An exploratory pipeline for generating performance based façade system using Houdini with geometry inputs from Rhinoceros

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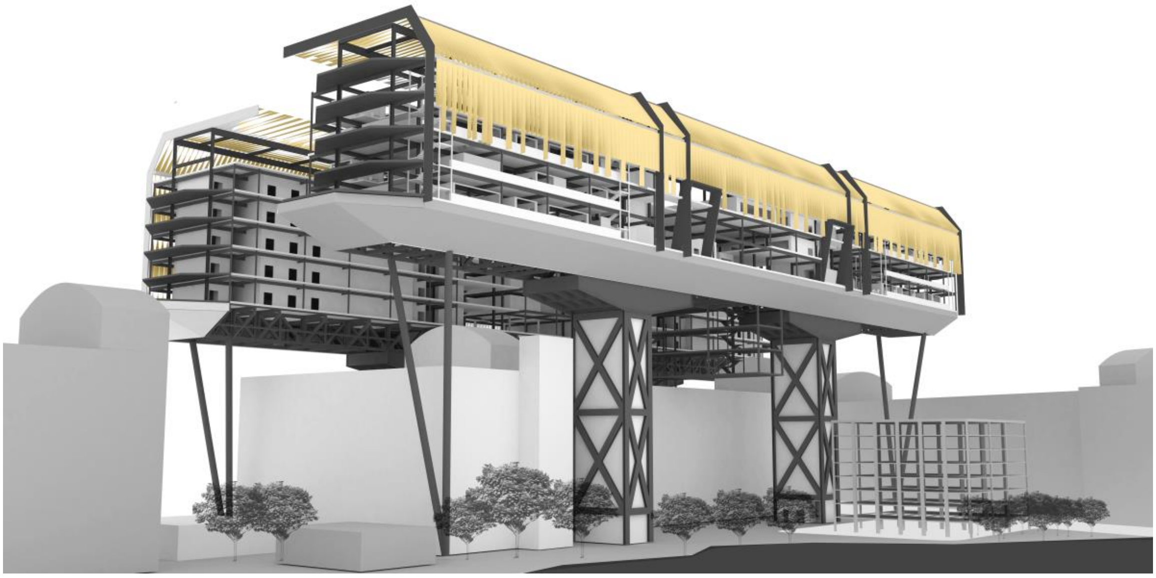


Fig 1. Rendered view of a proposed project. The façade system acts like a porous shell.

Introduction

The premise for this experiment is based on the need for a façade system that shields the interior of a building from direct sunlight, while still enabling adequate amount of diffuse light to enter, based on the specific requirements of each rooms behind the façade. Architectural expression is achieved through the parametric variation of individual façade elements, which responds both to large objects in front as well as the rooms behind, generating a distinct pattern (Fig.2).

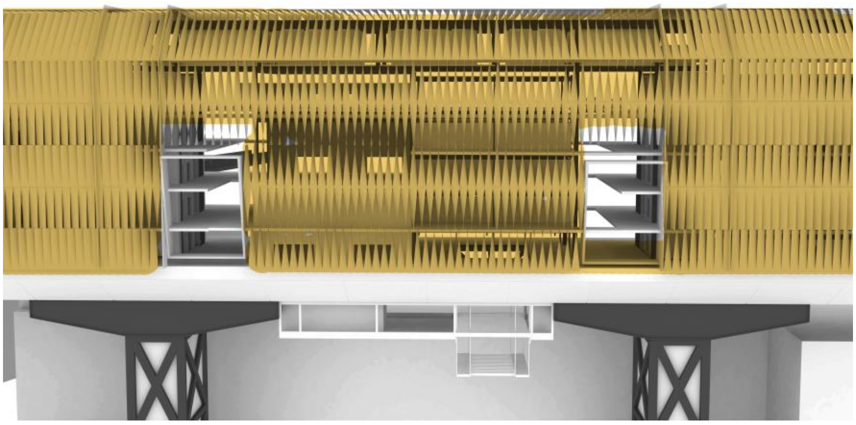


Fig 2. Proposed façade generated with Grasshopper.

Due to the requirements of the building program and site constraints, the proposed scheme has a long stretch of spaces that is directly exposed to the harsh western sun of Singapore in the afternoon. Hence the façade is conceived to mitigate the solar exposure as well as using it as an opportunity for architectural expression.

Objective

There are 2 main objectives for this experiment

1. To create a “room map” within Rhinoceros that can interface with the Houdini environment, to allow Houdini to generate and evaluate façade geometries that can be imported back into Rhinoceros. Rhinoceros provides greater precision and provides a myriad of tools that are optimised for generating and organising architectural models as compared to modelling within Houdini. Hence, there is an emphasis in the exploration of a pipeline between the 2 software.

2. To create within the Houdini environment, a functional node network that would allow facades to be parametrically generated based on programmatic requirement that is defined in the “room map” and evaluated using the evolutionary method.

The resulting façades should then be exported as an appropriate file format and be imported into Rhinoceros.

Experiment Setup

Here, I will introduce the model setup that will be used for the experiment as well as the façade mechanism. A portion of the building floor is replicated within the model for the purpose of generation and evaluating the façade.

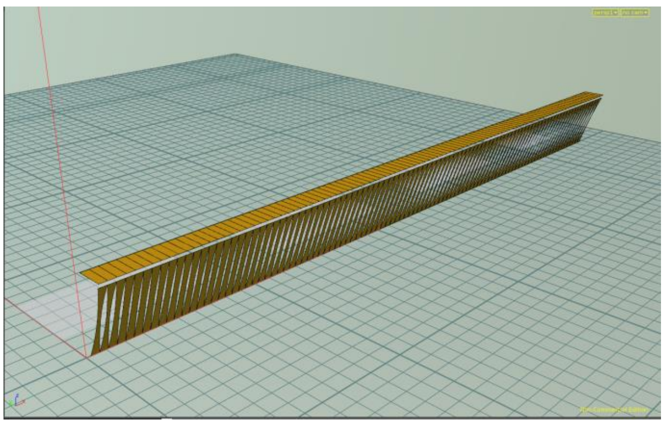


Fig.3 Façade eaves close up

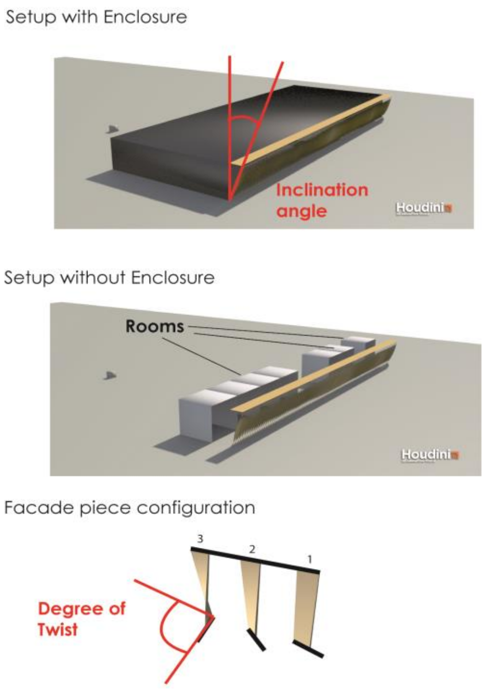


Fig.4 Experiment Setup & Façade mechanism

The experiment setup within consists of 3 elements (Fig. 4). *The enclosure, façade pieces* and *the position of the rooms*.

The enclosure sets up a barrier to ensure that the only light coming through the façade affects the simulation results.

