ADDRESSING FLOOD RESILIENCE IN JAKARTA'S KAMPUNGS THROUGH THE USE OF SEQUENTIAL EVOLUTIONARY SIMULATIONS

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Abstract. The urban superblock of Kampung Melayu, located in Jakarta, Indonesia, is a typology amalgamated by the environmental and infrastructural challenges caused by Jakarta's urban sprawl. Rapid and unregulated urban growth, fluctuating tropical conditions, rising sea levels and unprecedented environmental stresses have led to a city that is sinking, leaving unregulated low-income settlements, such as Kampung Melayu, most vulnerable. To address these issues, the presented research employs the use of a multi-objective evolutionary algorithm for an in-depth analysis of the various relationships within the urban fabric. The simulations present an alternative urban approach to the design of a flood resilient Kampung; addressing environmental and demographic stresses while maintaining the irregularity that has become ingrained in the history of the urban form.

Keywords. Jakarta; Kampung Melayu; Sequential Simulations; Evolutionary Algorithm; Computational Design; Urban Growth; Flood Resilience; SDG 3; SDG 6; SDG 10; SDG 11; SDG 13.

1. Introduction

Annual flooding is a prominent urban disaster in many countries in the Asia Pacific region, particularly during the monsoon season. This leads to the contribution of urban implications in aspects including water, sanitation, waste management and destruction of property (Yenny et al., 2017). The effects of annual flooding are amplified in heavily populated and low-income urban centres, in which government funding and aid are not readily available (Alzamil, 2020). One prominent locale is Jakarta, Indonesia; a city that has been attributed to be 'sinking', (Lyons, 2015) causing the government to relocate the country's capital city to another locale, yet for the millions living within the city, the problem still remains.

The causes of flooding in Jakarta ranges from over-extraction of groundwater, deforestation in upstream areas, lack of river dredging, and the conversion of green areas to residential, commercial, and industrial developments. Climate change has also

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exacerbated the floods in Jakarta by increasing the frequency of extreme weather conditions, endangering the dominating communities of Kampungs situated along the riverbanks (Dovey et al., 2019).

The paper examines one of the most populated urban fabrics in Jakarta that is affected by annual flooding, the Kampung. Through the use of a multi-objective evolutionary algorithm (MOEA) with a thorough selection process applied to the generated results, the presented experiment investigates an alternative urban approach to the design of a flood resilient Kampung, addressing environmental and demographic stresses while maintaining the irregularity that has become ingrained in the history of its urban form. This allows for a thorough examination of issues under the Sustainable Development Goals (SDGs) published by the United Nations (UN), addressing the provision of clean water and sanitation (SDG 6); production of sustainable cities and communities (SDG 11); the promotion of good health and well-being of the residents (SDG 3), reduced inequalities of living standards within Jakarta (SDG 10), and finally, addressing climate action through the integration of environmental and climatic design goals within the all aspects of the conducted experiment (SDG 13).

2. Context and Research

2.1. KAMPUNG MELAYU, JAKARTA

Located in the heart of central Jakarta, within the neighbourhoods of Kebon Pala and Tanah Rendah; Kampung Melayu is an unregulated, disorganised informal settlement home to a densely populated, compact community (Sihombing, 2004).

Kampung Melayu was a bustling trading centre during the Dutch colonial period in Indonesia, which lasted from the 16th through the 19th centuries. Established during the 17th century, it housed Malay communities from Malaysia and it thrived due to its location along the Ciliwung River route, which turned out to be the most active trading avenue for people and goods. Residents of Kampung Melayu were mainly traders or vendors who owned small businesses (Yenny et al., 2017). The majority of the current population is not of Malaysian heritage, but rather come from other regions of Java Island that have lived in the area for centuries.

2.2. FLOODING

Kampung Melayu, which is only 15 meters from the fast-flowing Ciliwung River, is prone to considerable frequent flooding, especially during the rain season. Numerous floods have affected the residents of Jakarta, in 2002, 2007 and 2013, peaking at 3.5 metres in height (Budiyono et al., 2015).

The Ciliwung River is the largest among 13 rivers running through Jakarta and is heavily polluted with heavy metal concentrates, mainly lead and zinc. Studies of viruses, infectious diseases and bacterial indicators were found to be within the contaminated floodwaters, surging especially during the wet seasons between January and February (Mishra et al., 2018).

