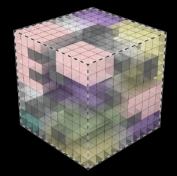
GEN-ARCH



PLATFORM FOR DEVELOPING
ARCHITECTURAL CONFIGURATIONS
USING GENERATIVE DESIGN
METHODOLOGIES.

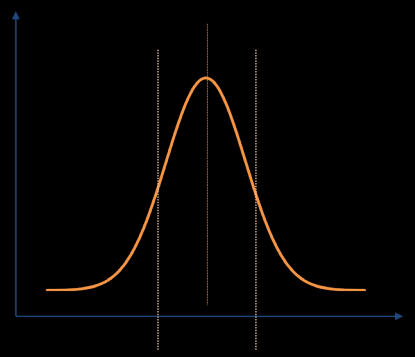
Mentors:

Dr. ir. Pirouz Nourian
Prof.ir.Thijs Asselbergs
Ir.Shervin Azadi

Background

The Global construction industry is growing ***exponentially.*** The world is expected to build ***230 billion square meters*** in new construction , in the span of next ***40 years*** (Thibaut Abergel, 2017)

Most of these buildings will lie in the middle segment of the economic cost. Access to good design is paramount for these buildings since they will have the ***maximum impact*** on the ***urban environment and sustainability.***

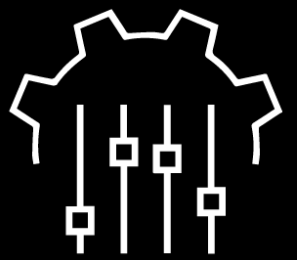


Problem Statement: Mass Customization

1.

In the Netherlands itself there is a need of constructing ***1 million affordable new homes*** by ***2030.*** Such a massive demand for new buildings has given rise to a need for a solution for ***mass customization*** of architectural configurations.

Simple repetition can lead to a badly configured building which in turn creates a lot ***of social and environmental problems. Generative Design*** can offer a digital solution for this ***mass customization problem.***



Problem Statement: Participatory Design

2.

There is a ***lack*** of an ***participatory aspect*** in the configuration process for the occupants. More often than not the Architectural configuration is planned to satisfy the ***architectural vision*** and the requirements of the stakeholders having ***the maximum monetary investment*** in the project.

Such an undemocratic approach lacks the inclusive element and creates ***unsatisfactory*** *solutions* which often leads to modification in spaces by the occupants after they are built, leading to a lot of ***resource wastage.***



Research Questions

1.

How can the 3D layout problem be solved computationally considering all the layers of complexities like ***multi-dimensional*** (spatial complexity), ***multi-criteria*** (Multiple conflicting design criteria), ***multi-actor*** (Stakeholders and their requirements), ***multi-value*** (Socio-cultural, environmental value etc.) together ?

Research Questions

2.

How can the ***3D layout configuration*** process become more ***participatory*** for the various ***stakeholders*** involved in the project?

Research Sub- Questions

1. How do you ***select*** an ***appropriate computational method*** for solving the layout problem ?

2. How do you create a ***participatory framework*** for the stakeholders involved ?

3. What is the ***methodology*** for ***analyzing the design variants*** ?

Research Methodology

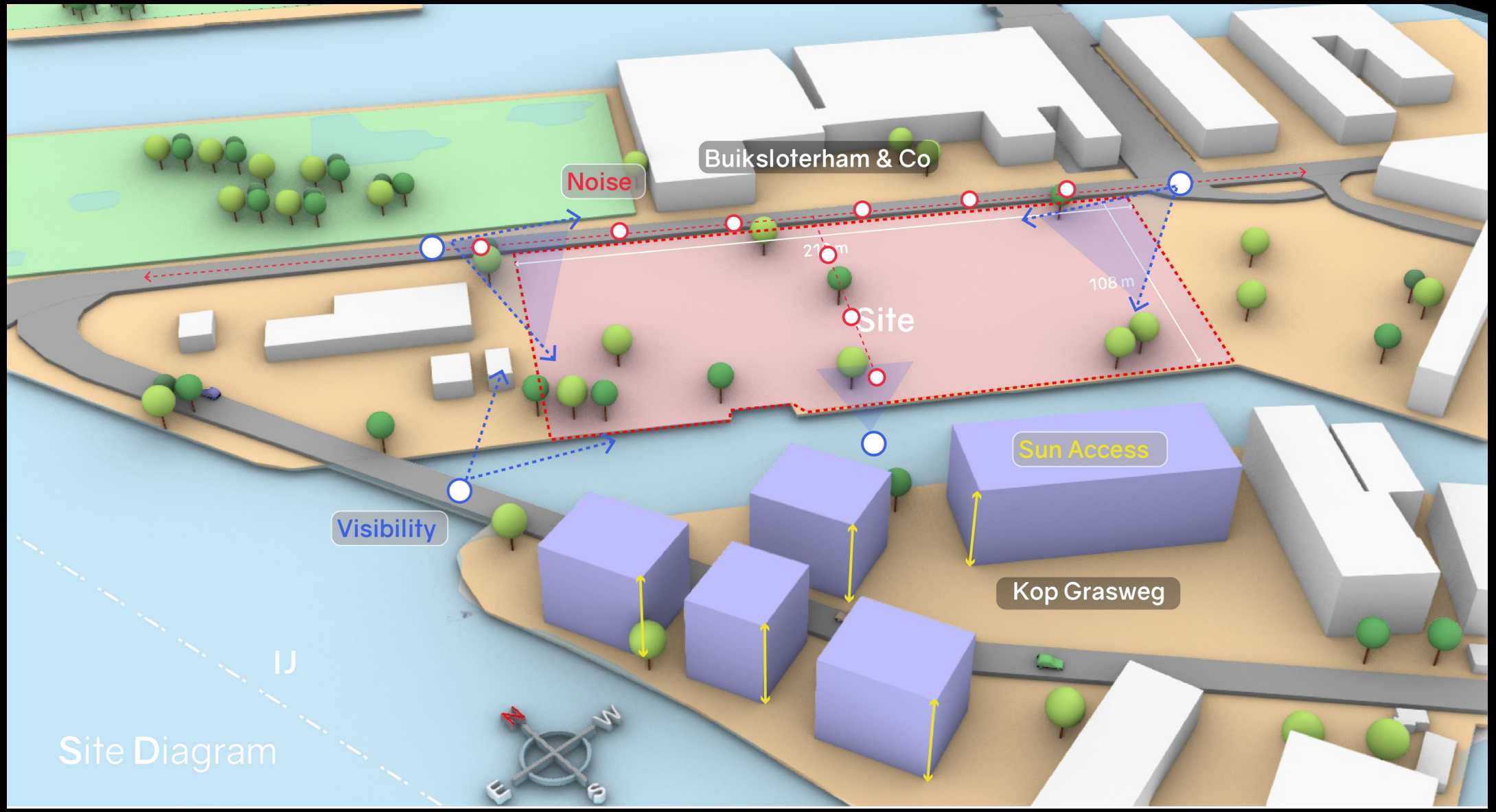
1. **Literature Review**
   - Generative Space Layout
   - Participatory Design
2. **Problem Formulation**
   - Nested levels of the 3D layout problem
3. **Case Development**
   - Develop a test case to test the newly developed methodology
4. **TOY Problems**
   - Develop small TOY problems to test out the method
5. **Solving the Case**
   - Use the methods in the TOY problem to solve the Case
6. **Conclusions**
   - Derive Conclusions about the methodology from the test case
7. **Future Development**
   - Draw a framework for the future development of the platform

THE PROBLEM CASE

1.

In order to test the methodology proposed a problem case was considered for the design of a ***mixed used*** residential and commercial open building in the ***Buiksloterham neighborhood*** in ***Amsterdam.***

1. Buiksloterham has a lot of ***empty plots*** and no ***monumental buildings*** which provides a ***blank slate for experimentation*** of a new methodology of designing buildings as proposed in this thesis
2. Buiksloterham is the first ***circular neighborhood*** in Amsterdam and is envisioned as the test bed for the future of Amsterdam with an aim of creating a ***makers economy.***
3. It is designated as an ***Living lab or experimental zone*** which makes it perfect for applying new technological and management approaches.
4. It is pushing for an ***inclusive development*** where several plots are reserved for the citizens to develop themselves and calls for inclusive governance in general.

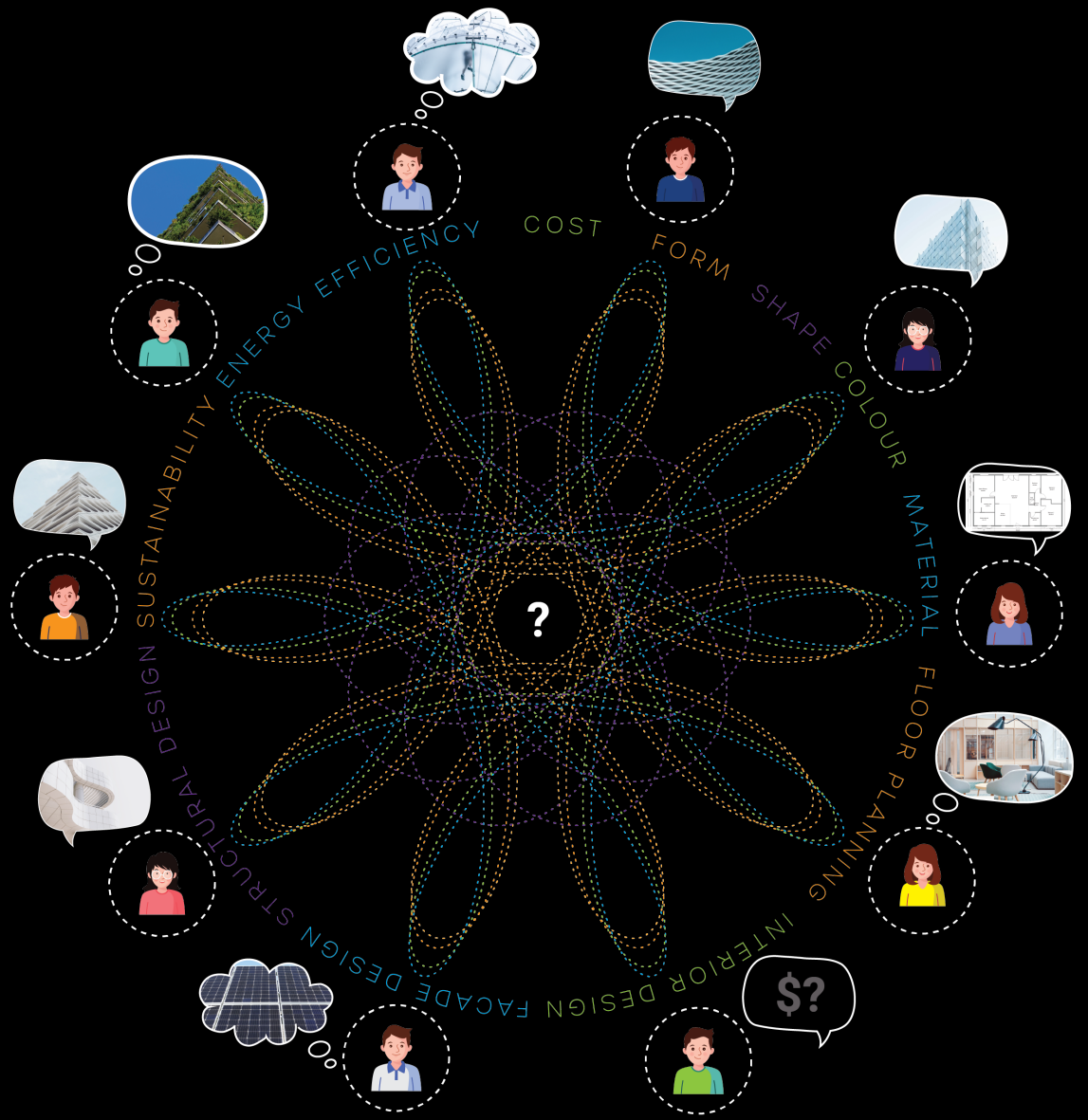

Noise
Buiksloterham & Co
Site
108 m
Sun Access
Visibility
Kop Grasweg
IJ
Site Diagram

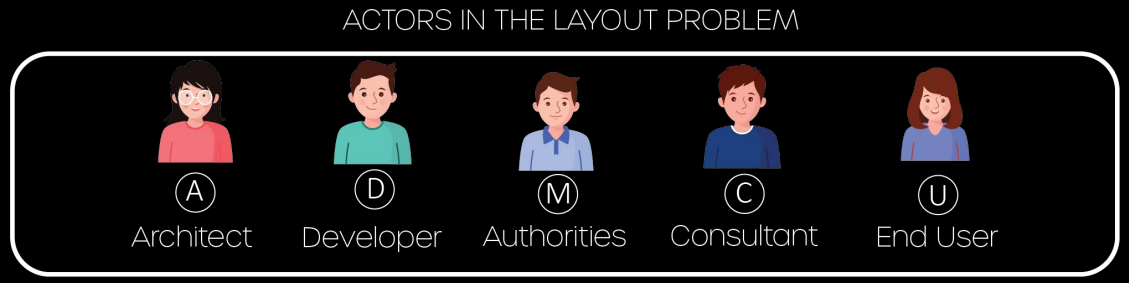
THE 3D LAYOUT PROBLEM

3D Layout Problem :

The problem of 3D layout configuration, when regarded in its full sophistication, is a classical example of a ***wicked problem*** that is at the same time a ***complex combinatorial problem*** due to the various ***Human/Physical complexities*** involved.

Coming to a ***consensus about the goals of the layout problem*** itself becomes a complex task often due to the ***multi-actor*** complexities involved.

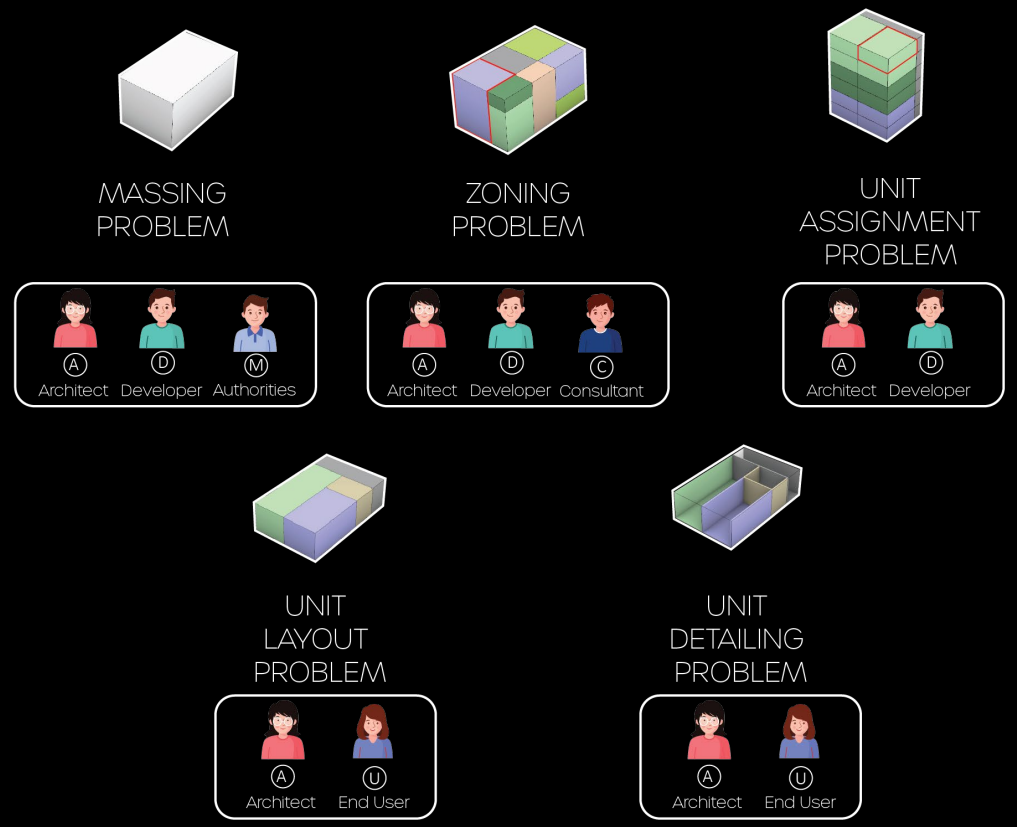




3D Layout Problem : Nested Problems

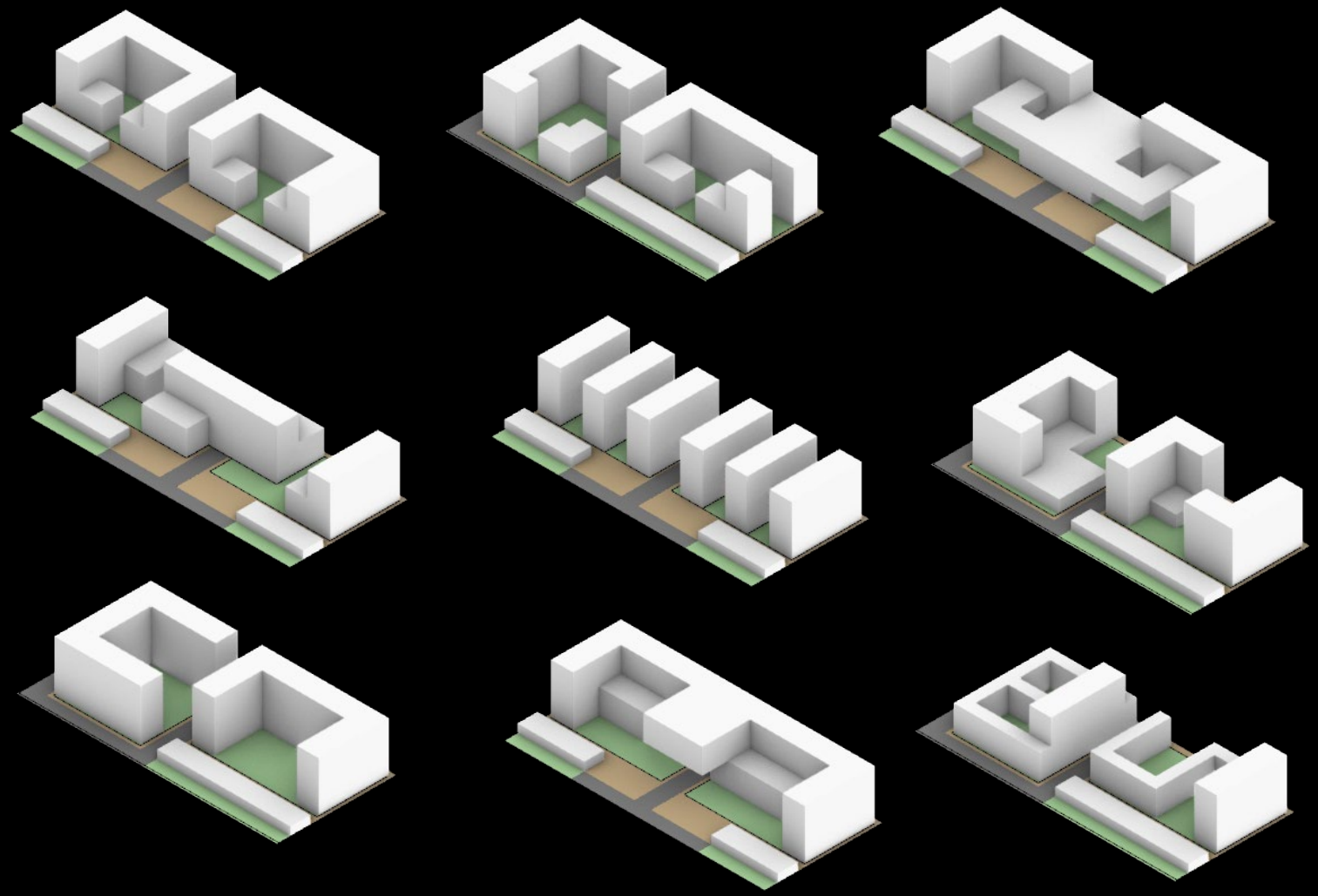
In this thesis an attempt is made to systematically ***separate the process*** of 3D layout configuration as a series of steps with ***local goals*** and with a certain set of ***assumptions and simplifications*** to achieve the ***global spatial planning goals***

