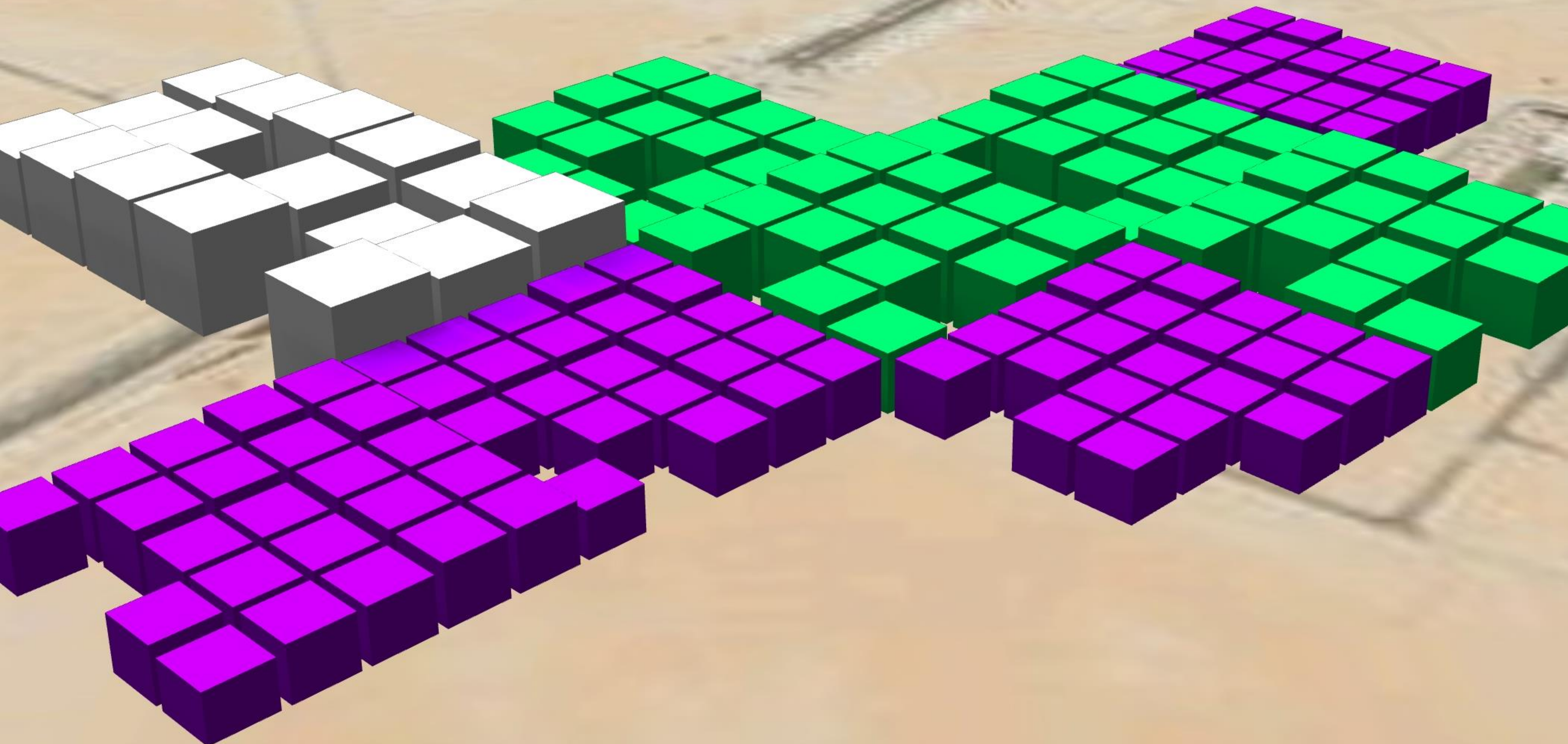
MASDAR Mk2

A COMFORTABLE OUTDOOR DEVELOPMENT



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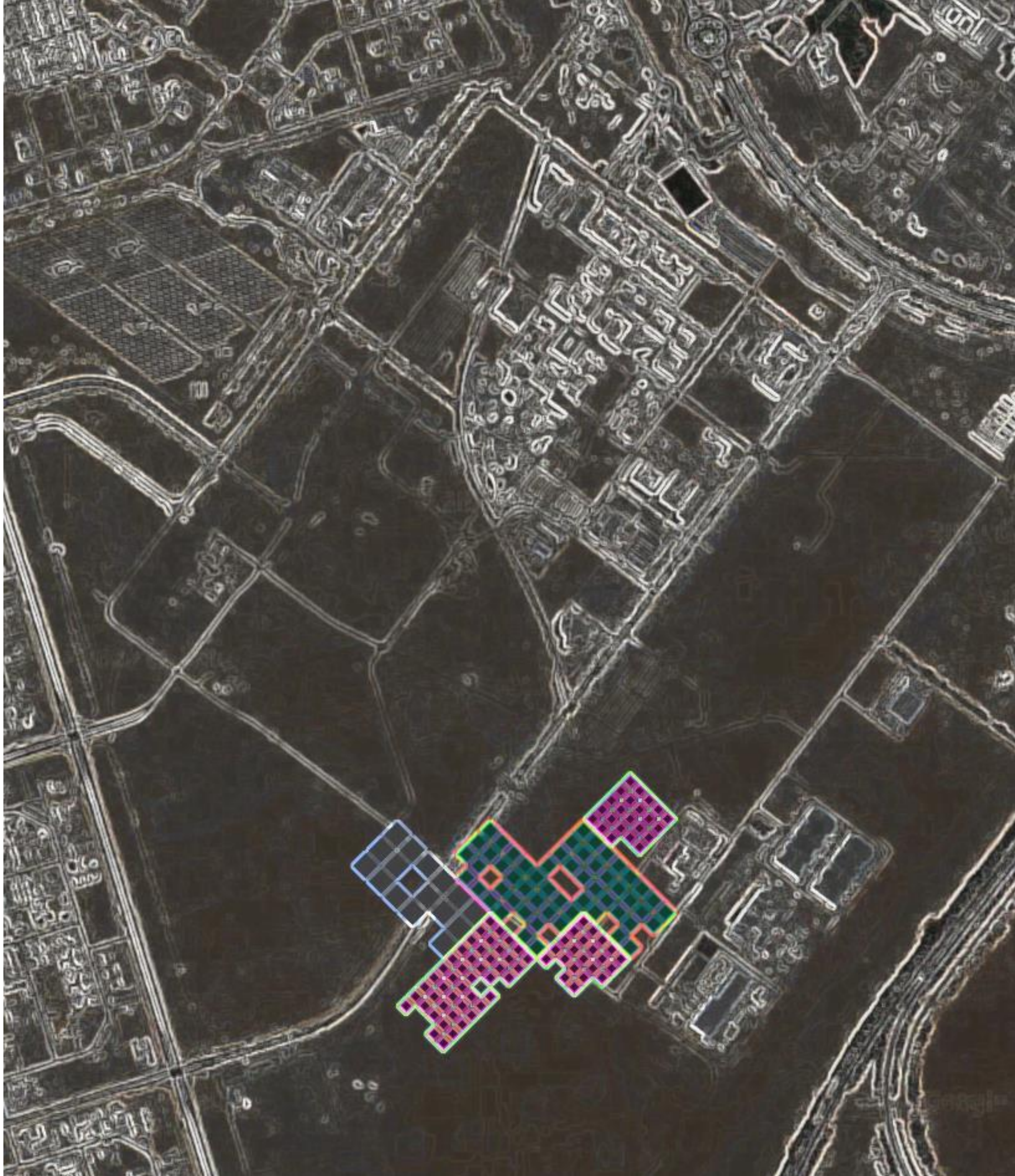
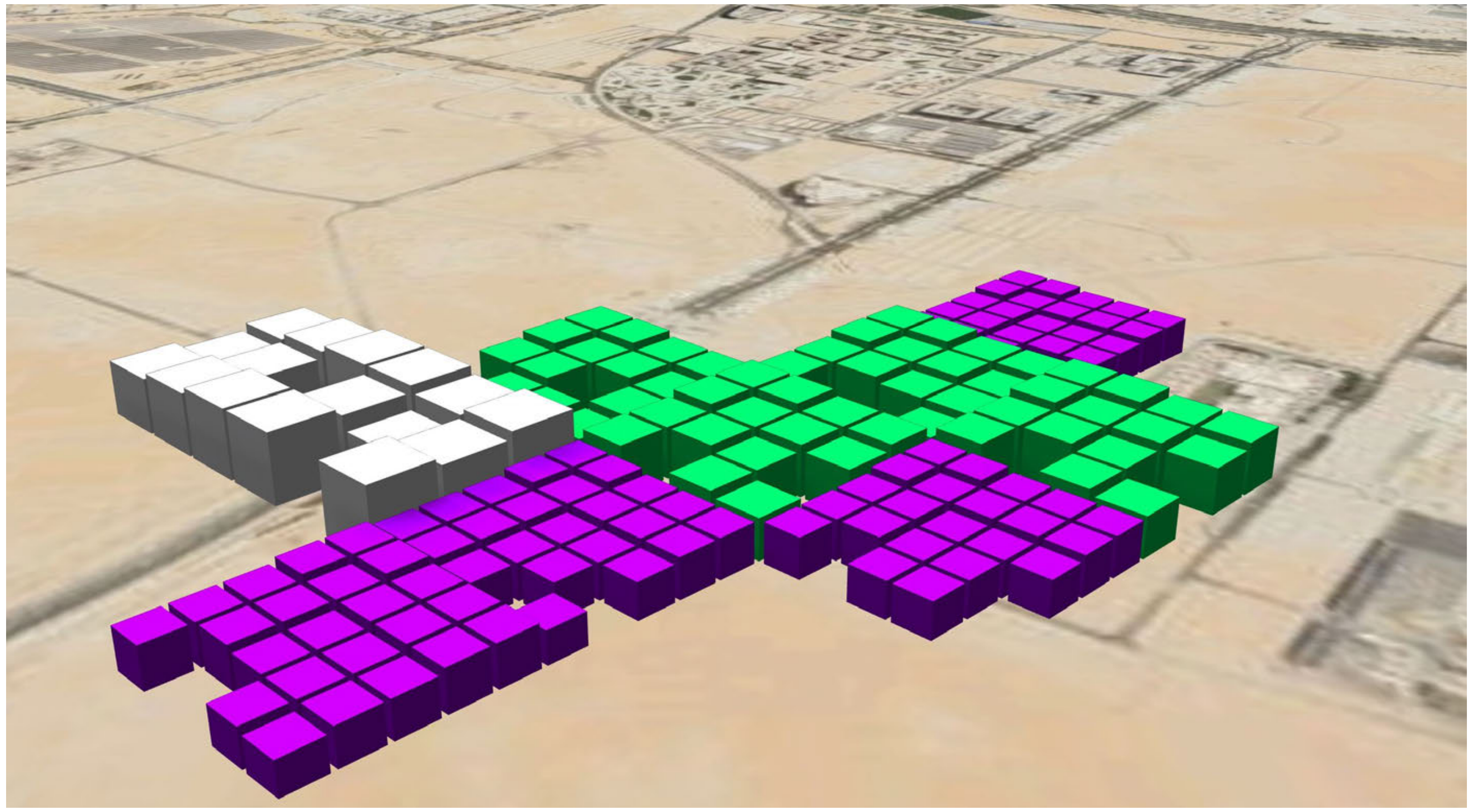


ABSTRACT

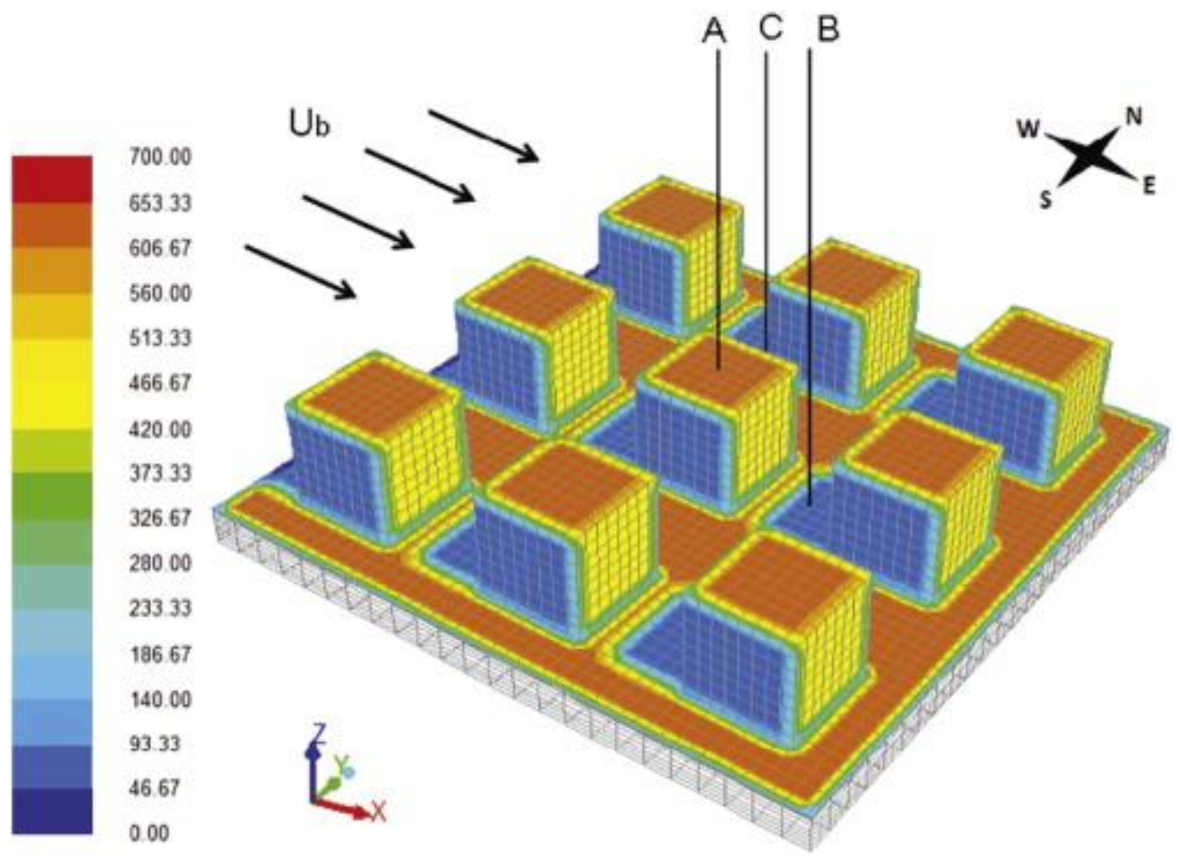
This project work is a proposal done with a focus on the optimization of thermal comfort at Masdar city. The existing design of the city that addressed the thermal comfort parameters used were studied, analysed and considered for improvement. This is about the most relevant factor that determines the effectiveness of the such an "Eco-City" in a hot climate. A detailed investigation of what Masdar has done to tackle the negative impacts of the climate on the city was carried out to learn and to improve on it. Ladybug plugin in Grasshopper was used to carry out different analysis such wind rose, solar radiation, mean radiant temperature (MRT) and universal thermal climate index (UTCI). A genetic algorithm (GA) was used to carry out the fitness test for building heights variation for optimum shade, cell orientation for minimum solar radiation.



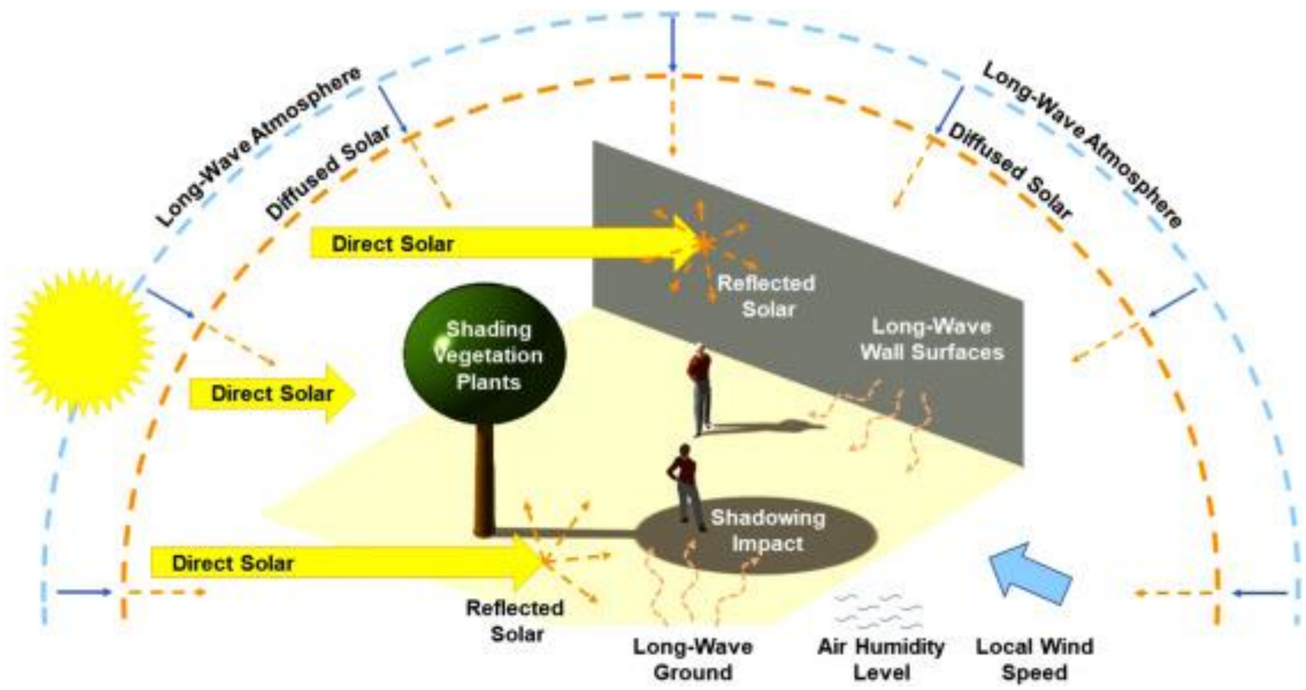
UTCI

OUTDOOR THERMAL COMFORT INDEX

The quality of outdoor space is becoming increasingly important with the growing rate of urbanization. Outdoor thermal comfort has a direct effect on the health and wellbeing of occupants of outdoor spaces. Urban morphology thus needs assessment and optimization to ensure favourable outdoor thermal comfort (OTC). This study aims to evaluate the thermal comfort of streets in Masdar City and tries to improve their comfort index to reveal optimum urban configurations. This evaluation is done by investigating the following urban design factors affecting OTC using computational simulation techniques: new boundary orientation, building typology, height-width ration and placement.



Outdoor thermal comfort analysis in urban environments



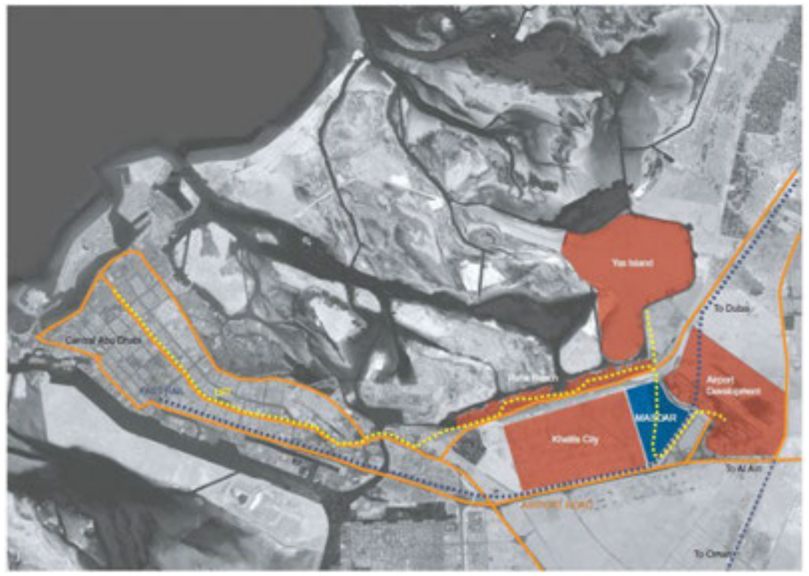
Outdoor thermal comfort factors

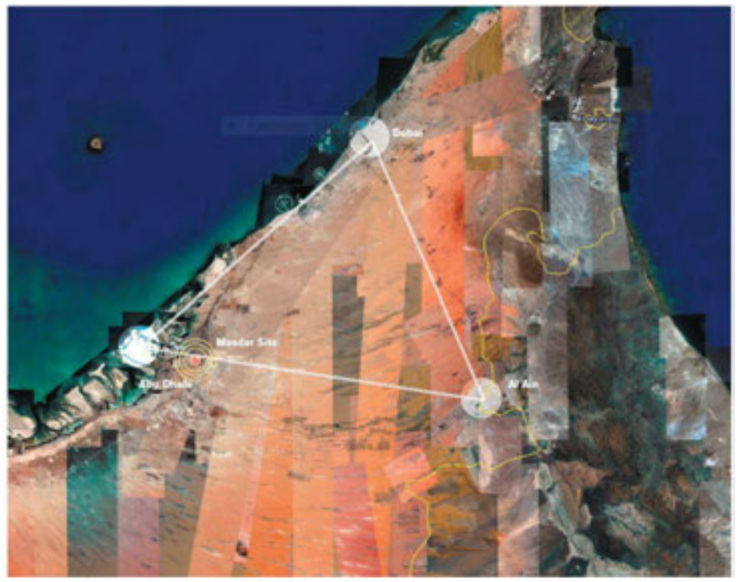
BACKGROUND RESEARCH

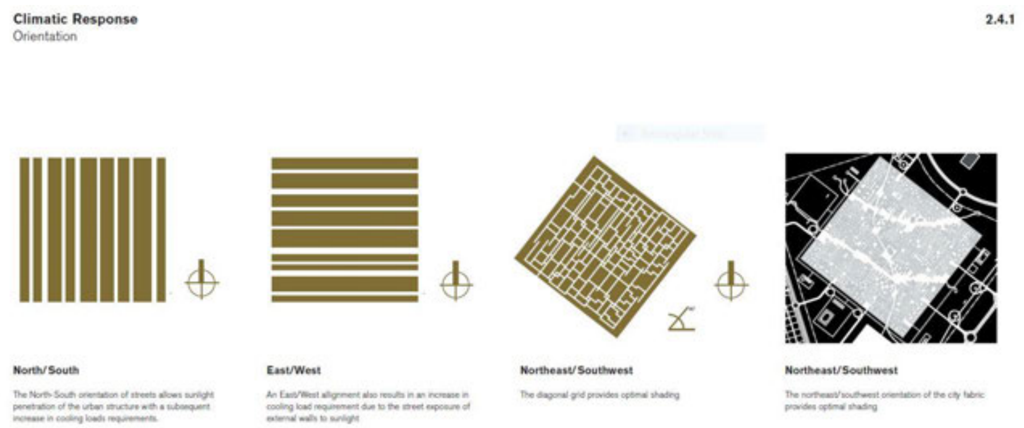
Masdar City project was established in 2006 by the government of Abu Dhabi, in the United Arab Emirates as an Eco-city designed to be a sustainable urban model with zero carbon emissions and zero waste . It occupies a total area of six square kilometers (640 hectares) located about 17 kilometers south-east of the city of Abu Dhabi.

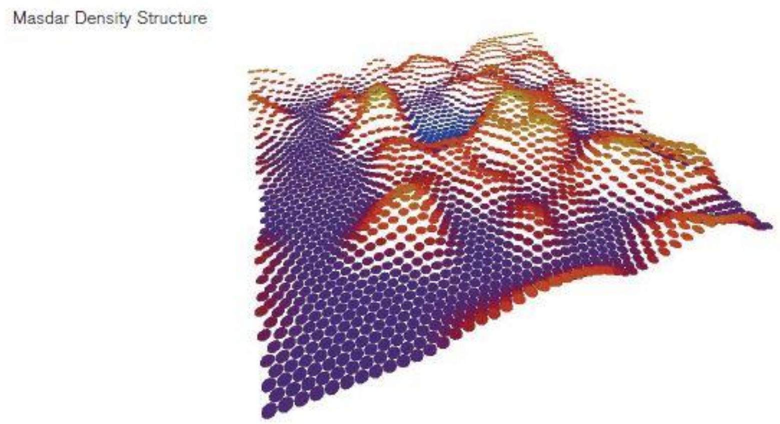
Masdar.ae.(2019) described the philosophy of urban development of the city as economic, social and environmental sustainability. Masdar City is a 'green print' for the sustainable development of cities through the application of real-world solutions in energy and water efficiency, mobility and the reduction of waste creating a comfortable and efficient city in a harsh and arid climate. The design of the city is based on the principles of sustainable urban design, low rise-high density accommodation, sustainable transportation and dense neighbourhoods. The city when completed will be home to 50,000 people.

In achieving this highly ambitious goal, the designer (Foster and Partners) introduced several innovative climatic design response systems to address the peculiarity of the climate, including urban green, density structure, street shading, courtyards, wind catchers, orientation and so on, Anon, (2017).