The façade pieces are the **only** pieces subjected to the generation and evaluation process. Each façade piece is can be transformed through **Inclination Angle** and **Degree of Twist (**Fig. 4). As the façade pieces inclines, the eave above the façade pieces extends accordingly. Essentially the transformation parameters are:

- **Inclination Angle** (float, 0-20 degree)
- **Degree of Twist** (float, 0-90 degree)

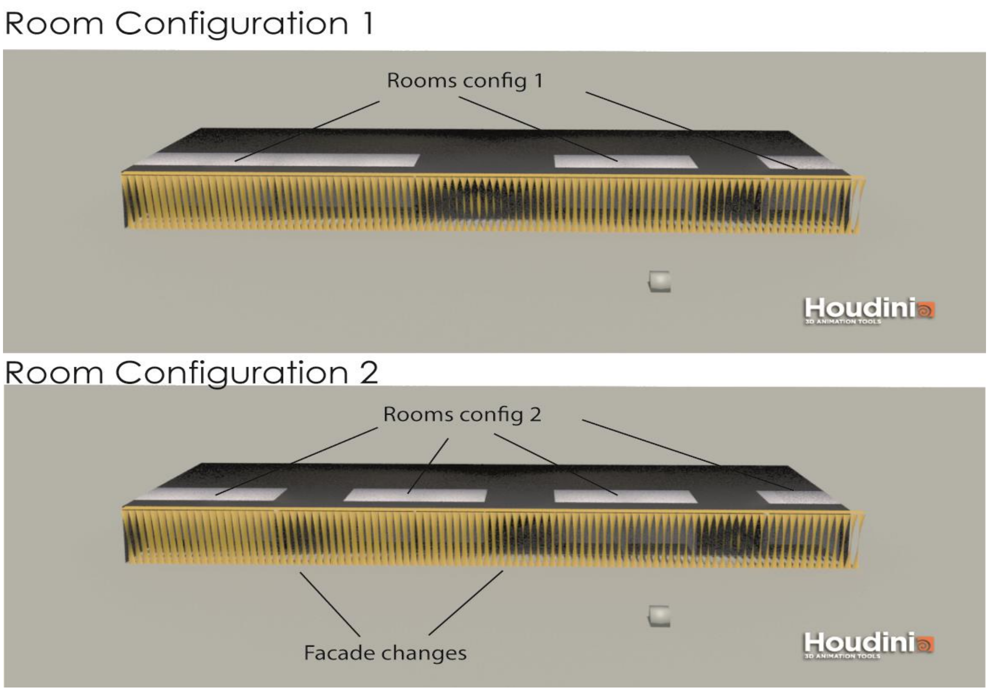


Fig.5 Façade Changes

The position of the rooms and daylight requirements of each room will affect the final form of the façade (Fig. 5). In positions that do not have a room, the façade pieces' Degree of Twist will take the default value of 90 degree. In the positions where a room is present, the façade pieces will adjust according to illumination levels within the rooms. The function that controls Degree of Twist will be elaborated in a later section of this paper.

The following section will discuss the production pipeline used for this experiment.

Rhinoceros & Houdini Pipeline overview

The overview of the pipeline is illustrated in the following diagram. The "room map" is from Rhinoceros is imported into Houdini. Within Houdini, an evolutionary method is used to generate an optimised façade using Eddex. The optimised façade is then put through one more round of evaluation and visualisation within Houdini, before being exporting the resulting geometry back into Rhinoceros and the simulation results in a suitable format.

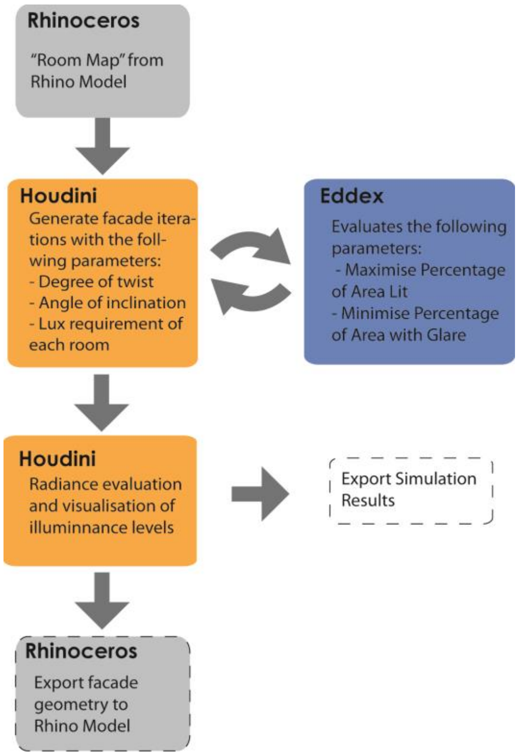


Fig.6 Pipeline Chart

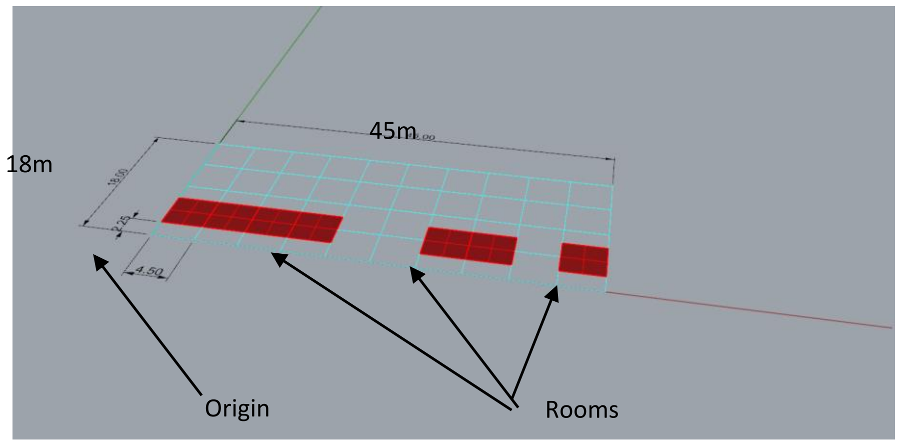


Fig.7 Room Map template in Rhinoceros

A "room map" is prepared within Rhinoceros at 1:100 scale (Fig. 7), which specifies the positions of the individual rooms based on building grid used in a proposed project. The grid is aligned to the origin point for easy reference within Houdini. In this experiment, each room units occupies a 4.5m x 4.5m grid square along the façade. There is a 2.25m corridor between the façade and the rooms that functions as a secondary climatic buffer after the main façade. The room geometries are then exported as an .obj file.

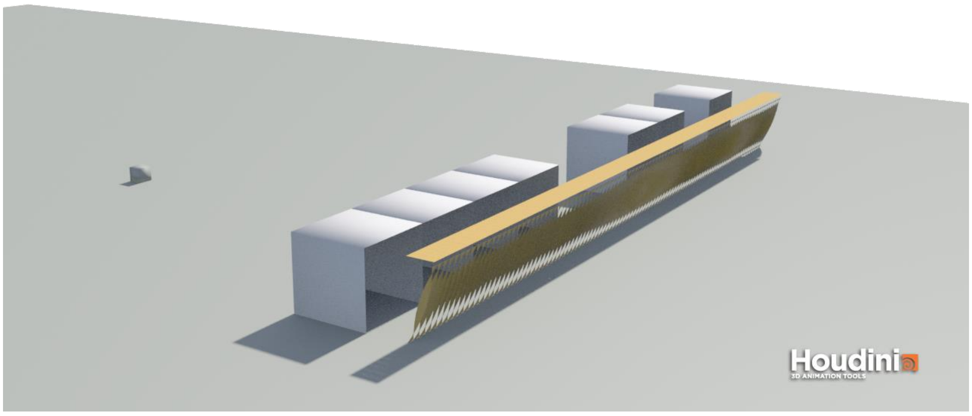


Fig.8 View of rooms without enclosure

The rooms that are modelled within Houdini are assumed to have a full height glass wall (Fig. 8), with no obstructions.

Next I will elaborate on the specific operations within the Houdini part of the pipeline, which processes the .obj exported from Rhinoceros to generate and evaluate iterations

Houdini Networks Overview

The following shows the organisation of Nodes on the object level.