Stakeholder participation at each stage is defined and the ***participation framework*** is included in the problem solving method



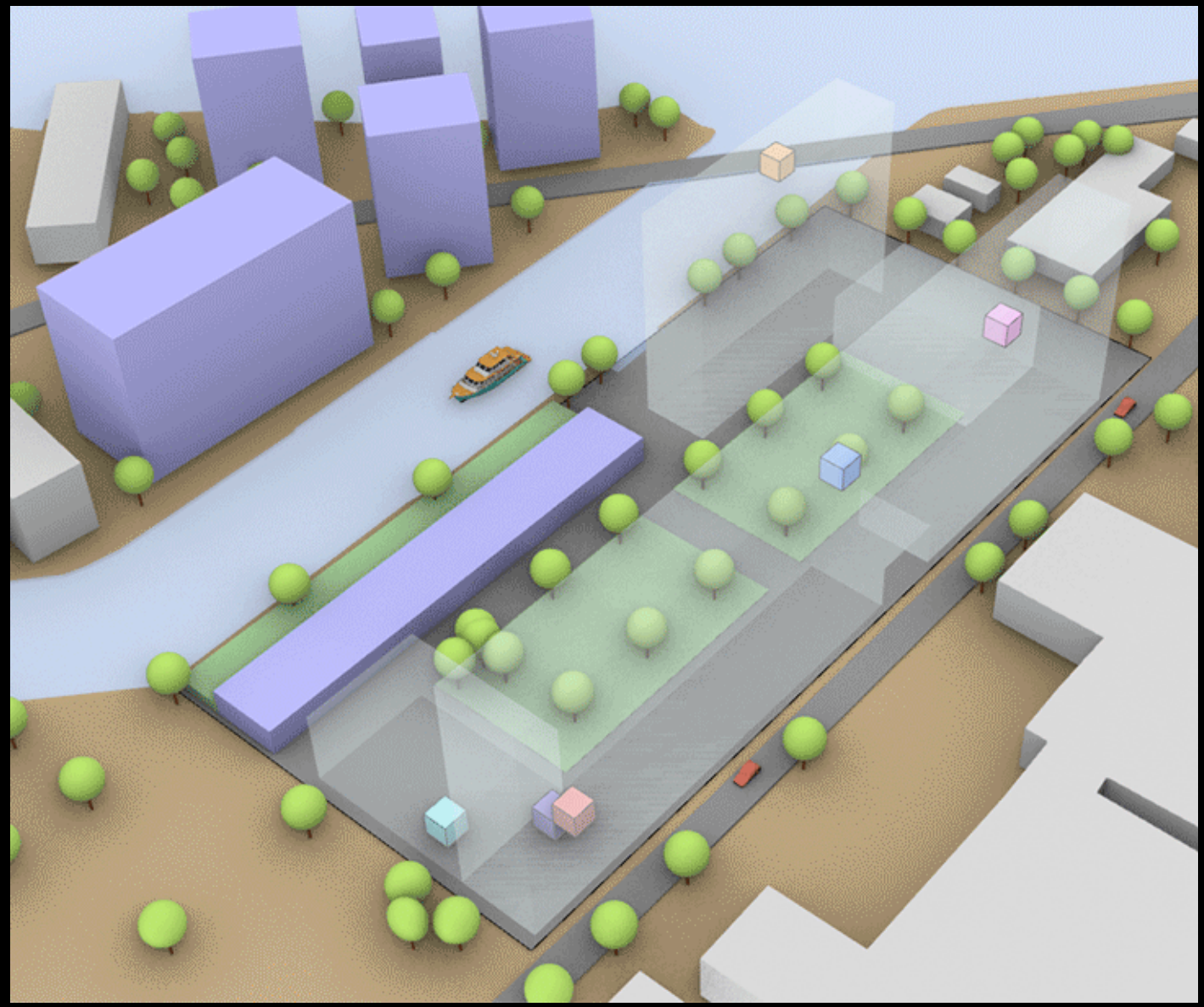
1. THE MASSING PROBLEM

The problem of finding the ***appropriate volumetric design*** of the building is the highest level of the space layout problem. In this stage the impact of placing volumes representing the built mass on the site is studied with respect to its effect on the surrounding buildings as well as its own performance in achieving the ***urban level design goals.***



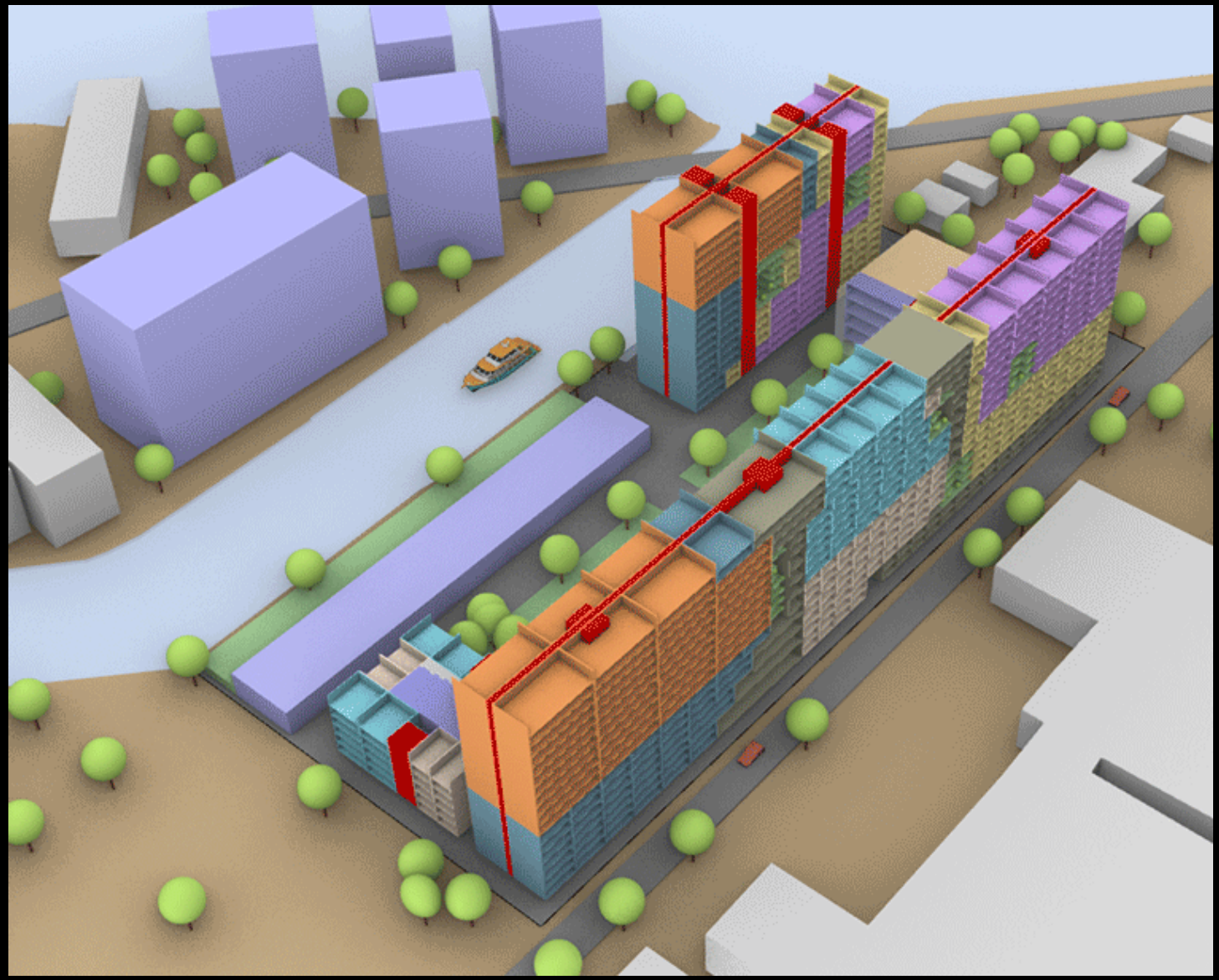
2. THE ZONING PROBLEM

The zoning problem deals with ***designating the appropriate locations*** for the various functions in the space program clubbed under particular zones. Two things are particularly important in a zoning problem the ***closeness requirement*** between the zones and the ***appropriateness of the location*** of the zones in the massing model.



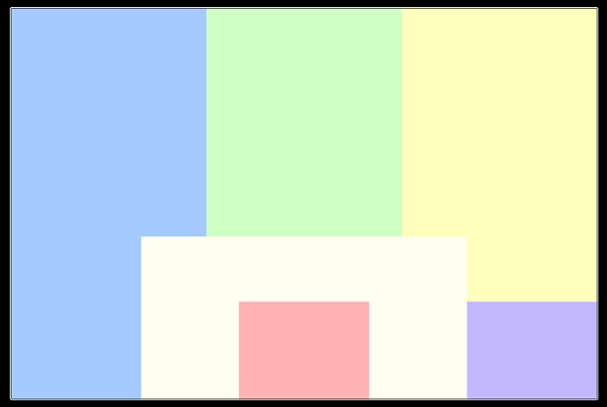
3. THE UNIT ASSIGNMENT PROBLEM

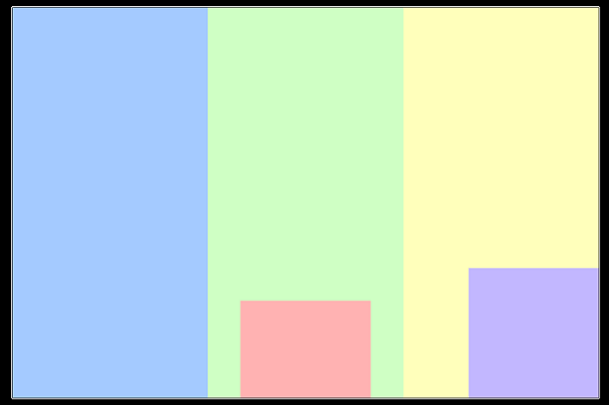
The Unit assignment problem deals with ***assigning units inside the zones*** created in the previous layer of the configuration problem. Unit can be defined as an entity in the space program which comprises of a ***self contained set of rooms*** collectively catering to a common function. A three room apartment in a zone dedicated for an apartment complex is example of unit inside a zone.

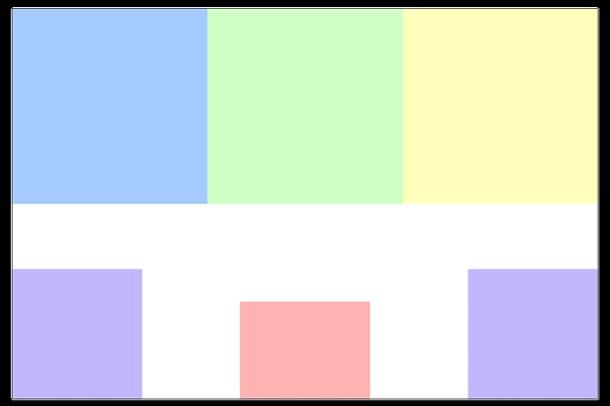


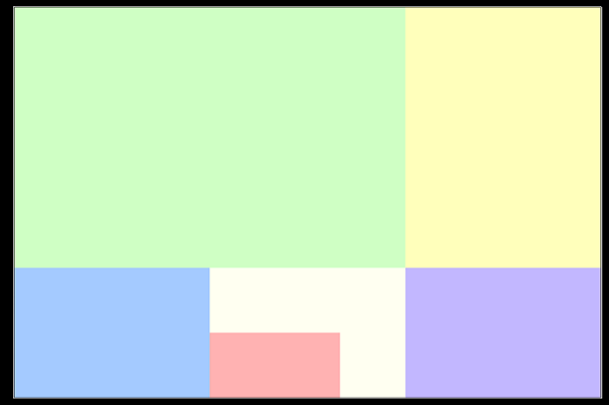
4. THE UNIT LAYOUT PROBLEM

The Unit layout problem deals with the ***generation of layout for individual units*** as defined in the unit assignment problem. The unit layout is highly dependent on the use case scenario of the space so the interaction and the participation of the user of the space is extremely important at this stage.



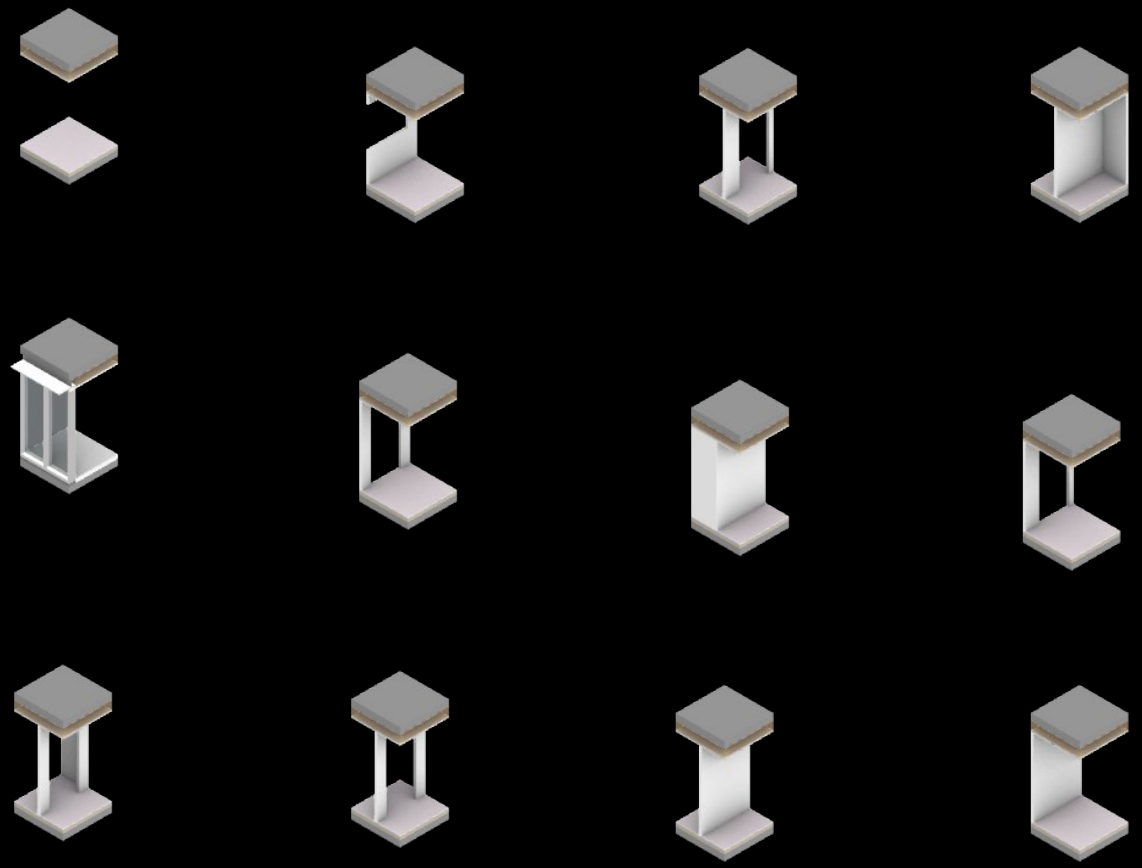






5. THE UNIT DETAILING PROBLEM

The Unit detailing problem deals with ***generation of design details*** for the units developed in the unit layout problem. Design details may consists of the following things: ***Materials and components of the various infill layers in the unit like Walls, Windows, facades, floors, ceilings, installations, furniture etc***.