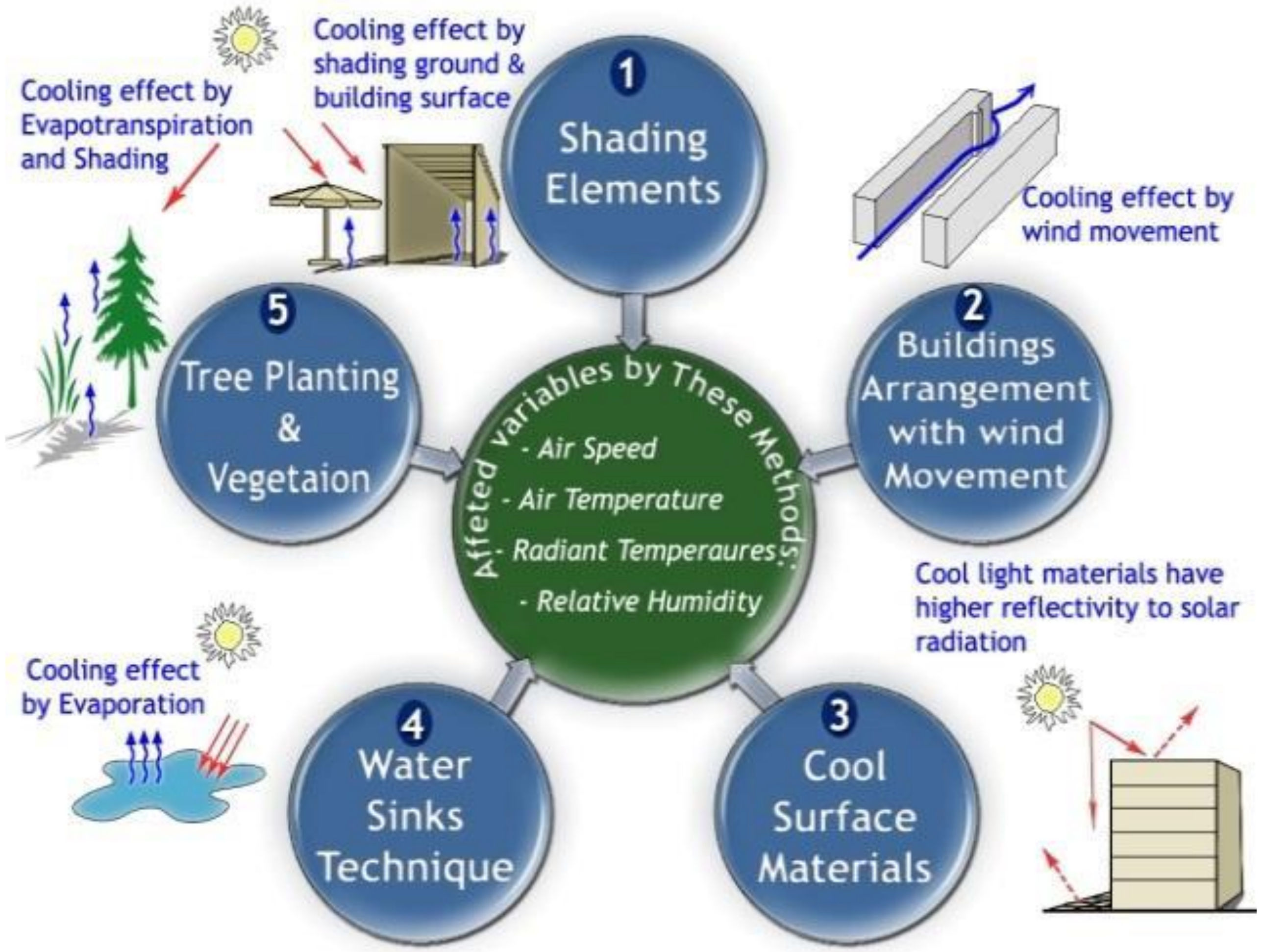
BACKGROUND RESEARCH

What is outdoor thermal comfort?

Thermal comfort is defined in British Standard BS EN ISO 7730 as: 'That condition of mind which expresses satisfaction with the thermal environment.' Setaih, K., Hamza, N. and Townshend, T. (2013) defined outdoor thermal comfort as the pedestrian satisfaction level of the thermal environment. The thermal environment contributes greatly to the viability and livability of the urban open space.

The four major microclimatic factors that have been identified as major determinants of outdoor thermal comfort are radiant temperature, wind speed, air temperature and relative humidity. There are also identified ways of controlling these microclimatic factors to creating comfort which are trees and vegetation, shading, materials and so on.

Image source (Setaih, K., Hamza, N. and Townshend, T. (2013))



BACKGROUND RESEARCH

Why is outdoor thermal comfort important for cities such as Masdar (Very hot) ?

Outdoor Thermal Comfort determines the quality of outdoor activities which also results in quality of life of urban dwellers . According to the research paper "A review of mitigating strategies to improve the thermal environment and thermal comfort in urban outdoor spaces" by Lai D., Liu W., Gan T., Liu K. and Chen Q. (2019), improving the outdoor thermal environment would create energy-saving opportunities by reducing the cooling load in buildings because of the cooler urban environment and also, as people spend more time in the outdoor spaces, their usage of air conditioners and other electronic equipment would decrease.

environment of outdoor spaces. As found by many researchers (Lin et al., 2012; Zacharias et al., 2001; Thorsson et al., 2004; Eliasson et al., 2007; Nikolopoulou and Lykoudis, 2007), the outdoor thermal environment or the concomitant outdoor thermal comfort is directly related to usage of outdoor spaces. In addition, improving the outdoor thermal environment could create energy-saving opportunities in two ways. First, the cooling load in buildings could be reduced because of the cooler urban temperature (Hassid et al., 2000; Santamouris et al., 2001; Hirano and Fujita, 2012; Fung et al., 2006; Davies et al., 2008). Second, as people spend more time in the outdoor spaces, their usage of air conditioners and other electronic equipment would decrease (Lai et al., 2014a).

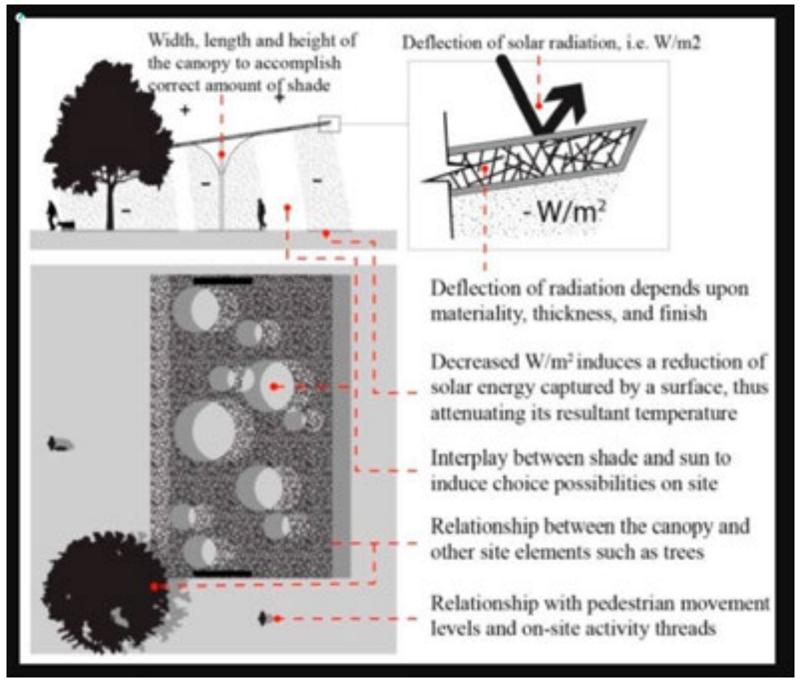
by Lai D., Liu W., Gan T., Liu K. and Chen Q. (2019),

BACKGROUND RESEARCH

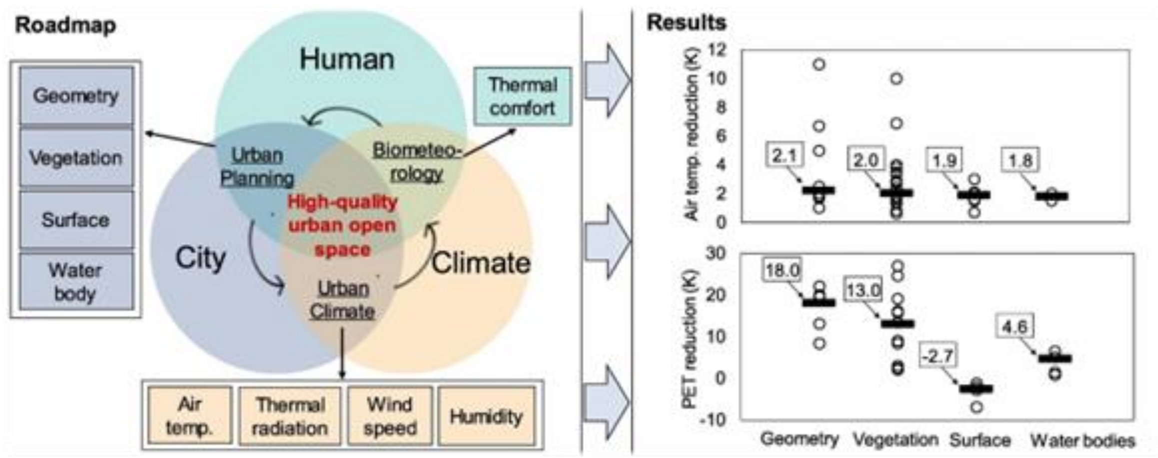
How can wind and solar radiation improve outdoor thermal comfort for urban planning proposals?

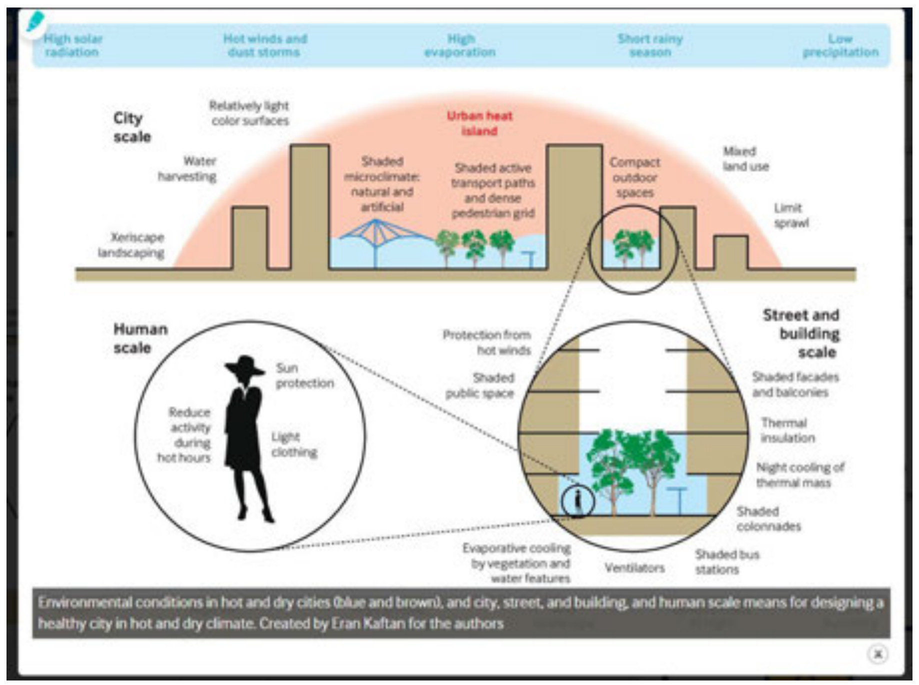
The average thermal sensation and comfort improve with the increase in air velocity at fixed wind frequency, and they also improve with the increase in wind frequency for a fixed air velocity, Ghali K., Ghaddar N. and Bizri M. (2011)

Solar radiation and mean radiant temperature have a great influence on how people perceive outdoor thermal comfort. High temperatures and intense solar radiation can cause thermal discomfort and heat stress. High temperatures are also associated with increased morbidity and mortality, Negev M., Khreis H., Rogers B., Shaheen M., Erell E. (2020)



Solar radiation analysis with shade
Santos Nouri A., Costa J., Santamouris M. and Matzarakis A. (2018)





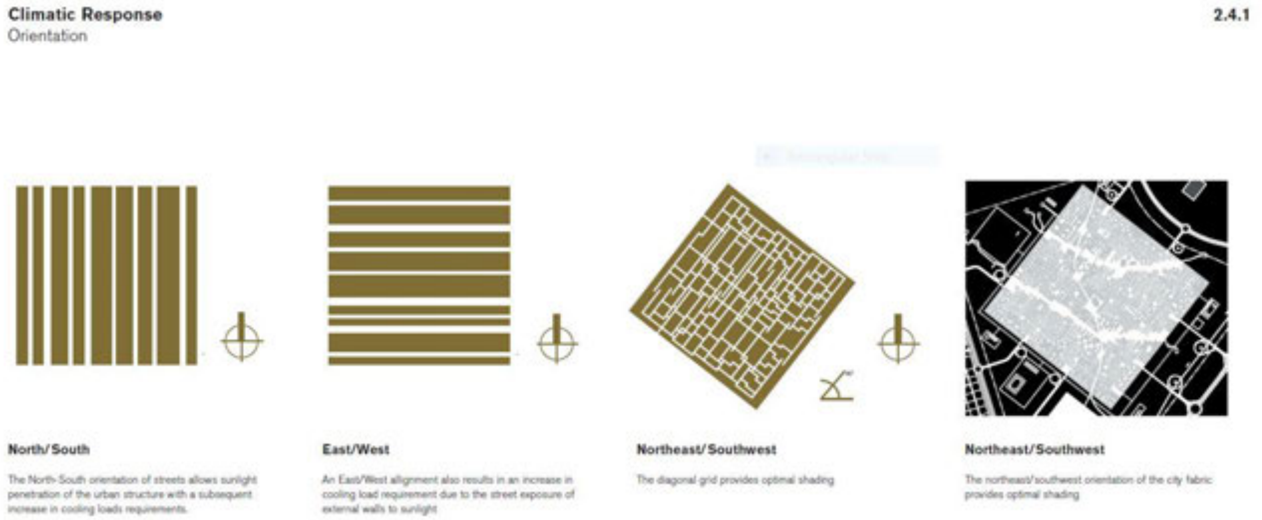
Solar radiation analysis with shade

Negev M., Khreis H., Rogers B., Shaheen M., Erell E. (2020)

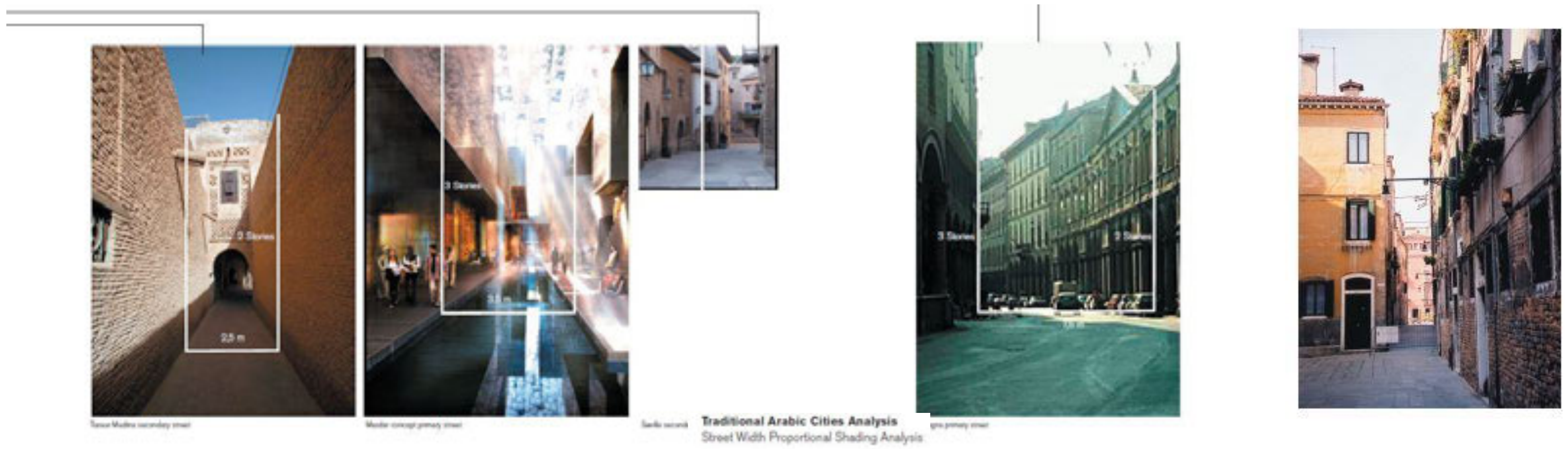
BACKGROUND RESEARCH

What has the Masdar plan tried in response to improving outdoor thermal comfort?

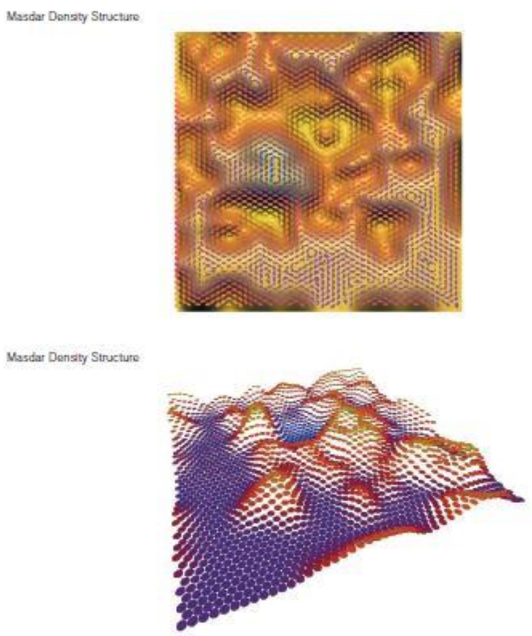
- Masdar's design in response to climate is as a result of intense research into traditional Arabic architectural design and consequently has major features of a typical Arabic city. with features such as narrow streets, orientation, greenery, density, building shape and heights and so on in reducing the impact of the Heat Island (HI).



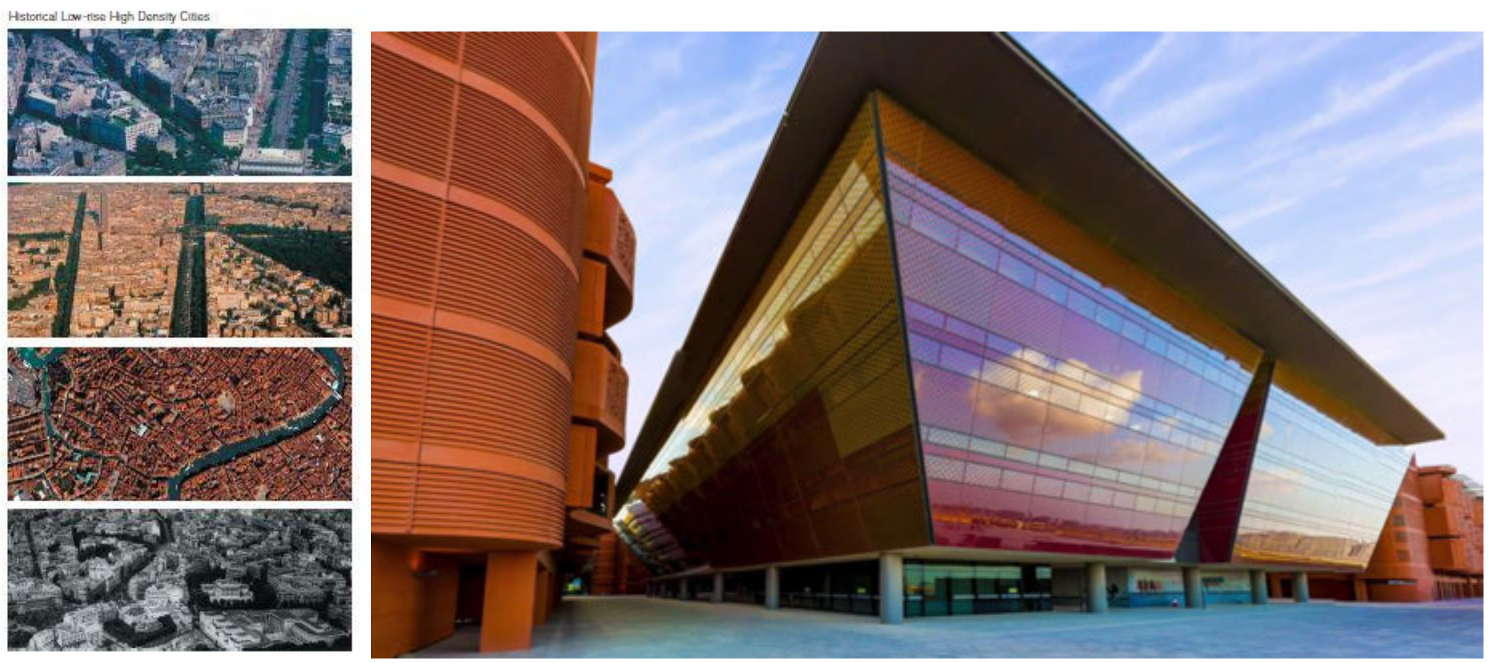
Orientation



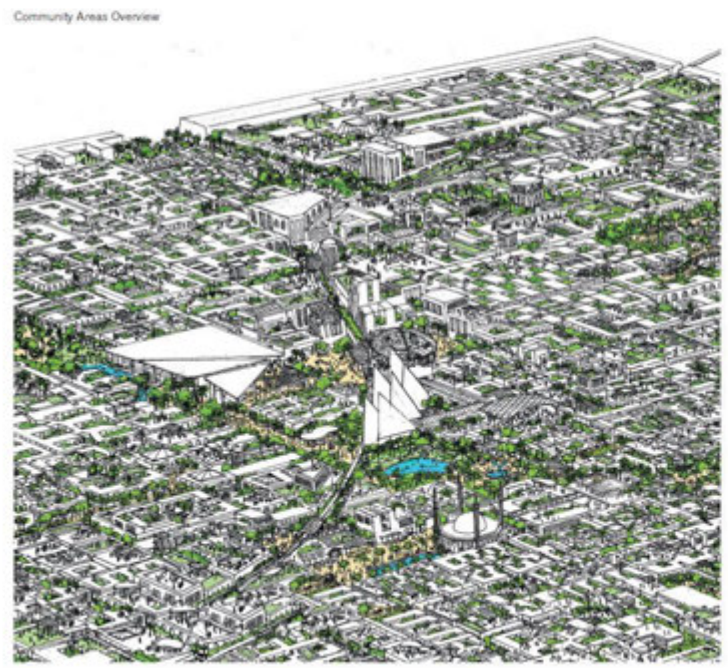
Street width



Density



Building shape and height



Greenery

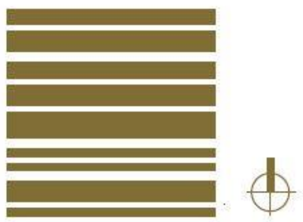
Images : Anon, (2017)

BACKGROUND RESEARCH

What is not new about the Masdar plan (square boundary) and could this be an opportunity for a new urban planning proposal (our plan/design).

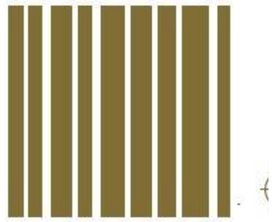
Even though the design of Masdar has tried to solve as much as possible the challenge of the negative effect of climate on the city, the use of computational method in determining the fittest orientation to solar and wind were not mentioned in the final report of the city. This perhaps is our introduction of the "New Masdar".

Orientation is normally a response to views or site restrictions, but can also be a response to climatic conditions. In general, the sun which is the principal source of discomfort in the Middle East tends to be the defining factor in climatic orientation. Religious buildings also form an exception to this rule by facing Mecca.



East/West

An East/West allignment also results in an increase in cooling load requirement due to the street exposure of external walls to sunlight

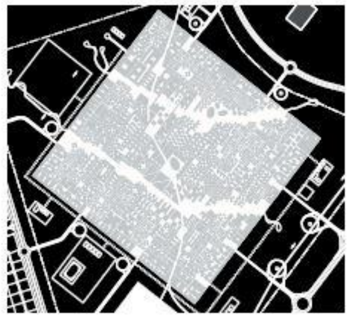


North/South

The North-South orientation of streets allows su penetration of the urban structure with a subsec increase in cooling loads requirements.