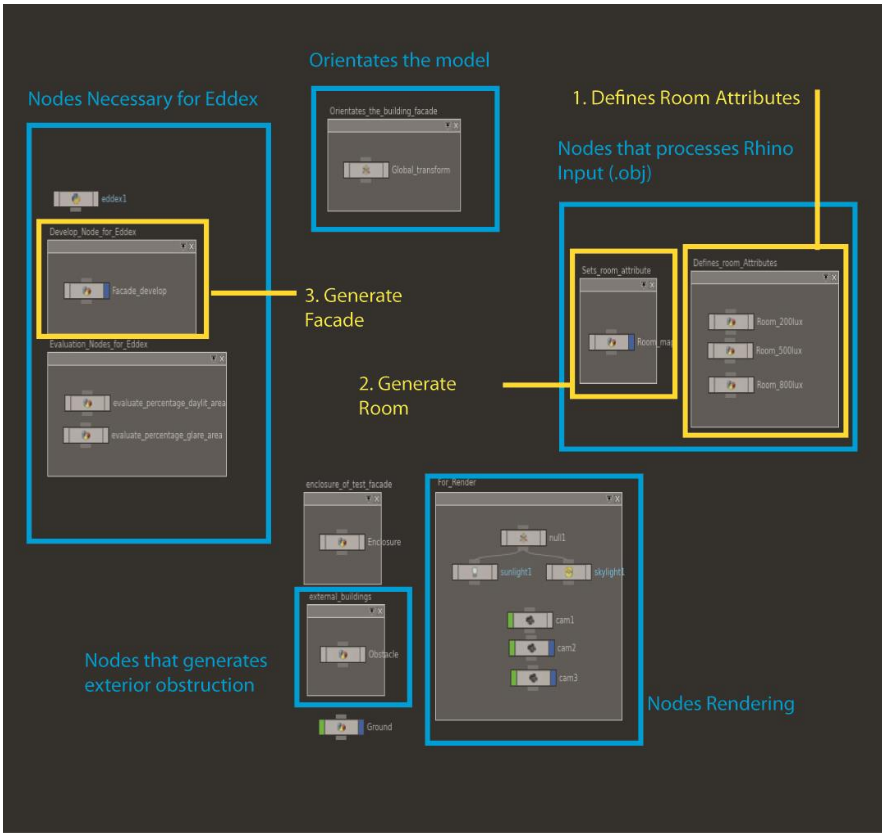


Fig.9 Overview of the Houdini file.

The key networks that we will be looking at are:

1. *Define Room Attributes*
2. *Generate Room*
3. *Generate Façade*

1 Define Room Attribute

Within "define room attribute", each room type is individually defined by a geo node. By encapsulating information within a geo node, we can easily modify or append additional attributes to each room type. An example of the "Room_200lux" node is shown below. The node sets the room dimensions, assigns reference groups for walls and floor, as well as assigning a minimum lux requirement of 200 lux to this room type (Fig. 10). The other room nodes are similar, with the difference being the minimum lux requirement assigned.

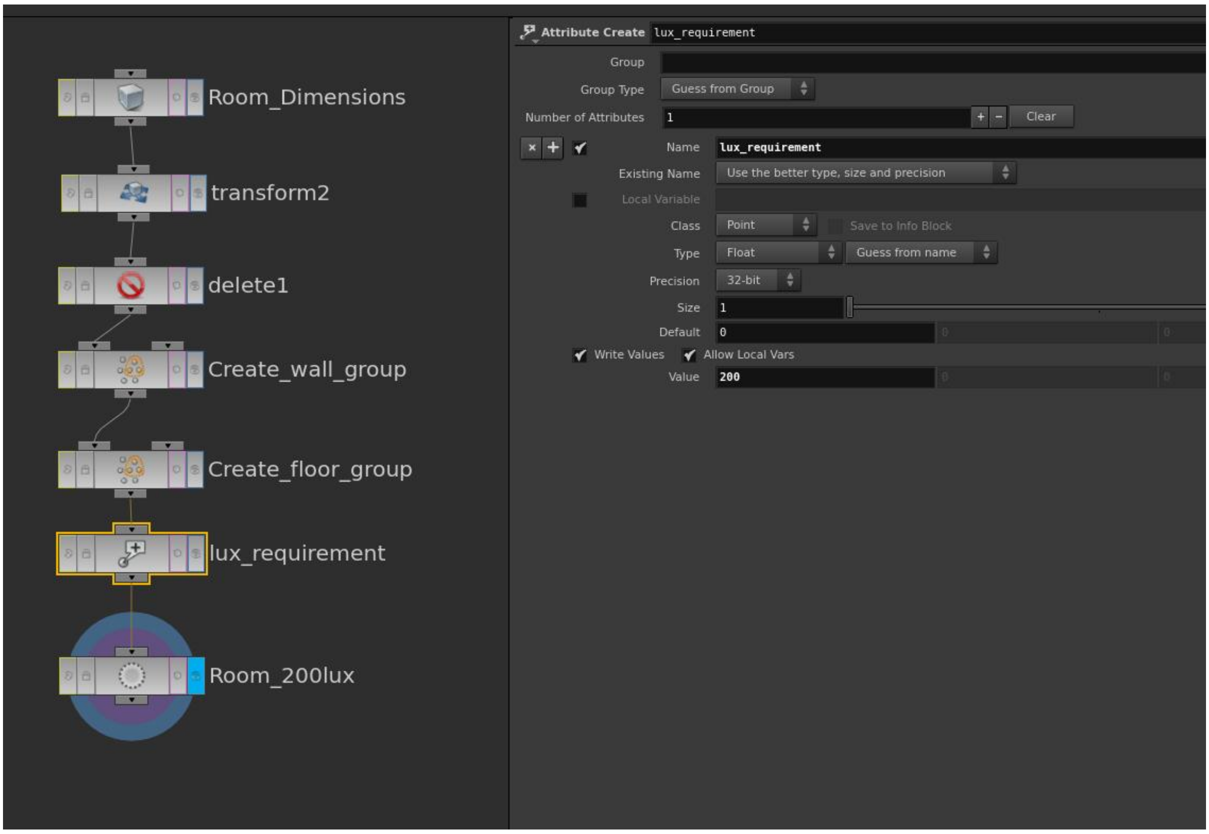


Fig.10 Room_200lux geo node expanded.

The 3 types of room are all of the dimension 4.5m x 4.5m x 4.2m (LxBxH), with 3 different type of minimum lux requirements, 200lux, 500lux, 800lux. These values will affect the rotation of the façade pieces.

2 Generate Room

Within “Generate room”, the “room map” file from Rhinoceros is processed generate the model (Fig. 11). Each room type is then assigned to the room map (Fig. 12). The node provides a completed set of rooms with all the required attributes, as well as the means to reference the various parts of the rooms (e.g. floors, walls).