Despite the circumstances, the residents still choose to continue living next to the river, where it is used for a variety of activities such as washing, defecation and swimming. It was believed that residing in a place with significant health hazards, limited infrastructure, inconsistent water and electricity supplies, and frequent floods was generally seen as an acceptable and typical part of everyday life (Purba et al., 2018).

In efforts of relocating the residents due to its unfavourable living conditions, the residents were apprehensive about moving or being transferred by the government to other sections of Jakarta with better living standards. Instead, public buildings, religious buildings, schools, and open spaces were used as evacuation zones for temporary shelters during times of flood (Yenny et al., 2017).

2.3. OVER-DENSIFICATION

Jakarta continues to grow and is beset by a slew of issues that have gotten worse over time. Growing environmental concerns, not only in Jakarta but also in the surrounding areas, are one of the most pressing issues it faces. According to reports, the carrying capacity of Java Island, where it is located, is already overburdened, due to land and water concerns (Rustiadi et al., 2021).

With an ever-growing population of 10,56 million residents in Jakarta in 2020 (BPS, 2021), the increased demand for housing is one of the consequences in irregular settlements or urban villages such as Kampung Melayu. In 2015, it had the greatest population density, with an estimated 640 people per hectare (Lestari & Sumabrata, 2018).

Houses were found to be overcrowded and have had poor levels of sanitation (Purba et al., 2018). Notwithstanding the circumstances, residents of Kampung Melayu refuse to be relocated as they worry about loss of income and cost implications when it comes to rental. It is understood that the fulfilment of living with their long-term neighbours is prioritised when given the opportunity of relocation despite urban or environmental implications. The preference for immediate solutions located close to their homes is observed in times of natural disasters and urban challenges (Yenny et al., 2017).

3. Method

3.1. EVOLUTION STRATEGY

The presented research examines the challenges listed above and aims to convert Jakarta's urban typology of the Kampung into an urban superblock which mitigates the current and future flooding and rising sea level challenges, whilst improving urban living conditions for the residents of the Kampung. The multi-objective evolutionary algorithm (MOEA) implemented in the experiment is 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 (Makki et al., 2018).

The experiment is presented in four key stages. Stage one examines the site and deconstructs its core urban characteristics; stage two builds the evolutionary matrix for the MOEA, the matrix examines the relationship between the chromosomes (the parameters), the phenotype (the urban form), and the fitness objectives (design goals); stage three analyses the results of the algorithm and applies a thorough multi-step selection process and stage four identifies the selected solution and examines it within an urban context in relation to the original design goals of the experiment.

Finally, the experiments address the challenge of selection usually associated with the utilisation of MOEAs in design, in which the optimisation of conflicting objectives generates multiple 'optimal solutions', whereas the user usually requires a single solution as a design output. The presented addresses this issue by integrating a thorough selection process that is both data driven, as well as user driven, to identify the best solution from the optimal solution set.

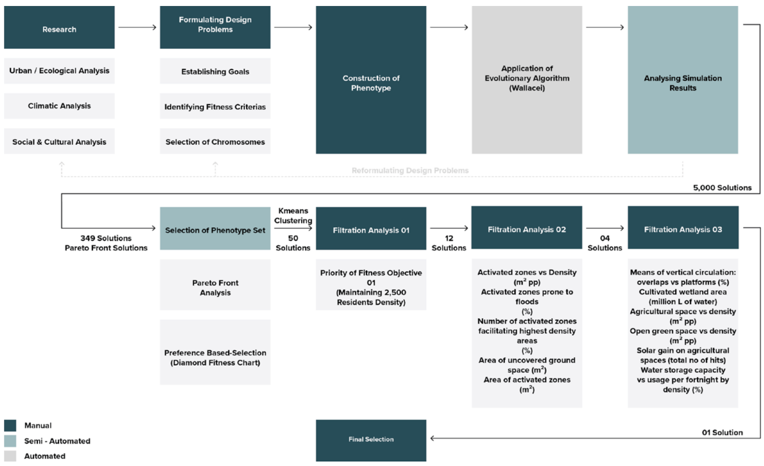


Figure 1. Pseudo Code

4. Experiment Setup

4.1. PARAMETRIC DEFINITION

The definition utilises the existing site boundary, dividing the site into 30m x 30m platforms. Through a series of trial and error, it was found that this size best accommodates variation in building footprints. The platforms were then moved in the X, Y and Z axis to re-introduce natural light to the ground plane while raising the platforms at varying heights between three to six metres to ensure flood resilience. Points along the existing site boundary were taken as reference and rotated, allowing the platforms to emulate the random orientation of the kampung and surrounding urban context. Platforms that encroached the site's surrounding context were culled, and those that encroached on the boundary along the river were retained.