THE ZONING PROBLEM

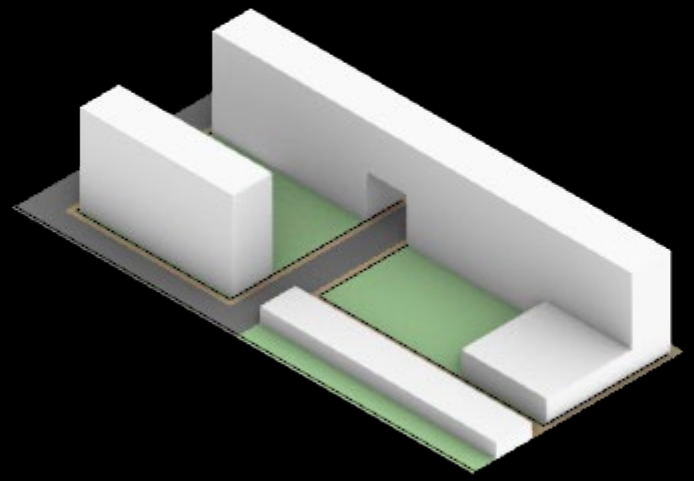
THE ZONING PROBLEM

1. The zoning problem involves ***generation and allocation of zones*** inside a building mass which will cater to a specific function from the program of requirements of the building.
2. There are two aspects to this problem, the first one being the ***location of the zones considering their closeness requirements*** and the and the second one is the ***shape*** and ***topological structure*** of the zones with respect to the ***island formation, connectivity and form.***
3. Generating a good zoning solution will involve balancing the two aspects of the problem.
4. In this project the concept of a ***multi-agent system*** is used to solve the problem of Zoning because of its ***flexibility*** and for ***didactic*** reasons.

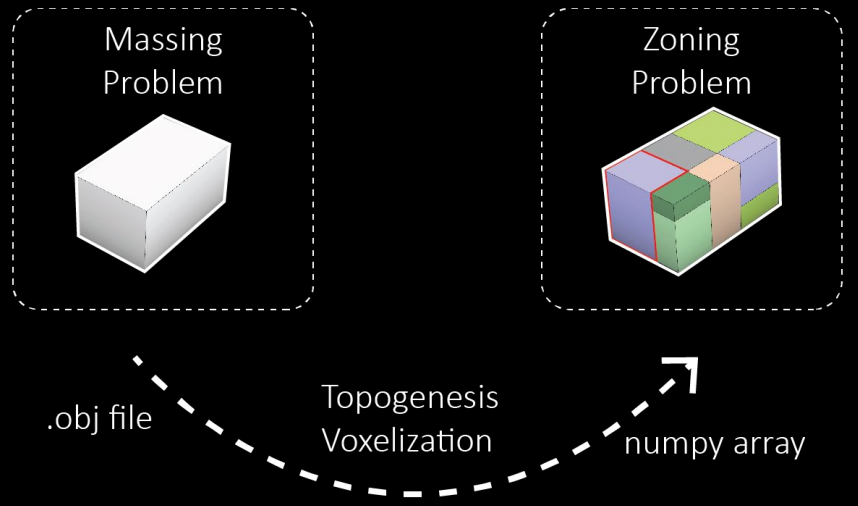
ZONING REQUIREMENTS

Zones	Volume in m^3	Number of Voxels (6x6x6)m
1.Privately owned Housing	97,416	451
2.Free Sector Rental Housing	87,048	403
3.Social Sector Rental Housing	65,061	301
4.Offices	20,088	93
5.Restaurants	4,104	19
6.Retail	15,768	73
7.Parking	11,016	51

* The volumes and space program is derived from literature research about the location , plans and regulations of the municipal corporation and the site areas

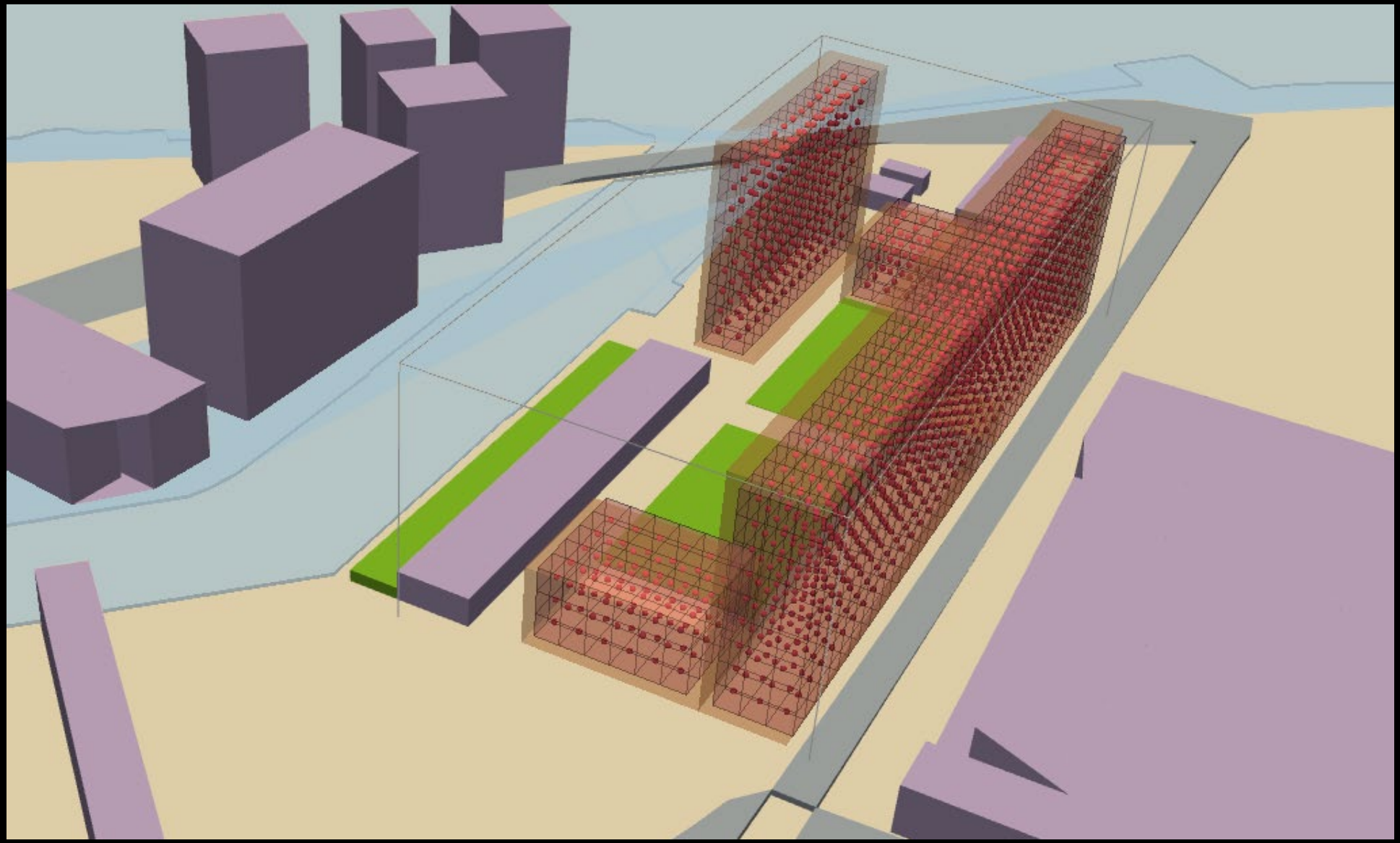


Selected Massing model



1.

THE MASSING MODEL IS VOXELATED.



MULTI-AGENT SYSTEM

A multi-agent system was developed where the ***computational agents act as proxies for the human actors*** and try to ***satisfy the criteria and maintain the validity constraints.***

In doing so, the agents pursue the adaptable agenda of the actors and ***grow a design decision*** for the zoning problem together as a multi-agent system.

There are three main elements of the Multi-Agent System:

1. ***Environment lattices*** which are nothing but spatial quality indicators for the voxels in the discretized massing model.
2. ***Desirability Lattices*** indicate the desirability for each voxel in the massing model with respect to the decision making done by the actor regarding the spatial qualities for a particular zone.
3. ***Agent behaviors*** are the actions which the agents representing the actors can perform to achieve the goals set by the actors for the zoning.



ENVIORNMENT LATTICES

The Spatial indicators developed for the project are specific to the problem case and can be modified according to the context in which the project is located. The indicators generated can be classified into two types:
The first one is based on ***calculating distances either Euclidean or Manhattan*** and the second one is based on ***calculating intersections between the rays originating from the reference geometry and the context.***

Distance / Closeness Based

- Closeness to Ground
- Closeness to Roof
- Closeness to East Façade
- Closeness to West façade
- Closeness to North Façade
- Closeness to South Façade
- Quietness

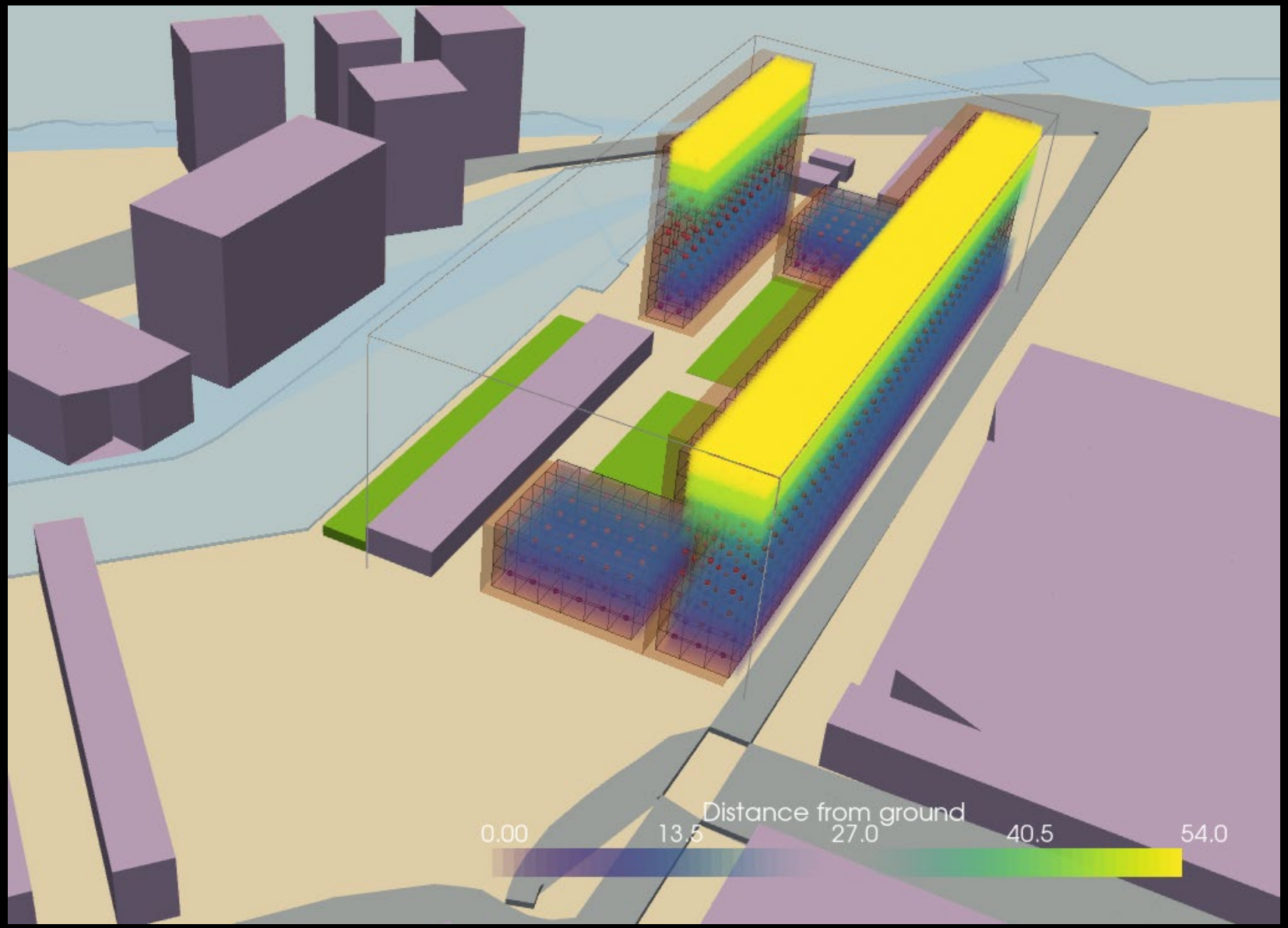
Mesh Intersection Based

- Visibility towards the IJ
- Visibility from the Adjacent Road
- Sun-access lattice

1.

DISTANCE FROM THE GROUND SIMULATION

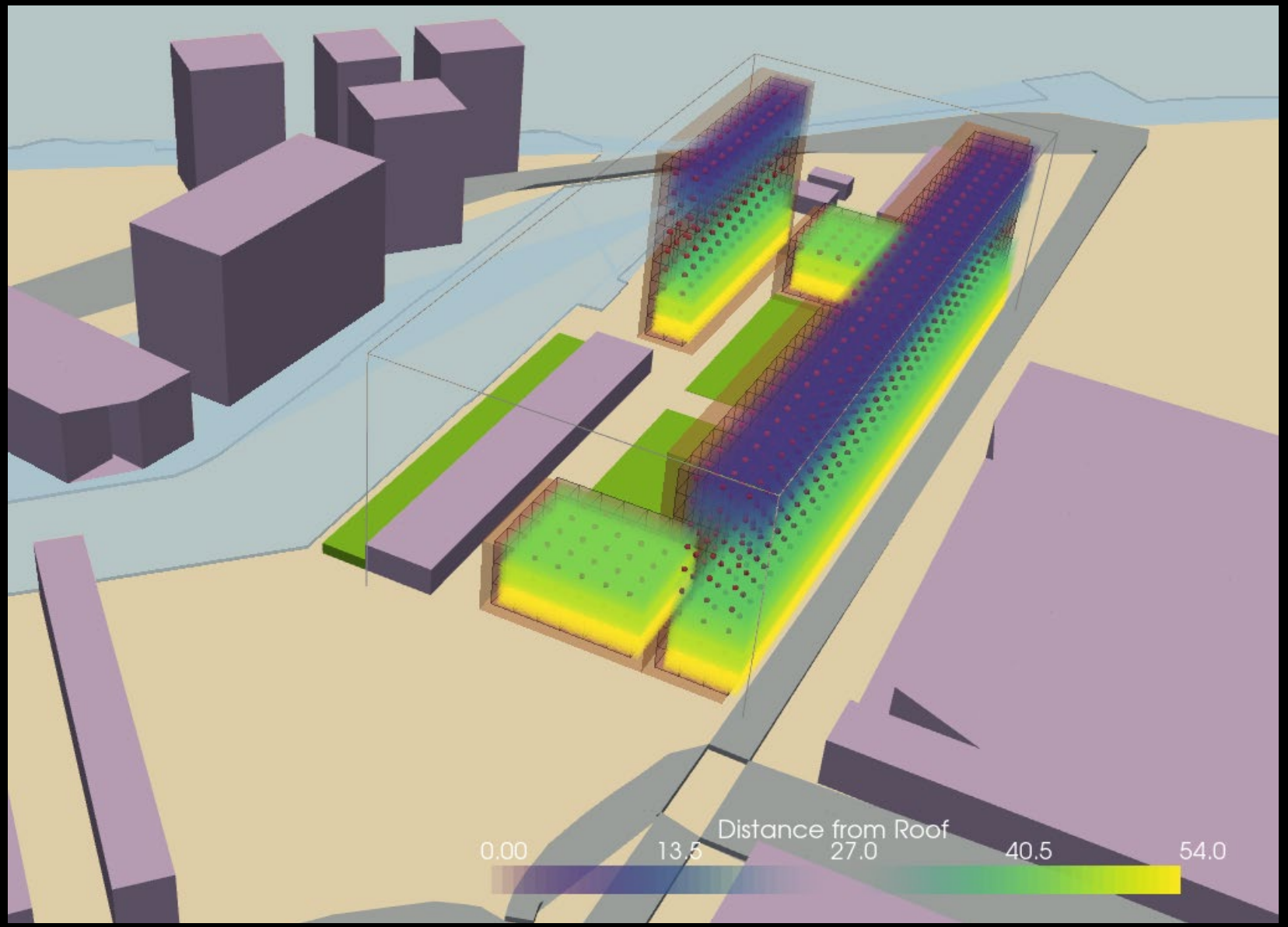
Distance based simulation



2.

