Institute for advanced architecture of Catalonia | BARCELONA

MASTER IN ADVANCED COMPUTATION FOR ARCHITECTURE & DESIGN

Digital Tools for Structural Optimization Strategies - Timber Concrete Hybrids

SENIOR FACULTY MANJA VAN DE WORP
STUDENT ASSISTANT HANNA LEPPERØD

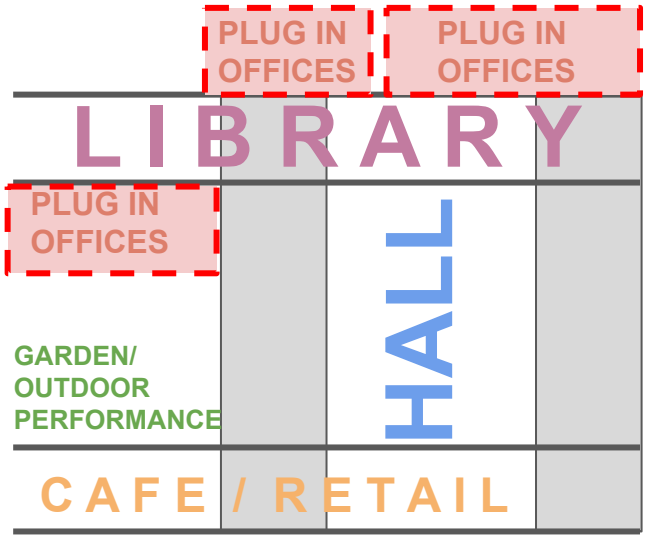
2020/2021

FINAL PRESENTATION

AMAR GURUNG
PEDRO RIBEIRO
MARISSA RIDZUAN

02

What sort of structural strategies allow us to have uninterrupted floor space that would allow us to plug in spaces in the future if needed?



SELF-STRUCTURE PLUG IN

FIXED STRUCTURE / TRUSS

HANG

FLEXIBLE SPACE

STACK

FIXED STRUCTURE / COLUMN

INITIAL STRUCTURE

CROSS SECTIONS

CONCRETE CORES

Height	15cm

TIMBER FLOORS

Height	30cm

TIMBER COLUMNS

Height	-
Upper Width	50cm
Lower Width	50cm

TIMBER BEAMS

Height	30cm
Upper Width	30cm
Lower Width	30cm

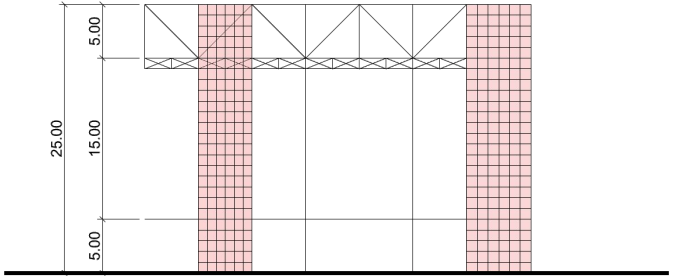
TIMBER TRUSS

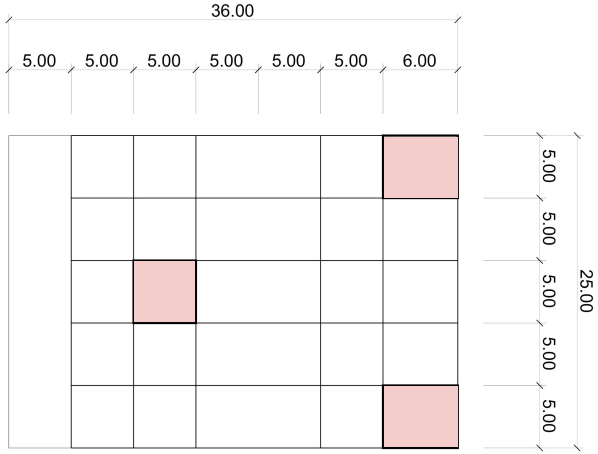
Height	30cm
Upper Width	30cm
Lower Width	30cm

