Wallacei Objective Space(Simulation 02) .

		Pareto Solution 1	Pareto Solution 2	Pareto Solution 3	Pareto Solution 4	Pareto Solution 5	Pareto Solution 6	Pareto Solution 7	Pareto Solution 8
		Gen. 99 Ind. 0	Gen. 99 Ind. 1	Gen. 99 Ind. 2	Gen. 99 Ind. 3	Gen. 99 Ind. 4	Gen. 99 Ind. 5	Gen. 99 Ind. 6	Gen. 99 Ind. 7
Solar Gain (Building)	100 %	7.26	7.26	7.24	7.25	7.23	7.21	7.23	7.24
	66 %	9.33	9.40	9.39	9.46	9.39	9.45	9.41	9.37
	33 %	20.66	20.56	20.64	20.53	20.70	20.59	20.60	20.63
	0%	62.75	62.78	62.73	62.76	62.68	62.75	62.76	62.76
Solar Gain (Terraces)	100 %	18.47	20.23	19.01	18.47	18.99	19.09	18.42	18.84
	66 %	30.04	30.31	31.53	31.24	29.72	30.65	30.93	30.46
	33 %	25.99	25.12	24.74	26.02	25.41	25.10	25.17	20.00
	0%	25.5	24.34	24.72	24.27	25.88	25.16	25.48	30.7
Terraces	Terrace (m²)	71,936	71,600	71,920	72,128	71,904	72,160	71,792	71,824
	% of Floor Area	10.38	10.33	10.37	10.40	10.37	10.40	10.35	10.36
	Building (m²)	621,292	621,292	621,292	621,292	621,292	621,292	621,292	621,292
	% of Floor Area	89.62	89.67	89.63	89.60	89.63	89.60	89.65	89.64
	Total (m²)	**693,228**	**692,892**	**693,212**	**693,420**	**693,196**	**693,452**	**693,084**	**693,116**
Structural Displacement	Total Movement of Floor Plates (m)	1419.16	1432.76	1426.28	1422.83	1419.59	1422.09	1421.43	1419.72



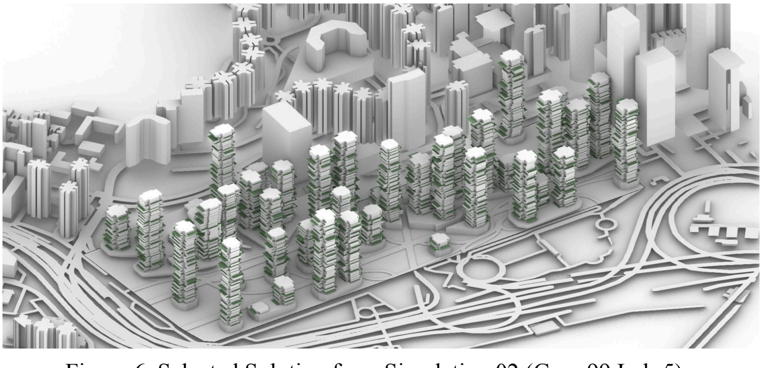


Figure 6. Selected Solution from Simulation 02 (Gen. 99 Ind. 5).

6. Conclusion and Discussion

In the experiments presented, the Taikoo Shing Superblock in Hong Kong was utilised as a case study to address demographic and environmental contextual stresses impacting the urban fabric. By no means is the evolved solution above proposed as a replacement of the existing Taikoo Shing superblock; rather, it puts forward an alternative approach to designing a superblock that incorporates within it a greater degree of variation amongst the urban tissue, thus allowing for greater resilience towards contextual stresses. Therefore, and in the context of Hong Kong's growing population, adopting an approach of urban development that aims to optimise for multiple criteria (perhaps with preference of some criteria over others), serves as a more robust alternative to the conventional, top-down approach of the arrayed distribution of the same block across a given district.

Through the identification of multiple hierarchies of scale, it allowed for the definition and application of sequential evolutionary simulations as a method to better and more efficiently optimise for the design problem; and although the secondary simulation produced better results than the primary simulation, in applying sequential simulations, it highlighted the significance of selection and the analytic methods and reasoning associated with it. Additionally, It is imperative to note that the success rate of running multi-objective evolutionary algorithms is highly dependent on running multiple iterations of the same simulation, in which the design problem is continuously reformulated in order to achieve better results. Where the design problem of the above experiments has been reformulated multiple times, there remains the opportunity to further refine the design problem - specifically for the primary simulation

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