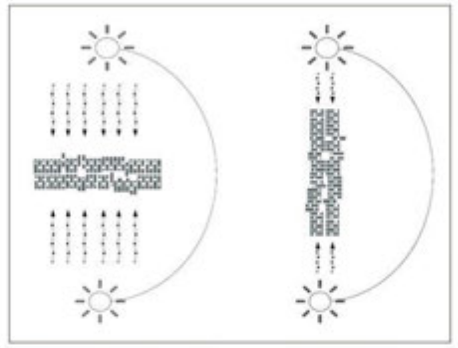
Northeast/Southwest

The diagonal grid provides optimal shading



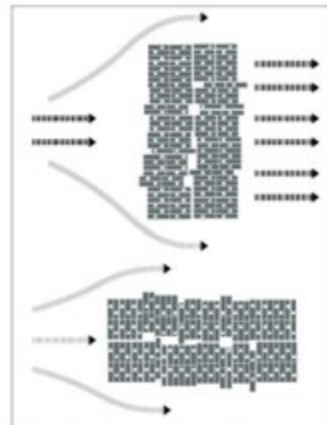
Northeast/Southwest

The northeast/southwest orientation of the city fabric provides optimal shading



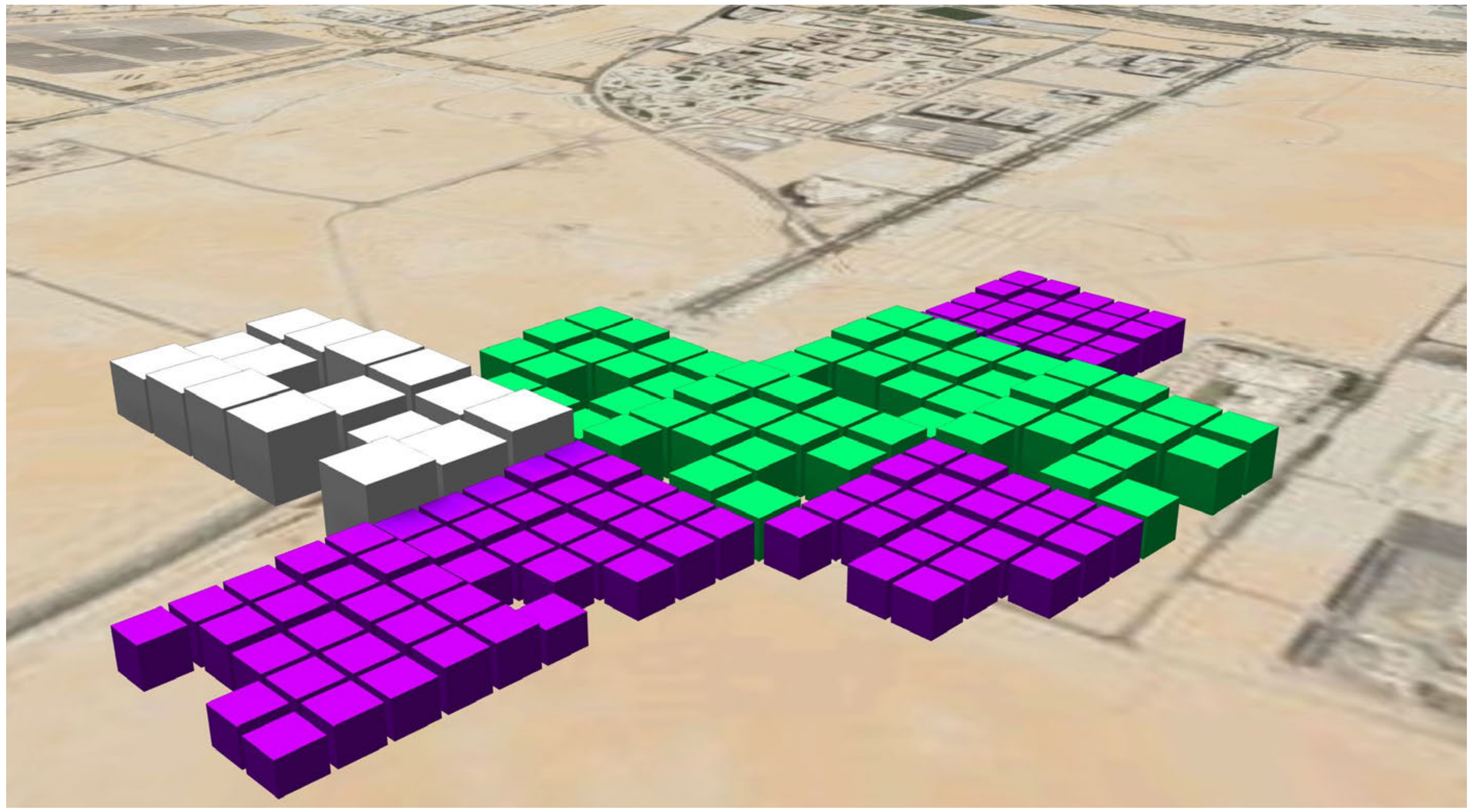
Minimal solar gain; protected east and west walls; any large windows face north; south facing windows screed with awnings/ shading devices; rectangular plots with smaller dimensions north and south

High solar gain; large surface area of exposed walls and window openings



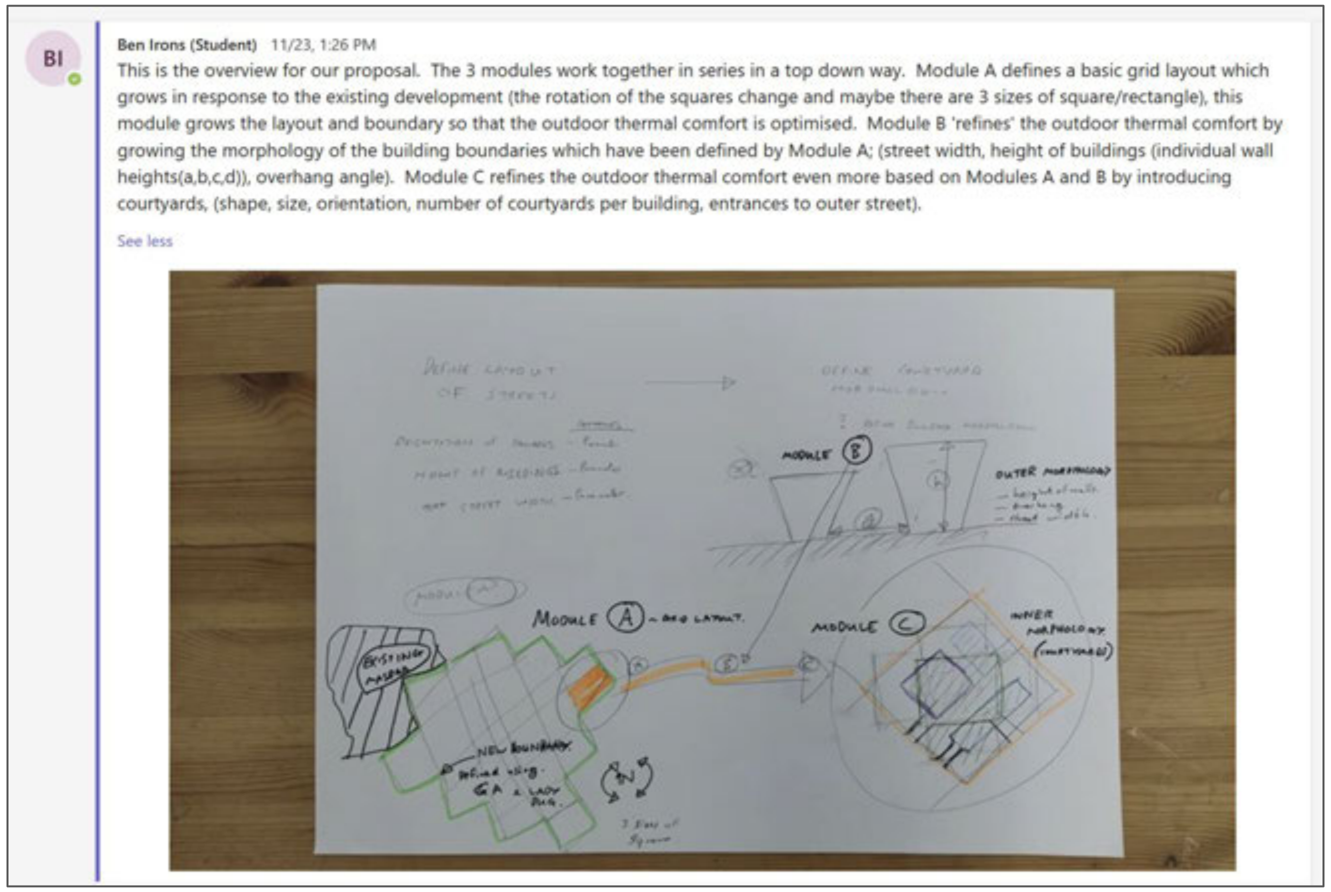
Orientation perpendicular to the predominant wind is better for cooling as it increases wind turbulence

Masdar Square boundary orientation for optimum wind and shade



Genetic Algorithm (GA) generated Masdar city orientation based on fitness for solar radiation, wind, MRT and Universal Thermal Comfort Index

METHODOLOGY



AIMS

Propose a new development of Masdar City with an area of approx. 0.25km2 which targets improving outdoor thermal comfort at street level.

TOP-DOWN APPROACH

- Firstly, an urban boundary is defined, then it is filled with building typologies, street networks and open spaces.
- The Urban boundary definition is based primarily on wind exposure and the building typologies based upon solar radiation and UTCI levels.

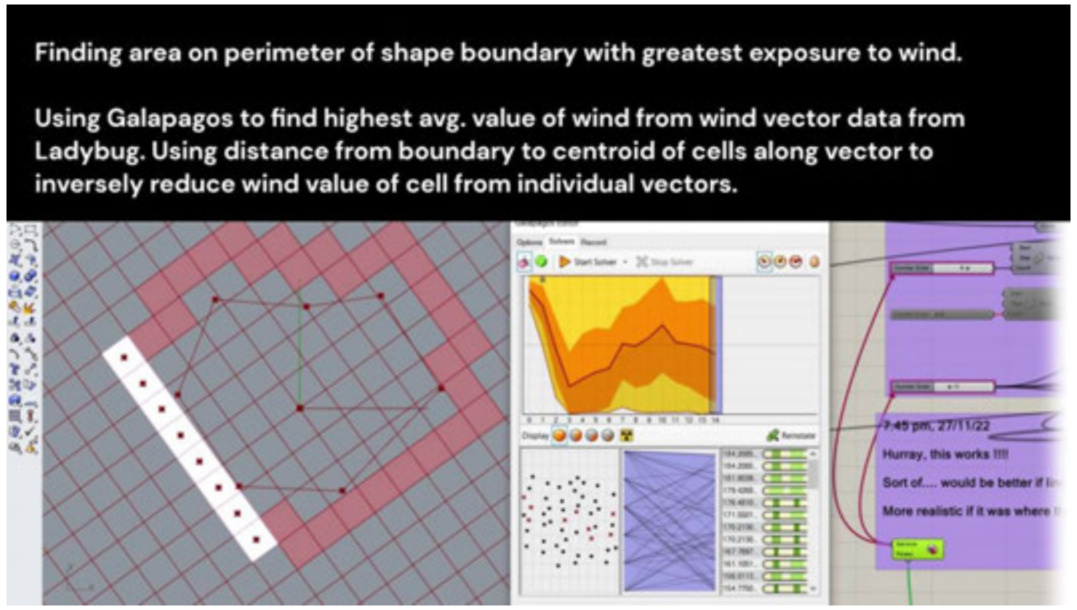
This is the overview for our proposal. The 3 modules work together in series in a top down way. Module A defines a basic grid layout which grows in response to the existing development (the rotation of the squares change and maybe there are 3 sizes of square/rectangle), this module grows the layout and boundary so that the outdoor thermal comfort is optimised. Module B 'refines' the outdoor thermal comfort by growing the morphology of the building boundaries which have been defined by Module A; (street width, height of buildings (individual wall heights(a,b,c,d)), overhang angle). Module C refines the outdoor thermal comfort even more based on Modules A and B by introducing courtyards, (shape, size, orientation, number of courtyards per building, entrances to outer street).

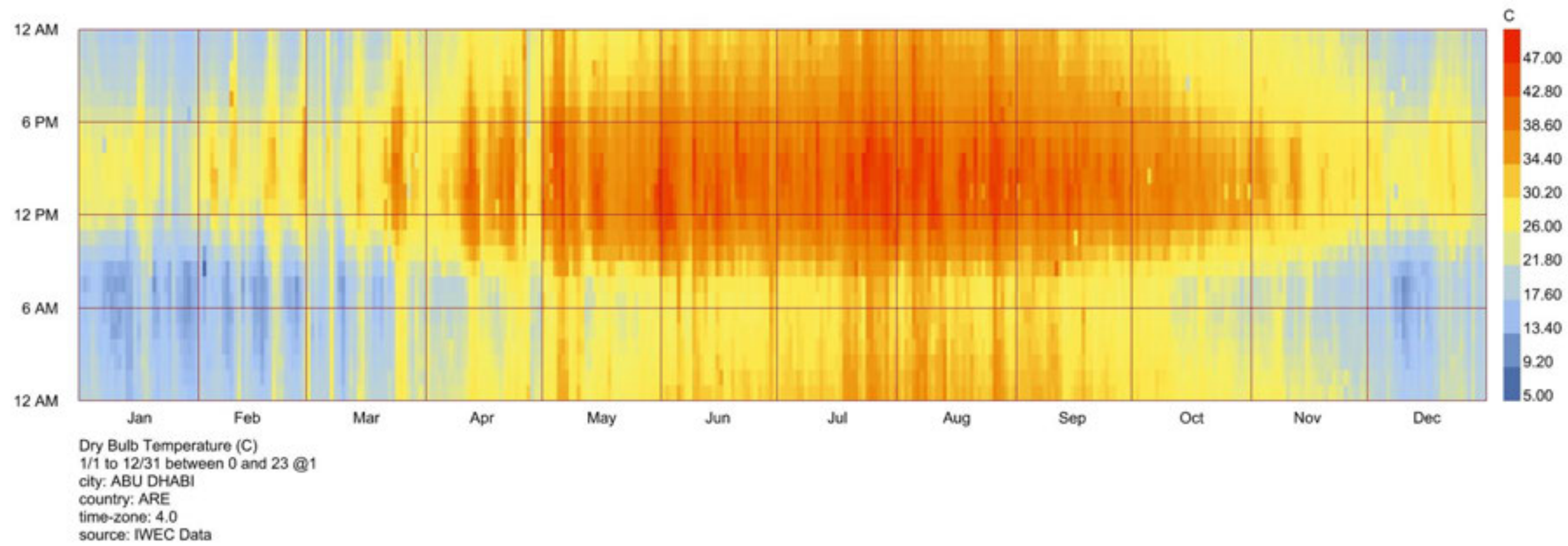
	Large Scale	Medium Scale	Small Scale	
START	**Module A** *Basic optimisation*	**Module B** *Mid optimisation*	**Module C** *High optimisation*	FINISH
Existing development of masdar master plan	defines a basic grid layout and urban boundary which grows in response to the existing development. Using GA and Environmental Analysis.	refines' the outdoor thermal comfort by growing the morphology of the building boundaries which have been defined by Module A. Using GA and Environmental	refines the outdoor thermal comfort even more based on Modules A and B by introducing courtyards. Using GA and Environmental Analysis.	Our Proposed new development Top down scale approach to growing the city towards enhancing overall levels of outdoor comfort based on the passive effects of the urban morphology. potentially analysed against masdar master plan?
	Fitness Thermal Comfort level of Outdoor street level.	**Fitness** Thermal Comfort level of Outdoor street level.	**Fitness** Thermal Comfort level of Outdoor street level.	
	Genomes rotation of street axis for shading 3 classes of square size? Rectangle size options (h & w) 3-5 classes of height per block	**Genomes** Height of the 4 walls (corner point z height) overhang of the 4 walls (angle) street width (5-20m)	**Genomes** Orientation of courtyard placement of courtyard number of courtyards per block closed/open to street	
	Parameters 0.25km2 total area +- 0.05 Existing boundary and topography of masdar (current)	**Parameters** Min, Max height Max angle	**Parameters** Mininum building thickness Maximum % of plot size that is courtyard (for population density)	

URBAN AREA FINDING

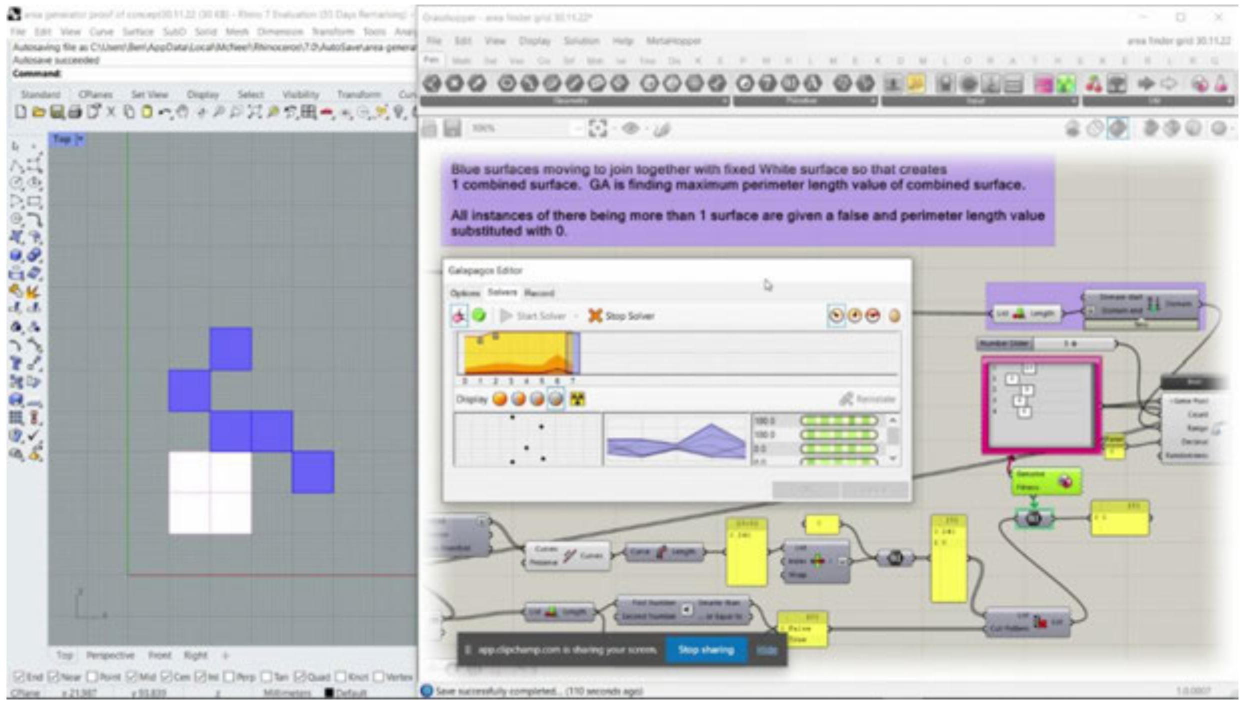
Development of an Area finding tool

Using Wind Data values between April 1st – October 31st (where outdoor avg. temperatures are above 30 °c) from Abu Dhabi airport situated within 1 km of Masdar city to the NE with to position the new urban development of Masdar City.





Initial thoughts and experiments within Grasshopper focused on creating a tool which could select a string of cells from a series of cells surrounding a curve (representing an urban boundary). Values for the combined cells were based on the length of a curve from the cell's centroids to the combined highlighted cells outer boundary in 1 direction.



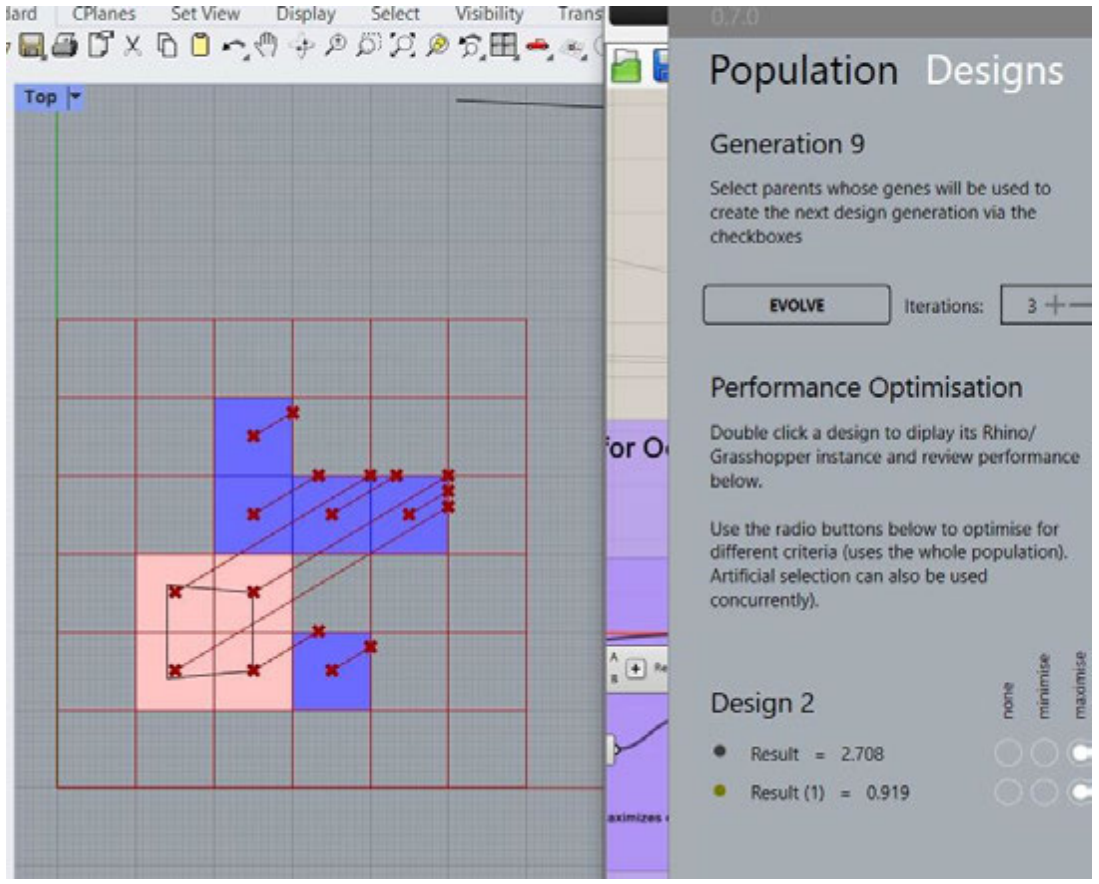
Further experiments explored generating an additional surface that could vary in shape.

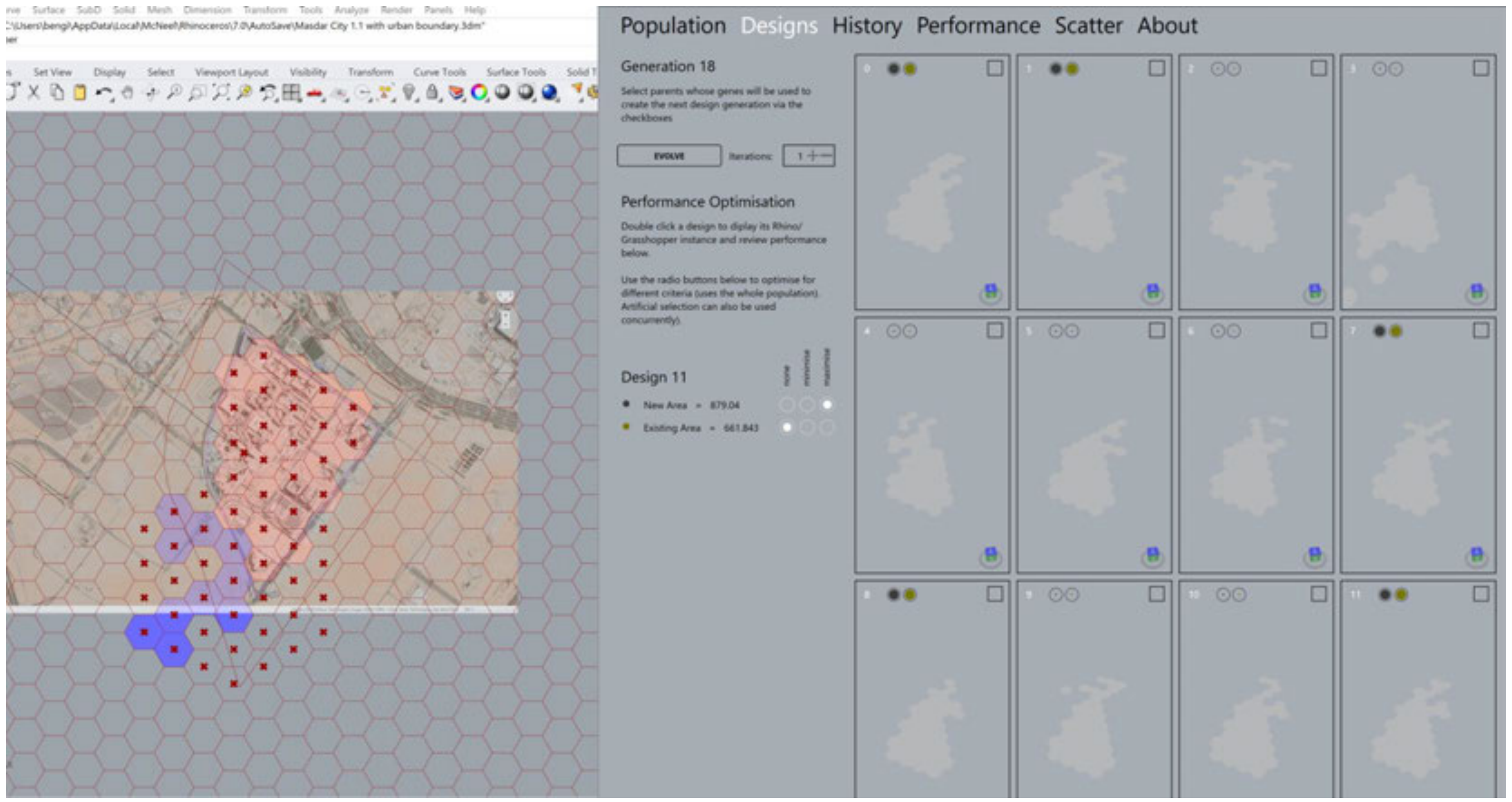
There could be multiple surfaces and surfaces not adjoined to the fixed surface (representing an urban boundary).

URBAN AREA FINDING

Development of an Area finding tool

BIO-MORPHER allowed the input of 2 fitness targets which were tested as the combined cell values of old area and new area, however the nature of BIO-MORPHER, using multiple user choice inputs tended to produce few usable results.