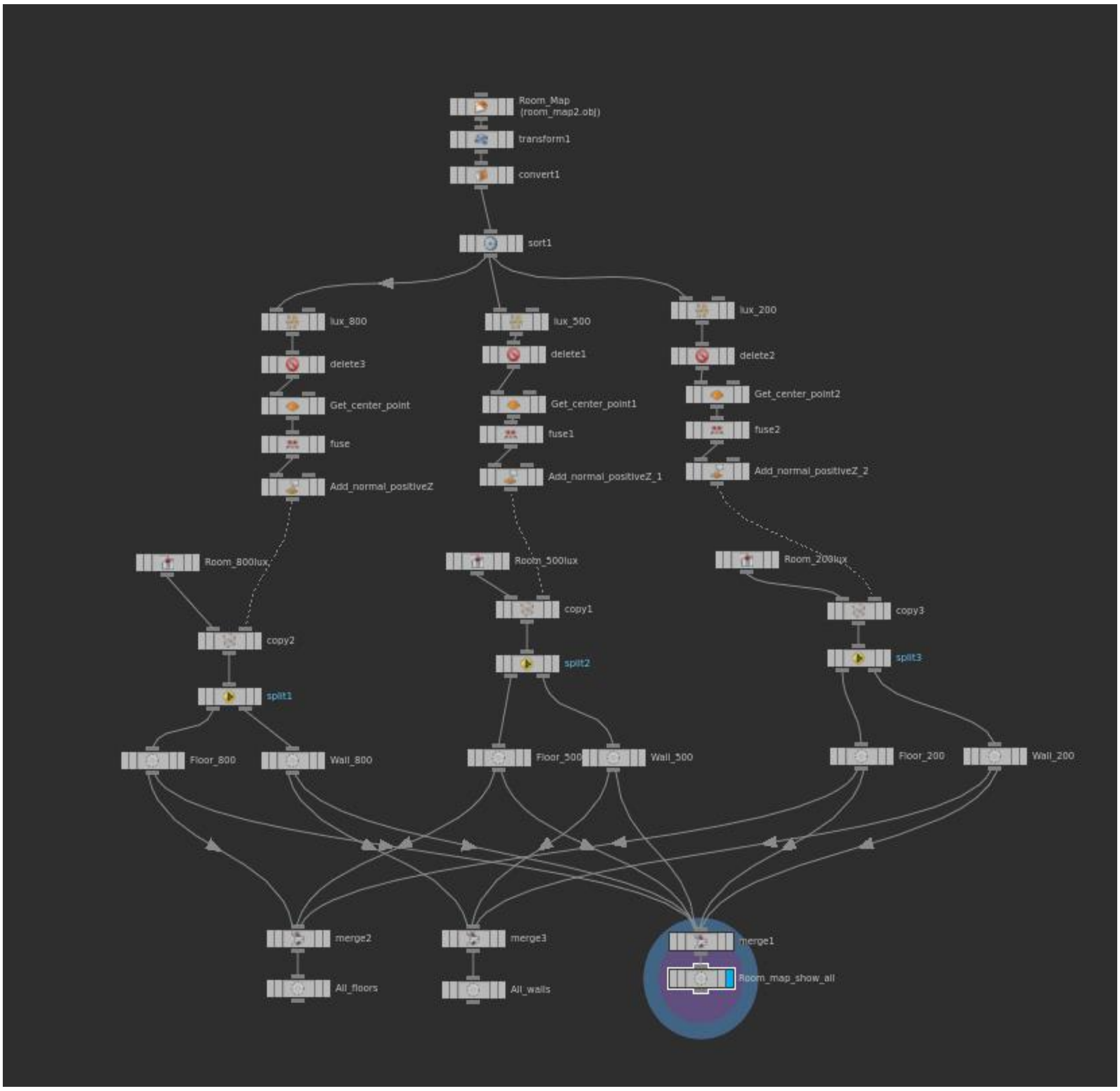


Fig.11 Room Node expanded

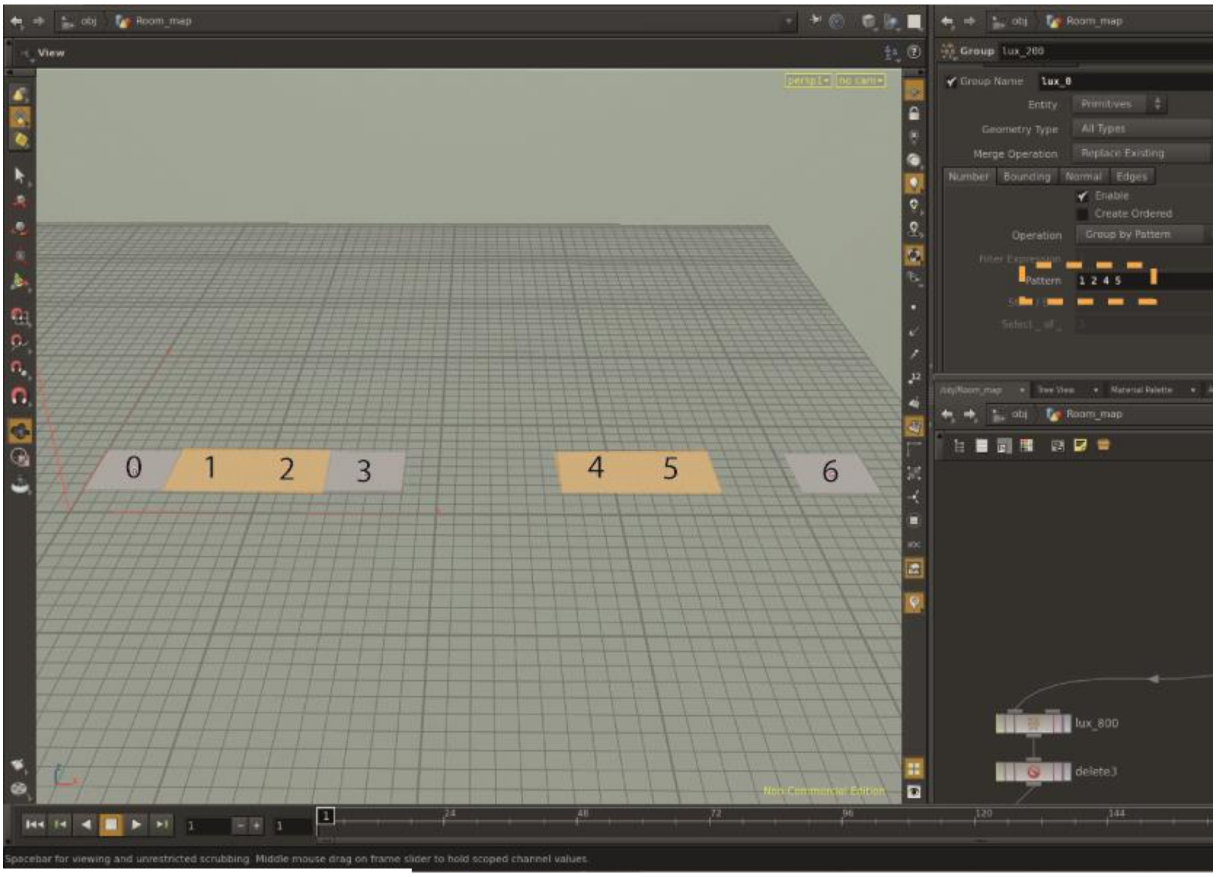


Fig.12 Room assignment

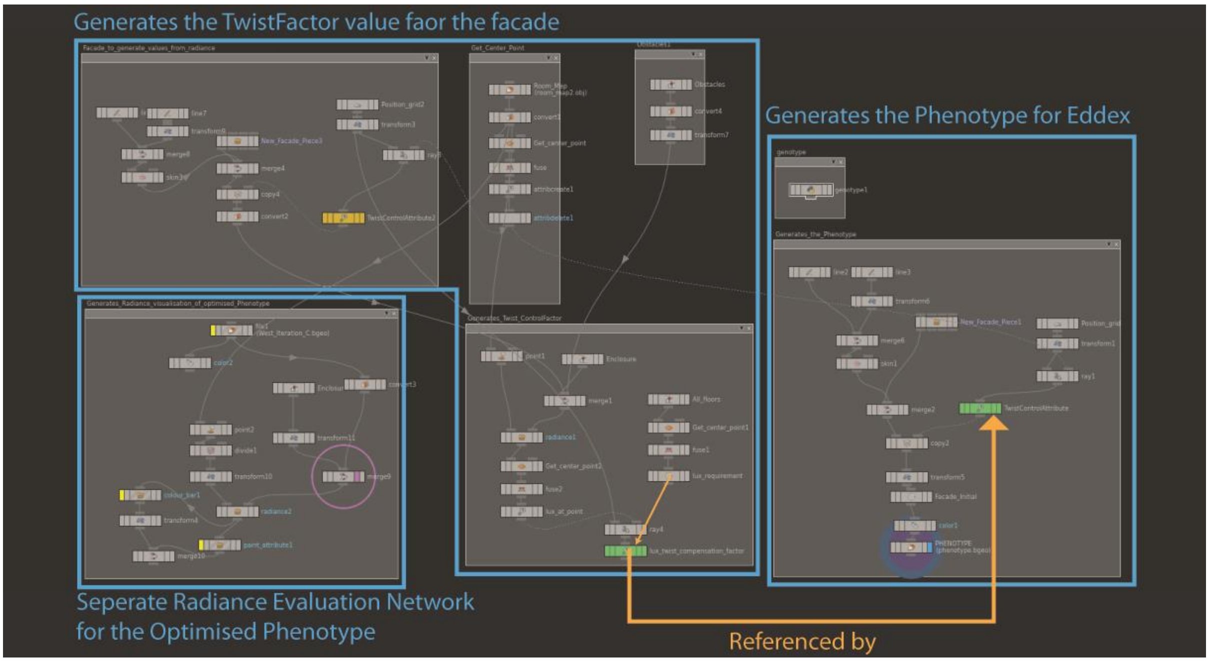


Fig.13. Generate Room Expanded. Refer to Annex A for a larger image.