DISTANCE FROM THE ROOF SIMULATION

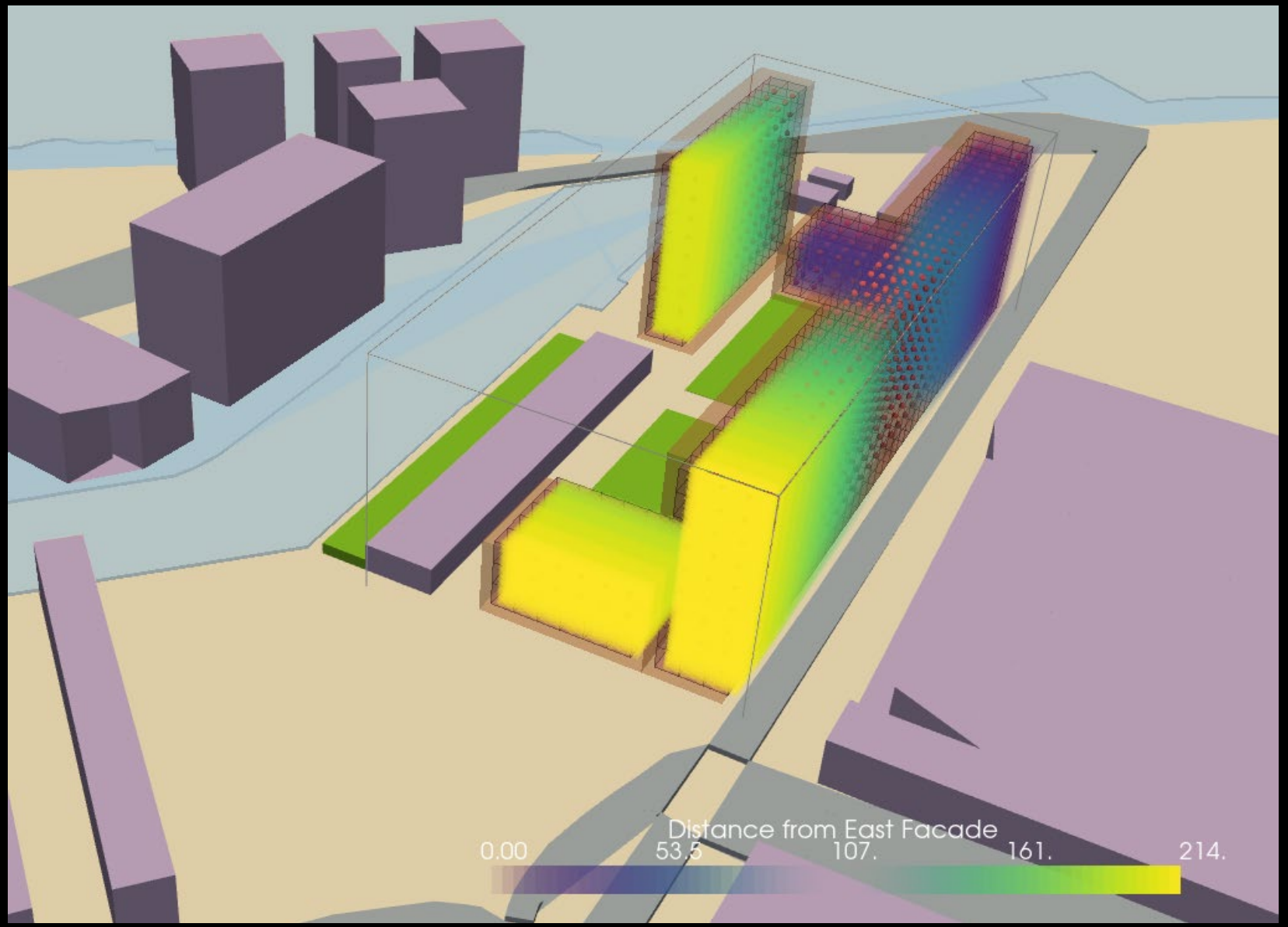
Distance based simulation



3.

DISTANCE FROM THE EAST FACADE SIMULATION

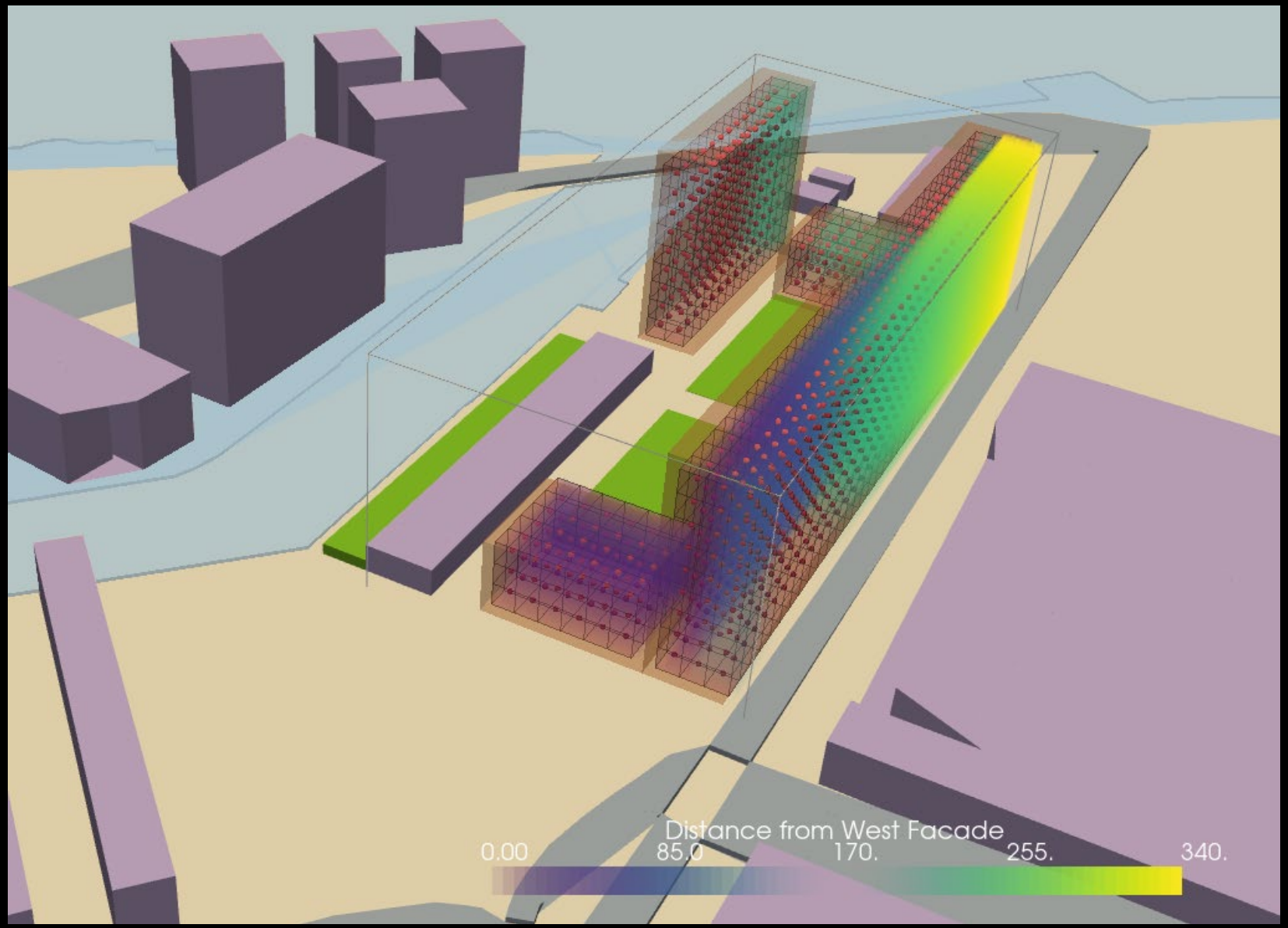
Distance based simulation



4.

DISTANCE FROM THE WEST FACADE SIMULATION

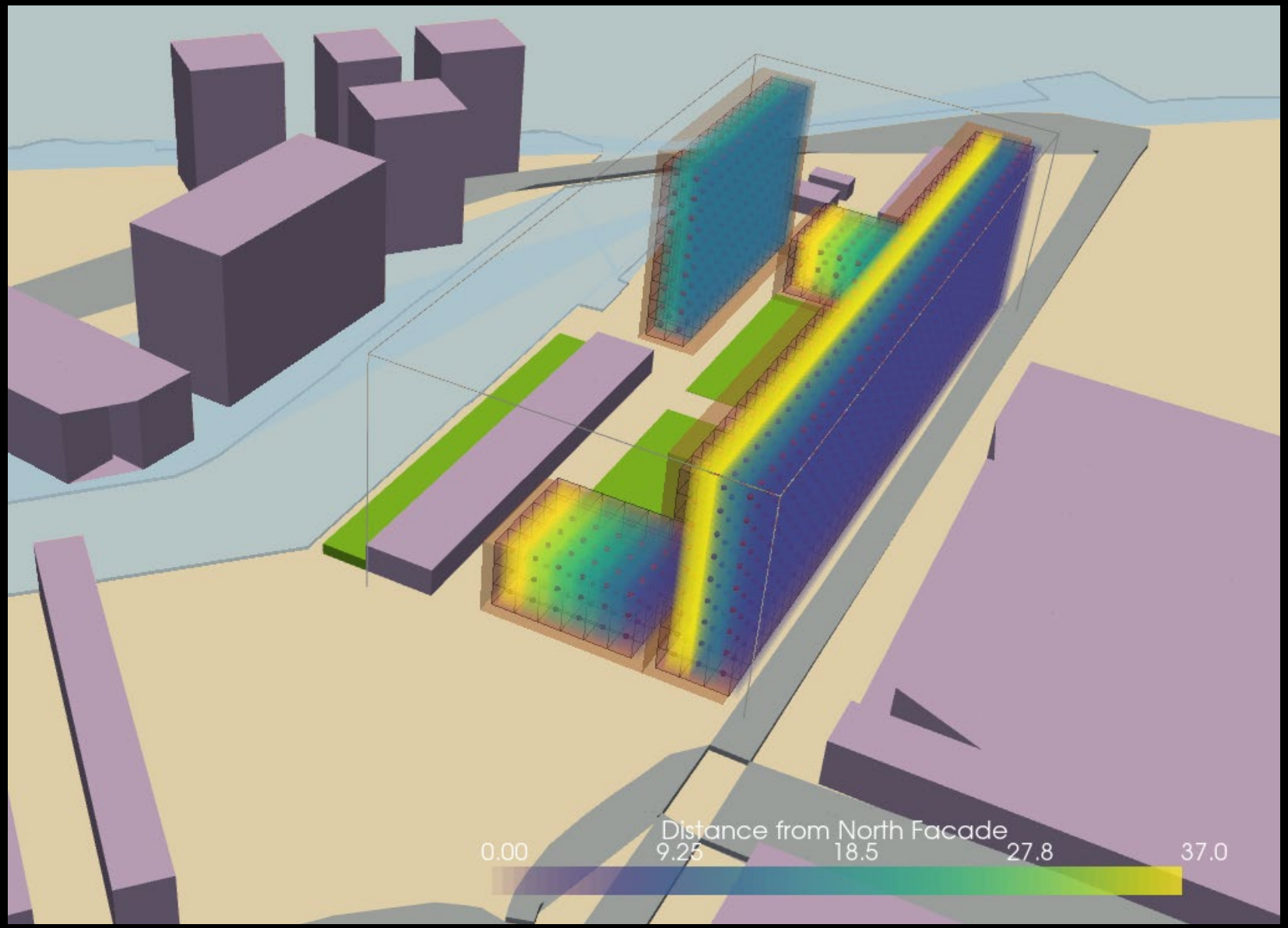
Distance based simulation



5.

DISTANCE FROM THE NORTH FACADE SIMULATION

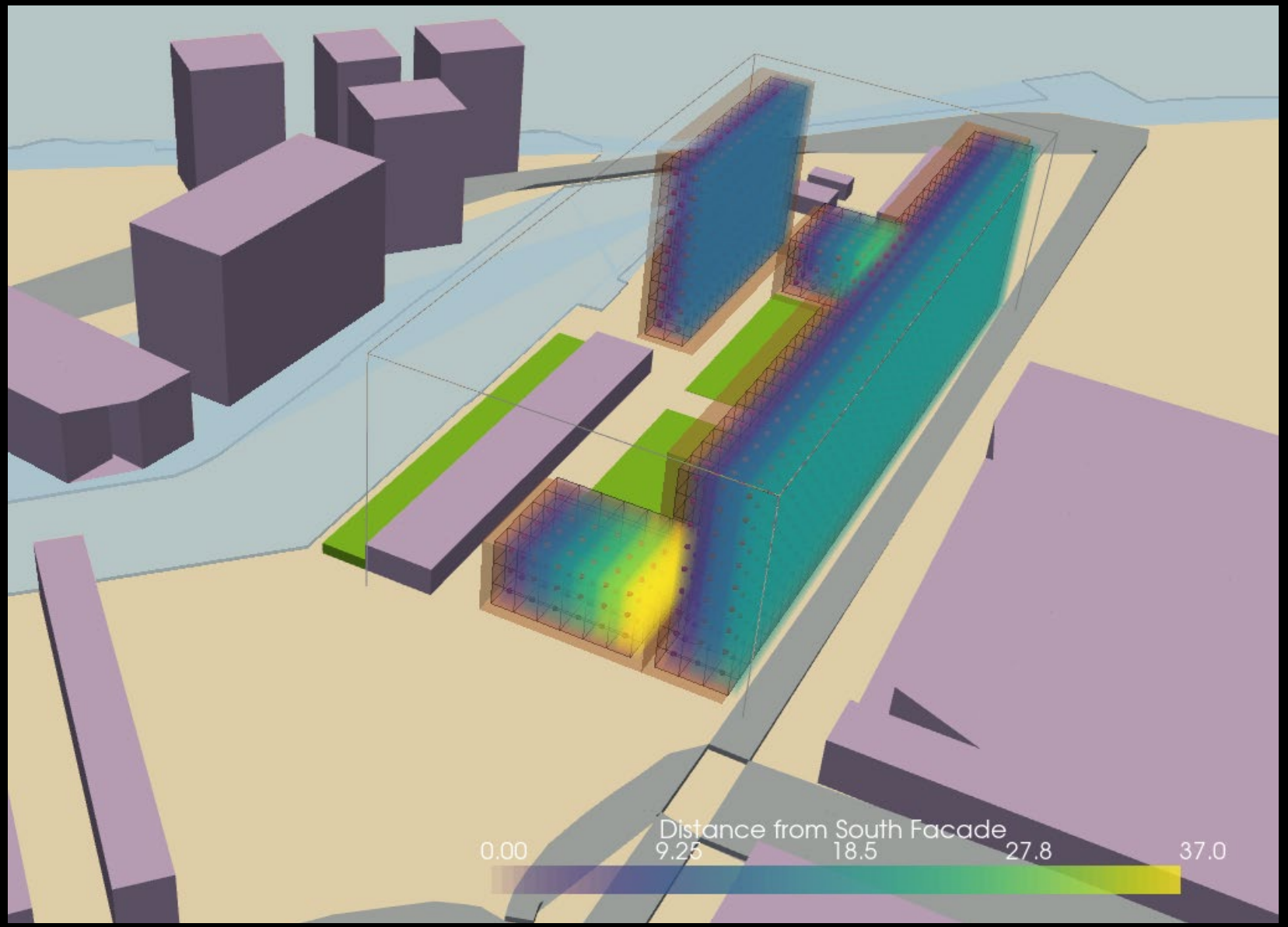
Distance based simulation



6.

DISTANCE FROM THE SOUTH FACADE SIMULATION

Distance based simulation

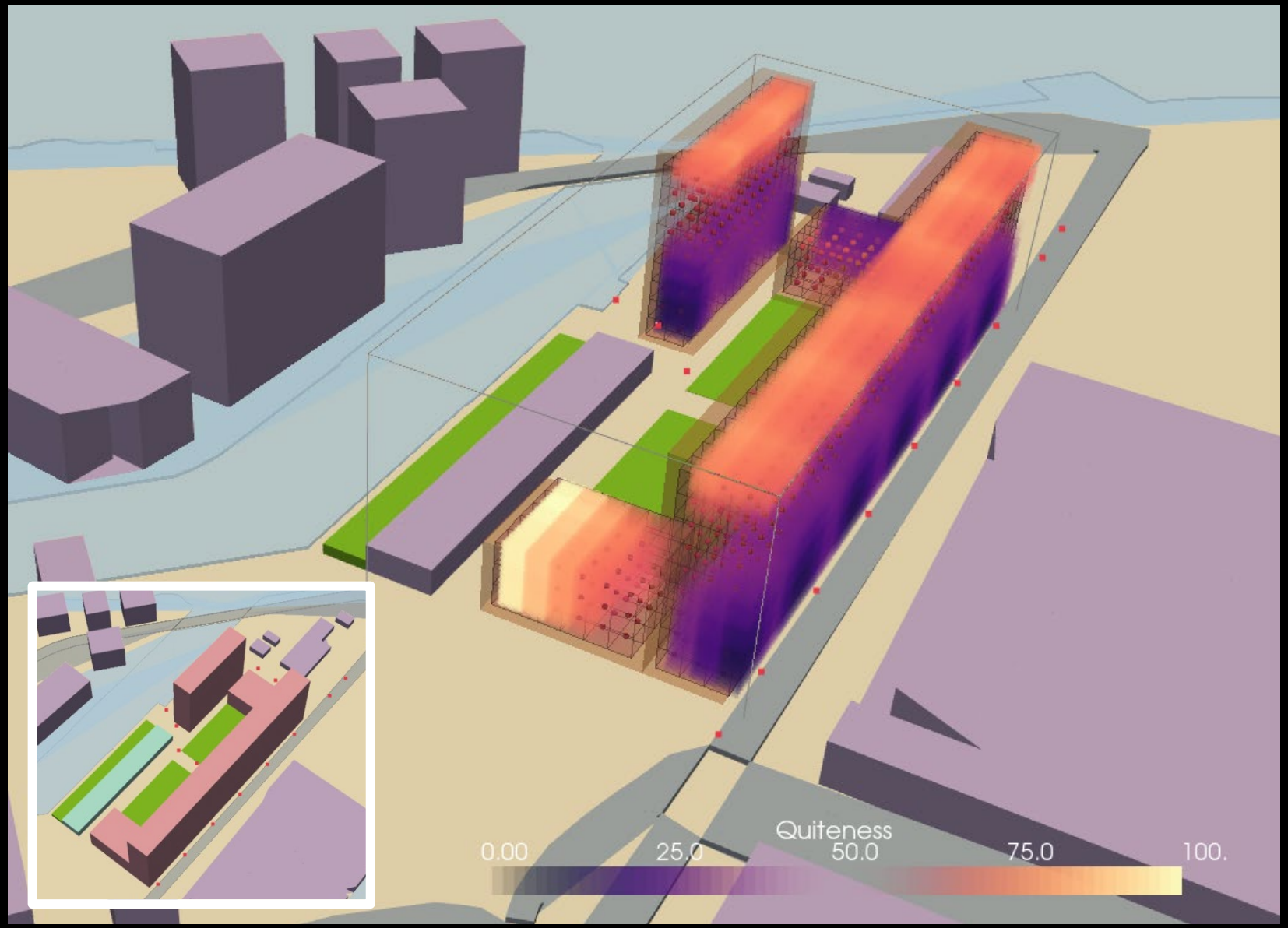


7.