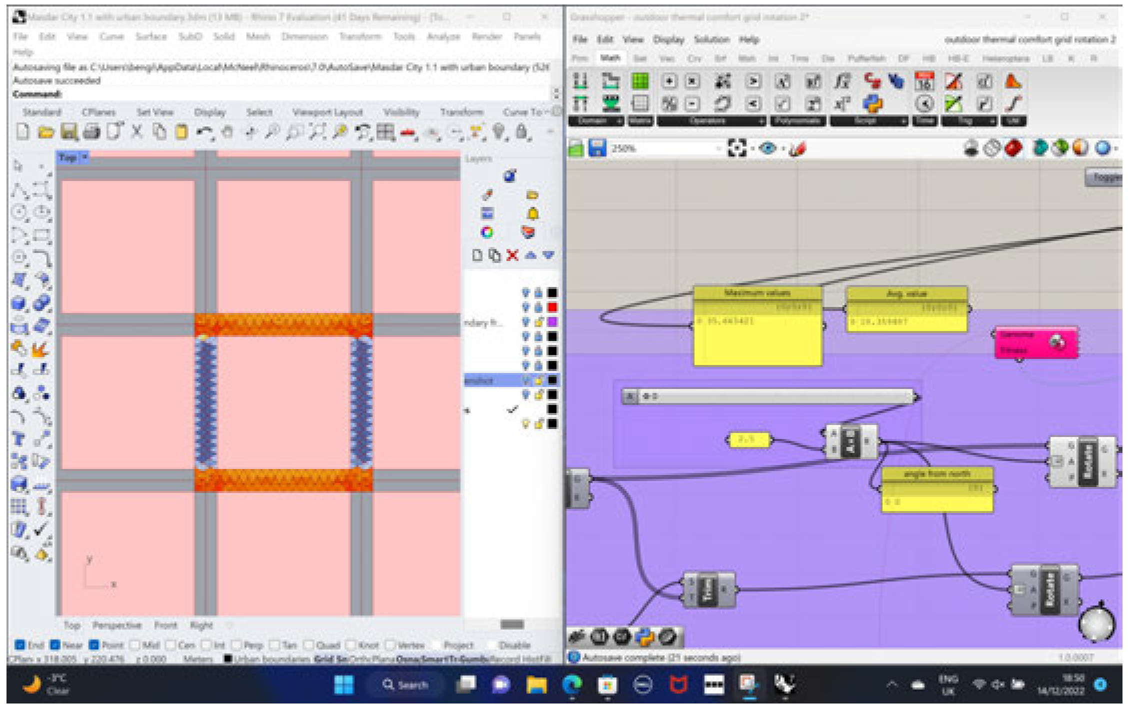


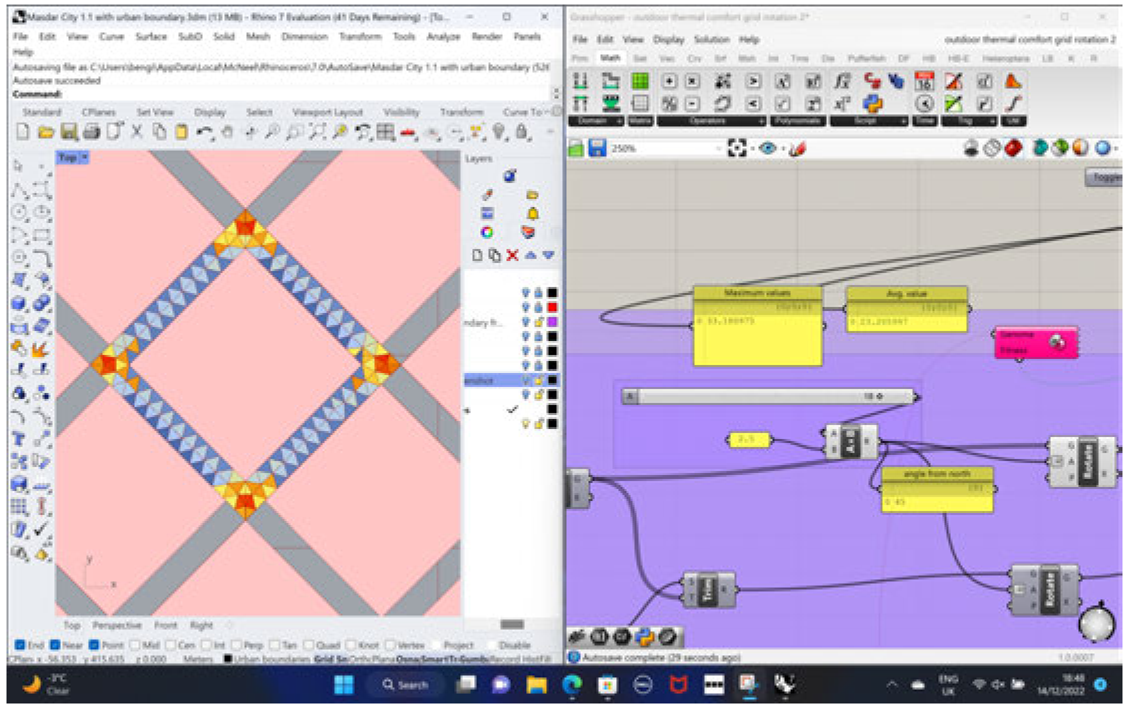


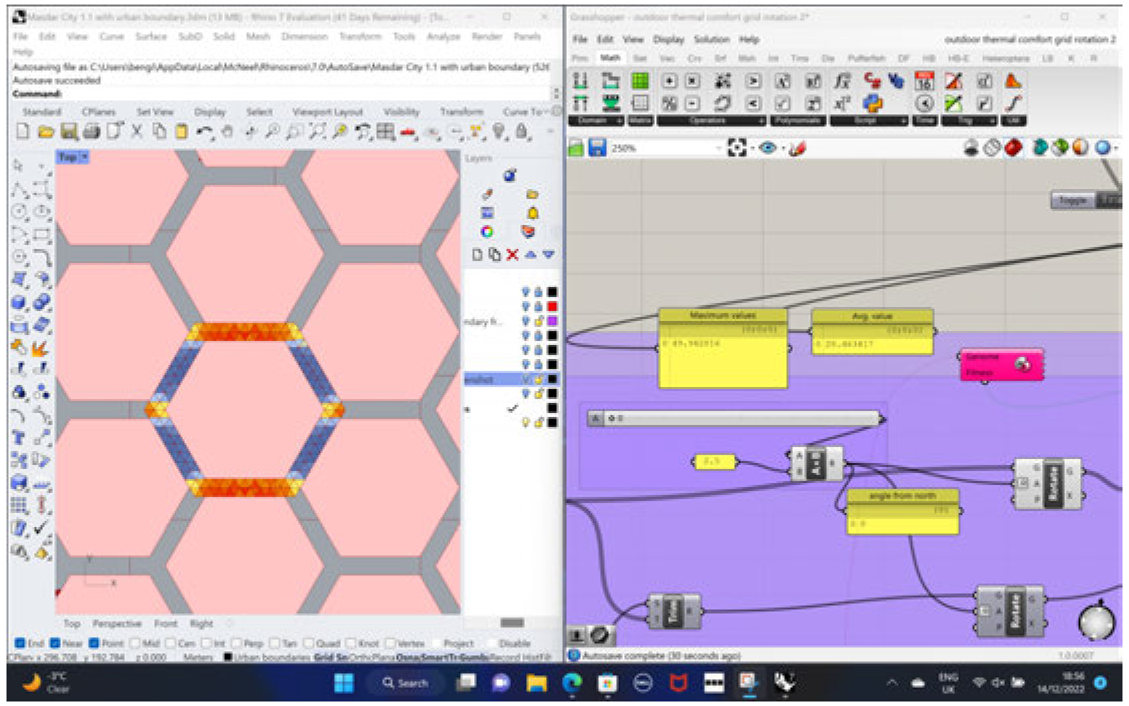
URBAN AREA FINDING

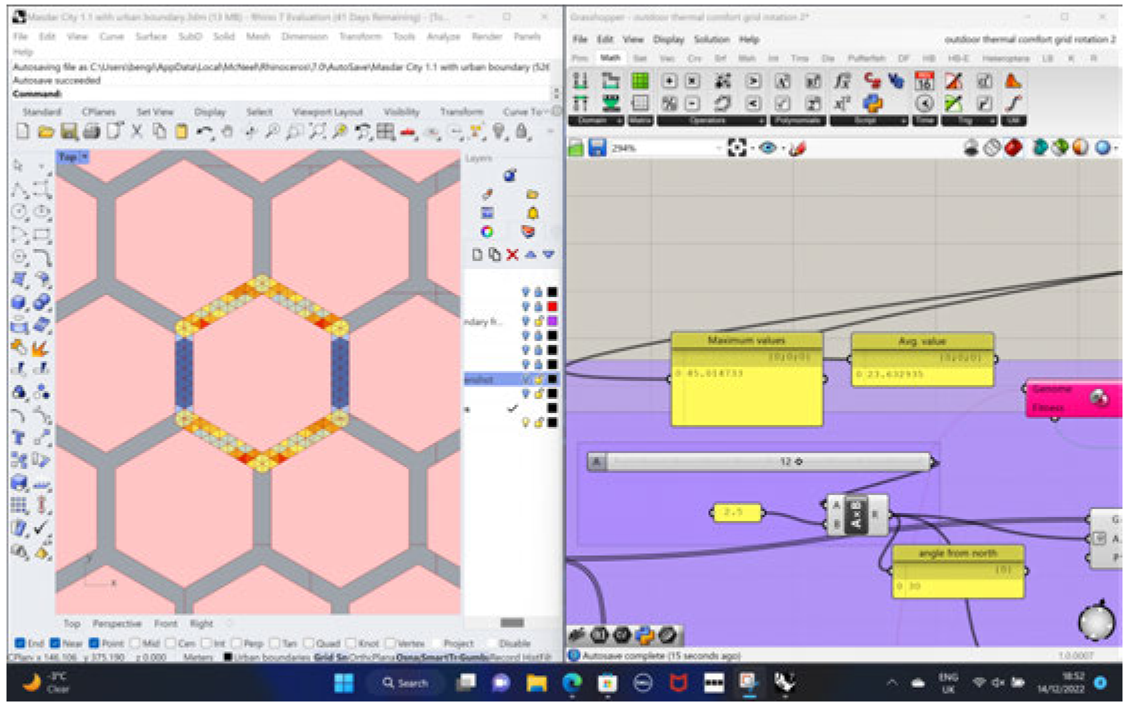
Development of an Area finding tool

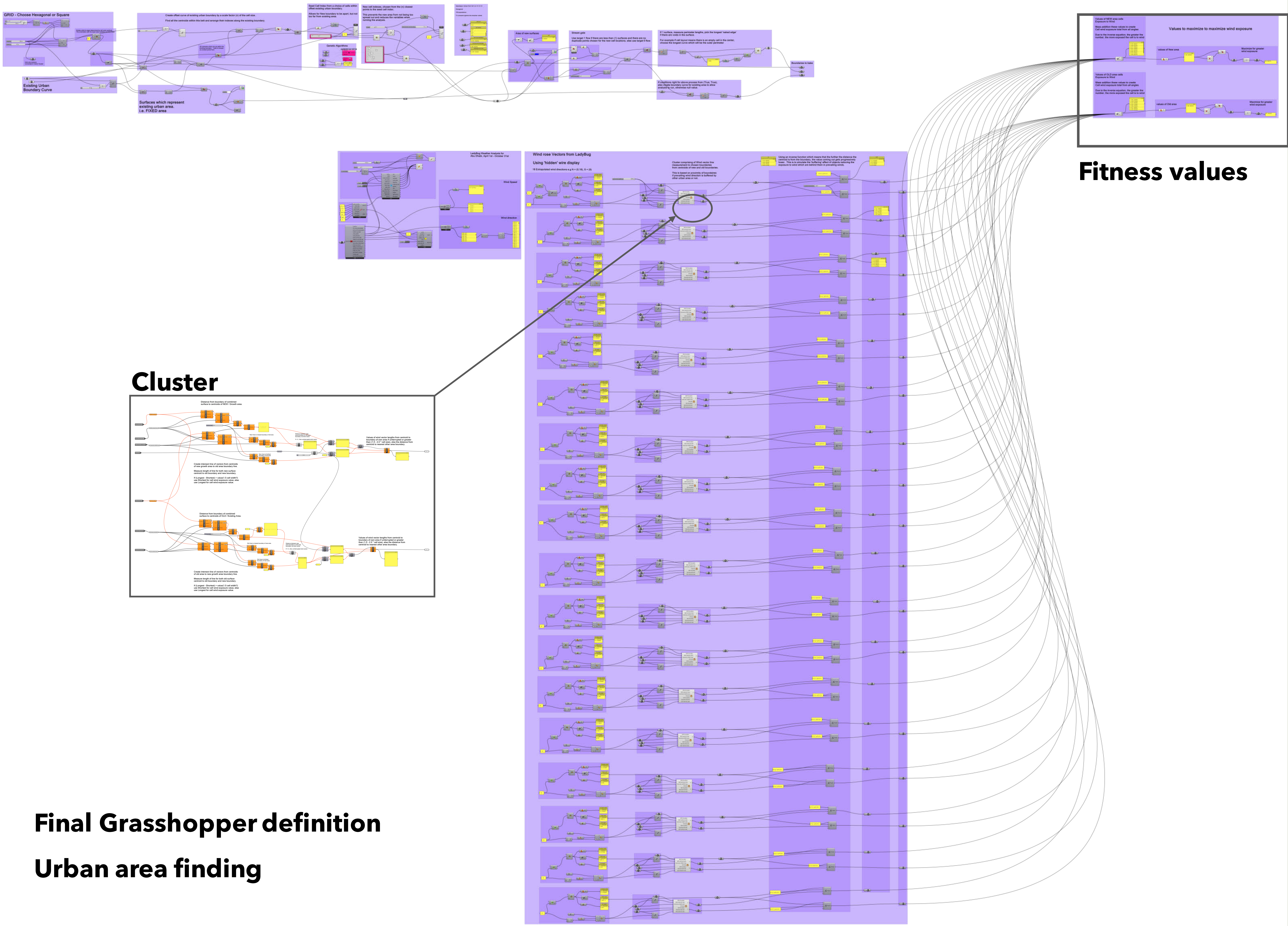
Testing of different cells to find the best orientation and shape of cells which provide the lowest solar radiation at street level.





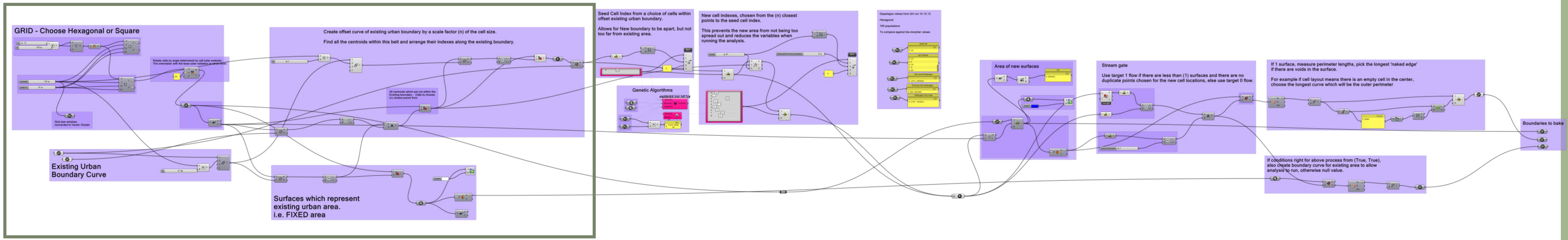


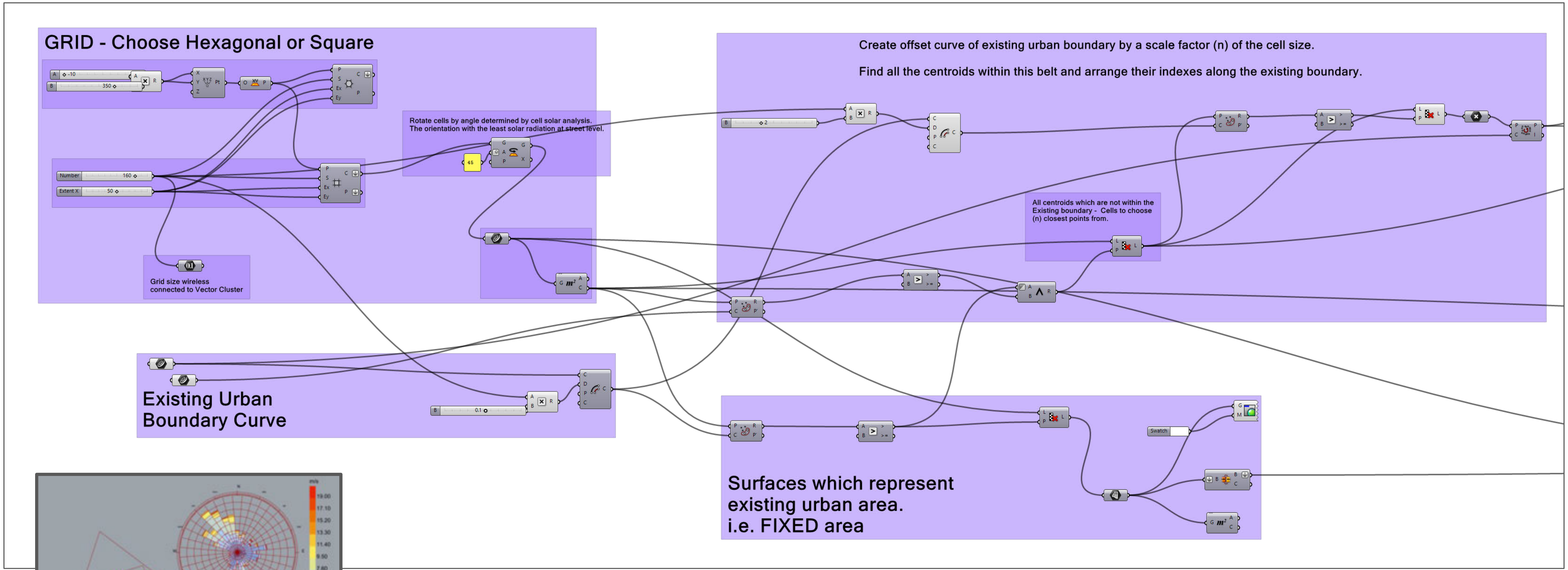


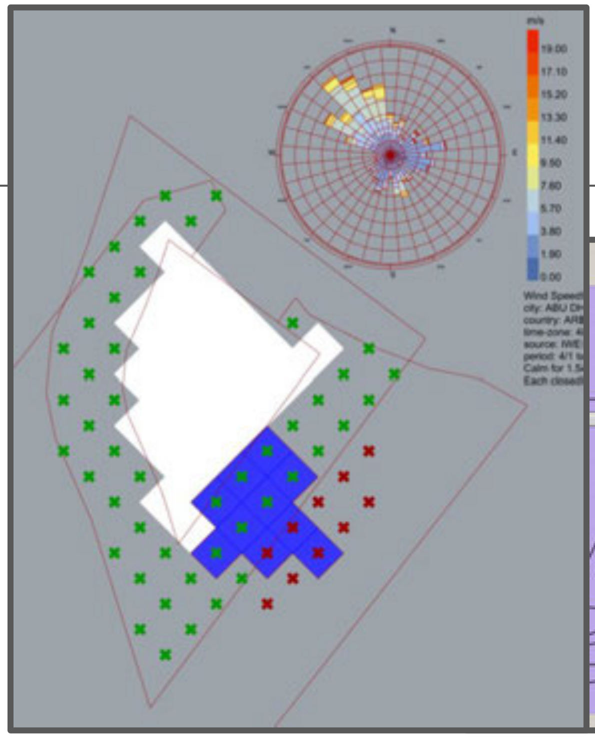


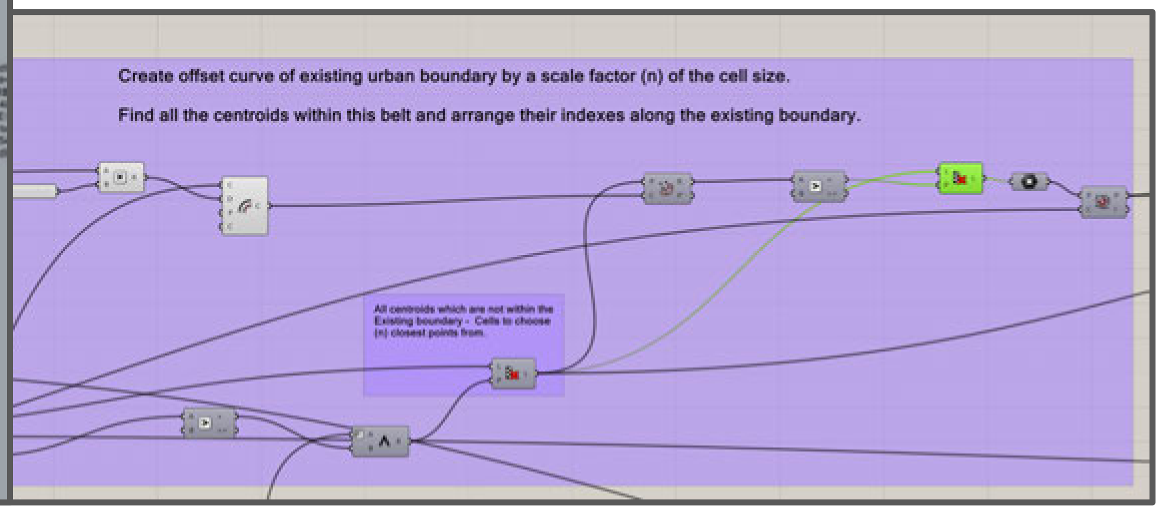
Final Grasshopper definition

Urban area finding

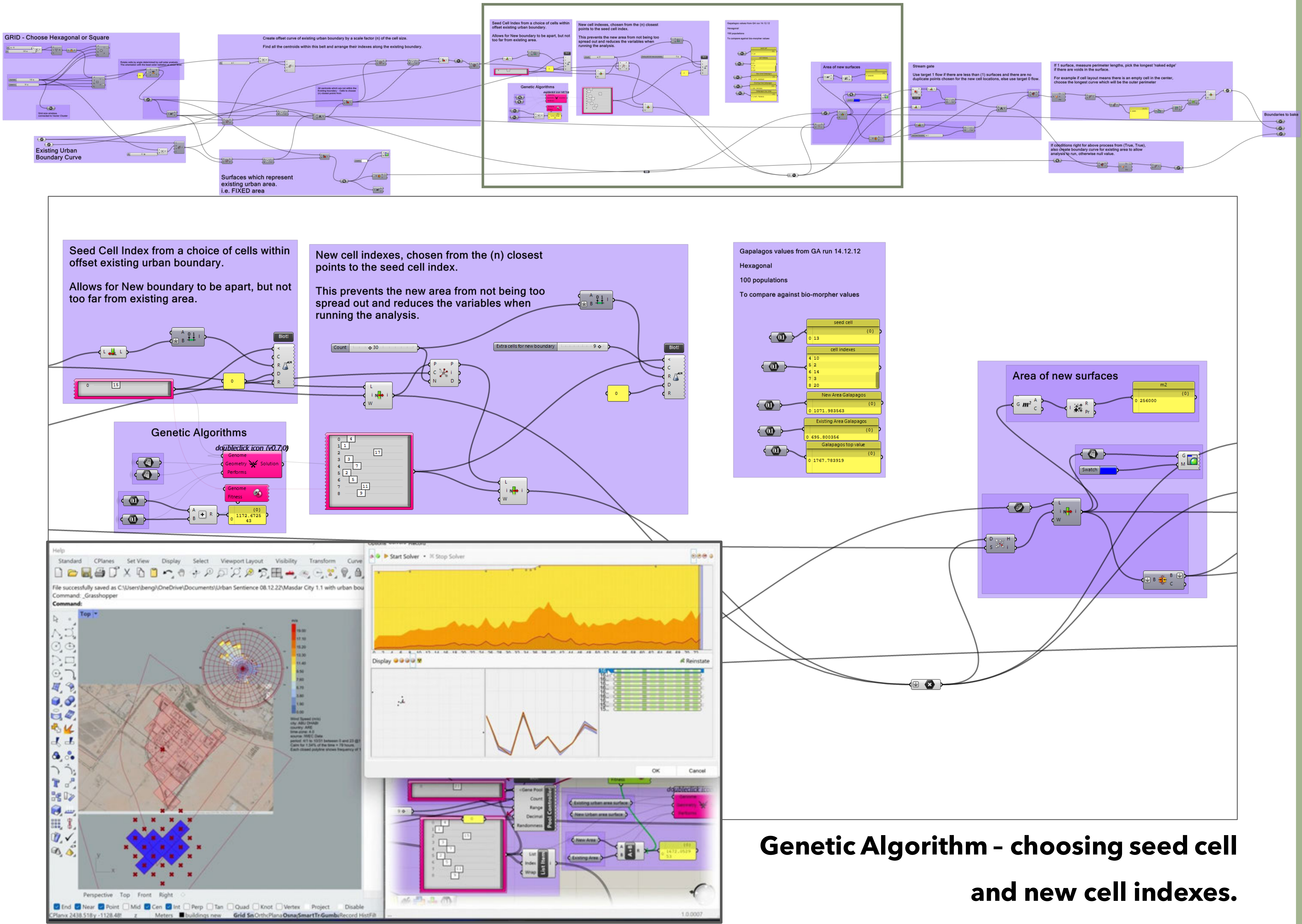




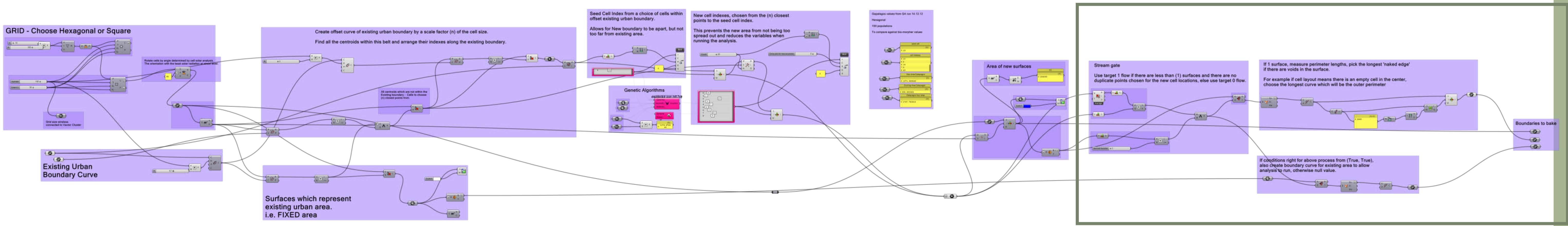


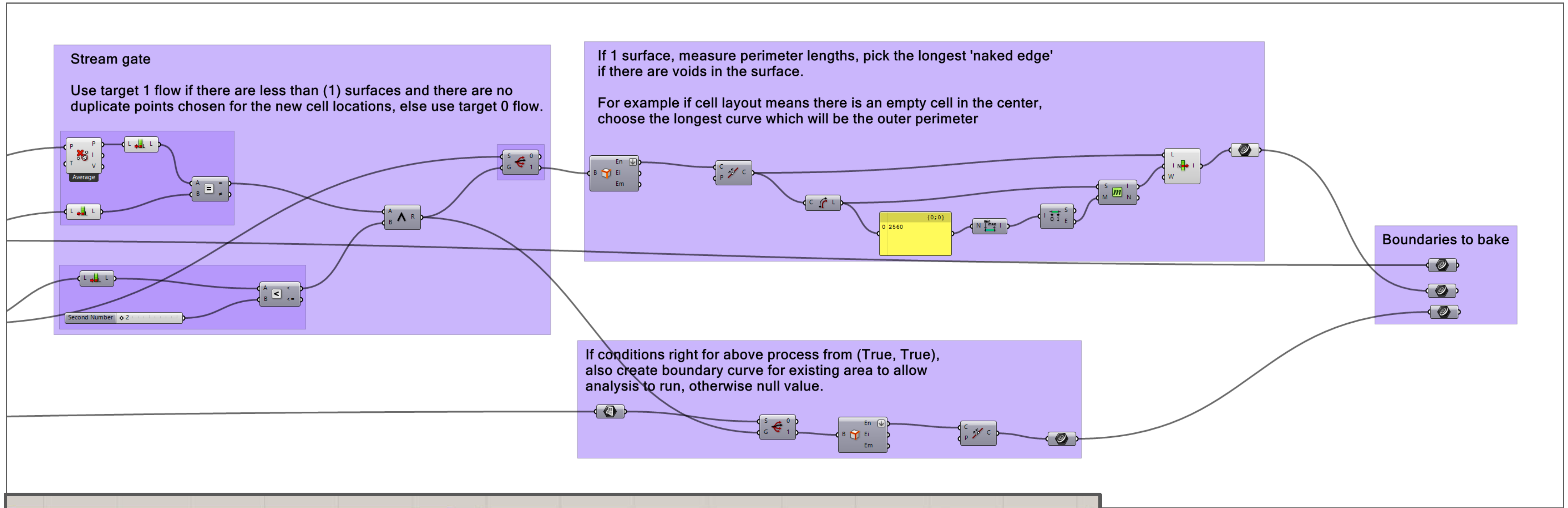


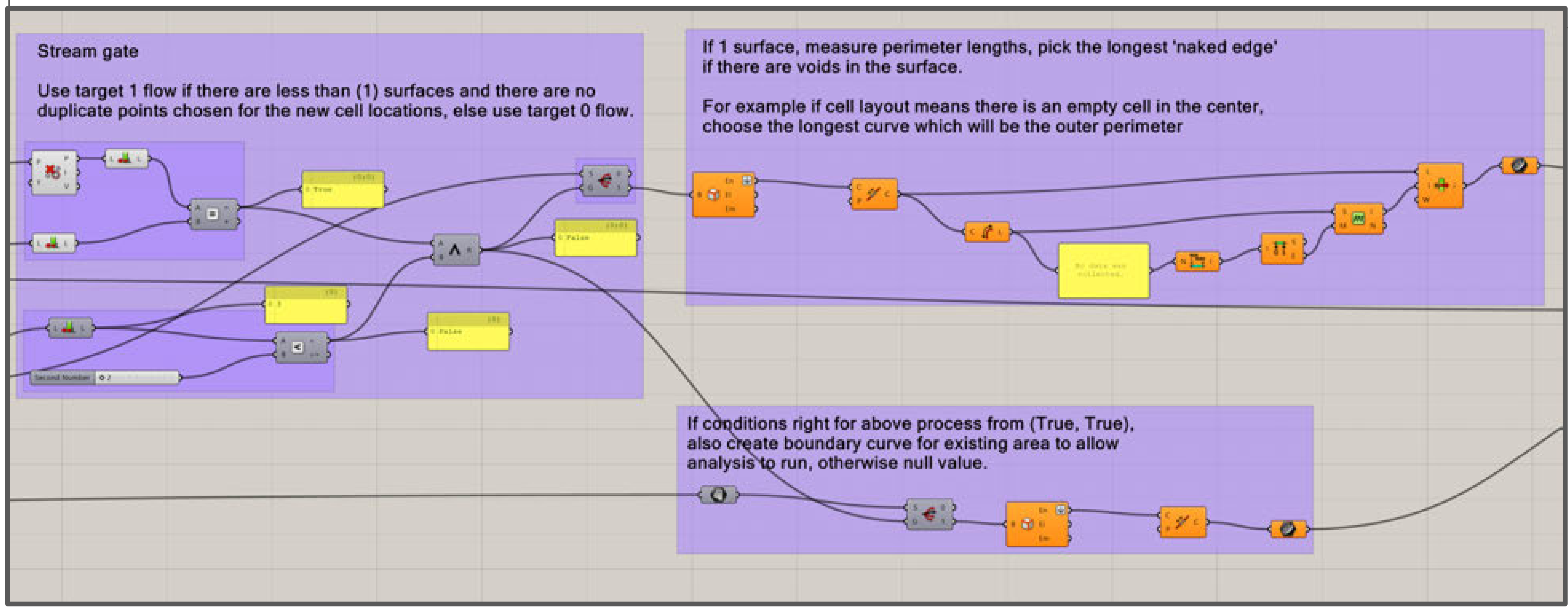
Creating seed and new cell location options.