A condition unique to the phenotype's construction was the typology of overlaps. Based on the analysis of the overlapping areas, larger overlaps were converted into voids to allow for more light to access the ground plane while smaller overlaps were converted into water storage units. After which, building footprints were created using the setback of the platform's current footprint, allowing the primary network to also be defined at three metres in width. The building footprints were further divided into smaller components to replicate the building scale in the surrounding context, creating a secondary network with a 2m width.

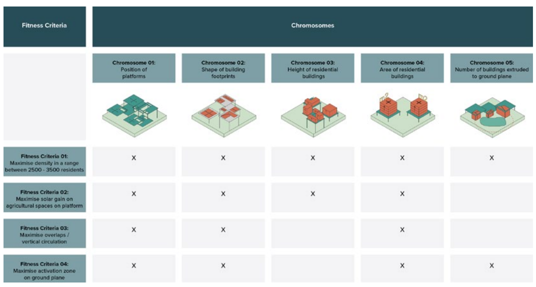
The building footprints were then differentiated as viable and non-viable footprints. Non-viable footprints were blocks that were either too small or had odd corners deemed unfit for residential use; these footprints were converted into agricultural spaces on the platforms. Viable footprints were extruded to create buildings ranging from one to four storeys. Thereafter, the buildings that were only single storey high had their roofs converted into an open green space for the resident's recreational use. This summarises the approach taken to address the platform level.

To address the ground plane, the uncovered ground spaces were identified and the areas that had the largest areas of connected green space would be converted into activation zones for residents to gather. The centre points of these activation zones were used as a reference to create varying circumferences, in which the buildings that would fall within these circumference zones would be extruded to the ground plane as means of vertical connectivity. The introduction of cultivating wetlands and green tissues on site have been explored as it would help in flood inundation around nearby areas, and will aid in purifying the river water (Figure 2).

Figure 2. Key Steps of Construction of Phenotype

4.2. FITNESS OBJECTIVES

The evolutionary matrix presented in Figure 3 highlights the relationship between the fitness objectives, chromosomes (explained in the previous section) and the phenotype. The matrix is vital in identifying the impact of each chromosome on each fitness objective, which is critical when debugging the design problem.



Fitness Criteria	Chromosomes				
	Chromosome 01: Position of platforms	Chromosome 02: Shape of building footprints	Chromosome 03: Height of residential buildings	Chromosome 04: Area of residential buildings	Chromosome 05: Number of buildings extruded to ground plane
Fitness Criteria 01: Maximise density in a range between 2500 - 3500 residents	x	x	x	x	x
Fitness Criteria 02: Maximise solar gain on agricultural spaces on platform	x	x	x	x	
Fitness Criteria 03: Maximise overlaps / vertical circulation	x	x		x	
Fitness Criteria 04: Maximise activation zone on ground plane	x	x		x	x

Figure 3. Evolutionary Matrix

4.3. ALGORITHMIC SETUP

The algorithm evolved 5000 solutions (generation size 50 and generation count 100) and the simulation runtime was 11 hours and 19 minutes. The simulation was run on a consumer-grade PC, Intel(R) Xeon(R) W-10855M CPU, 2.80GHz with 32.0 GB of RAM.

5. Experiment Results & Selection Process

5.1. SIMULATION RESULTS

Examining the results produced by the algorithm (Figure 4) indicates that the simulation was successful in improving the mean fitness values for objectives 1, 2 and 3, while objective 4 (maximise ground level activation zones) struggled to optimise throughout the algorithmic run. Analysis of the standard deviation charts indicates that although the mean fitness was improving, the variation of solutions was fluctuating throughout and not converging towards a local or global optima.