3 Generate Facade

Within "Generate Façade", there are 3 main networks that perform the following functions (Fig. 13):

- Generates the Phenotype for Eddex
- Generates the TwistFactor for the façade
- Radiance evaluation network for the selected optimised Phenotype from Eddex

It is important to note that the radiance evaluation network does not affect the generation of the Phenotype. I shall now elaborate on how the TwistFactor is calculated before discussing how the phenotype is evaluated within Eddex.

The TwistFactor consists the sum of 2 components that are derived from the centre point of the rooms (Fig. 14), which determines how much each façade piece twists:

- Distance between each façade piece and the centre point of the nearest room
- The illumination level at the centre point of the room

The distance between the façade pieces and the centre point allows for the creation of gradual patterns on the façade. The illumination levels at the centre of the room provides the performance based adjustments that regulates the amount of light entering the room. Using the distance attribute to control the opening sizes from the twisting of the façade in addition to the illumination level, allows for greater control on the aesthetics of the façade to express the presence of volume and void while not compromising the performance of the façade as a daylight filter. This is especially useful when the difference in illumination values itself is not sufficient to generate an obvious pattern. Annex B shows the exact function used as well as the values derived from the simulation.

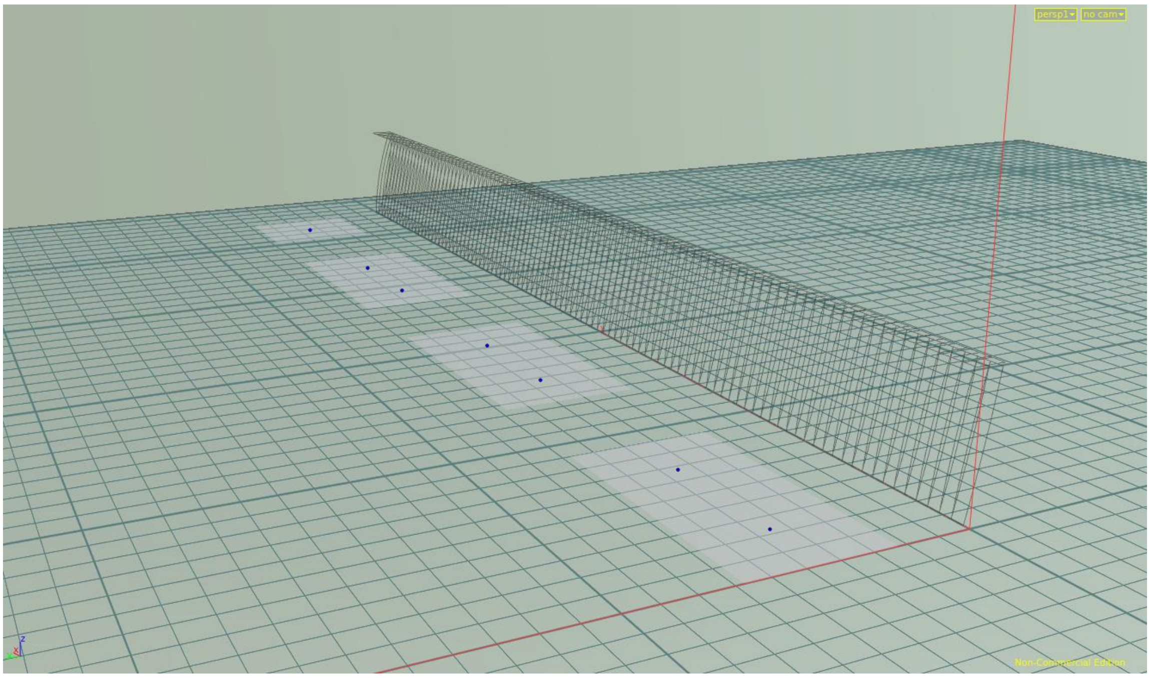


Fig.14 Center points of room in relation to the facade

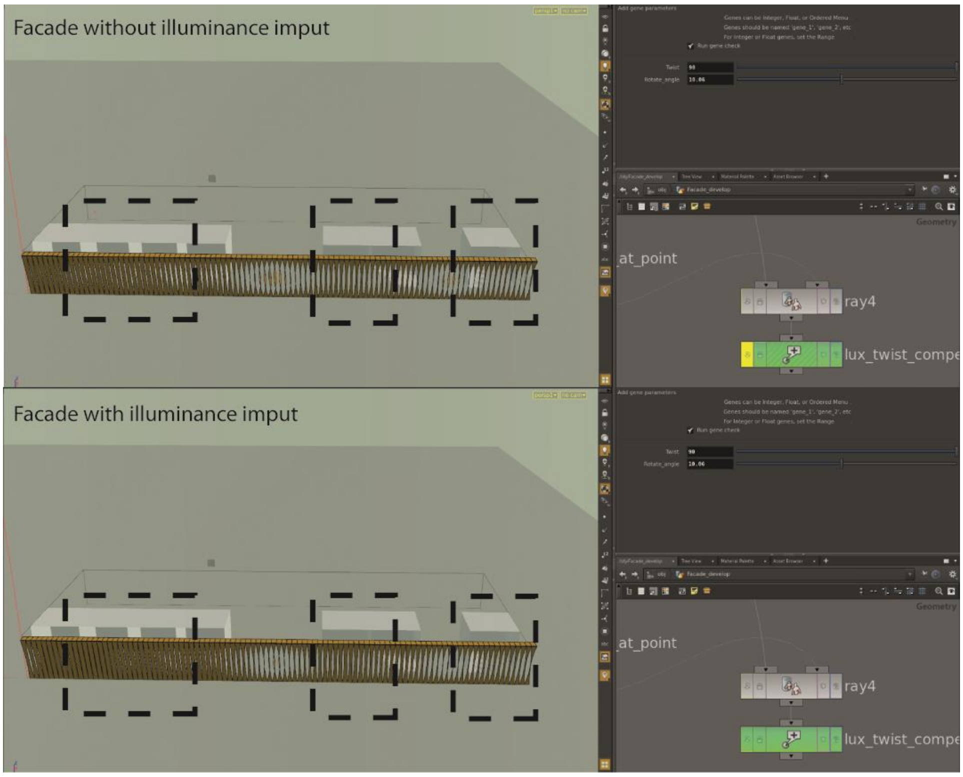


Fig.15 Façade comparison. With and without illuminance input

The above setup allows the façade pieces also respond to external objects (e.g. large buildings) which blocks daylight (Fig.16). In the example shown below, the façade openings increases in response to the decrease of illumination levels cause by an external obstruction.

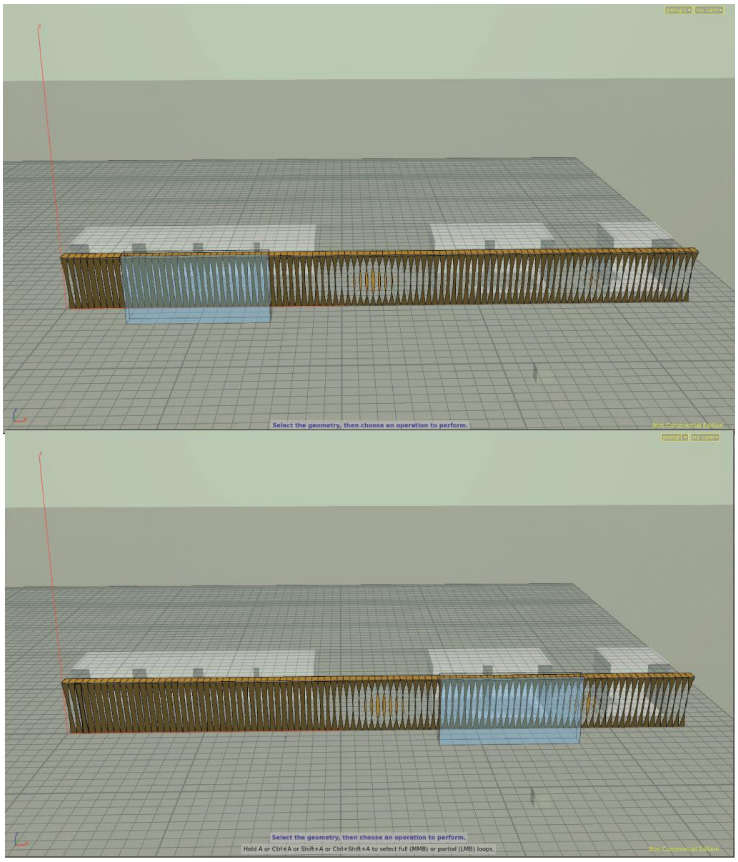


Fig.16 Façade reacting to external obstruction.