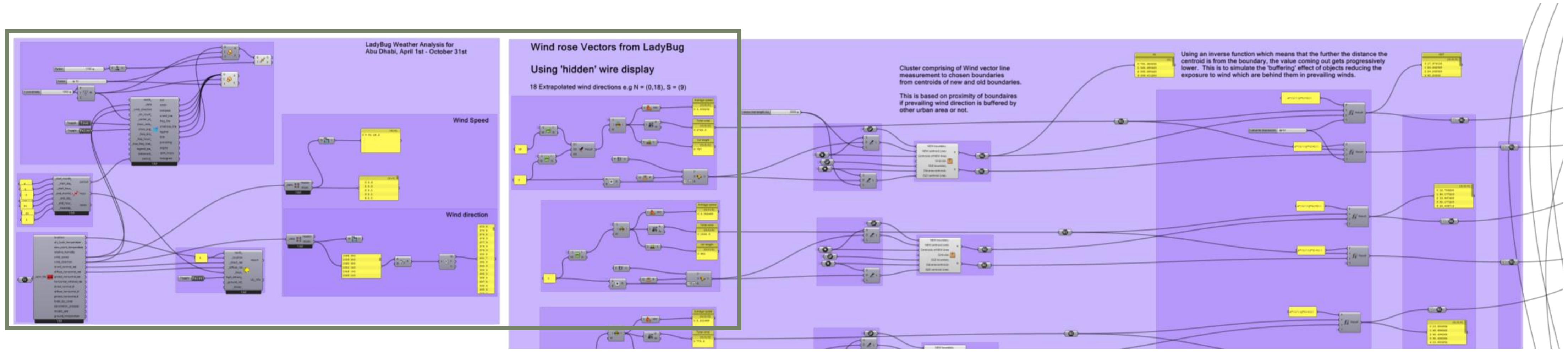
Genetic Algorithm – choosing seed cell and new cell indexes.



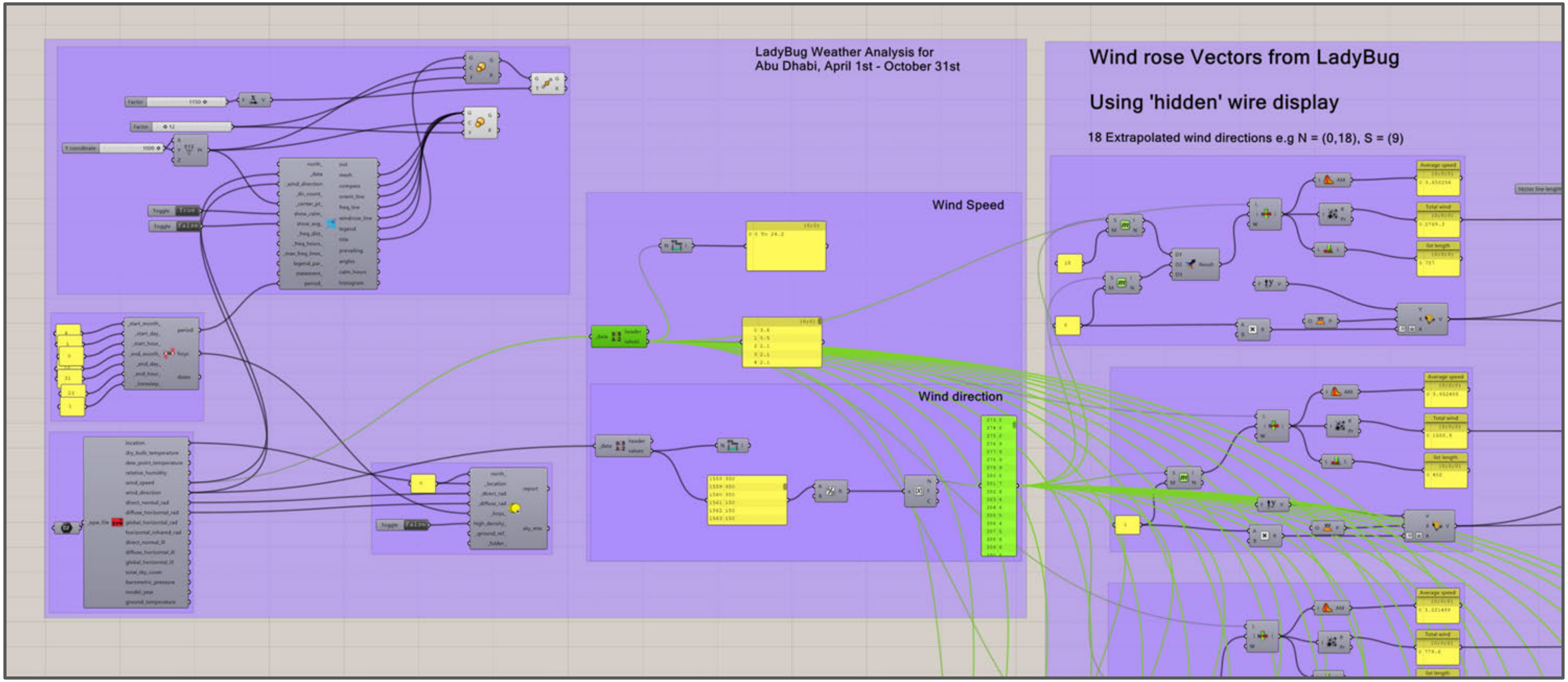




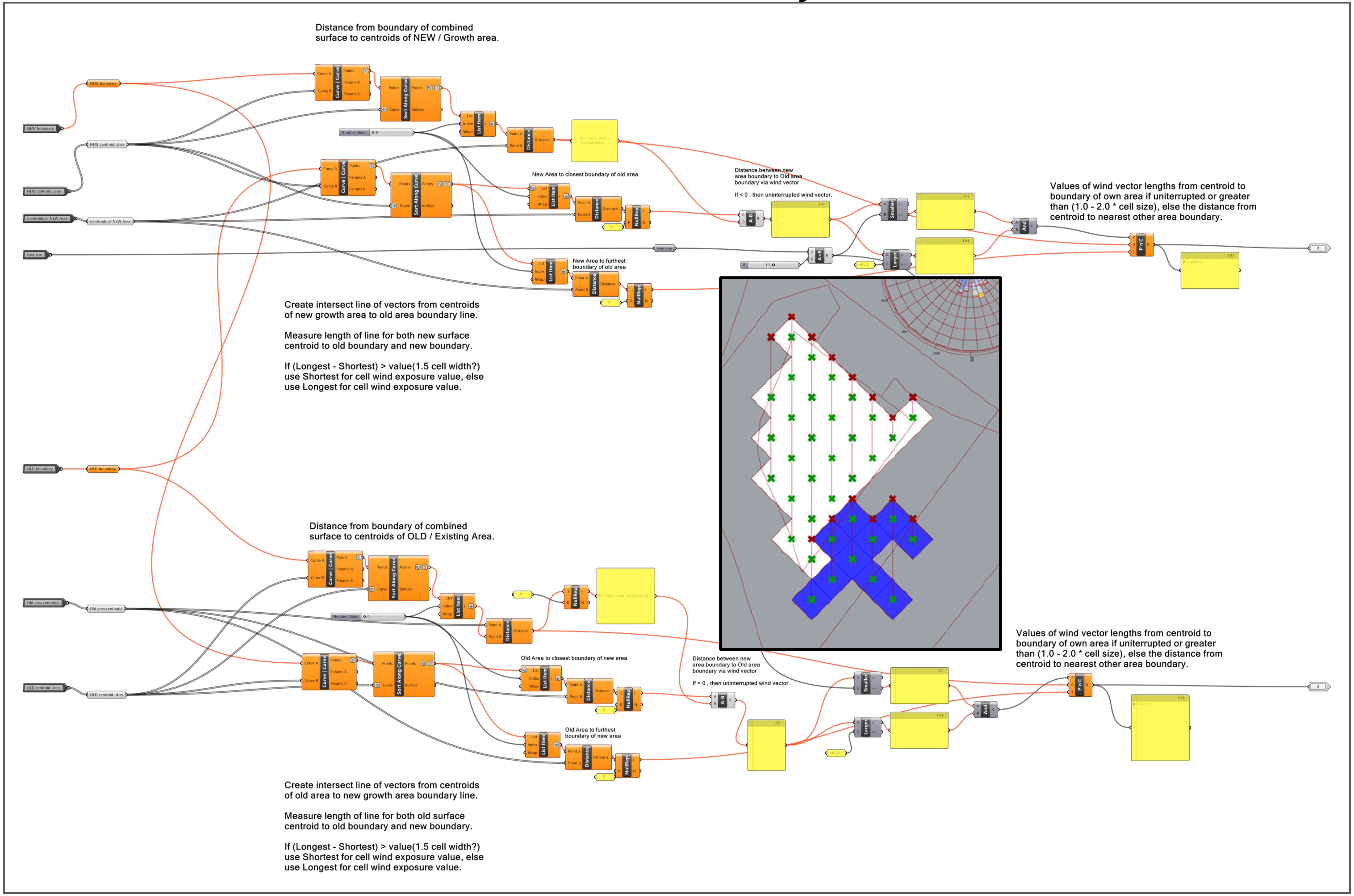
Using stream gates and gates to choose to run analysis to reduce unnecessary calculations

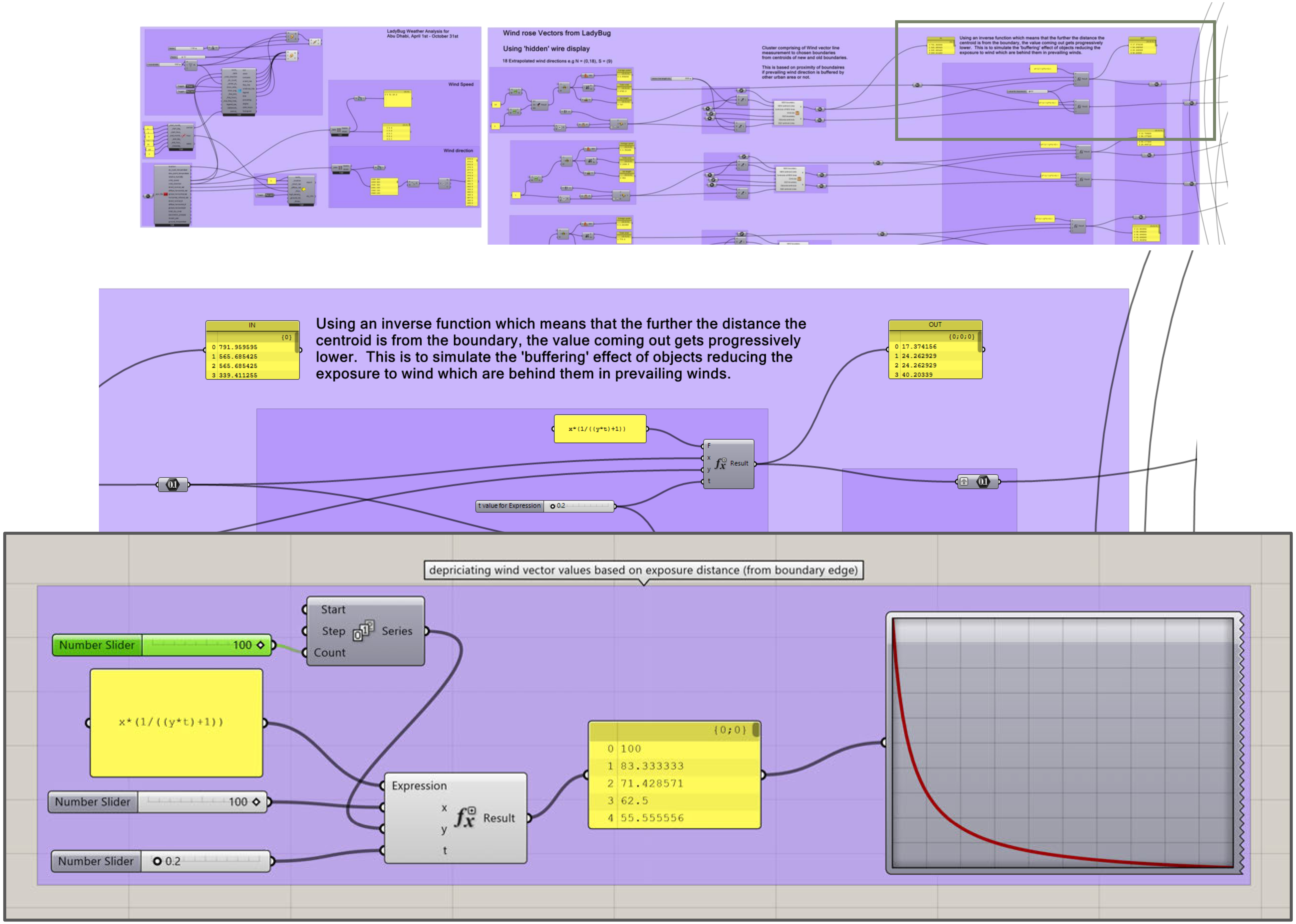


Wind vector values to Wind Line cluster

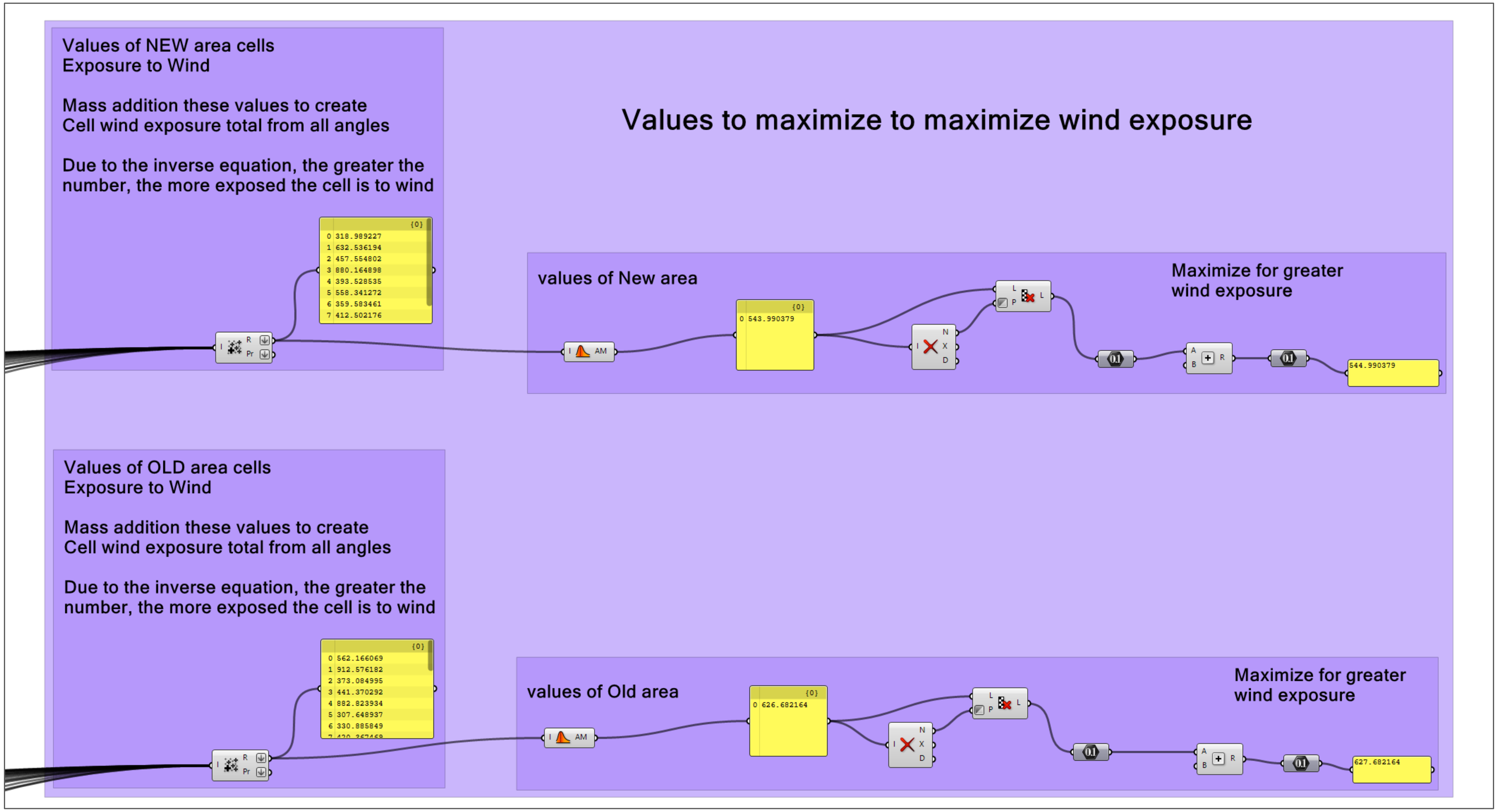


Cluster details – wind vector lines to centroid from boundary intersection





Inverse function – wind values per cell



Average cell values of new and existing areas to use as fitness for Genetic Algorithm

BUILDING TOPOLOGY

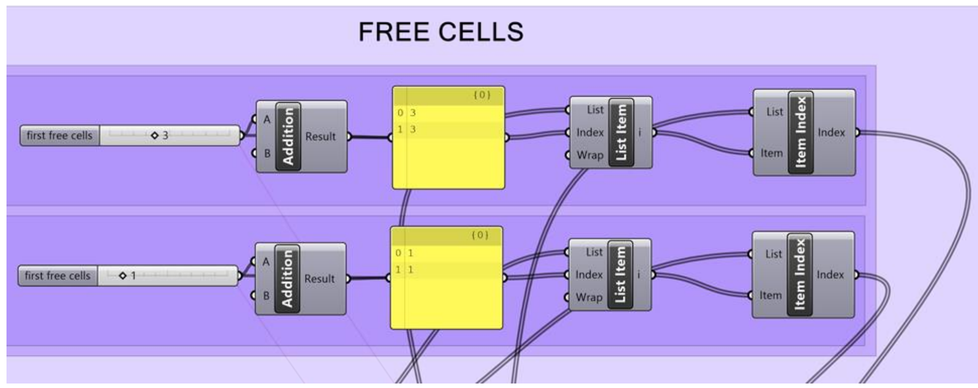
To Generate Free Cells (Open Spaces)

First, We determined 3 different types of buildings; Residential, public mix used and office buildings. Specific features were determined for each of them based on research

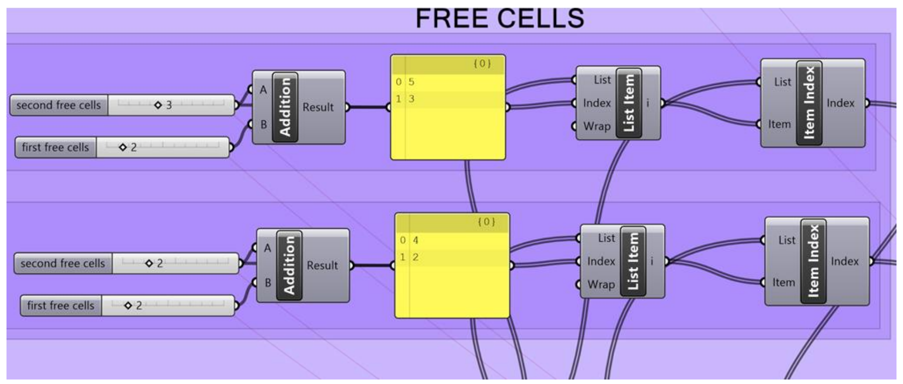
Amount	Grid size	Type	Min Height	Max Height
4	5x5	Residential	30	15
4	4x4	Public mixed-used	40	20
2	3x3	Offices	50	25

Amount of Grid	Grid type	Free Cells
4	Residential	3
4	Public mixed-used	2
4	Offices	1

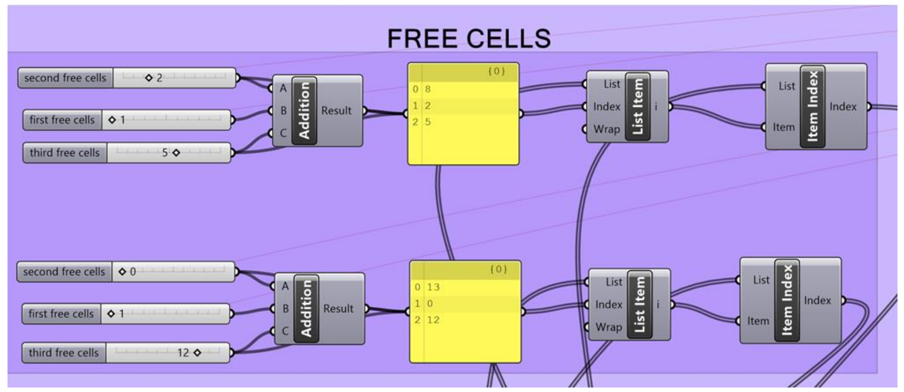
We generated free cells for each type. We determined number of free cells according to building density in the grids. Our fitness for the location of free cells is solar radiation



Free cells code for Offices
1 free cell for each grid



Free cells code for ppublic mix-used
2 free cell for each grid



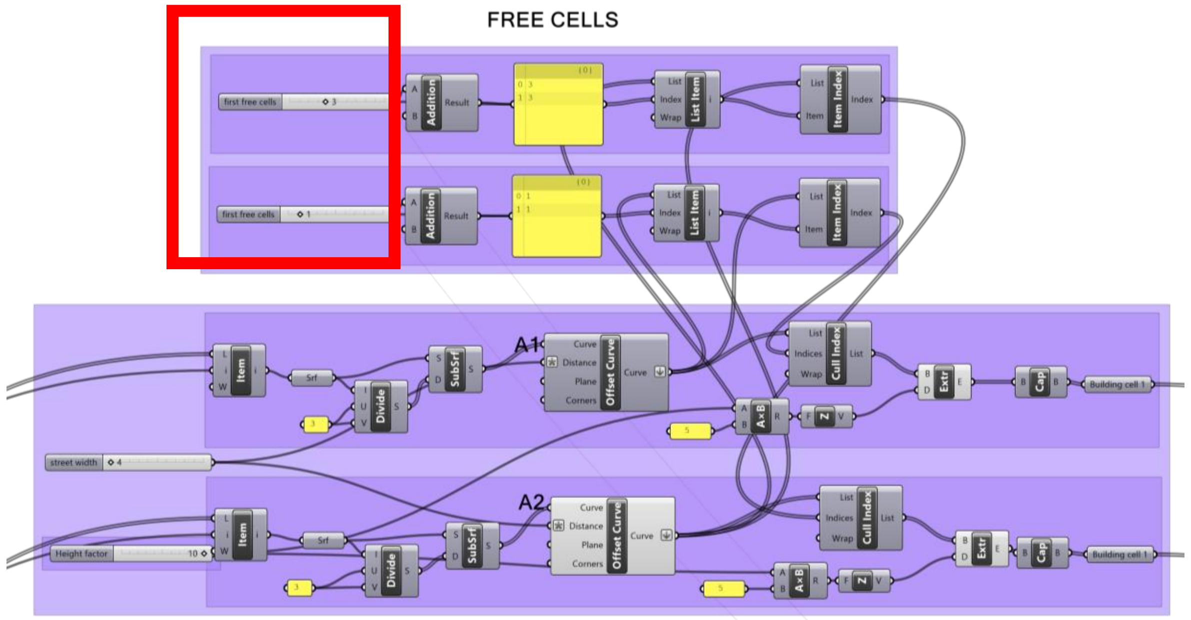
Free cells code for Residential
3 free cell for each gridt

BUILDING TOPOLOGY

To Generate Free Cells (Open Spaces)

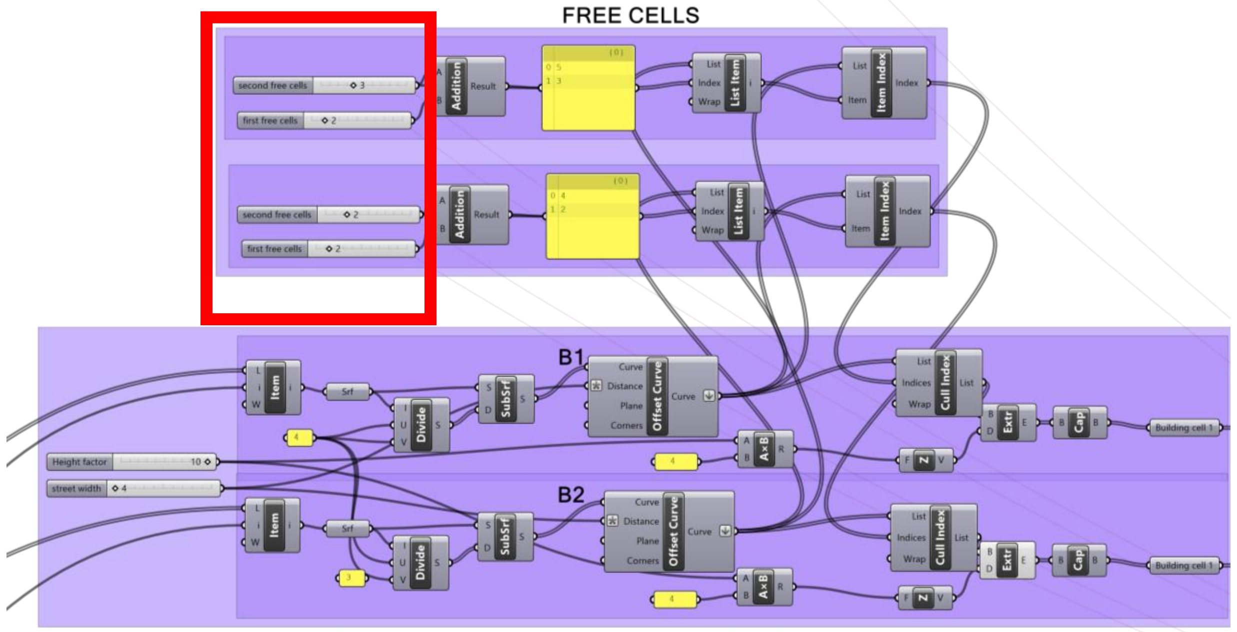
Buildings were extruded by max height values for each type to keep this parameter same for analyse the location of free cells .