Through the analysis of the results, it is clear that the complexity of the design problem necessitates a longer algorithmic run. Improving mean fitness while maintaining variation indicates that a higher generation count (which will also result in a longer simulation runtime) is critical to allow the algorithm to converge towards an optimal solution set. As such, the assessment criteria used to analyse the output of the algorithm, for the purposes of selection, will therefore be critical for a comprehensive understanding of the results, and to identify the impact of the various parameters on the morphology of the urban form.

Figure 4. Simulation Results

5.2. SELECTION PROCESS

Analysis of the Pareto Front, along with a series of manual filtration analyses are employed to identify the best solution evolved by the algorithm.

To better understand the amount of variation generated by the algorithm, the pareto front solutions (i.e., the solutions in the population that are not dominated by any other solution), were clustered using K-means clustering with a K-value of 50. In total, the algorithm outputted 349 Pareto Front solutions; the cluster centres of these solutions were selected for further analysis.

The first filtration analysis aims to prioritise maintaining the site's original density, despite the algorithm optimising to maximise it. Among these 50 cluster centres, ten solutions closest to the site's original population density of 2,500 residents were selected, along with two additional solutions that did not meet the original density but had unique fitness values. These 2 additional solutions aim to be experimental, kept as observation points to examine how they perform when compared to the other solutions optimised for density.

The second filtration analysis conducts manual calculations of density and the ground plane. A ranking matrix was used to score the solutions based on a series of primary and secondary requirements when compared with one another. These requirements were the analysis of the density distribution, activation zones and uncovered ground space. From this analysis, the top four solutions were selected based on their highest scores. Figure 5 presents this analysis using a colour scheme to identify the solutions with a poor, average and good ranking.

	Gen 95 Ind 24	Gen 95 Ind 42	Gen 99 Ind 49	Gen 79 Ind 9	Gen 81 Ind 12	Gen 84 Ind 48	Gen 62 Ind 32	Gen 66 Ind 43	Gen 56 Ind 26	Gen 42 Ind 44	Gen 24 Ind 39	Gen 28 Ind 42
Activated space vs Density (m^2 pp) Scoring Poor: 0 - 1.4 = 0 point Average: 1.4 - 2.8 = 1 points Good: 2.8 - 4.2 = 2 points (Primary)	3.4	2	2.1	1	1.2	1.3	1.6	1.4	4	1.5	4.2	2
Activated zones prone to floods (% of total number) Scoring Poor: 0 - 33 % = 0 points Average: 33 - 66 % = 1 point Good: 66 - 100% = 2 points (Primary)	37.5% (3/8 Zones)	50% (2/4 Zones)	33% (2/6 Zones)	0% (0/2 Zones)	50% (1/2 Zones)	50% (1/2 Zones)	60% (3/5 Zones)	0% (0/3 Zones)	20% (2/10 Zones)	40% (2/5 Zones)	37.5% (3/8 Zones)	20% (1/5 Zones)
Number of activated zones facilitating highest density areas (% of total number) Scoring Poor: 0 - 33 % = 0 points Average: 33 - 66 % = 1 point Good: 66 - 100% = 2 points (Primary)	67.5% (5/8 Zones)	50% (2/4 Zones)	50% (3/8 Zones)	100% (2/2 Zones)	100% (2/2 Zones)	100% (2/2 Zones)	100% (5/5 Zones)	66% (2/3 Zones)	50% (5/10 Zones)	60% (3/5 Zones)	87.5% (7/8 Zones)	80% (4/5 Zones)
Area of uncovered ground space (m^2) Scoring Poor: 0 - 6236m^2 = 0 points Average: 6236 - 12,473m^2 = 0.5 points Good: 12,473 - 18,709m^2 = 1 point (Secondary)	18,709m^2	8198m^2	8379m^2	7230m^2	7230m^2	7520m^2	8379m^2	8016m^2	11,828m^2	7593m^2	9589m^2	8198m^2
Area of activated ground zones (m^2) Scoring Poor: 0 - 3237m^2 = 0 points Average: 3237 - 6473m^2 = 0.5 points Good: 6473 - 9710m^2 = 1 point (Secondary)	8531m^2	5143m^2	5324m^2	2783m^2	2904m^2	3297m^2	4296m^2	3297m^2	9710m^2	3539m^2	7744m^2	4001m^2
Total Points	8	3	4	4.5	2.5	3	5	7	7.5	4	7.5	6