QUITENESS SIMULATION

Quietness is a simplified version where only the Euclidian distance from the source of sound is considered.

Distance based simulation



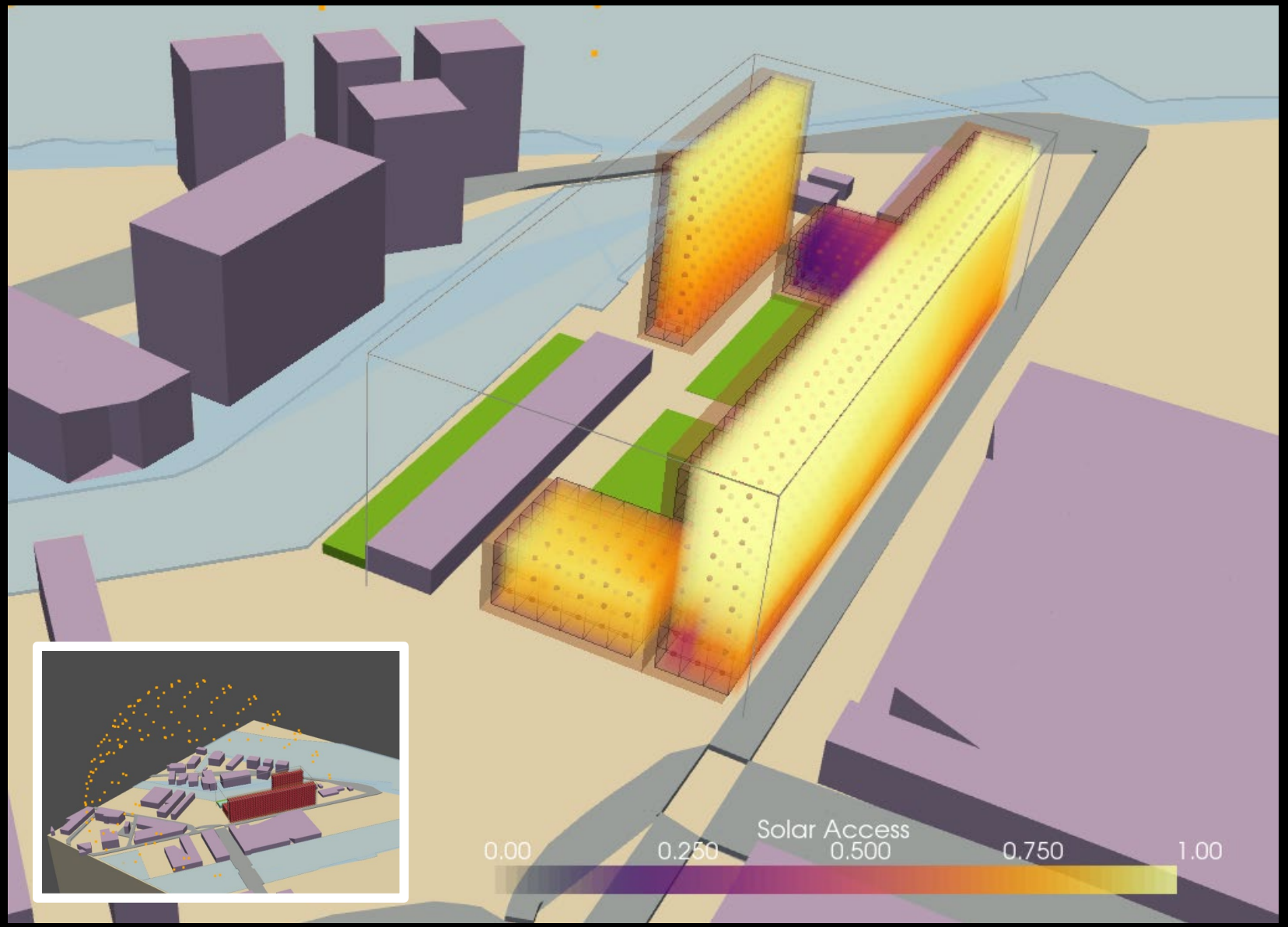
8.

SOLAR ACCESS SIMULATION

Sun-access is represented in percentage of visibility for each voxel towards the

selected sun positions.

Mesh intersection based simulation

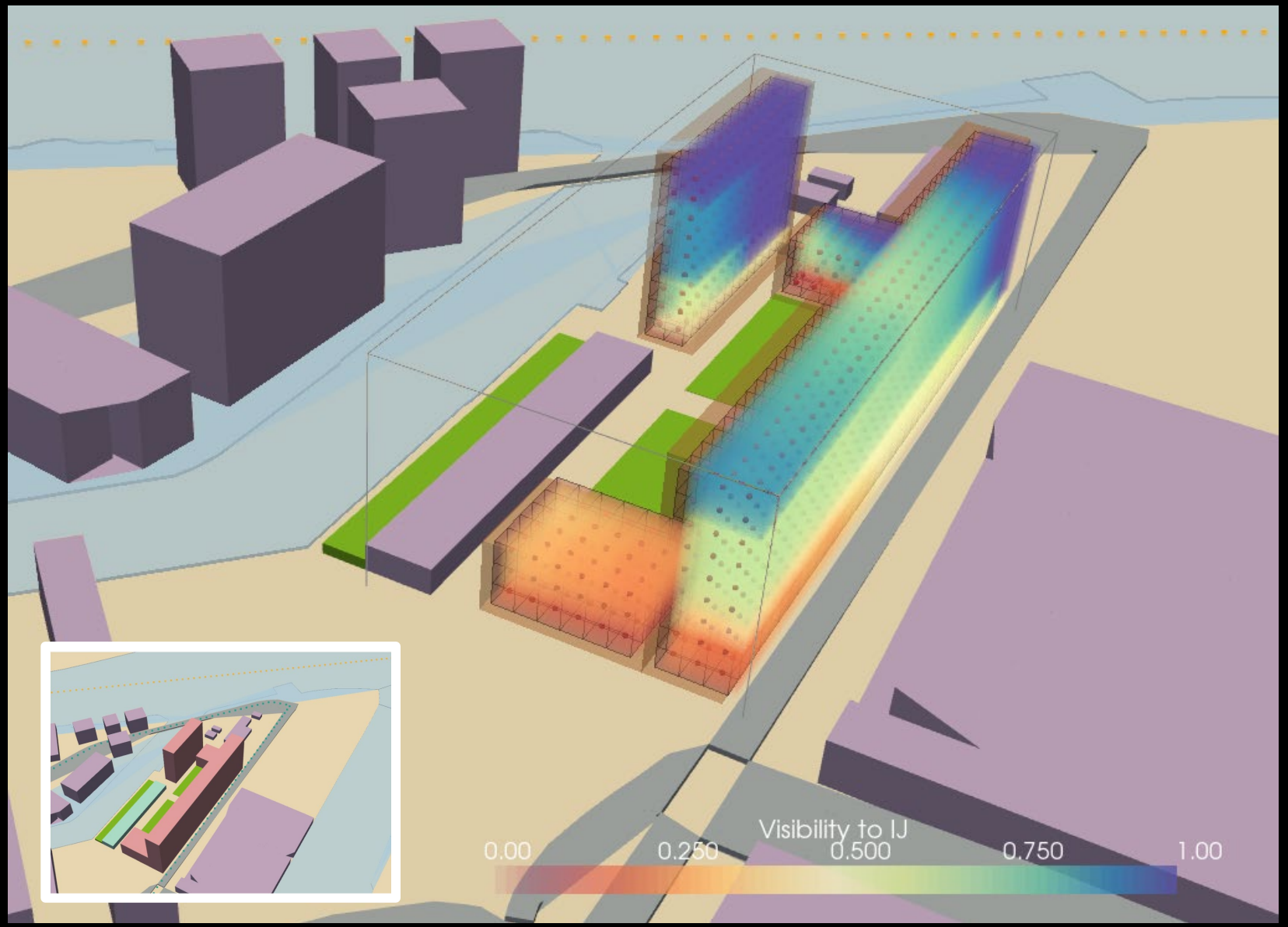


9.

VISIBILITY TO IJ SIMULATION

Visibility is represented in percentage of visibility for each voxel towards the points of interest.

Mesh intersection based simulation

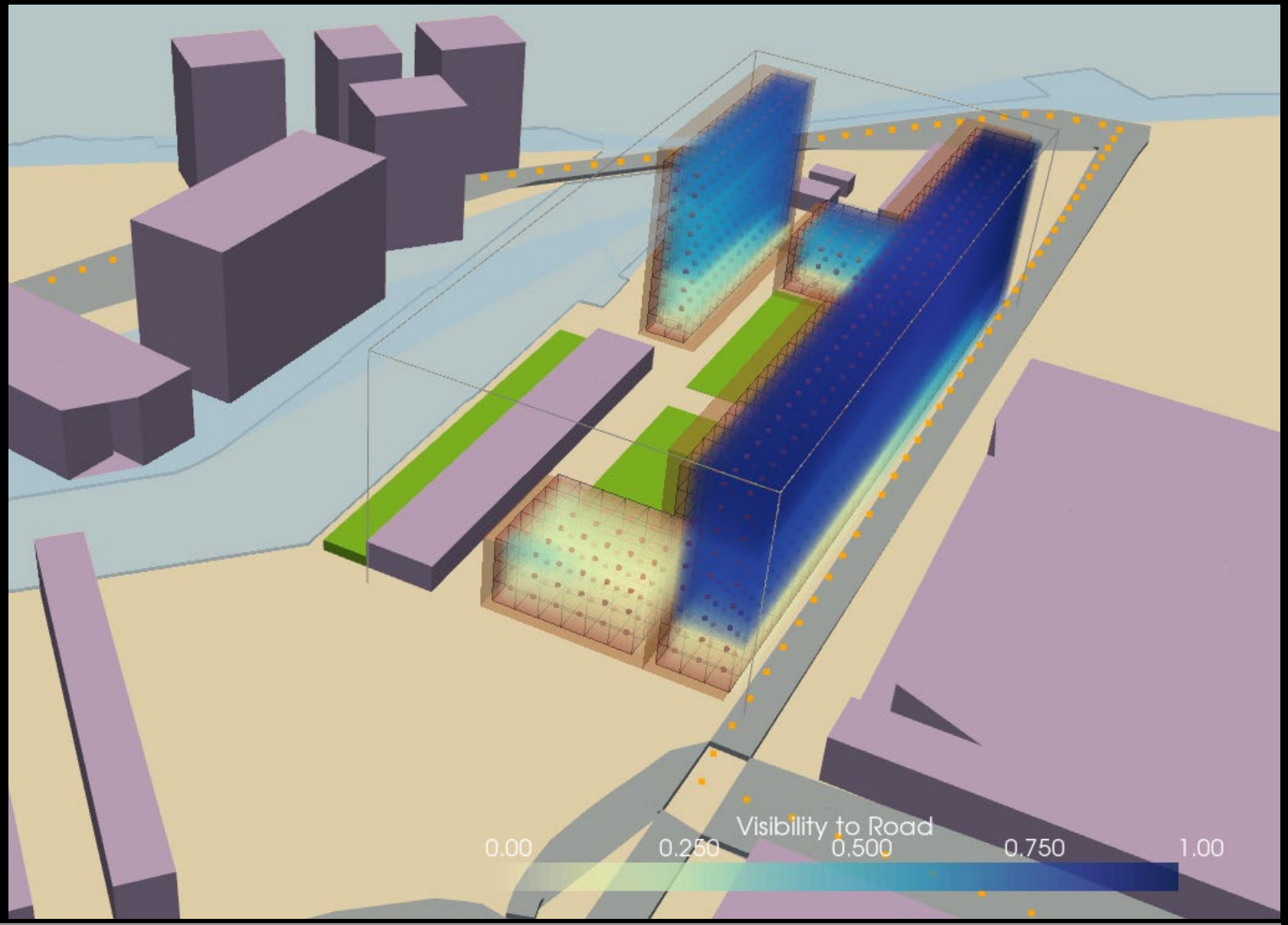


10.

VISIBILITY FROM ROAD SIMULATION

Visibility is represented in percentage of visibility for each voxel towards the points of interest.

Mesh intersection based simulation



MULTI-CRITERIA-DECISION ANALYSIS

The process of MCDA is capable of solving a decision making problem which has ***conflicting criteria and weights***

To develop the desirability lattice the actors have to ***choose the spatial qualities*** needed and ***generate decisions*** based on them for each zone.

The results of these decisions will be used as in input for the ***MCDA process*** to generate the desirability lattice which indicates the desirability of a voxel for the zone.

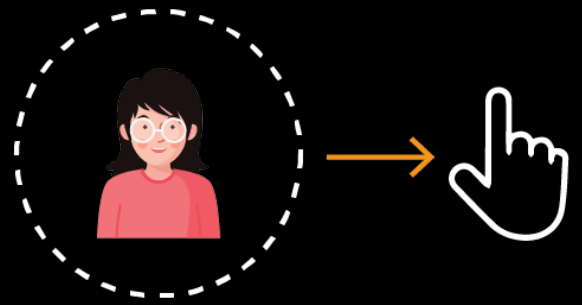
The selected MCDA method used in the project was TOPSIS method ***TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution)*** is a multi-criteria decision making technique used to rank a finite set of alternatives based on the ***minimization of distance from an ideal point*** and the ***maximization of distance from an anti-ideal point.***

It has the Quality to compare unequal units which is the case for this problem.

* MCDA = Multi-criteria decision analysis

GENERATION OF DESIRABILITY LATTICES

ZONE WISE DECISION MAKING

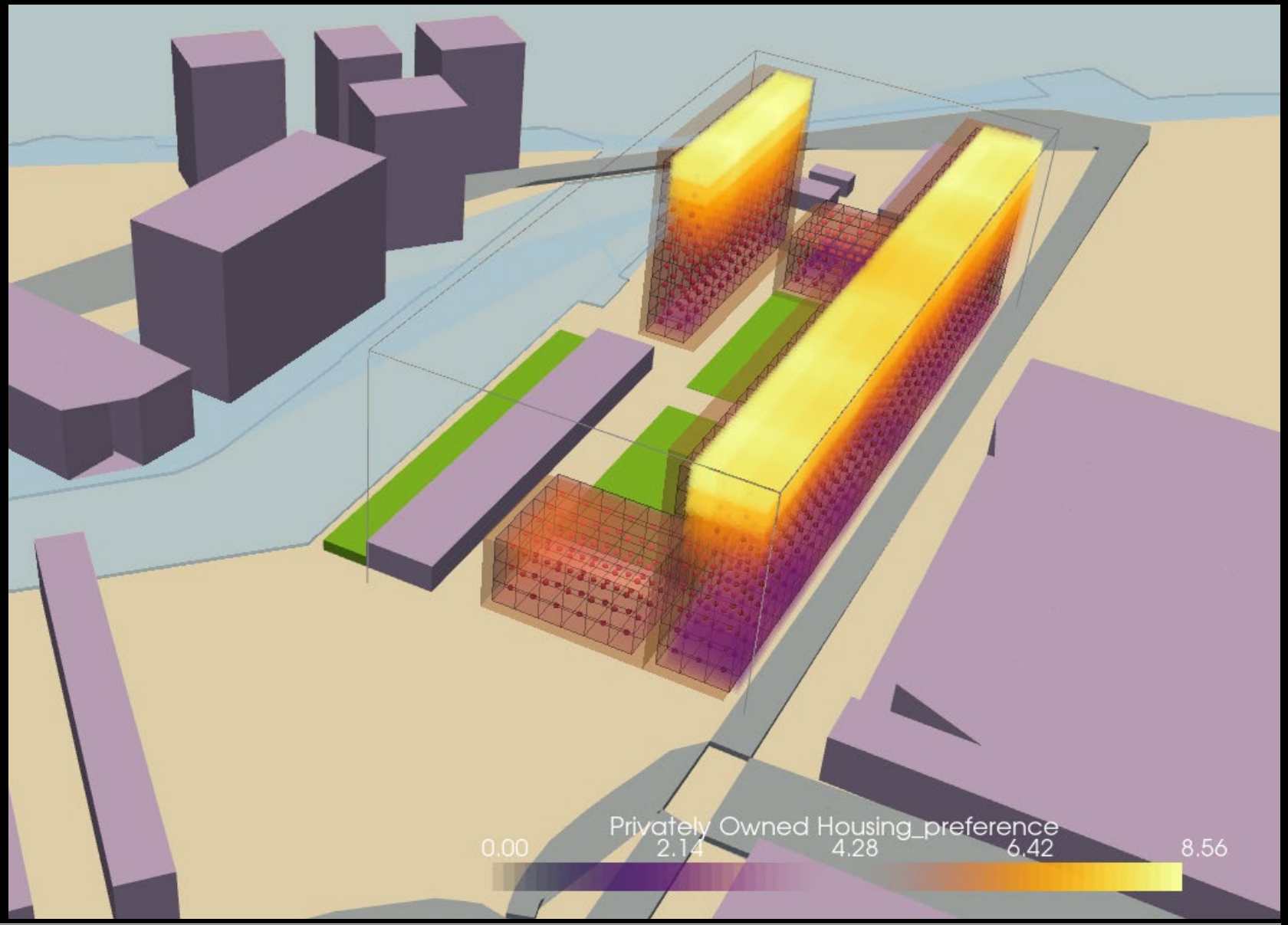


Closeness to facade N	0
Closeness to facade S	0
Closeness to facade W	0
Closeness to facade E	0
Closeness to Roof	0
Closeness to Ground	9
Quiteness	8
Visibility to IJ	9
Visibilty from street	0
Solar access	7

1.