The setup is then put through an evolutionary evaluation process with the following parameters.

Genes:

- **Inclination Angle** (float, 0-20 degree)
- **Degree of Twist** (float, 0-90 degree)

Evaluation Parameters:

- Percentage of Lit Area
- Percentage of Glare Area

The lit condition is determined by attributes of the room. A grid on the analysis plane is considered lit if the illumination level is **above either 200 lux, 500 lux, 800 lux.**

The glare condition is defined as the room receiving excessive levels of illumination**.** A grid on the analysis plane is considered to have glare it contains readings that are **above 1000 lux**.

The results of the above simulation will be discussed in the next section.

Results

Eddex was left to generate 3712 iterations. The graph that is generated illustrates a clear Pareto front (Fig. 17).

The results from Eddex indicates that it is possible to get a 0% Percentage Glare if Percentage Lit value is between 0%-36%. There seems to be little benefit for a higher Percentage lit value as percentage glare increases exponentially with a small increment. By comparing the resulting façade geometry from the two ends of the graph (i.e. Iteration A and Iteration B), we can observe that the more prominent eave in Iteration A

Iteration A was then selected and put through Radiance to visualise the effects of the façade in the room. By comparing the default façade before optimisation with Iteration A, we can see a marked improvement in the glare situation within the rooms. In the darker areas of within Iteration A, we are still getting illumination levels within the region of **400 lux**, which is ideal for normal office work (Fig.18).

Iteration A is then exported as an .obj file and imported into Rhinoceros. The rendered result within the Rhinoceros shows that there is no abnormally in geometry (Fig. 19).

Facade Orientated to face West

(3712 Iterations)