Poor Average Good Best

Figure 5. Ranking Matrix for the Purposes of Selection

The final filtration analysis focuses on the urban attributes of the platforms while calculating the impacts of solar gain and areas of cultivated wetland areas. Using the same ranking matrix as the previous step, it was observed that generation 66, individual 43 had the highest score of compared to the other solutions. This solution however was the 'experimental' solution that was selected in step one, a solution that did not meet the density requirements identified. This was a clear indication that the density requirements significantly affected the solution's performance value for all other criteria. Although solution Gen.66_Ind.43 is only experimental and thus will not be selected, it demonstrates the value of assessing the solutions generated by the algorithm within the context of the design goals and objectives being pursued. As such, the best ranking solution that met the density threshold was generation 95, individual 24 (Figure 6).

Figure 6. Final Solution - Generation 95, Individual 24

5.3. ANALYSIS OF FINAL SOLUTION

Having selected generation 95, individual 24 as the final solution, two focal points within the site were selected as part of the manual design process. This aims to bring a higher level of design thinking and exploration of street typologies and urban form from the perspective of the end-user of the space.

Retaining the importance of communal culture and the spirit of a Kampung, an analysis of colours, materiality and urban characteristics were revisited, in order to implement a sense of place within the newly designed superblock. Integration of new ideas of gathering spaces and communal bridges aims to enhance the Kampung's overall connectivity.

A study of the components within each focal point was conducted to understand the urban form make-up of each area and the importance of ensuring a balance of public facilities and private useable spaces, despite high variation and orientation between the platforms (Figure 7). An analysis of the section also provides an insight of the functionality of the wetlands and the vertical connectivity of the spaces, ensuring ample spatial interaction between the platform datum and the ground plane.

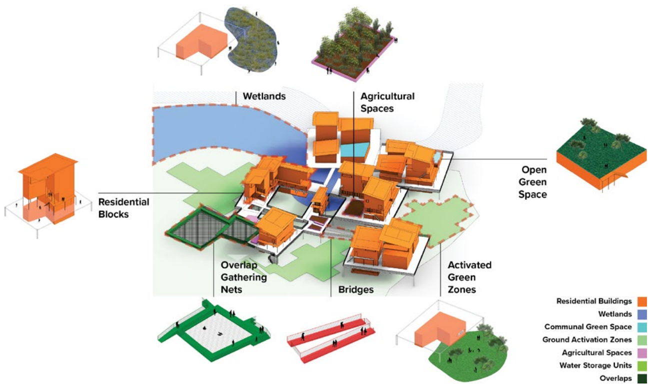


Figure 7. Components of Focal Point

This process of designing the evolved solution outside the scope of the algorithm aids in the critical reflection of the selected phenotype, addressing the above demographic and environmental challenges while comparing it to the pre-existing site condition.

6. Conclusion and Discussion

Kampung Melayu in Jakarta was used as a case study in the experiments presented to address demographic and environmental challenges affecting the urban fabric of high density, low-income superblocks impacted by extreme climatic conditions; in this case, flooding. The presented model, although applied within Jakarta, can be adapted to other regions as well. The approach of generating a strong relationship between parameters (genes), design goals (fitness functions) and morphological characteristics (phenotype) can be adapted to incorporate environmental, social, and cultural characteristics of sites located in alternative locations. The presented experiment is not intended to replace the existing Kampung Melayu; rather, it proposes an alternative solution to creating a superblock that incorporates a higher degree of variation throughout the urban tissue, allowing for more resilience to floods through localised parameters as opposed to top-down decisions. It is imperative that there is an attempt to identify the morphological urban characteristics that represent the cultural and social traits of the superblock being investigated. These characteristics must form a core component of the formulation of the design problem, as well as the criteria used to analyse and select solutions from the pareto front. In the selected solution, open space plays a key role in the superblock, however, considering urban patterns in Kampung settlements, built form supersedes open space, and so although the selected solution maintained the existing population density of the Kampung, additional research that addresses population growth within the settlement, and its impact on urban form, is critical.

Finally, a limitation of the computational setup resulted in the evolutionary algorithm unable to optimise and converge for the selected fitness objectives, although one solution is to run a longer simulation, the time needed to do so may not be feasible. As such, an alternative solution is to revise the evolutionary matrix (presented in Figure 3) and reformulate the design problem to revisit the impact the various chromosomes and genes have on the fitness objectives being optimised.

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