PRIVATELY OWNED HOUSING

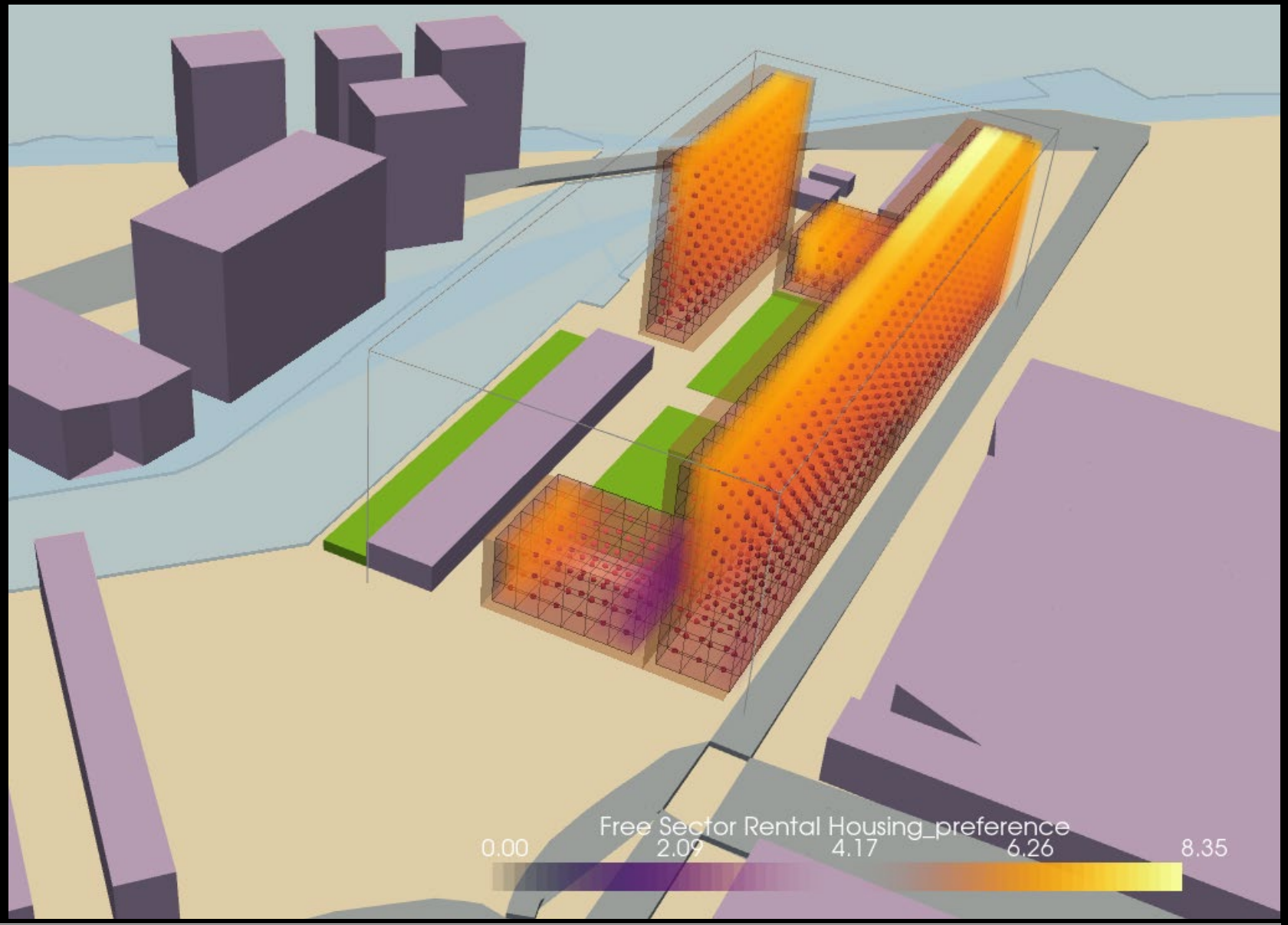
Closeness to facade N	0
Closeness to facade S	0
Closeness to facade W	0
Closeness to facade E	0
Closeness to Roof	0
Closeness to Ground	9
Quiteness	8
Visibility to IJ	9
Visibilty from street	0
Solar access	7



2.

FREE SECTOR RENTAL HOUSING

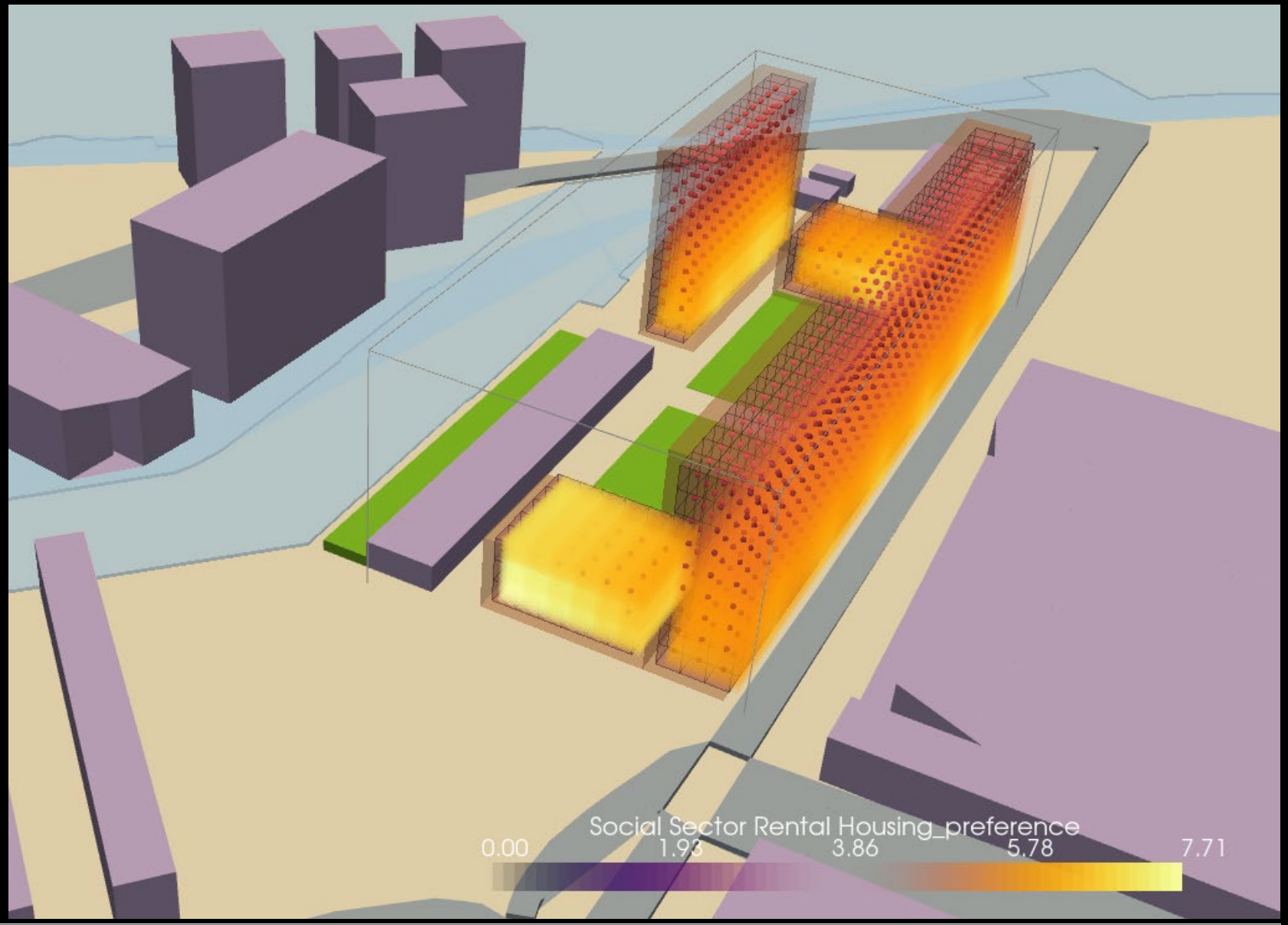
Closeness to facade N	0
Closeness to facade S	7
Closeness to facade W	7
Closeness to facade E	0
Closeness to Roof	0
Closeness to Ground	0
Quiteness	6
Visibility to IJ	7
Visibilty from street	0
Solar access	6



3.

SOCIAL SECTOR RENTAL HOUSING

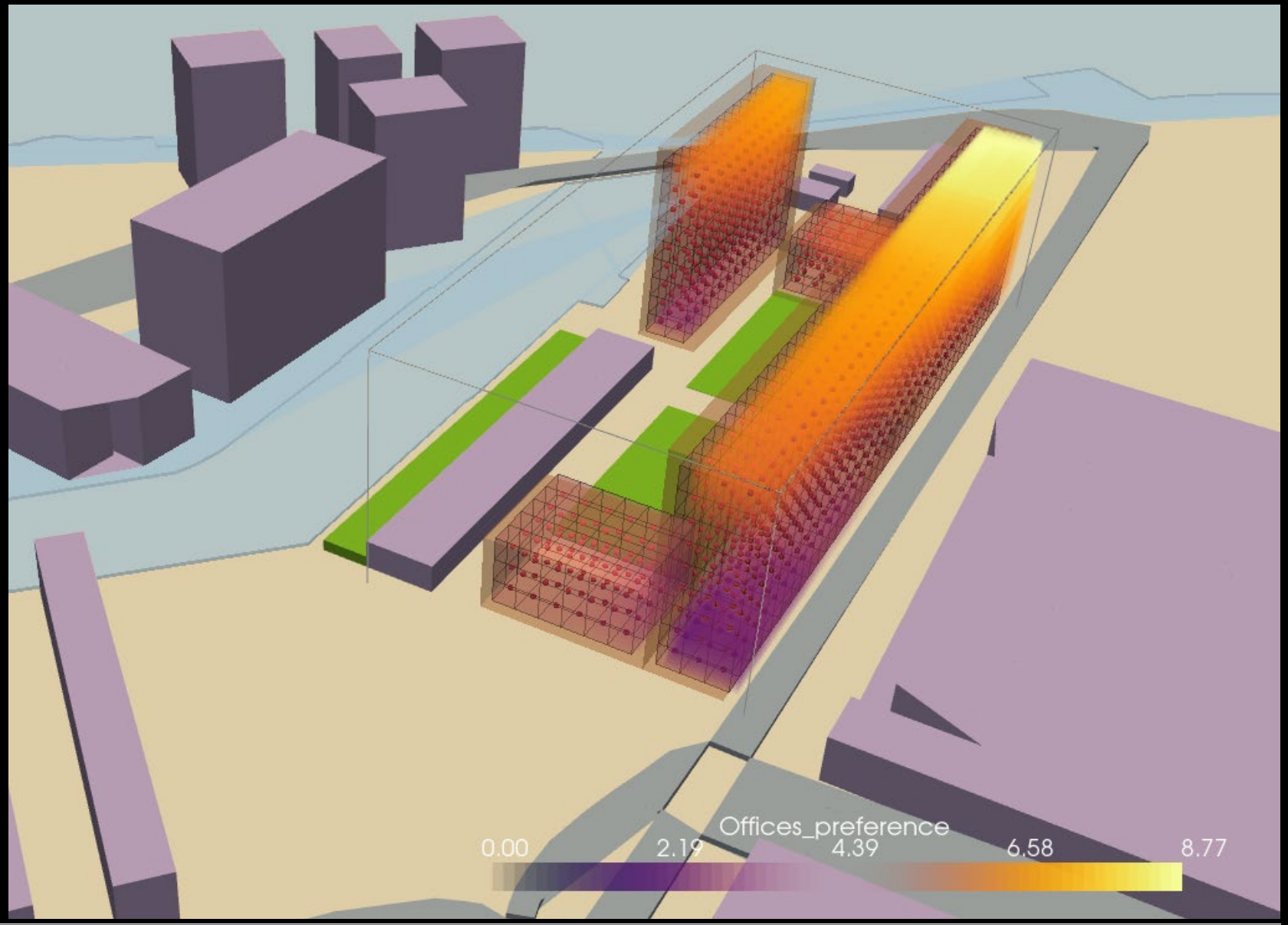
Closeness to facade N	0
Closeness to facade S	0
Closeness to facade W	0
Closeness to facade E	0
Closeness to Roof	0
Closeness to Ground	8
Quiteness	4
Visibility to IJ	4
Visibilty from street	0
Solar access	6



4.

OFFICES

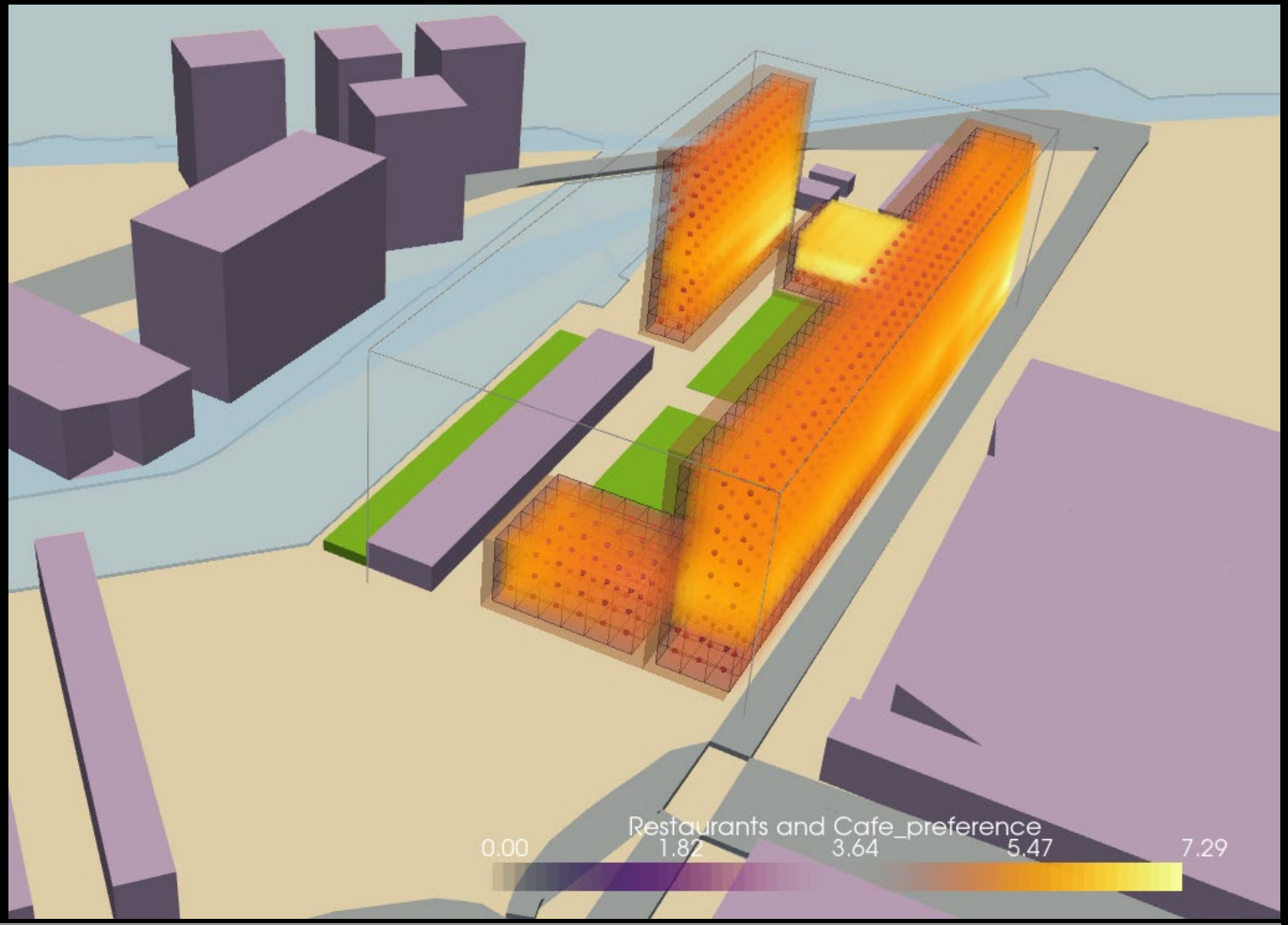
Closeness to facade N	0
Closeness to facade S	0
Closeness to facade W	0
Closeness to facade E	0
Closeness to Roof	0
Closeness to Ground	4
Quiteness	9
Visibility to IJ	7
Visibilty from street	0
Solar access	9



5.