Variables



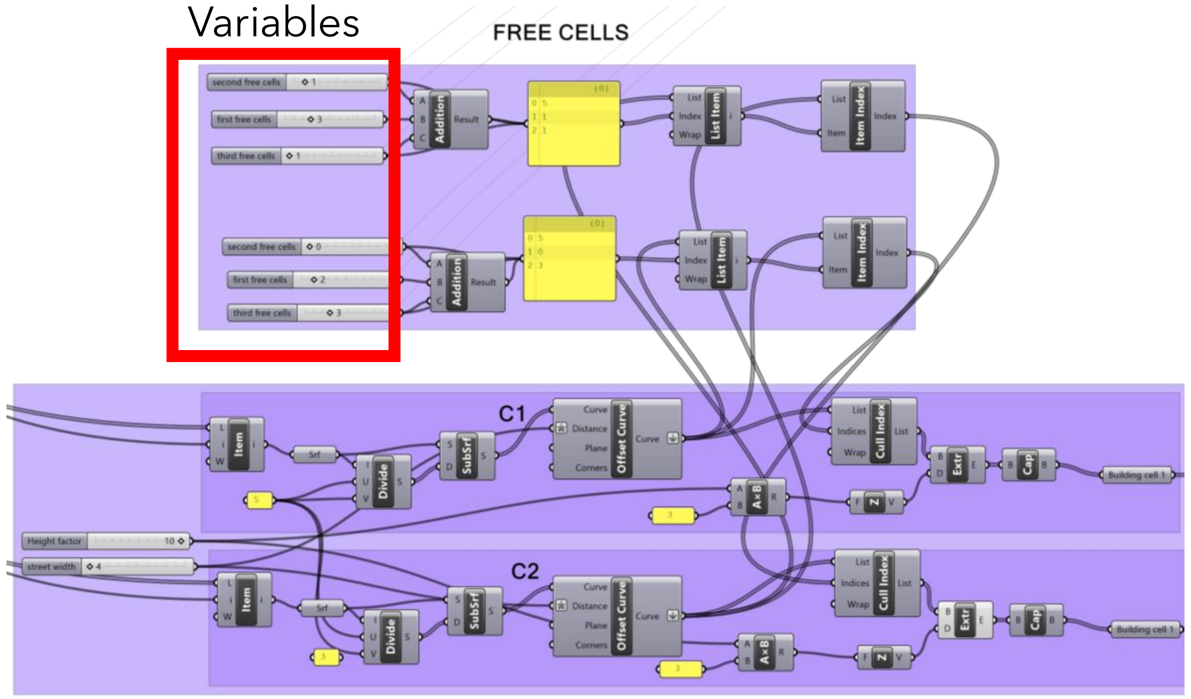
Free cells code for office buildings type

Variables

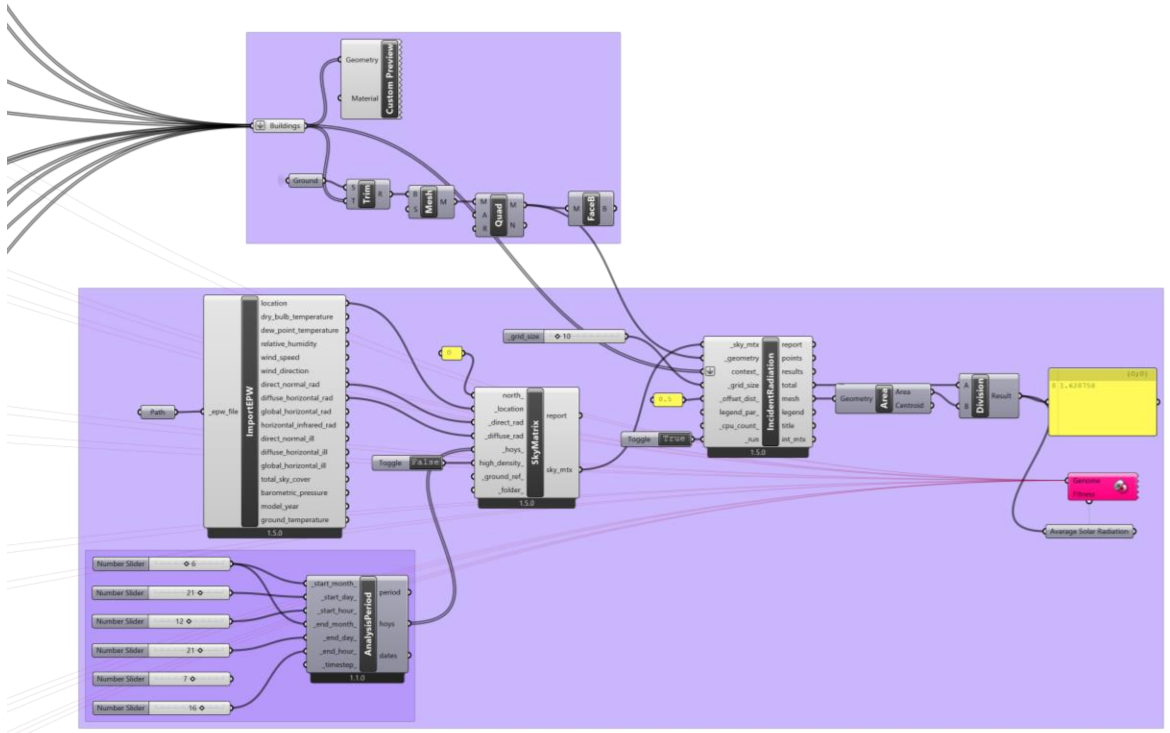


Free cells code for Public mixed use type

Variables



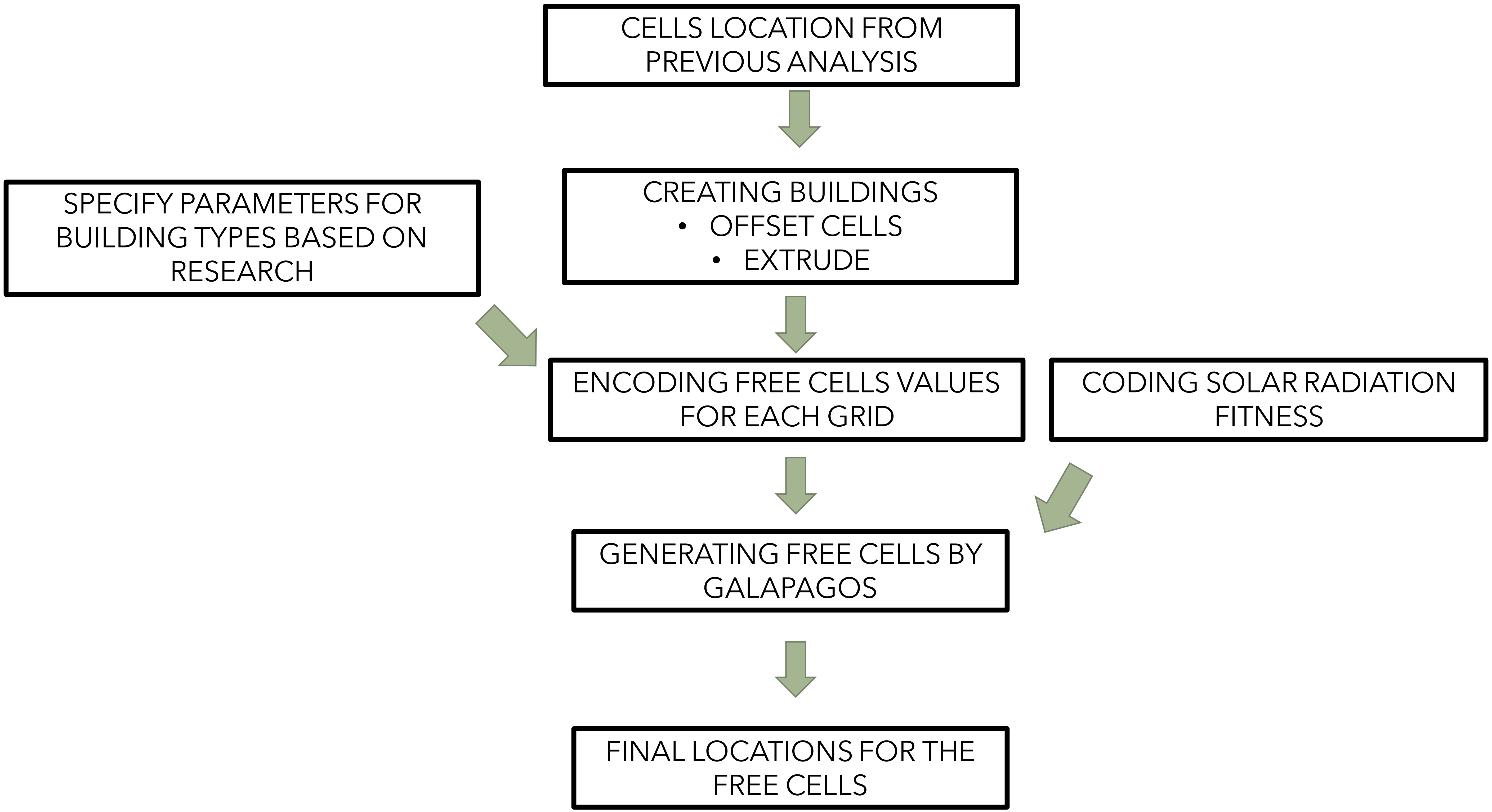
Free cells code for residential type



Solar radiation code for fitness

BUILDING TOPOLOGY

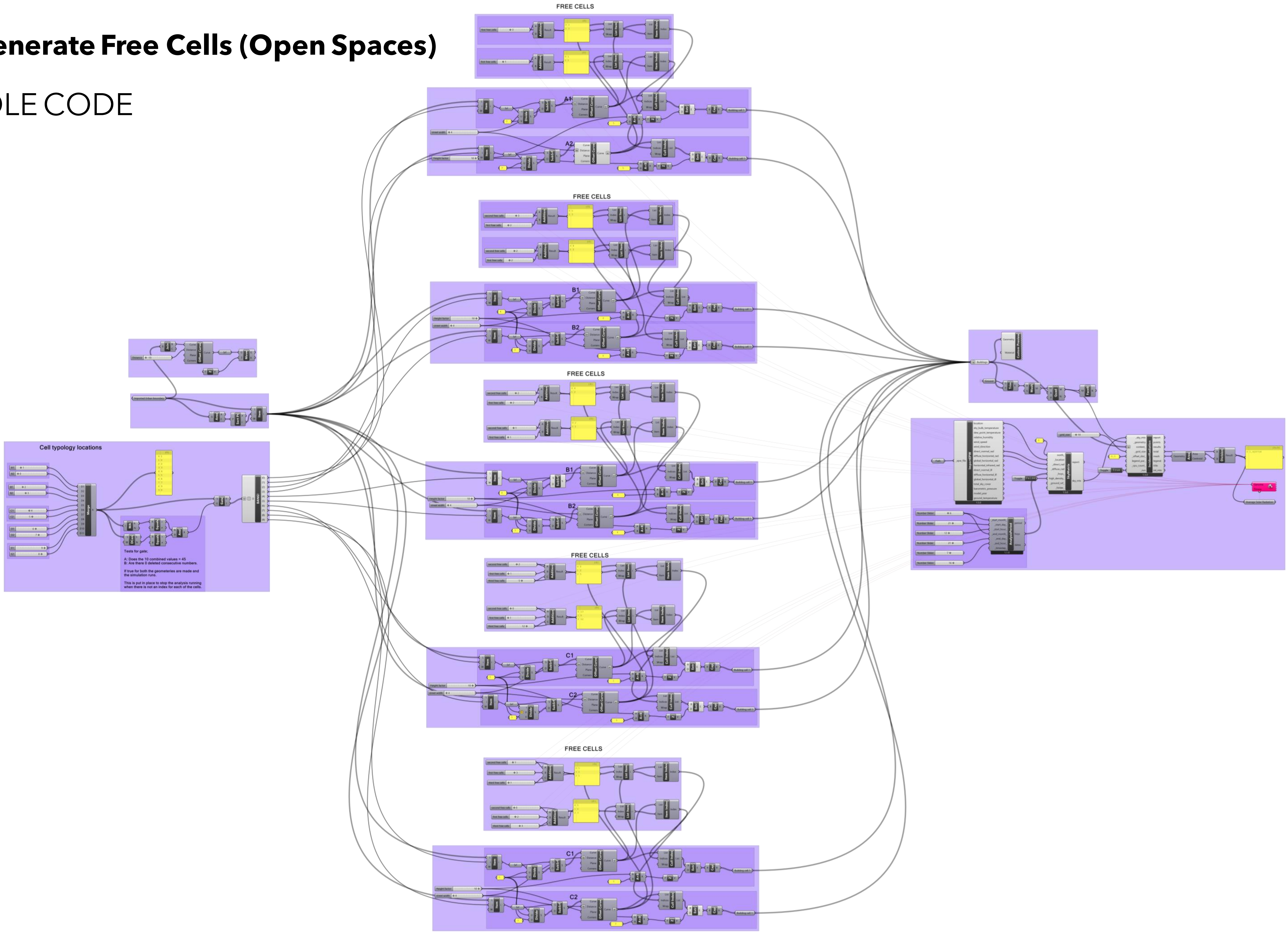
WORKFLOW



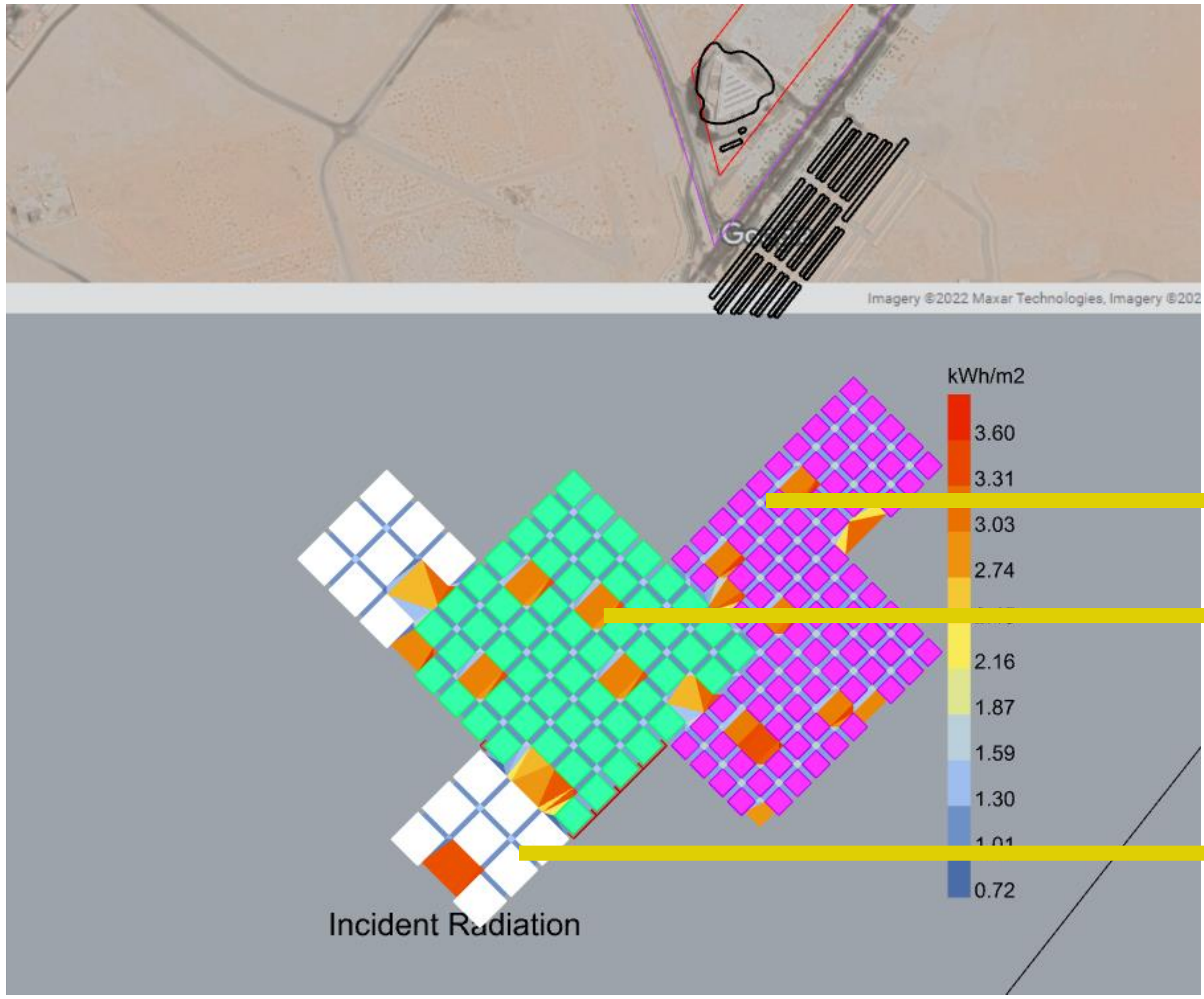
BUILDING TOPOLOGY

To Generate Free Cells (Open Spaces)

WHOLE CODE



BUILDING TOPOLOGY

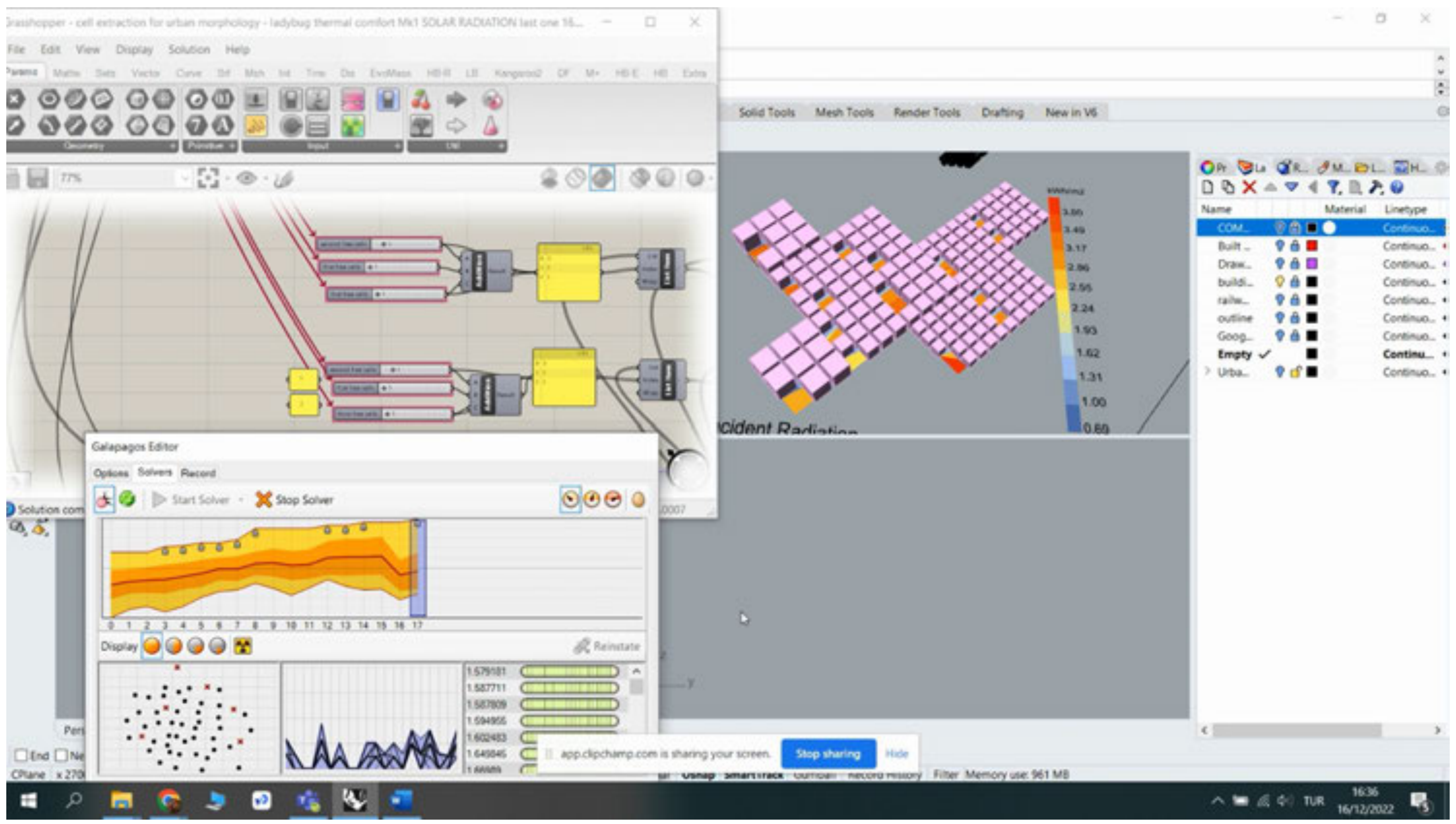


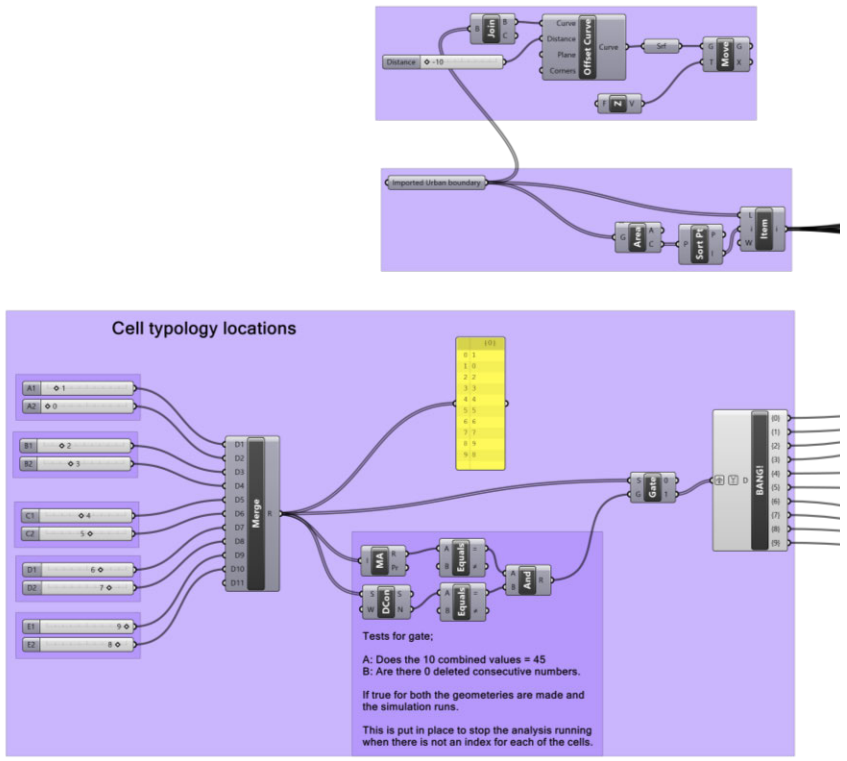
We got free cells for each grid according to optimum solar radiation.