LOADS

Self Load
Gravity Load
Wind load 1.5 kN/M2

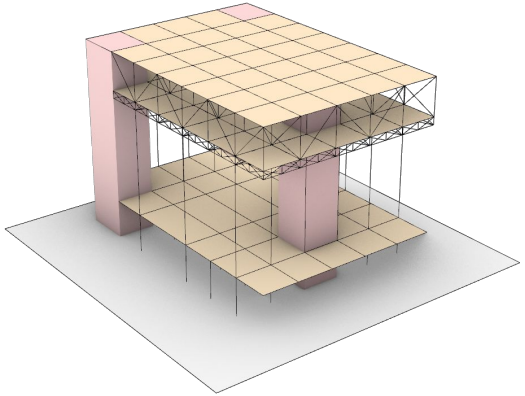
ELEVATION





PLAN

PERSPECTIVE



SHELLS

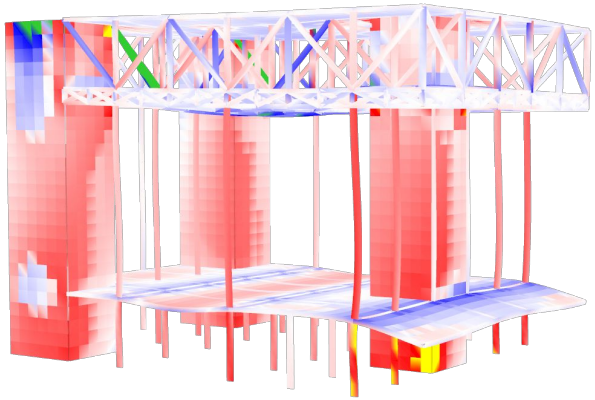
utilization
-29.6%
-25.9%
-22.2%
-18.5%
-14.8%
-11.1%
-7.4%
-3.7%
0.0%
3.8%
7.7%
11.5%
15.4%
19.2%
23.1%
26.9%
30.8%

Min -49.7%
Max 50.9%

BEAMS

utilization
-58.9%
-51.6%
-44.2%
-36.8%
-29.5%
-22.1%
-14.7%
-7.4%
0.0%
3.6%
7.2%
10.8%
14.5%
18.1%
21.7%
25.3%
29.0%

Min -99.2%
Max 58.2%



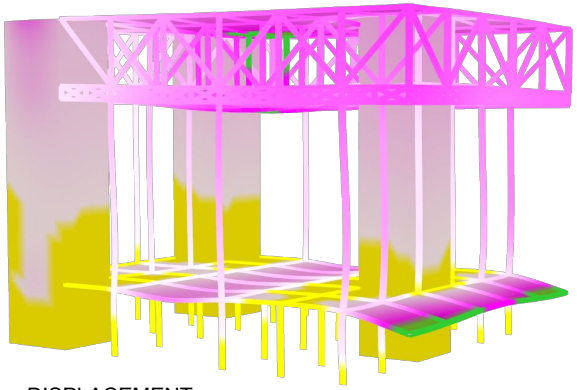
UTILIZATION

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1.05e+00
1.15e+00
1.26e+00
1.36e+00
1.46e+00
1.56e+00
1.67e+00
1.77e+00

Min 0.00cm
Max 2.53cm

res.disp.[cm]
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1.05e+00
1.16e+00
1.26e+00
1.36e+00
1.46e+00
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1.77e+00

Min 0.00cm
Max 2.53cm



DISPLACEMENT

INITIAL STRUCTURE

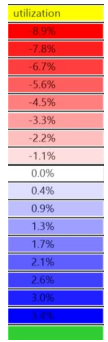
ALL ELEMENTS, **SELF LOAD ONLY**

CONCLUSION

With only self load the **cores on the left are working to stop the structure from caving in as the centre part of the building has less supports**. We can also see that the beams/truss at the centre of the upper floor are working the hardest. Beams and floor on the lower floor where they span 10m are also working more than the other parts.

There is little or no displacement in the lower half of the cores as there are columns here that are also supporting the structure. Other than the cantilevered part and area of 10m span of the lower floor most of the displacement are in the upper part of the building. The most displacements are in the central area where there are no vertical supports.