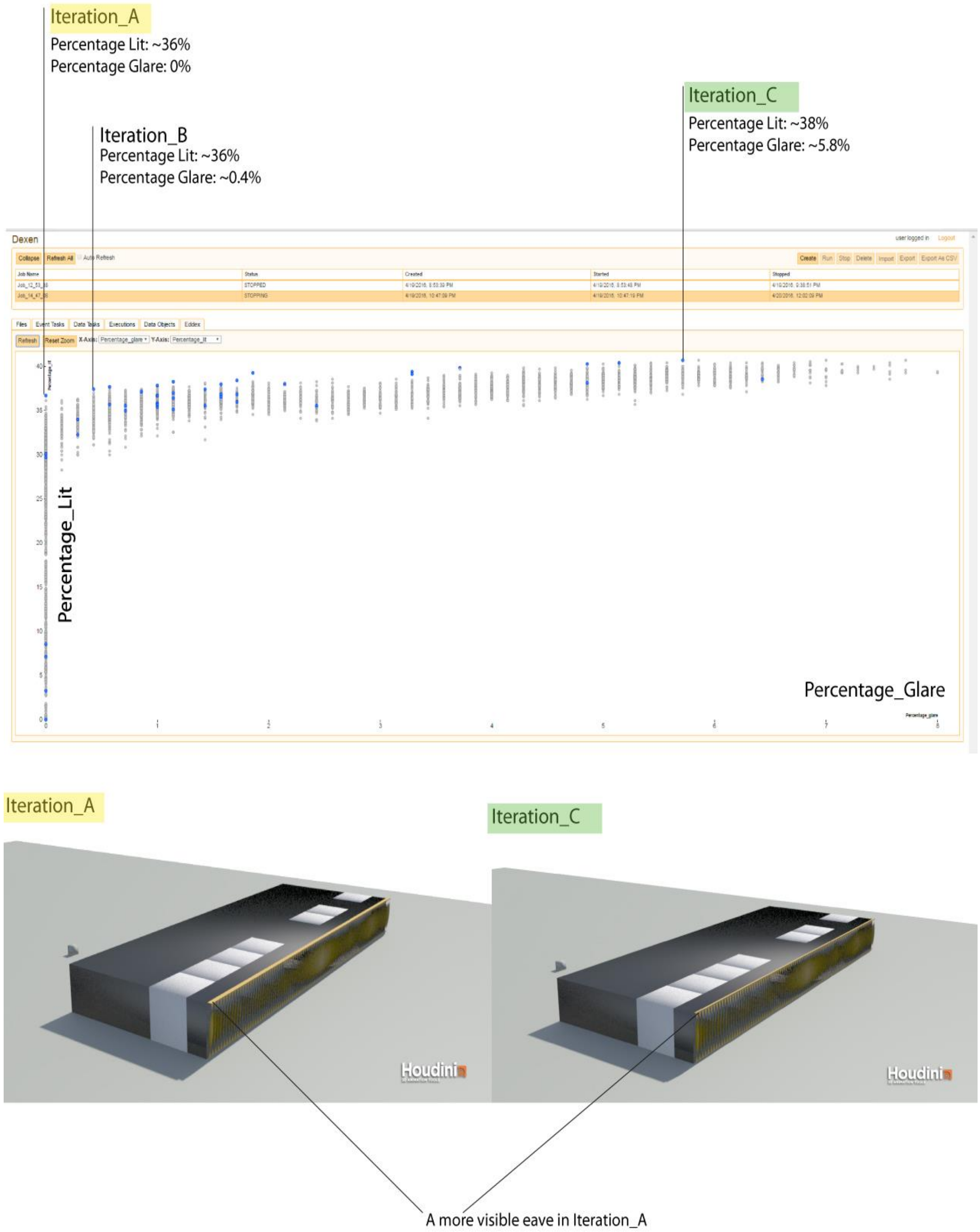


Fig.17 Results from Eddex

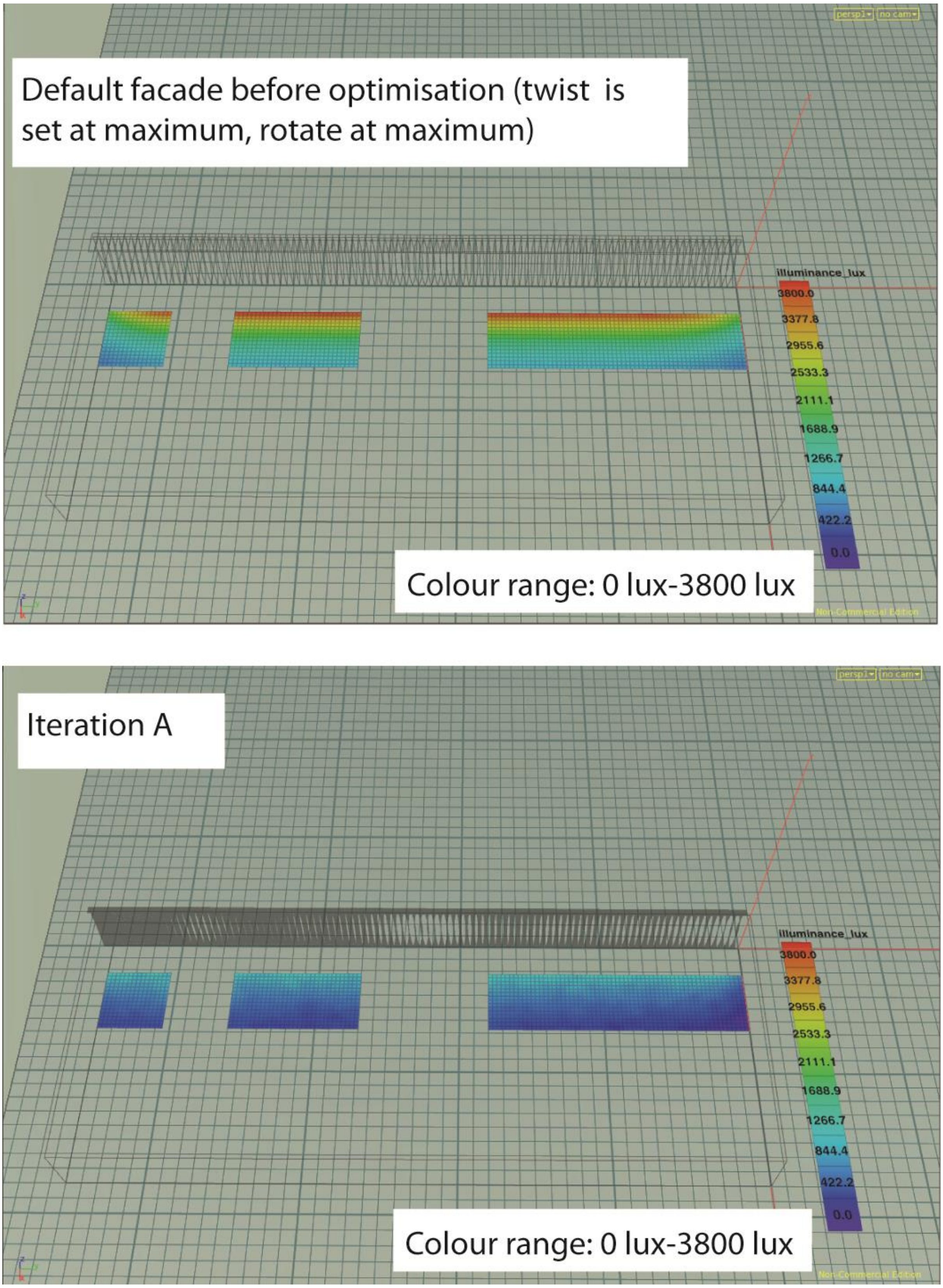


Fig.18 Visualisation of radiance simulation

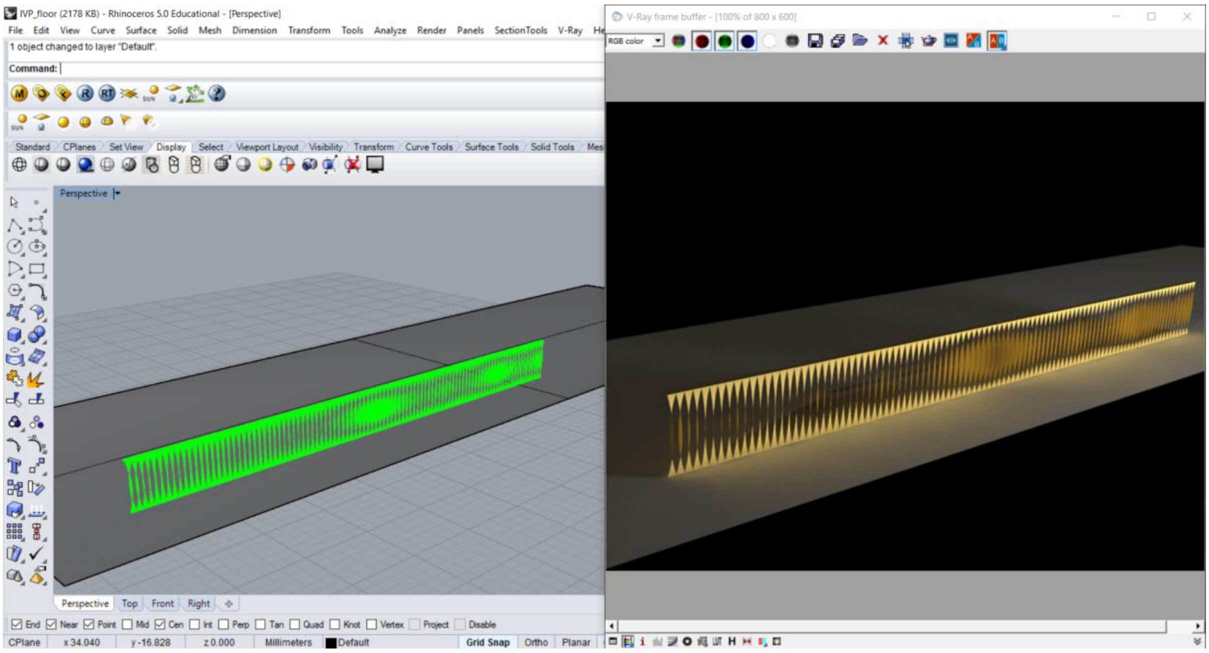


Fig.19 Geometry within Rhinoceros

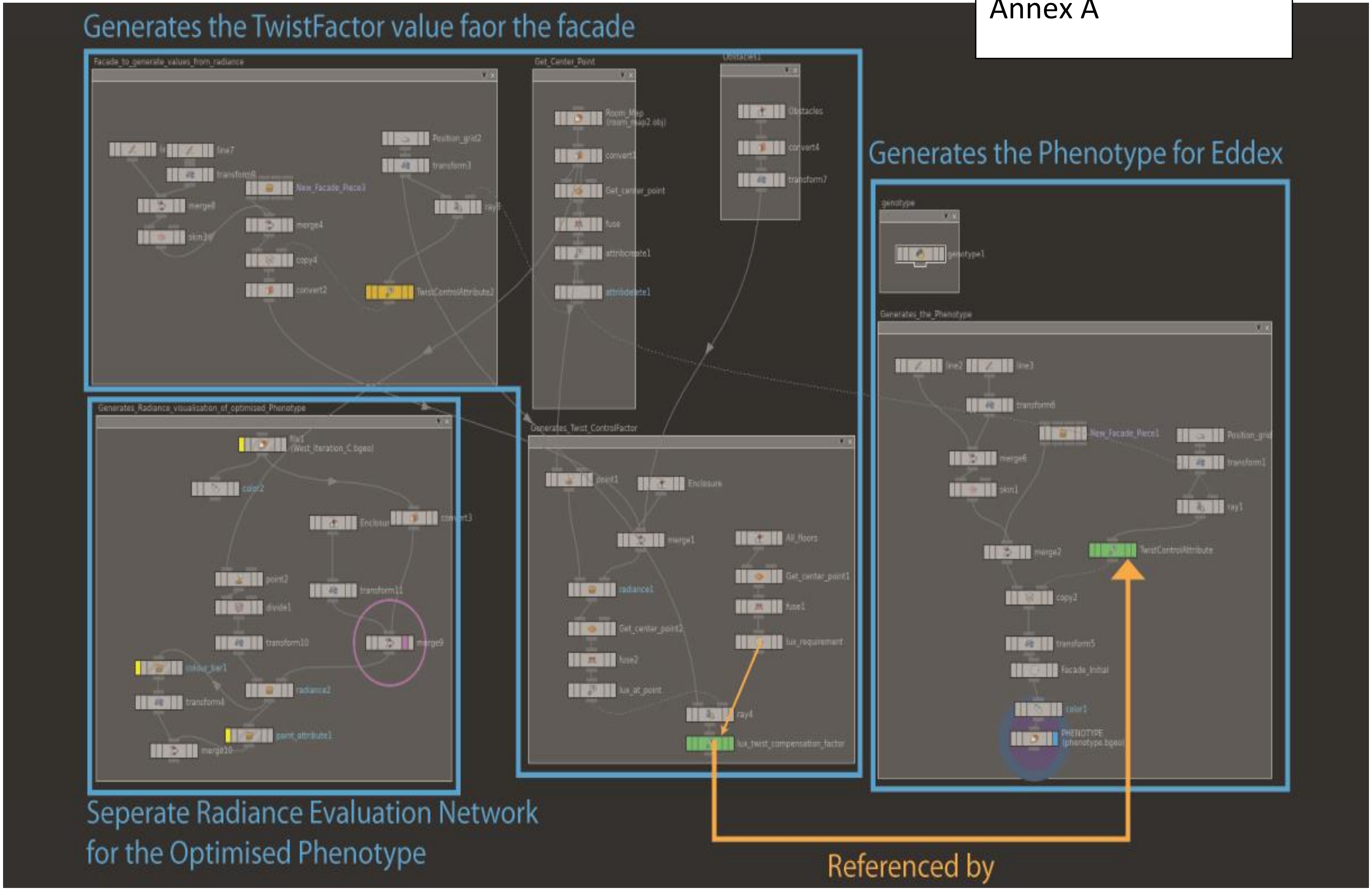
Discussion & Future Improvements

The experiment has shown a feasible of generating performance based geometries within Houdini based on inputs defined within Rhinoceros, which can then be imported back into Rhinoceros with a high degree of accuracy and no loss in model information. Future work can explore Houdini network that will automatically generate rooms of varying dimensions with.