Purple: Residential buildings

Green: Public mix used buildings

White: Office buildings

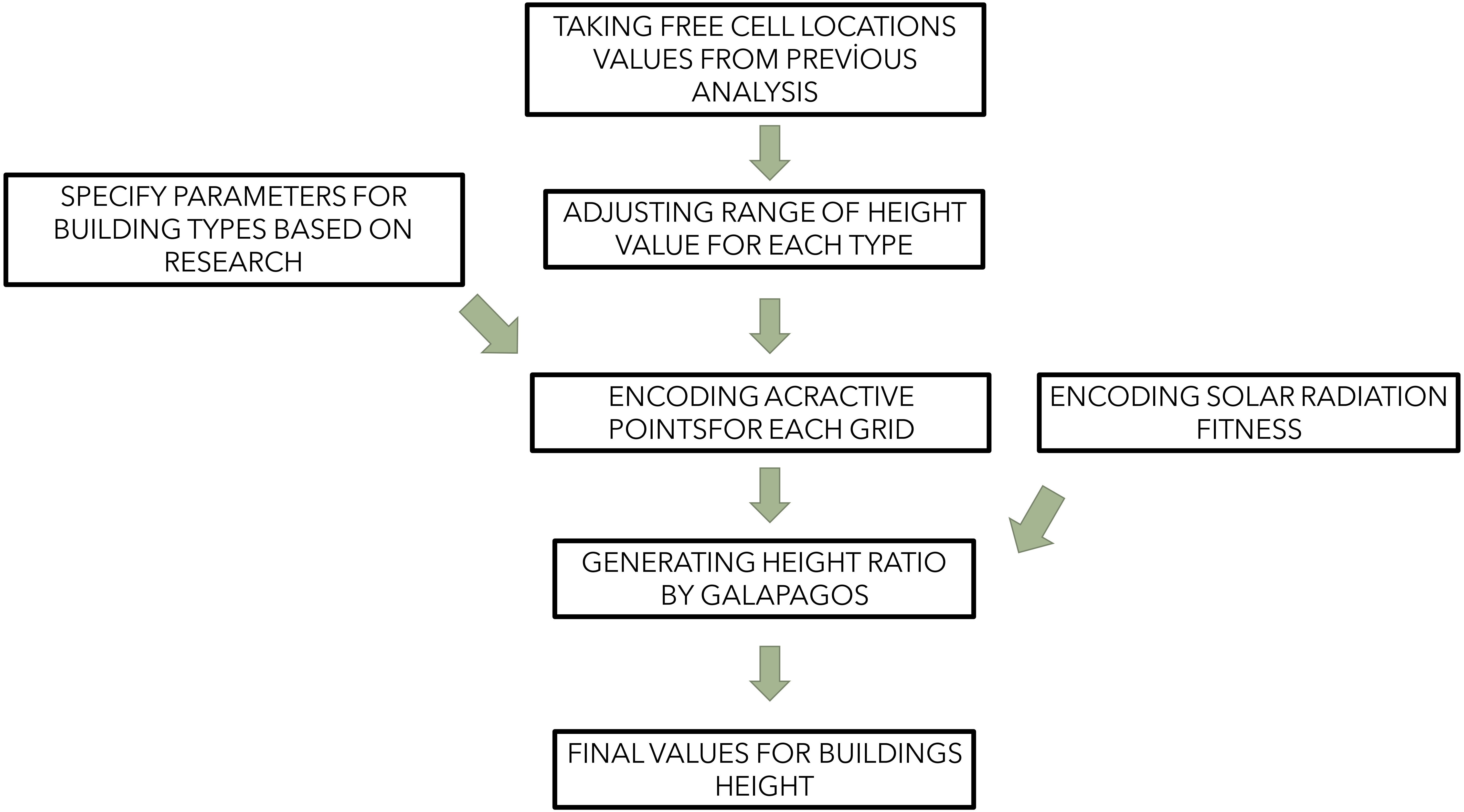




BUILDING TOPOLOGY

HEIGHT RATIO

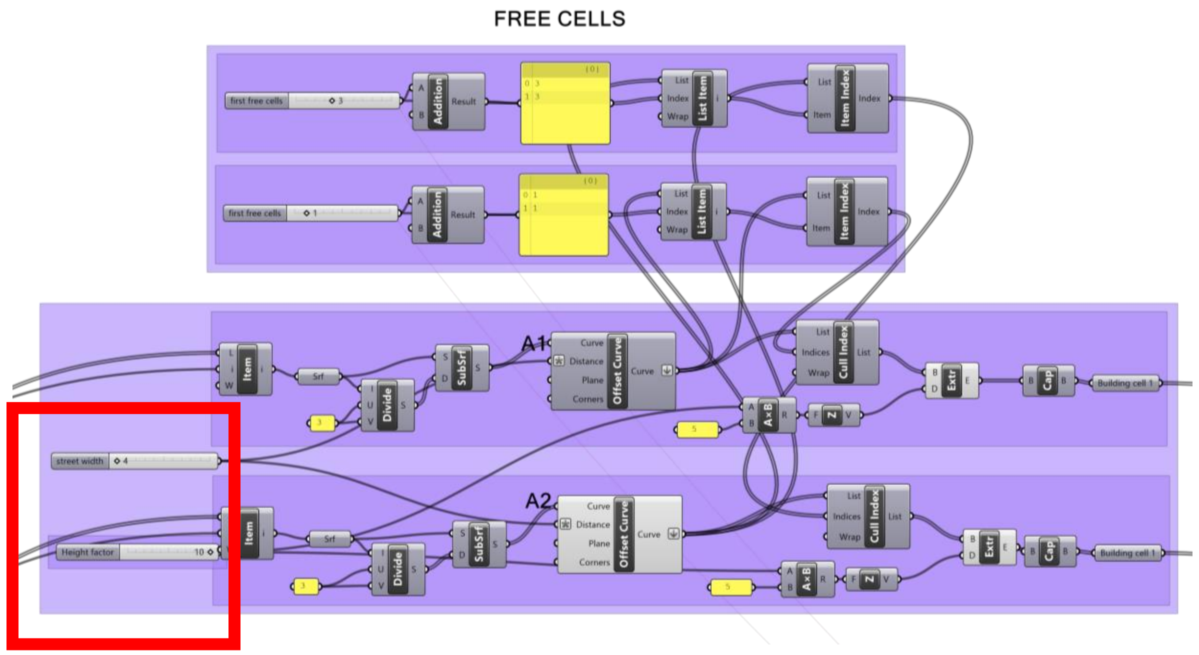
After acquire optimum free cell locations, now we are going to analyse height of building types with different values.After that we're gona use attractive point to analyze the height of each building within each type itself



BUILDING TOPOLOGY

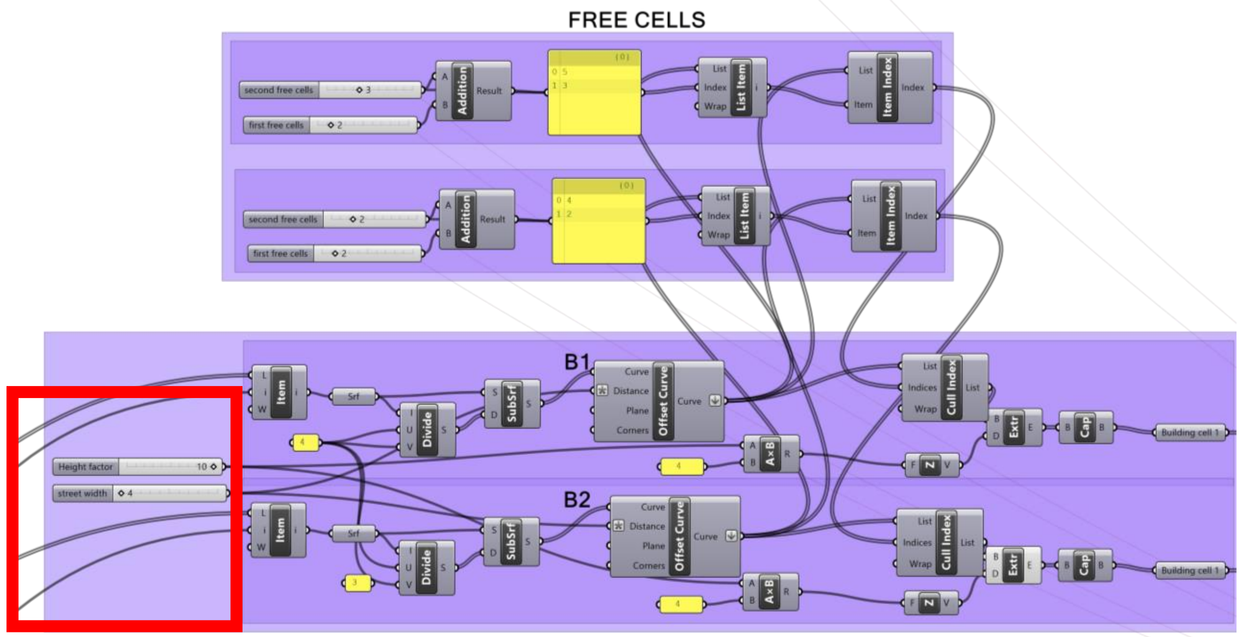
HEIGHT RATIO

CODES FOR HEIGHT RATIO



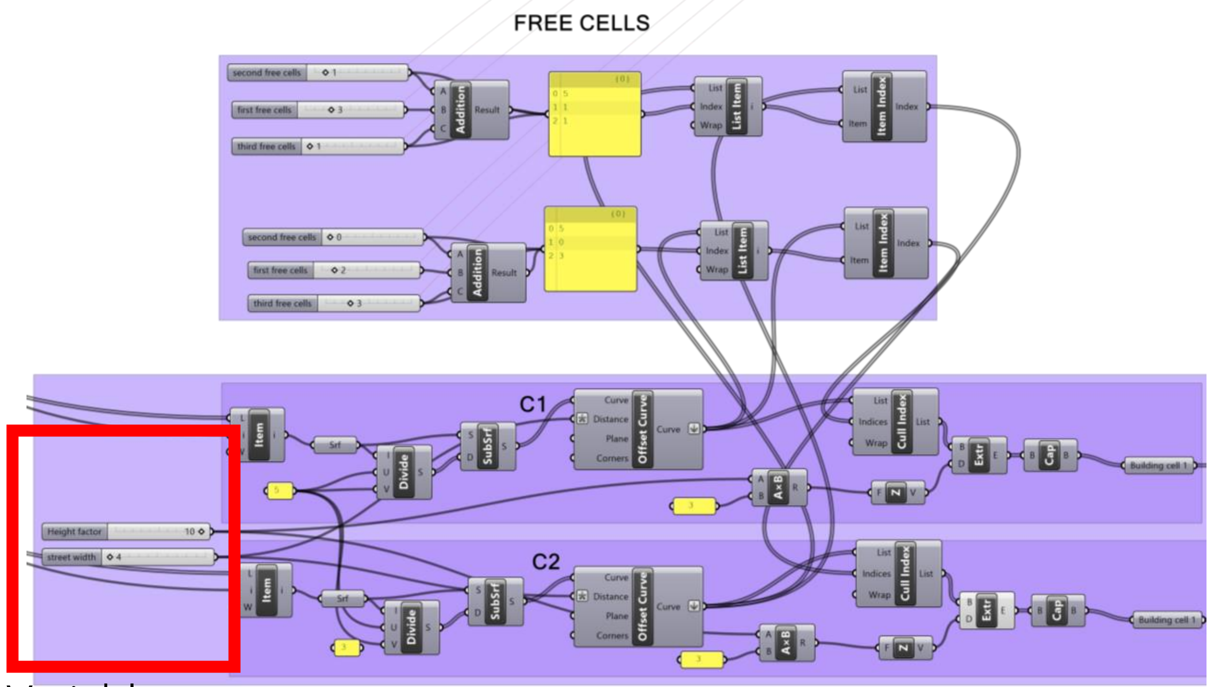
Variables
1. EXTRUDE
2. STREET WİDTH

Height ratio code for office buildings type



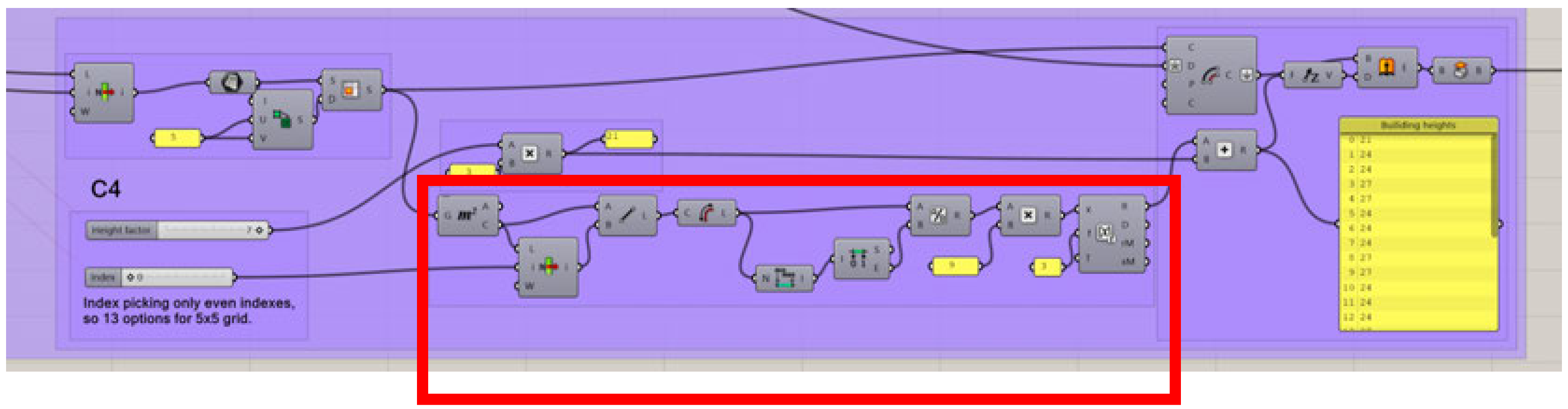
Variables
1. EXTRUDE
2. STREET WİDTH

Height ratio code for public mixed use buildings type



Variables
1. EXTRUDE
2. STREET WİDTH

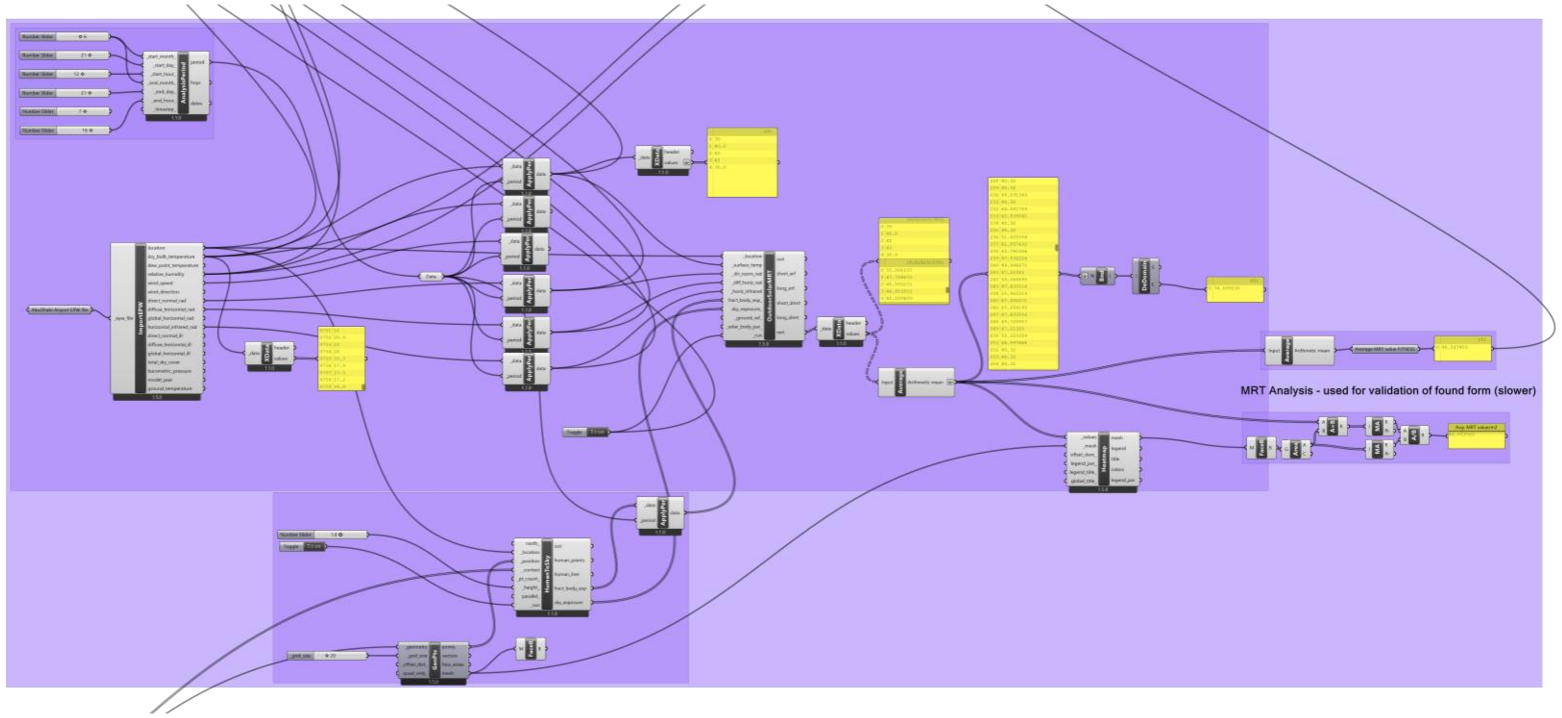
Height ratio code for residential type



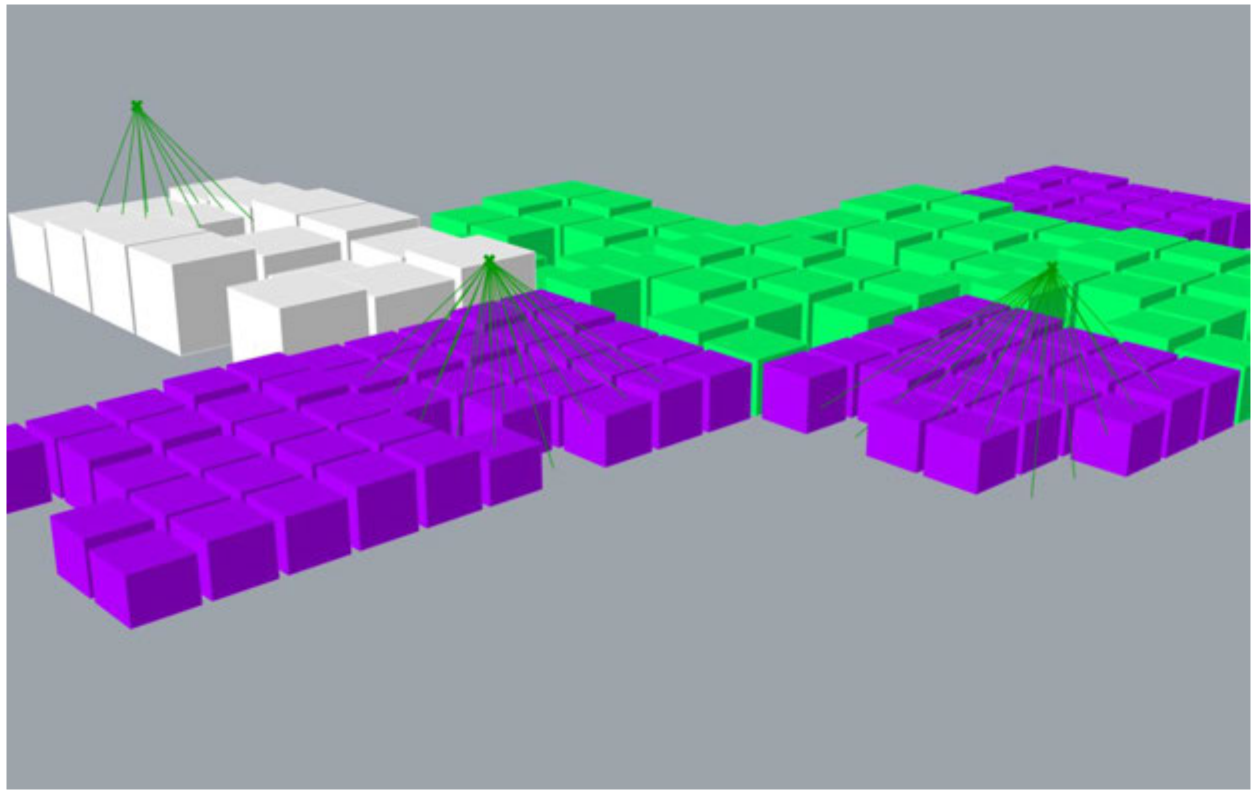
Attractive point code

BUILDING TOPOLOGY

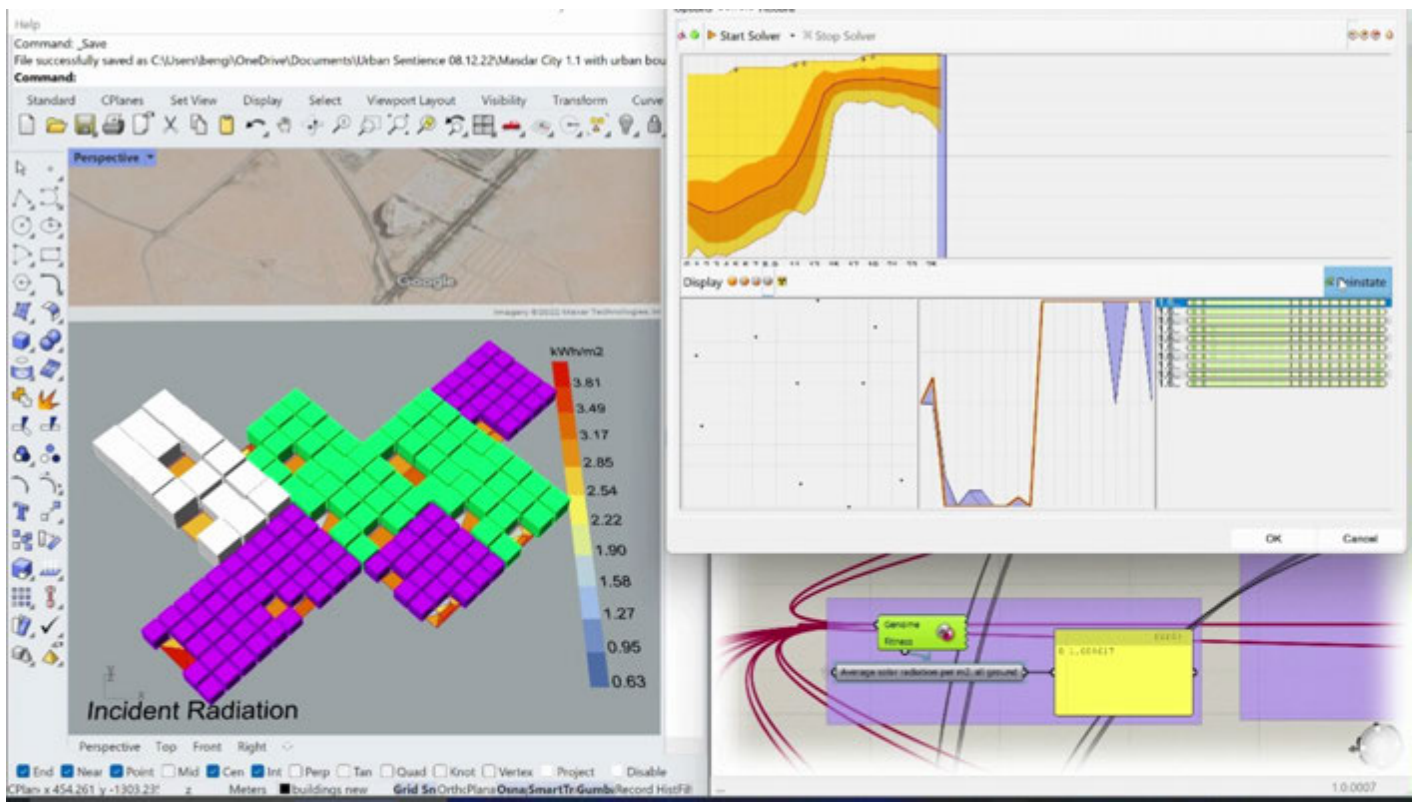
HEIGHT RATIO

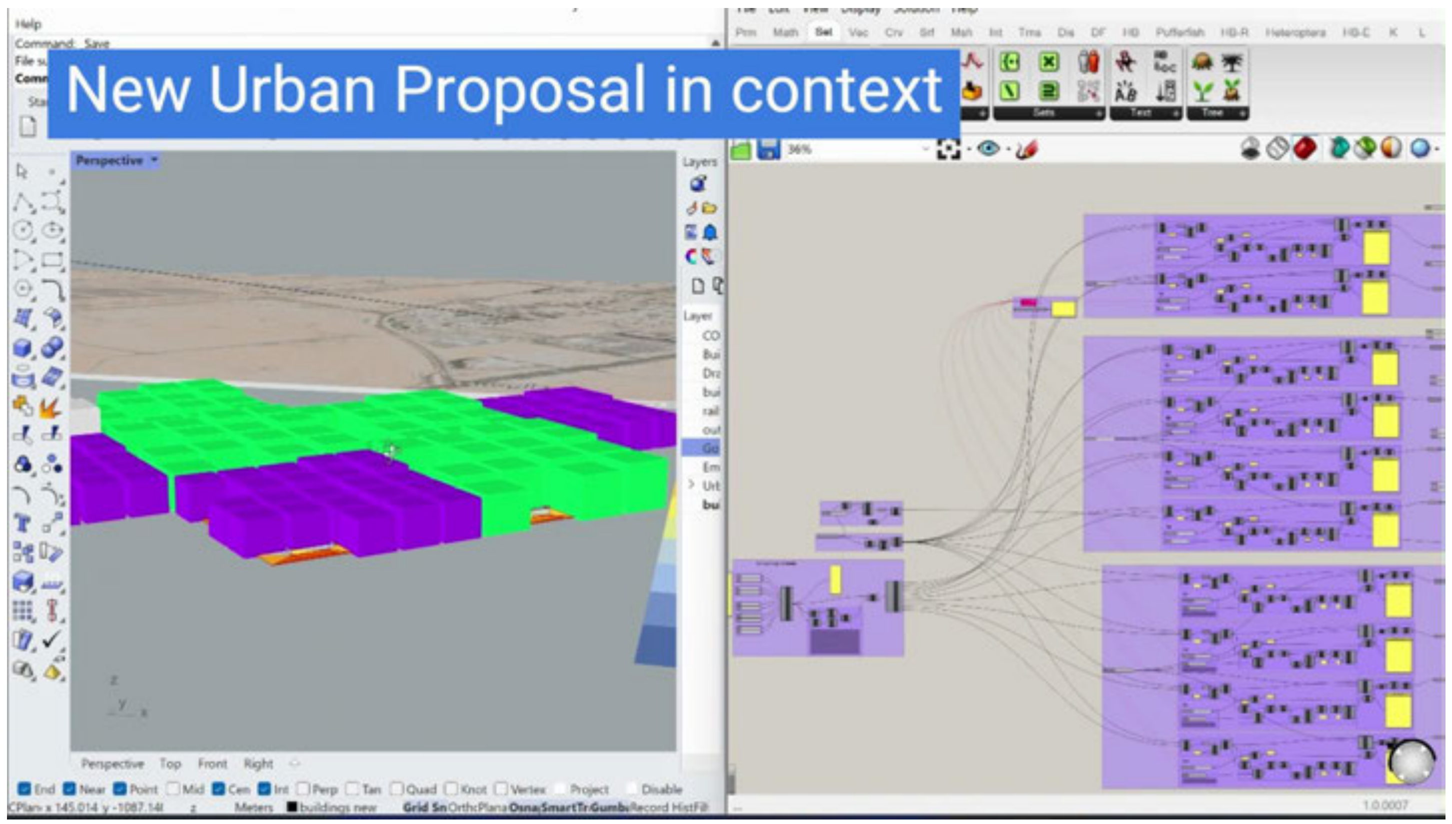


After all generating process, we evaluated MRT value



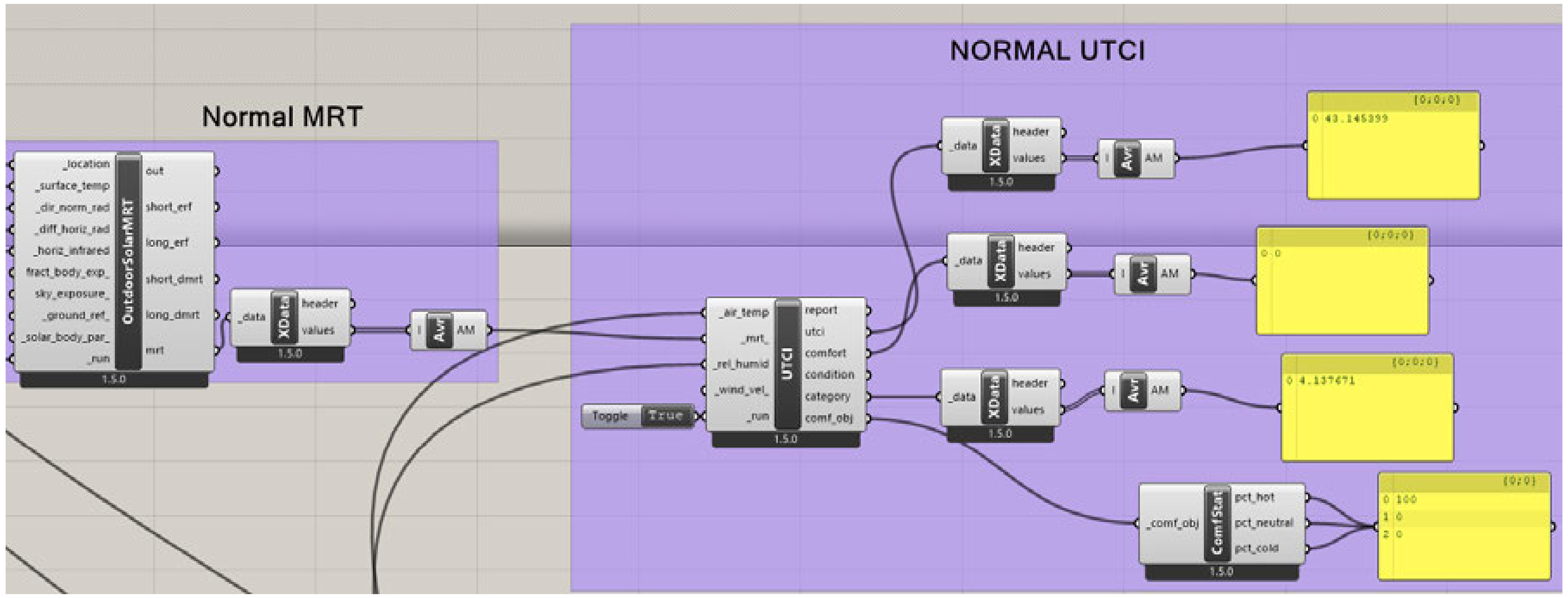
Attractive points for individual height of buildings