RESTAURANTS AND CAFE

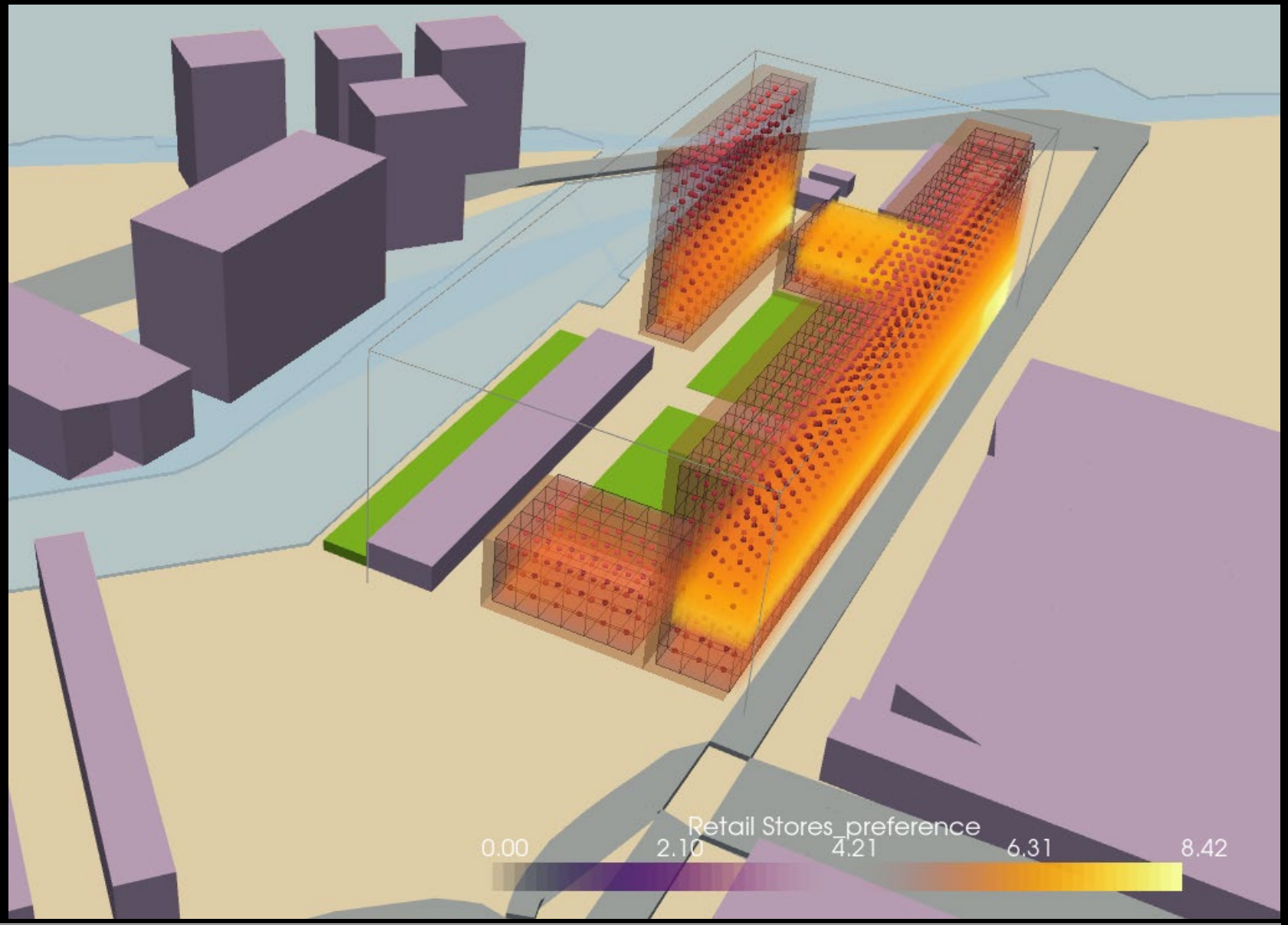
Closeness to facade N	0
Closeness to facade S	0
Closeness to facade W	0
Closeness to facade E	0
Closeness to Roof	0
Closeness to Ground	9
Quiteness	5
Visibility to IJ	8
Visibilty from street	9
Solar access	0



6.

RETAIL STORES

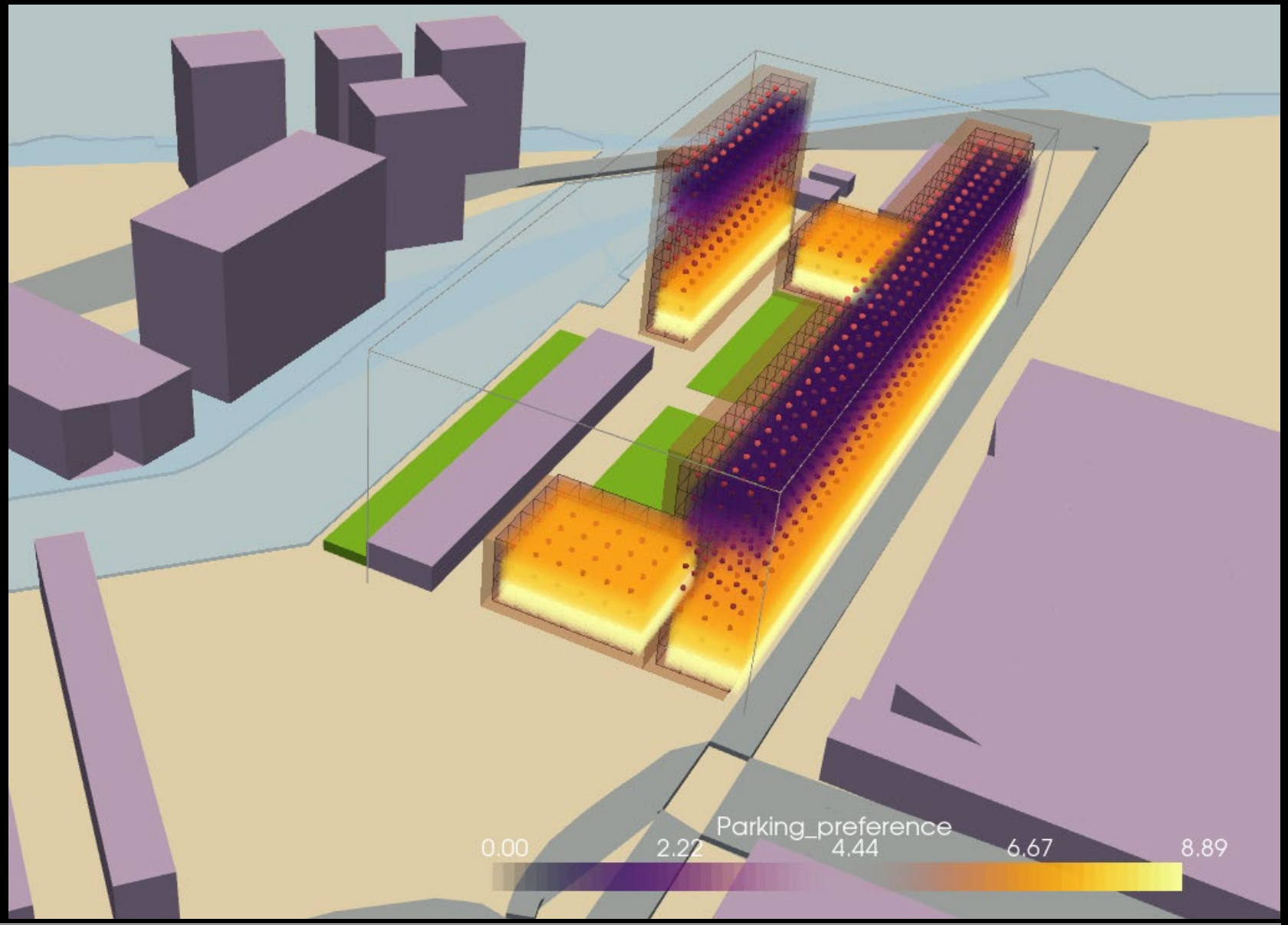
Closeness to facade N	0
Closeness to facade S	0
Closeness to facade W	0
Closeness to facade E	0
Closeness to Roof	0
Closeness to Ground	9
Quiteness	0
Visibility to IJ	0
Visibilty from street	9
Solar access	0



7.

PARKING

Closeness to facade N	0
Closeness to facade S	0
Closeness to facade W	0
Closeness to facade E	0
Closeness to Roof	0
Closeness to Ground	10
Quiteness	0
Visibility to IJ	0
Visibilty from street	0
Solar access	0



AGENT BEHAVIOURS

Agent behaviors are ***the actions*** which the computational agents can perform to achieve the ***spatial planning goals.***

The main behavior which the agents in the system can perform is the ***occupy behavior*** which ***reserves voxels*** for the agent in the ***discretized massing volume.***

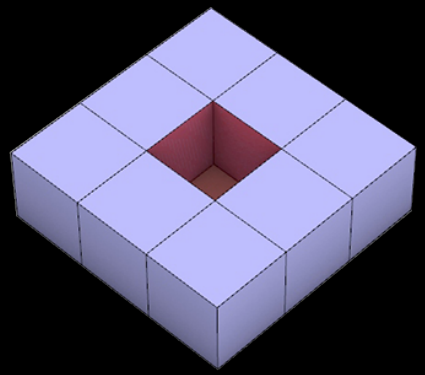
2D Occupy Behavior

- Rectangular occupy behavior
- Circular Occupy behavior
- Argmax occupy behavior
- Attraction/Repulsion behavior

3D Occupy Behavior

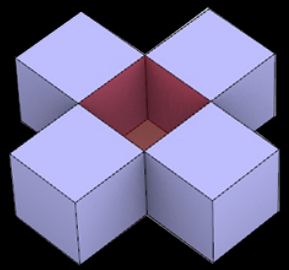
- Cuboidal occupy behavior
- Spherical occupy behavior
- Argmax occupy behavior
- Attraction/Repulsion occupy behavior

STENCILS (SEARCH SPACE OR NIEGHBOURHOOD DEFINITION)



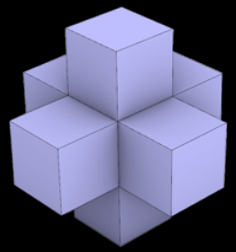
EIGHT NEIGHBOUR STENCIL

2D



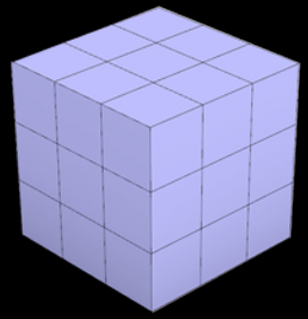
FOUR NEIGHBOUR STENCIL

2D



SIX NEIGHBOUR STENCIL

3D



TWENTY -SIX NEIGHBOUR STENCIL

3D

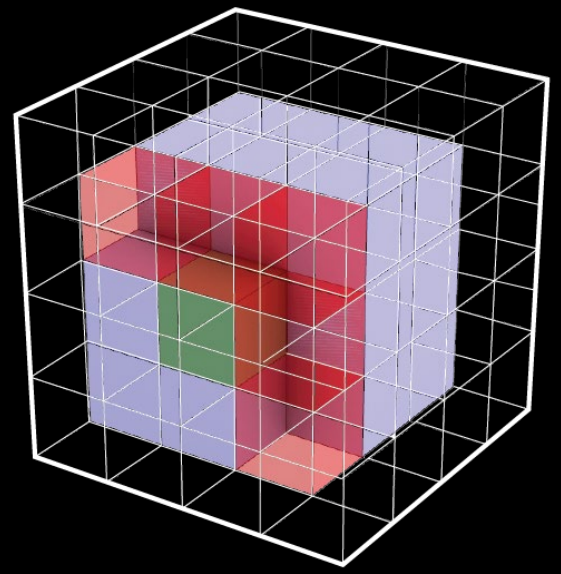
SHAPE REINFORCEMENT (NEIGHBOUR BOOST)

Argmax of red cells

				10.5	0.7
			×	10.7	0.1
0.5	0.3	10.7	10.9	10.3	0.2
0.2	0.7	0.1	0.8	0.6	0.4
0.1	0.4	0.7	0.5	0.3	0.5

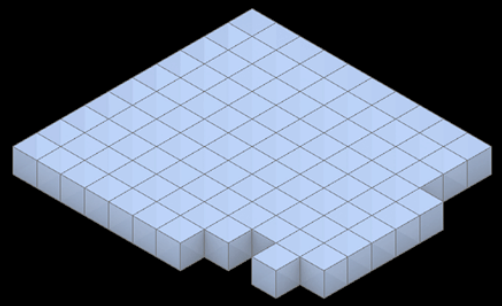
2D Neighbour Boost

Argmax of red cells

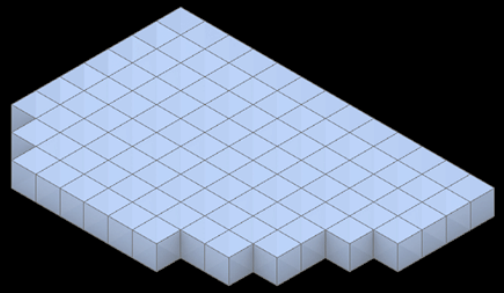


3D Neighbour Boost

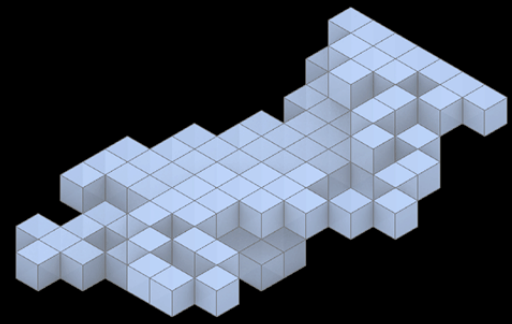
AGENT BEHAVIOURS (2D SEARCH SPACE)



Rectangular
Occupy
Behaviour

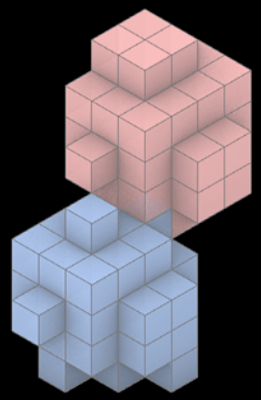


Circular
Occupy
Behaviour

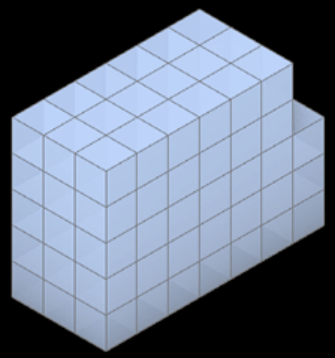


Argmax
Occupy
Behaviour

AGENT BEHAVIOURS (3D SEARCH SPACE)



Attraction/
Repulsion
Behaviour



Cuboidal
Occupy
Behaviour



Spherical
Occupy
Behaviour



Argmax
Occupy
Behaviour

USING THE MULTI-AGENT SYSTEM TO SOLVE THE ZONING PROBLEM

- LINEAR ASSIGNMENT METHOD
- SEQUENTIAL ASSIGNMENT METHOD

LINEAR ASSIGNMENT APPROACH

The first approach towards this problem is to deal with the zoning problem as an ***linear assignment problem researched extensively in operations research.***

The problem was first described by (Koopman et. al) as a relatively simple problem in the ***allocation of indivisible resources*** is that of ***matching two sets of an equal number n of objects***, by making up ***pairs of objects*** consisting of ***one object from each set.***

Objects belonging to the same set are similar in kind but not identical. For each of the possible pairs a score or value is given. The problem is ***to find a matching*** (or assignment to each other) of objects for which the ***sum*** of the ***scores of pairs matched is as high as possible***.

1. Determine the possible ***agent origin*** locations
2. Generating the ***Benefit matrix*** for the Agents at all locations
3. Linear ***Assignment Process (GOOGLE OR TOOLS SOLVER)***
4. Running the ***ABM Simulation*** according to the Permutation matrix

Locations
(1 2 3 4)

Agents

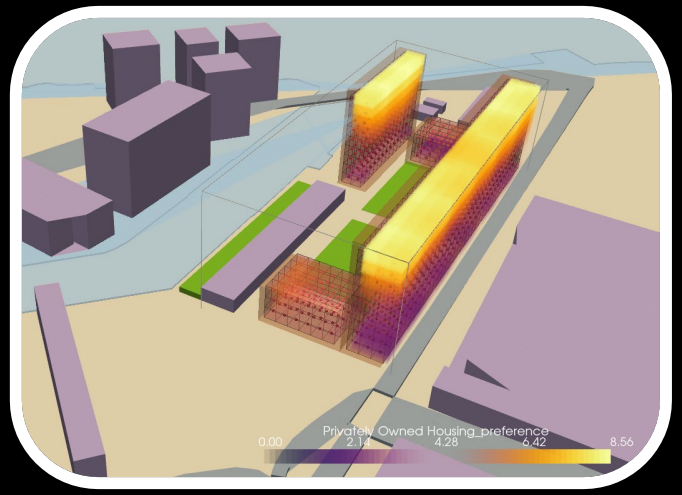
$$\begin{matrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{matrix} \begin{bmatrix} 6 & \textcircled{9} & 5 & 4 \\ 3 & 2 & \textcircled{7} & 4 \\ \textcircled{6} & 5 & 5 & 2 \\ 3 & 9 & 4 & \textcircled{9} \end{bmatrix} = a_{ki} = A$$

Locations
(1 2 3 4)

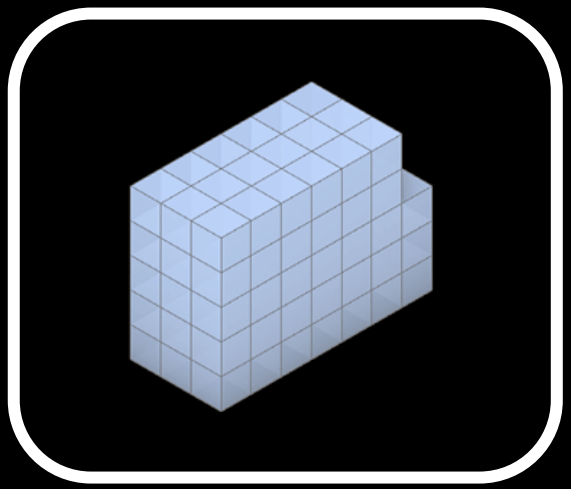
Agents

$$\begin{matrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{matrix} \begin{bmatrix} 0 & \textcircled{1} & 0 & 0 \\ 0 & 0 & \textcircled{1} & 0 \\ \textcircled{1} & 0 & 0 & 0 \\ 0 & 0 & 0 & \textcircled{1} \end{bmatrix} = p_{ki} = P$$

$$\pi = \sum_{k,i=1}^{4} a_{ki} p_{ki} = 9+7+6+9 = 31$$



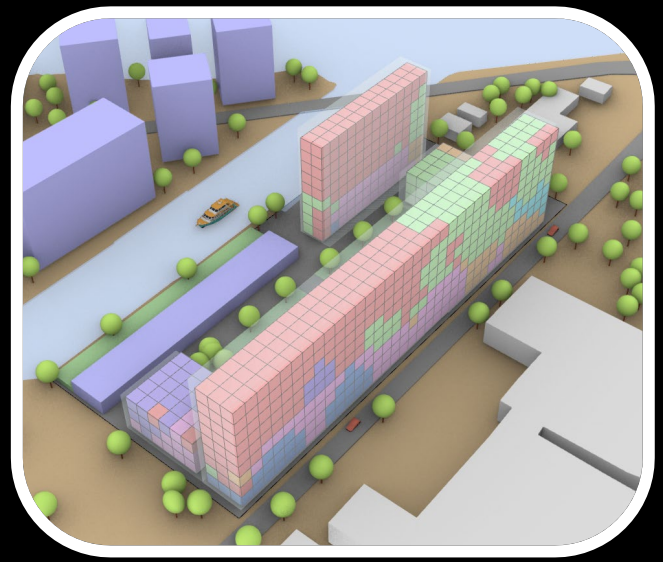
DESIRABIILITY LATTICES



AGENT OCCUPY BEHAVIOUR

=

ZONING SOLUTION





SEQUENTIAL ASSIGNMENT APPROACH

In the sequential assignment approach the approach is more towards replicating ***the manual design process*** with the ***intelligence of multi criteria assignment*** and ***form evolution*** offered by the ***agent based model.***

In this approach the functions in the space program are ***assigned sequentially*** from the ***biggest function to the smallest function.*** This approach gives ***priority according to the size*** assuming that the impact of the biggest function is going to be the most on the output of the benefit calculations of the zoning.