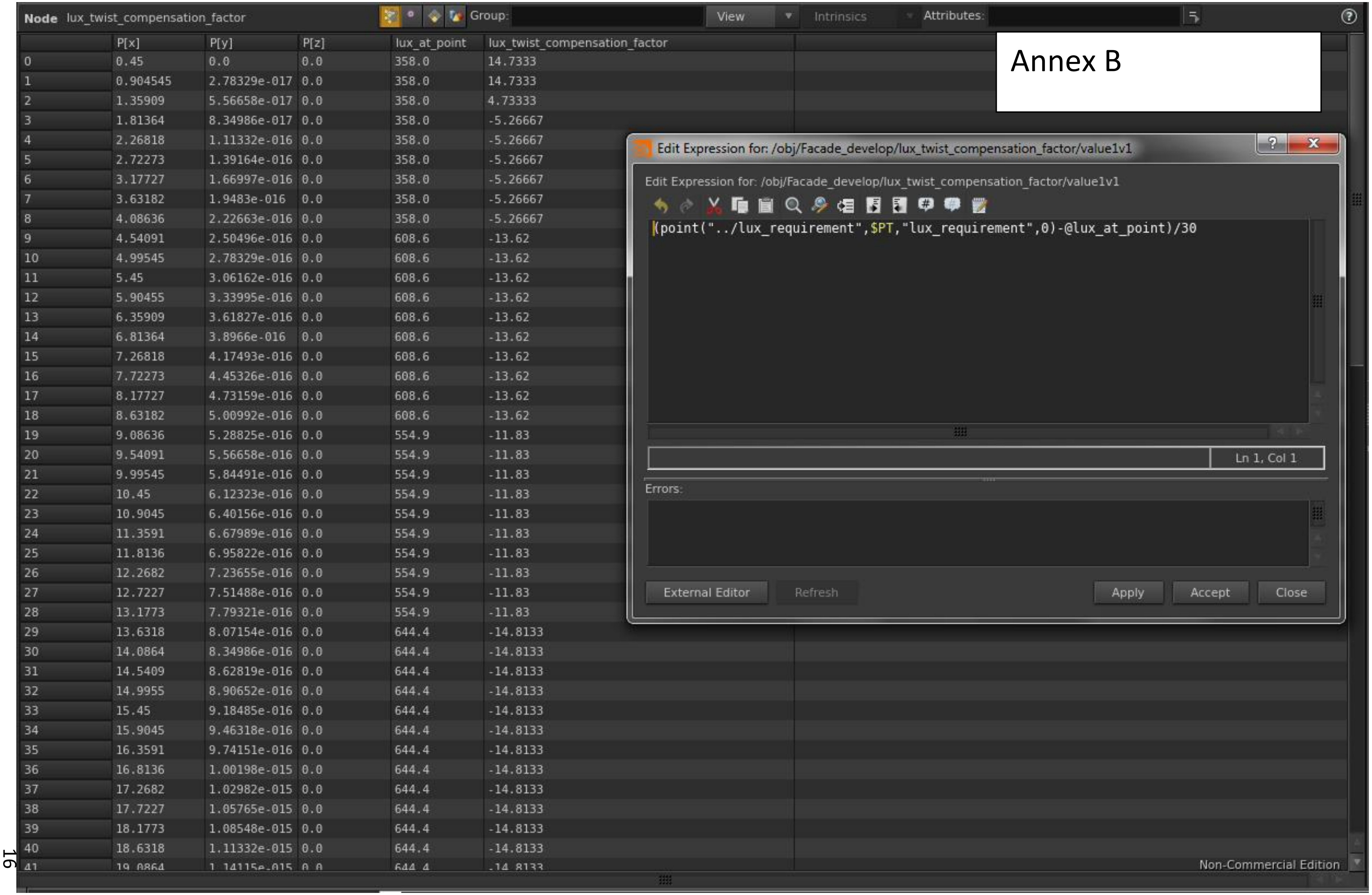
The experiment also demonstrated that the façade design can fulfil the objective of shielding the rooms from direct sunlight, but still provide adequate amounts of daylight.

The Houdini network managed to achieve most of the performance specifications, with the exception of meeting the light level requirements in each room. The radiance result shows very little distinction between the rooms. A possible improvement would be to use larger set of points to collect illuminance levels for the optimisation instead of the current single point located at the centre of the room.

Annex A


Generates the TwistFactor value faor the facade
Generates the Phenotype for Eddex
Seperate Radiance Evaluation Network
for the Optimised Phenotype
Referenced by

Annex B



	P[x]	P[y]	P[z]	lux_at_point	lux_twist_compensation_factor
0	0.45	0.0	0.0	358.0	14.7333
1	0.904545	2.78329e-017	0.0	358.0	14.7333
2	1.35909	5.56658e-017	0.0	358.0	4.73333
3	1.81364	8.34986e-017	0.0	358.0	-5.26667
4	2.26818	1.11332e-016	0.0	358.0	-5.26667
5	2.72273	1.39164e-016	0.0	358.0	-5.26667
6	3.17727	1.66997e-016	0.0	358.0	-5.26667
7	3.63182	1.9483e-016	0.0	358.0	-5.26667
8	4.08636	2.22663e-016	0.0	358.0	-5.26667
9	4.54091	2.50496e-016	0.0	608.6	-13.62
10	4.99545	2.78329e-016	0.0	608.6	-13.62
11	5.45	3.06162e-016	0.0	608.6	-13.62
12	5.90455	3.33995e-016	0.0	608.6	-13.62
13	6.35909	3.61827e-016	0.0	608.6	-13.62
14	6.81364	3.8966e-016	0.0	608.6	-13.62
15	7.26818	4.17493e-016	0.0	608.6	-13.62
16	7.72273	4.45326e-016	0.0	608.6	-13.62
17	8.17727	4.73159e-016	0.0	608.6	-13.62
18	8.63182	5.00992e-016	0.0	608.6	-13.62
19	9.08636	5.28825e-016	0.0	554.9	-11.83
20	9.54091	5.56658e-016	0.0	554.9	-11.83
21	9.99545	5.84491e-016	0.0	554.9	-11.83
22	10.45	6.12323e-016	0.0	554.9	-11.83
23	10.9045	6.40156e-016	0.0	554.9	-11.83
24	11.3591	6.67989e-016	0.0	554.9	-11.83
25	11.8136	6.95822e-016	0.0	554.9	-11.83
26	12.2682	7.23655e-016	0.0	554.9	-11.83
27	12.7227	7.51488e-016	0.0	554.9	-11.83
28	13.1773	7.79321e-016	0.0	554.9	-11.83
29	13.6318	8.07154e-016	0.0	644.4	-14.8133
30	14.0864	8.34986e-016	0.0	644.4	-14.8133
31	14.5409	8.62819e-016	0.0	644.4	-14.8133
32	14.9955	8.90652e-016	0.0	644.4	-14.8133
33	15.45	9.18485e-016	0.0	644.4	-14.8133
34	15.9045	9.46318e-016	0.0	644.4	-14.8133
35	16.3591	9.74151e-016	0.0	644.4	-14.8133
36	16.8136	1.00198e-015	0.0	644.4	-14.8133
37	17.2682	1.02982e-015	0.0	644.4	-14.8133
38	17.7227	1.05765e-015	0.0	644.4	-14.8133
39	18.1773	1.08548e-015	0.0	644.4	-14.8133
40	18.6318	1.11332e-015	0.0	644.4	-14.8133
41	19.0864	1.14115e-015	0.0	644.4	-14.8133