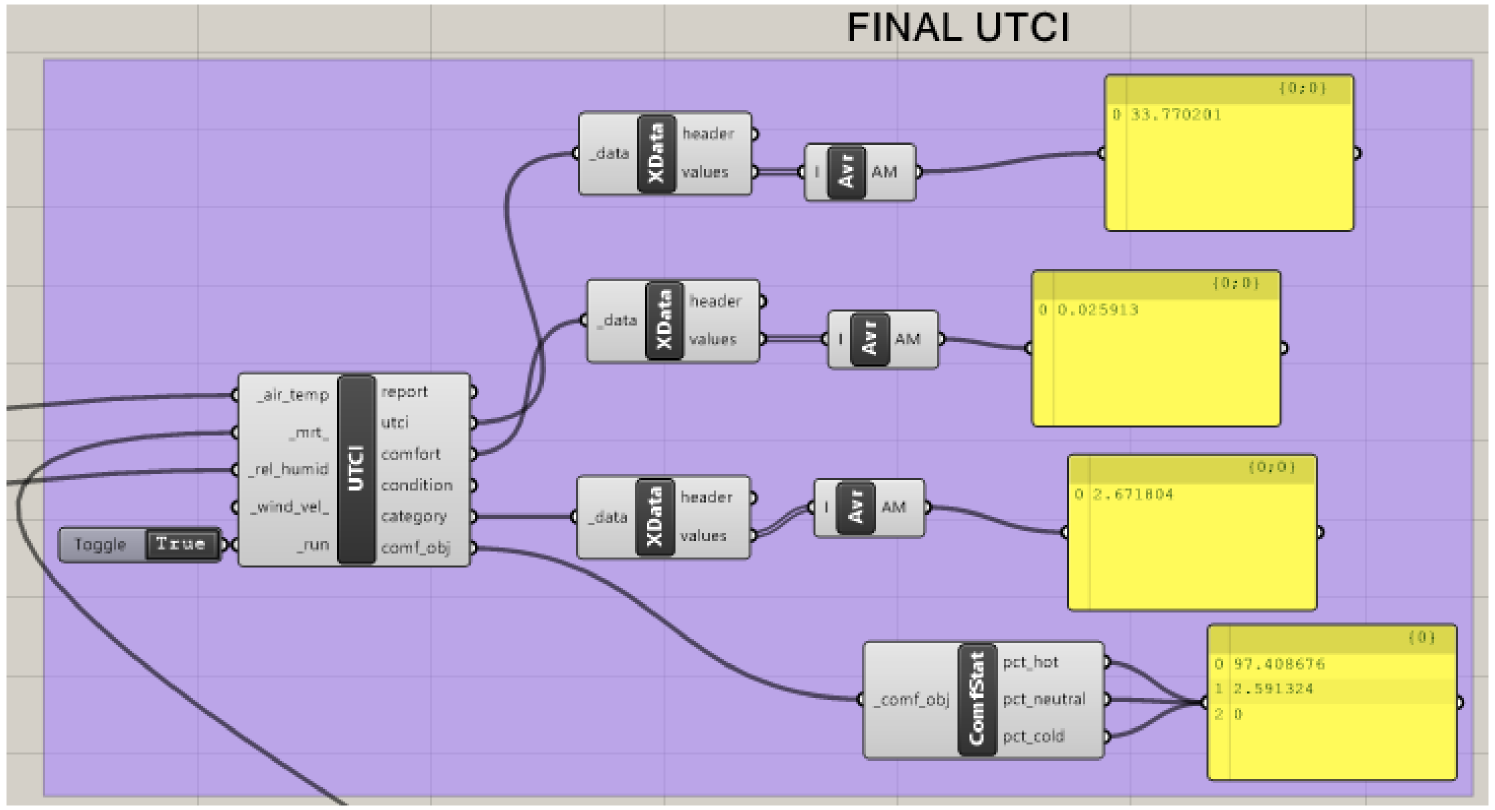


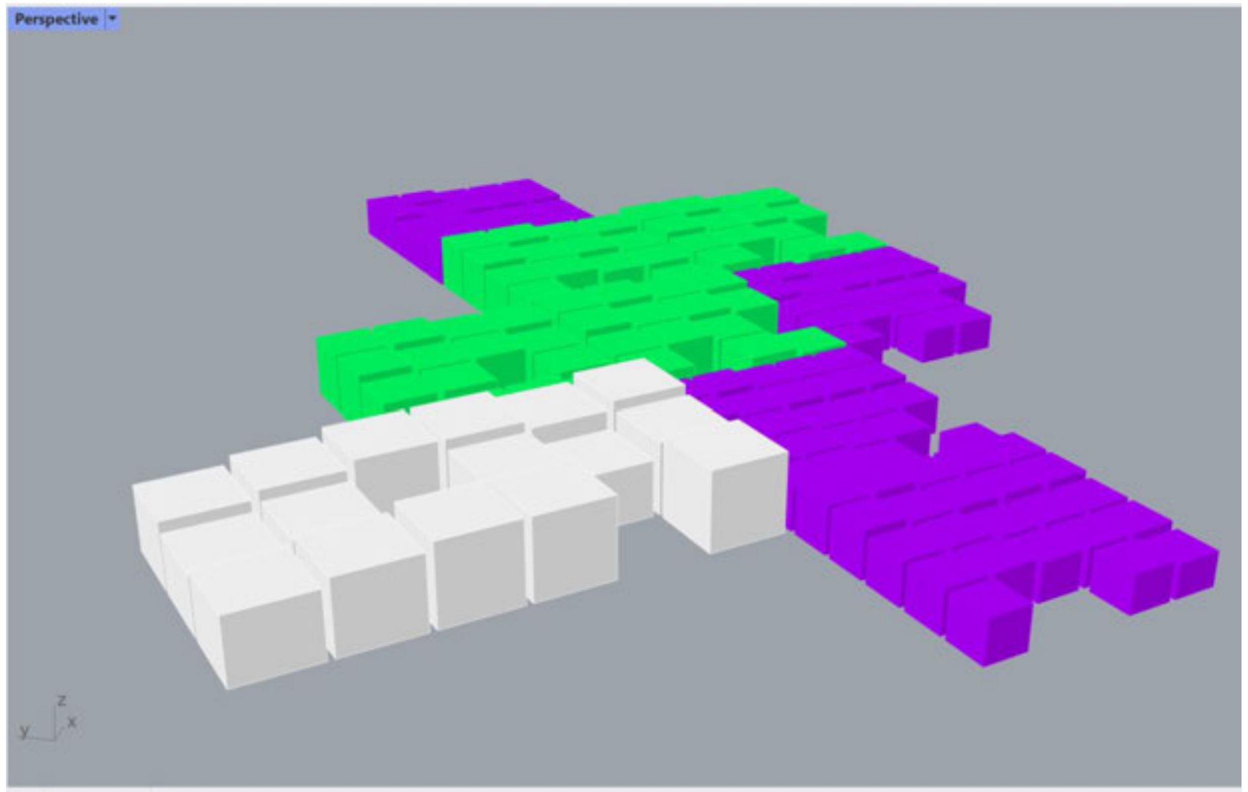
BUILDING TOPOLOGY

HEIGHT RATIO



Normal UTCI value is 43. We reduced this value to 33. So our comfort index between -5 /5 is 2 which is pretty good.(optium values is 0)

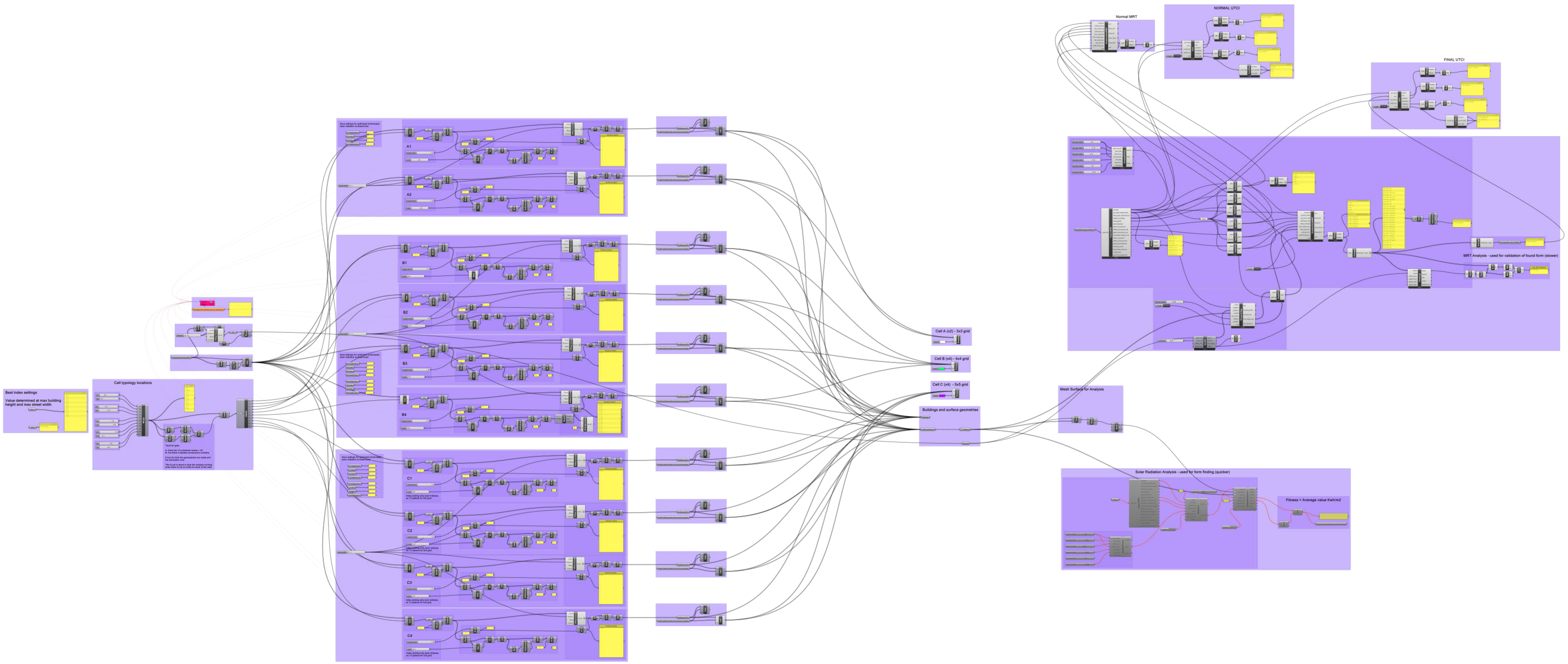




BUILDING TOPOLOGY

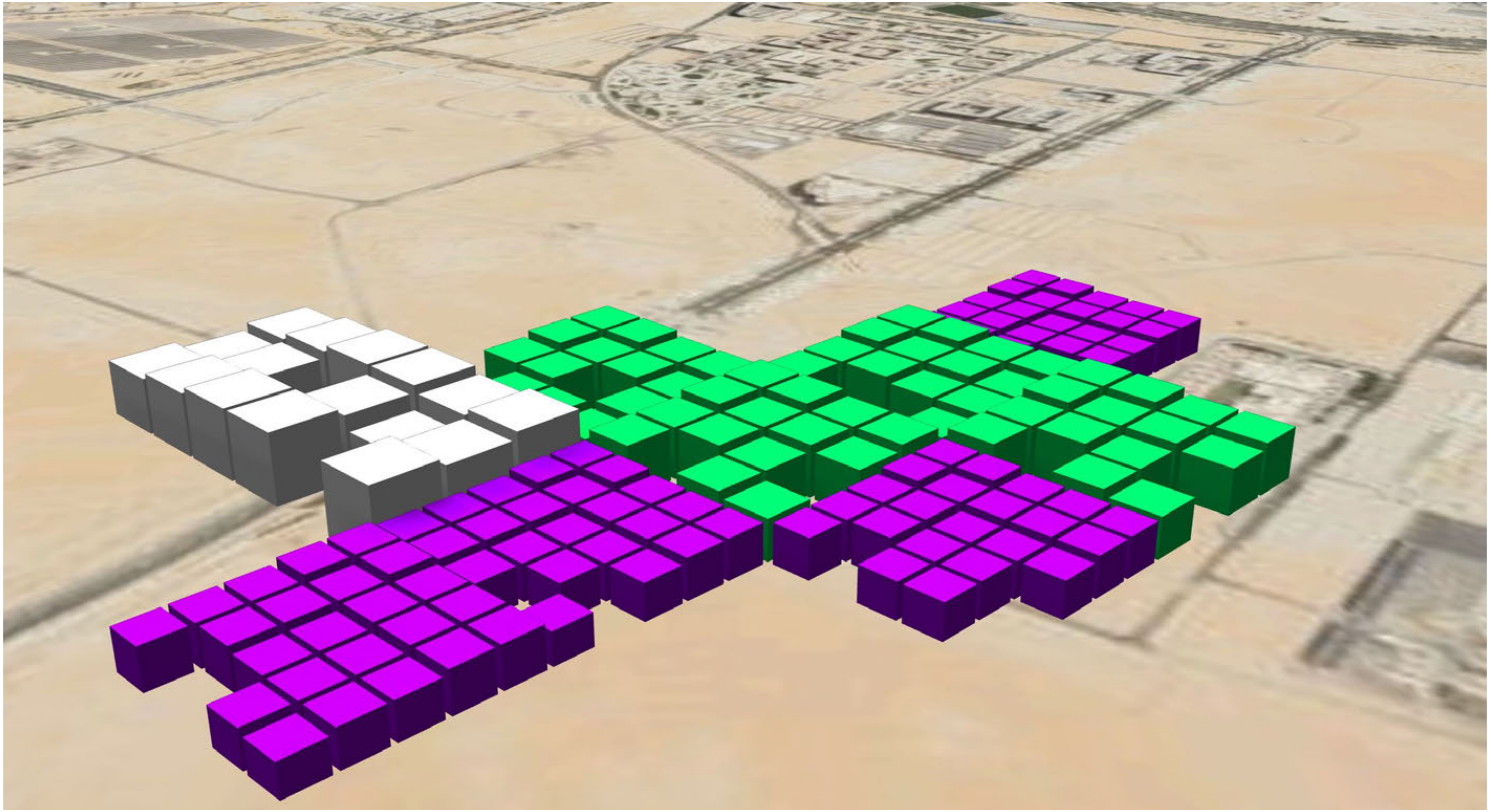
HEIGHT RATIO

Whole Code



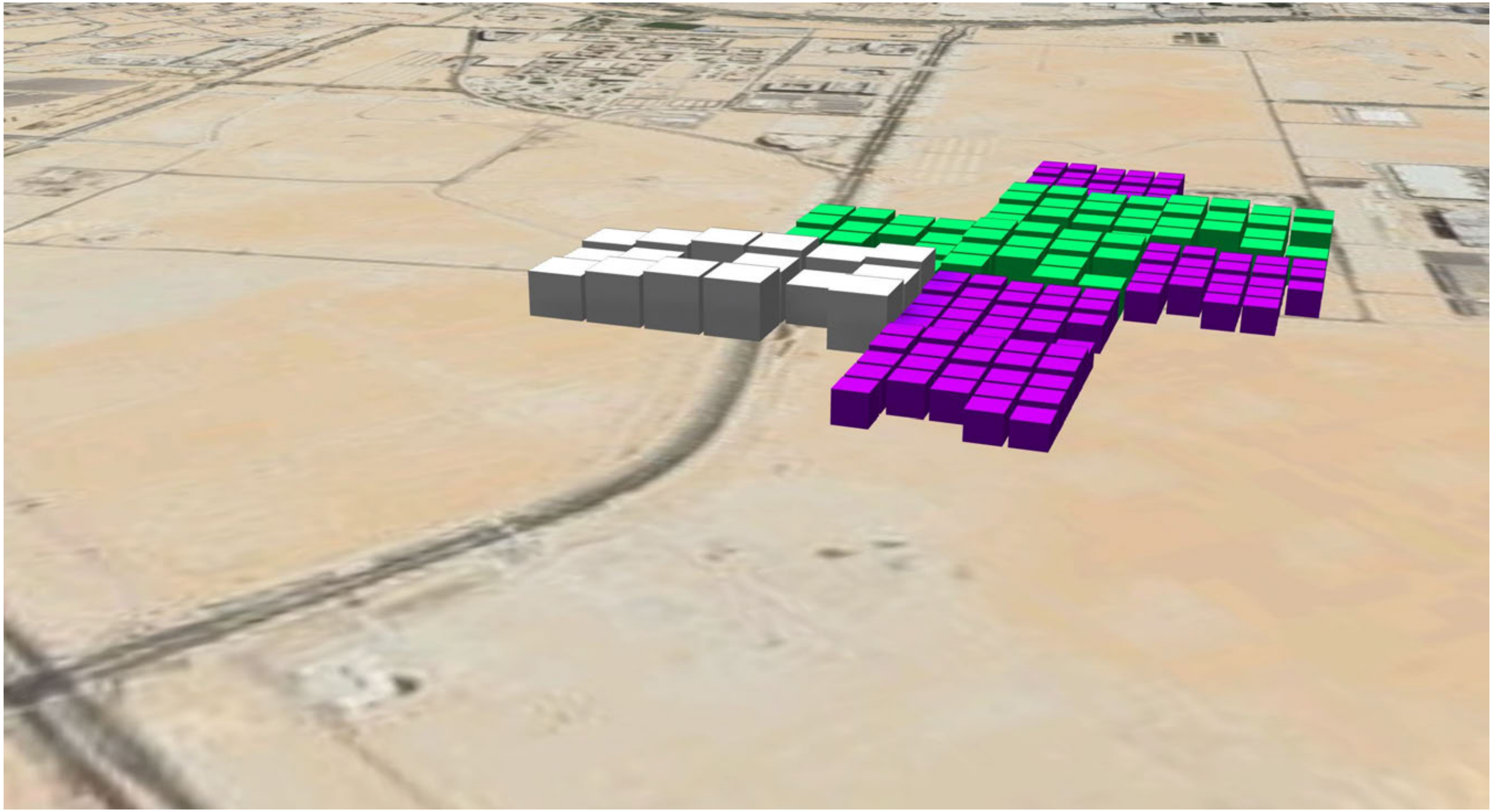
FINAL PROPOSAL

We designed next location of the Masdar City based on several fitness; Solar radiation, Wind, Mrt and Thermal comfort index.



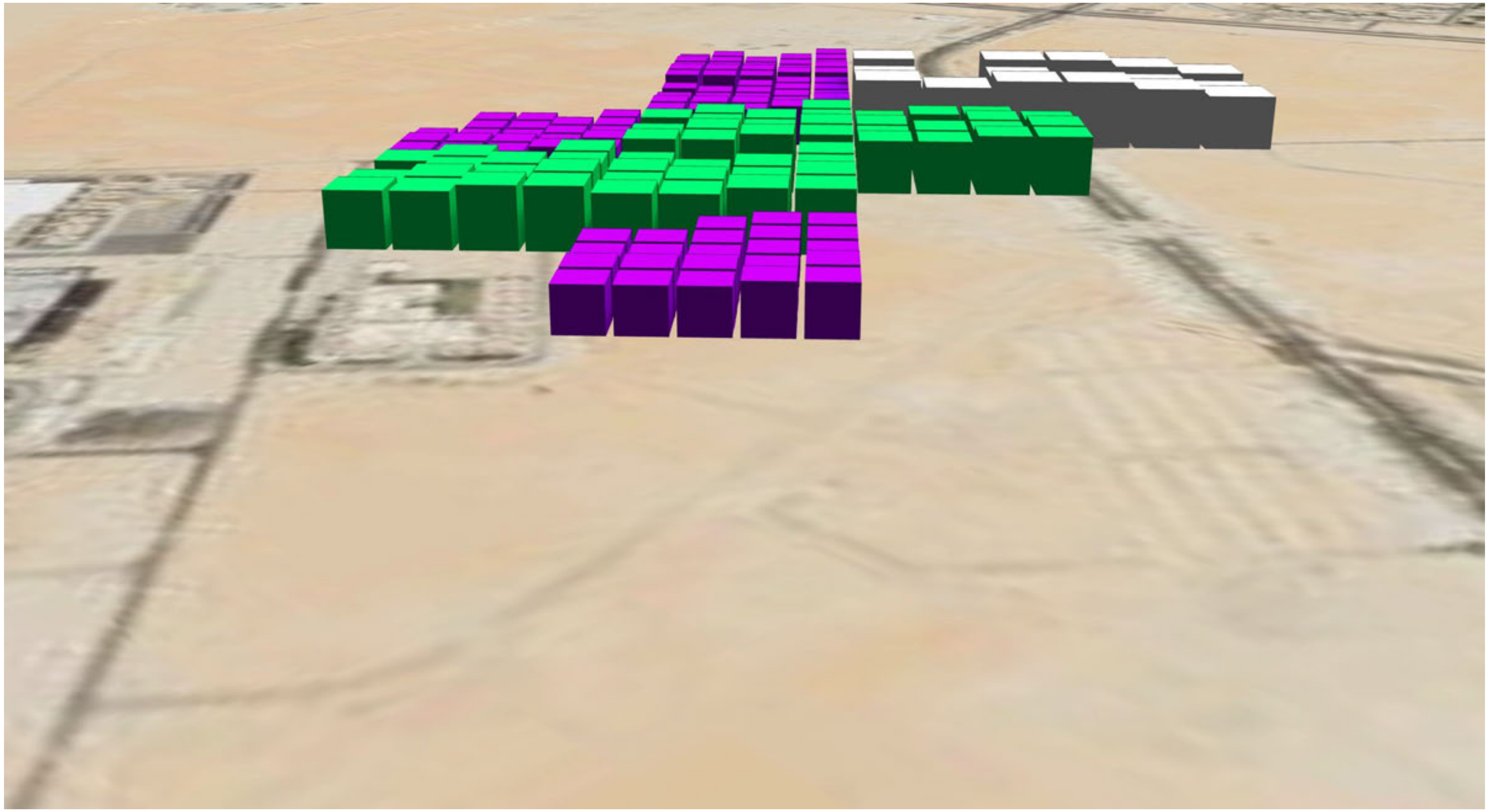
FINAL PROPOSAL

First, we generated next boundary for Masdar City. After then, defined the location of the 3 cell typologies based on avarage solar radiation at ground level



FINAL PROPOSAL

Height ration of buildings for each cell typology is determined by usin different values for each typology. Finally, by using attractive point based on avarage solar radiation, building heights were determined within the typologies themselves.



QR Code andlink for GA videos;
https://www.youtube.com/watch?v=79d2F8xtiR8

CONCLUSIONS

How new is our new?

The final proposal shares the same 45-degree oriented square grid layout with the Masdar plan. Simulations which analyze the solar radiation gained by the street surface show that this grid layout receives the least peak radiation at any 1 position compared to differently orientated hexagonal and square grid layouts.

The Urban boundary of the final proposal differs in emergence yet has similar roots to that of the Masdar plan. The Masdar plan includes avenues for the predominant winds to pass through, drawing the heat from the densely built areas. Instead, the final proposal positions the densely built areas where they are more directly exposed to all prevailing winds, perhaps cooling them more efficiently.

A reduced UTCI

The study has reduced the UTCI from 43°c to 33°c for the analyzed period. This could be reduced further if the empty cells that were generated (that currently increase the average UTCI across the street surface because they are unshaded) were modelled with vegetation providing the natural cooling effect they are well documented in providing.

Because final proposal is located where it is most exposed to the wind whilst allowing the existing area to remain as exposed to wind as possible, based on our hypothesis, the UTCI should be lower than calculated. This is because due to the complexity of wind simulations , we have not included the passive cooling effect of the wind when calculating the UTCI.

Further Developments?

Street width simulations, where the genetic algorithm was able to choose the preferred street width from between 4m – 8m for the least solar radiation at street level for each of the 10 cells, resulted in as expected, the narrowest streets. Too potentially add more street capacity for human activity and for passive cooling from prevailing winds to be more effective, investigating the optimized position of overhanging shading facades could enhance the livable viability of the final proposal beyond uniformly very narrow streets.

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