1. ***Rank the zones*** according to the level of impact based on ***size and function***.
2. Generating the ***Benefit matrix*** for the Agents at all origin locations
3. ***Sequentially assign*** agents according to the order determined in the first step
4. ***Loop*** until all agents are deployed and all zones are configured.



CONCLUSIONS

LINEAR ASSIGNMENT APPROACH

Strengths:
Since the agents are deployed on a wider search space the total benefit generated is higher in comparison to sequential assignment method.

Weakness:
Deploying multiple agents also leads to a staggered or incomplete growth patterns which can be topologically or spatially not acceptable.

Use Case:
Large mixed use programs with equal or near equal priority for all the functions in the space program.

SEQUENTIAL ASSIGNMENT APPROACH

Strengths:
Since the agents are deployed sequentially the spatial form and the topological connectivity is generally very good.

Weakness:
The sequential deployment of agents leads to unequal access and a poorer benefit outcome for the agents which are lower on the priority order.

Use Case:
For smaller space programs or for space programs where there is a strong hierarchical importance for functions in the space program.

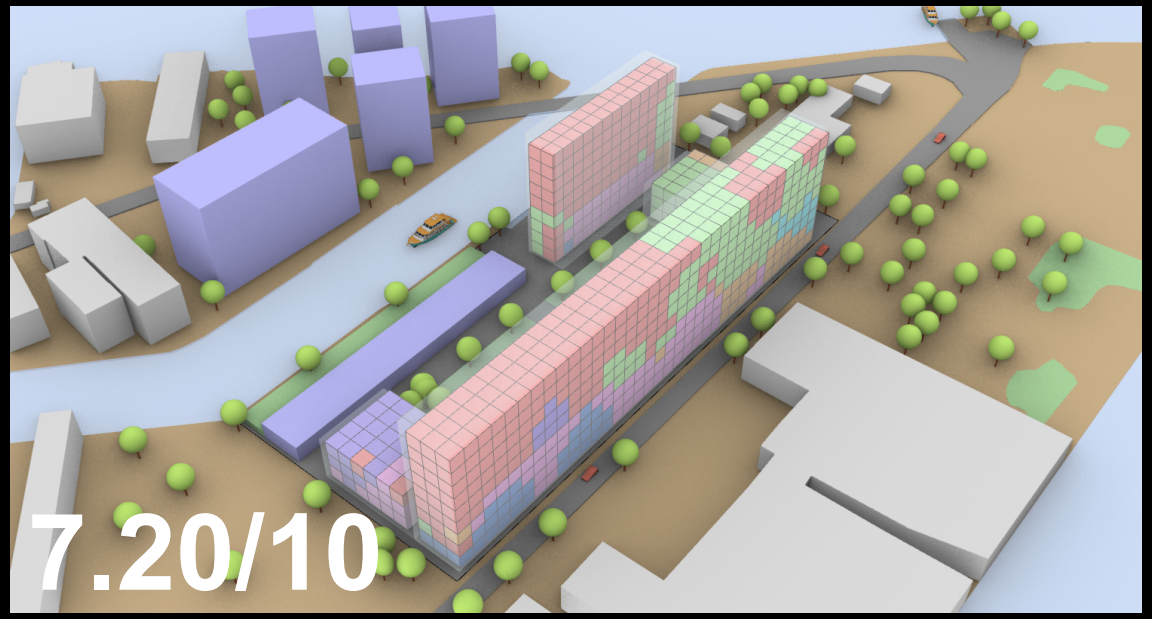
BRUTE FORCE APPROACH

Strengths:
It can do an exhaustive search for a good combination for the zoning problem.

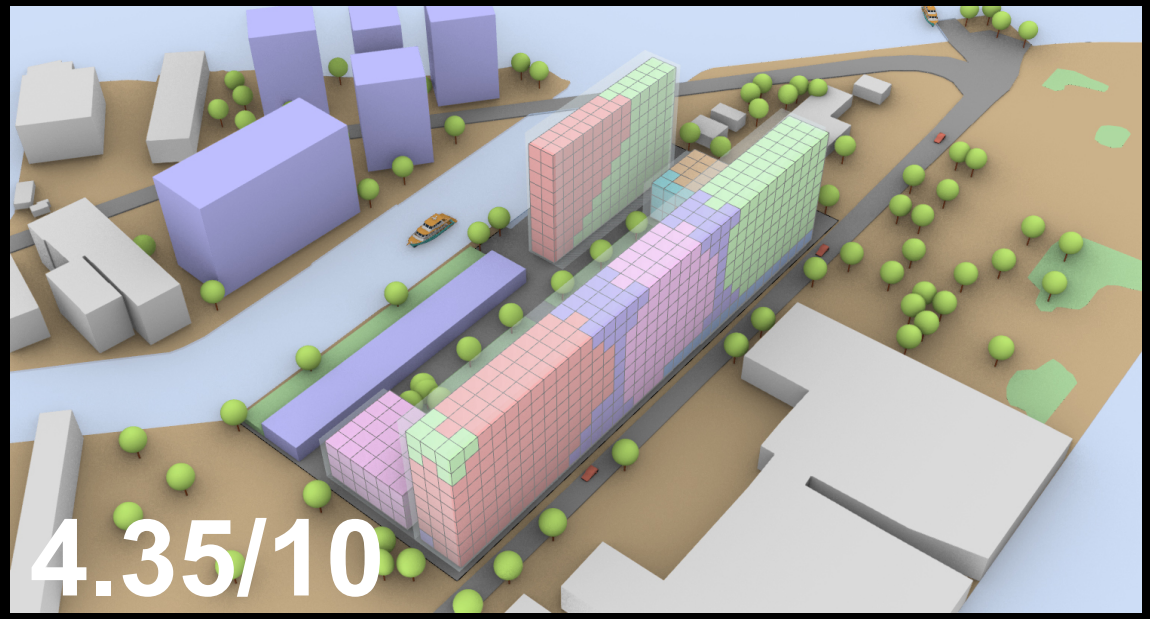
Weakness:
It cannot be used for even a slightly bigger problem or combinatorial complex problem.

Use Case:
Mainly for really small cases or for generating validation data for simulations.

COMPARISON OF RESULTS:



LINEAR ASSIGNMENT APPROACH



SEQUENTIAL ASSIGNMENT APPROACH

Zones	Linear Assignment	Sequential Assignment	Min	Max	Score (LA)	Score(SA)	Percentage	Aggregated Score (LA)	Aggregated Score (SA)
P_Owned_Volume	2761	2324	2228	2450	10	4,32	30	3	1,296
S-Rental_Volume	1916	1742	1600	1942	9,23	4,15	21	1,9383	0,8715
FS-Rental_Volume	2562	2560	2161	2604	9,05	9	30	2,715	2,7
Restaurant_and_Cafe_Volume	126	105	97	136	7,43	2,05	2	0,1486	0,041
Retail_stores_Volume	702	502	354	682	24	10,2	6	1,44	0,612
Office_Volume	506	513	484	499	4,84	4,63	7	0,3388	0,3241
Parking_Bikes_Volume	467	462	104	413	10	10	4	0,4	0,4
	9043	8236						9,9807	6,2446

* The scoring only considers the desirability of the occupied voxels in terms of their location.

CONCLUSIONS AND SCOPE OF IMPROVEMENT

1. In any multi-agent system the ***interaction*** between the agents is crucial and the ***negotiation part*** in the whole system was ***missing.***

2. Each agent was trying to achieve its own ***clustering goals*** which led to ***interesting cluster formations*** but for the ***requirement of a strict clustering form like a cuboid*** was very difficult to achieve because of it.

3. Conversion of the ***zoning problem*** into an ***assignment problem*** generated good solutions when the ***assignment goals were evenly distributed*** between the agents.

4. Which means ***more the agents better the result in terms of clustering***. However the increase in the number of agents led to ***increase in the abstraction*** in the topological formation of the clusters which was often ***unacceptable inspite of them performing highly in achieving their clustering goals.***

5. It would also be interersting to see ***cuboidal voronoi zoning*** and ***Quadratic assignment approach*** to solve the problem

IS THIS APPROACH MULTI-SCALAR THOUGH ?

LETS HAVE A OVERVIEW OF ALL THE STAGES OF THE PROBLEM IN A SMALL VIDEO COMPILATION



FUTURE DEVELOPMENTS

WHERE DOES THE PROJECT STAND IN THIS AGE OF METACREATION?

UNIQUE IDEAS PROPOSED IN THE PROJECT

1. The biggest advantage of this project over the others is the ***multi-scalar nature*** of the platform where not only ***the urban level massing problems*** can be resolved but even ***small scale room detailing*** can be solved.

2. Secondly the platform proposed is an ***open source one*** where ***collective design intelligence*** can be built thus making it ***more diverse*** than other platforms.

3. Thirdly it is linked to an existing style of design of ***open buildings*** and can potentially link to the ***vast information about projects and research*** having ***material and construction systems*** which are inherently pushing ***for circularity and sustainability.***

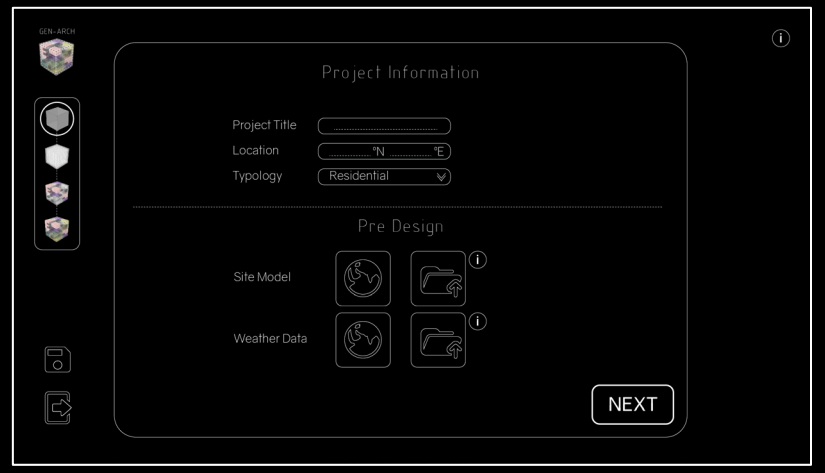
4. Finally the whole idea of ***participatory design or democratizing design*** is a unique one and is not part of the agenda of any of the platforms till now.

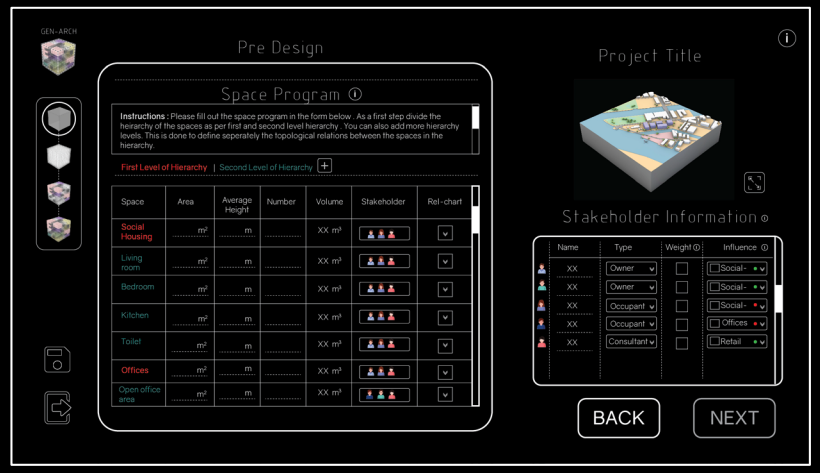
COMPARISON TO EXISITNG PLATFORMS

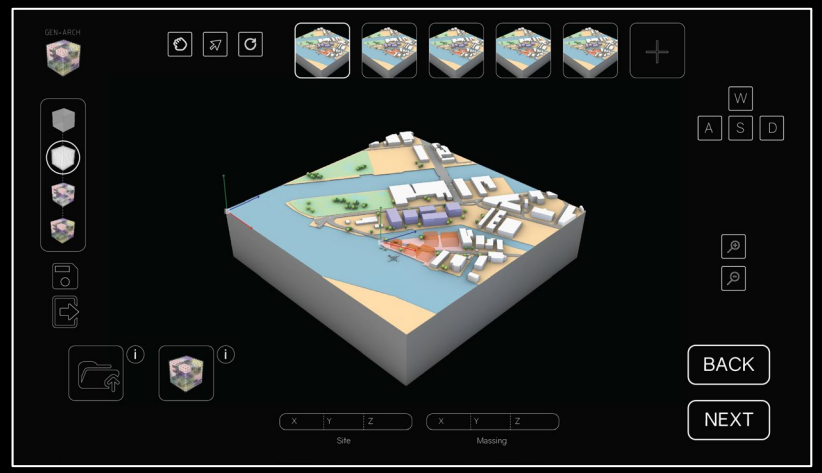
Configuration Platform	Capacity for Multi-scalar Generation	Is it Open Source ?	Is it Linked to a Building system ?	Does it enable Participatory design ?
Spacemaker.ai	No	No	No	No
Hypar.ai	Yes	Yes	No (Possible to dev)	No
Ostate	Yes	No	Yes	No
Digital Blue foam	No	No	No	No
GEN-ARCH	Yes	Yes	Yes	Yes

A POTENTIAL UI FOR THE PLATFORM AS PRESENTED IN P2 PRESENTATION





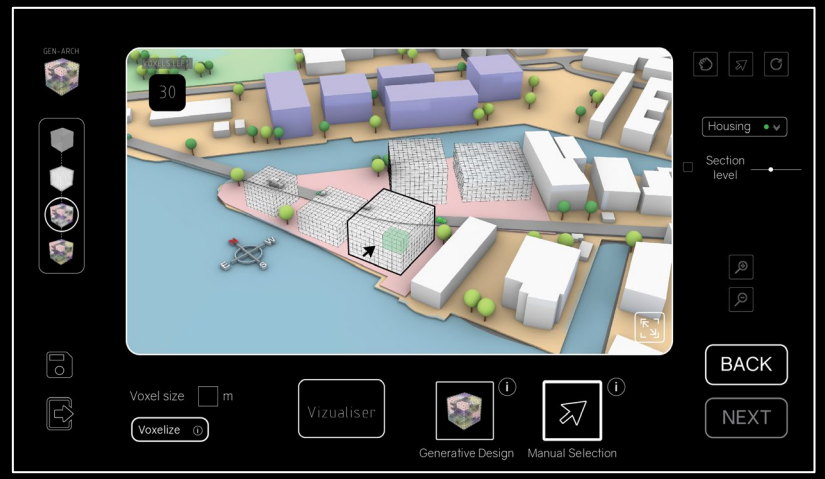








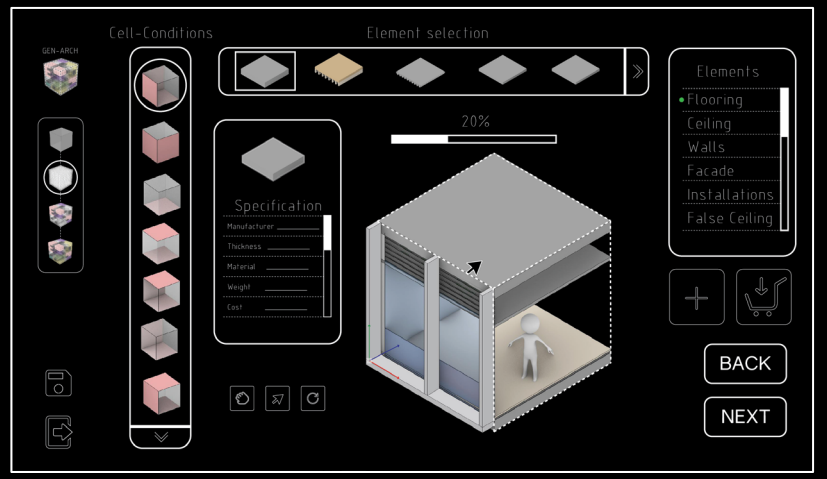
A POTENTIAL UI FOR THE PLATFORM AS PRESENTED IN P2 PRESENTATION













INTERESTED TO SEE HOW I SOLVED THE OTHER PROBLEMS ?

Then please visit computationaldesignworks.com

THANK YOU