SHELLS

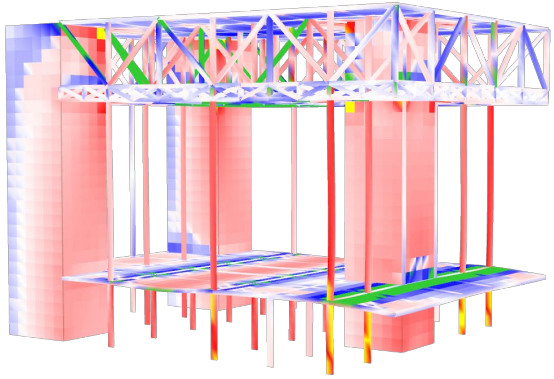


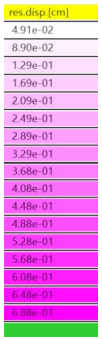
Min -18.2%
Max 12.7%

BEAMS

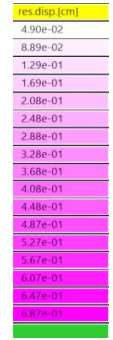


Min -32.6%
Max 19.9%

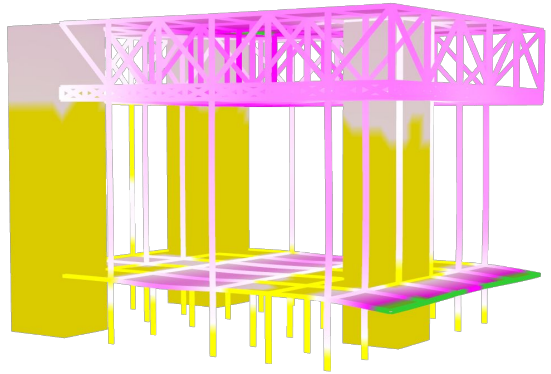




Min 0.00cm
Max 0.98cm



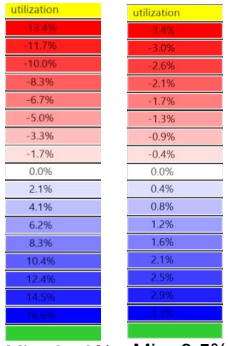
Min 0.00cm
Max 0.98cm



INITIAL STRUCTURE

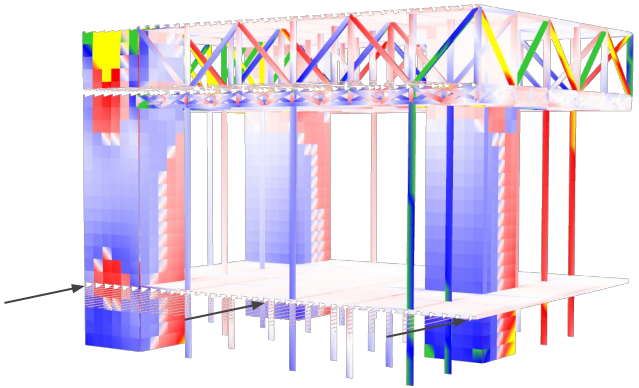
ALL ELEMENTS, **WIND LOAD ONLY**

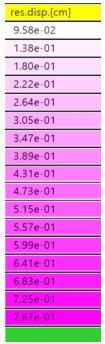
SHELLS **BEAMS**



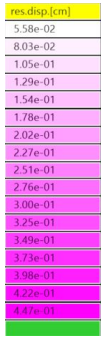
Min -35.8%
Max 39.0%

Min -8.5%
Max 8.3%

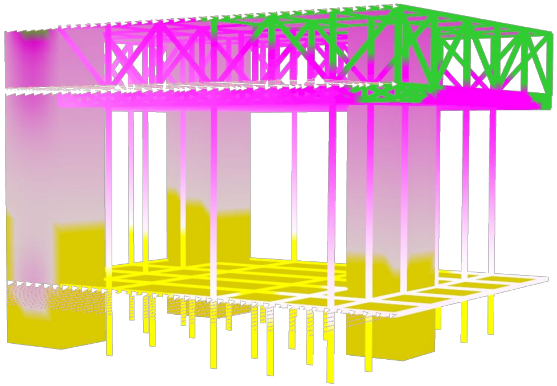




Min 0.00cm
Max 0.95cm



Min 0.00cm
Max 0.55cm



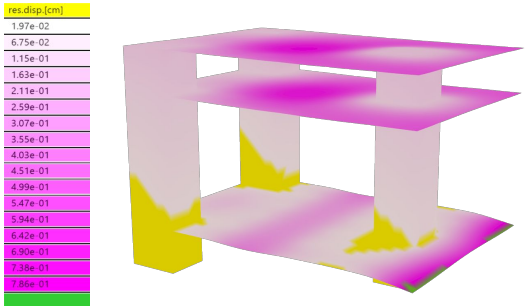
CONCLUSION

Here, we see that the cores behave very differently to when only self load is applied which is in vertical whereas the wind load is horizontal. The cores perpendicular and facing the wind direction are being utilized the most here. The columns closer to the facade where the wind is being applied is also working harder than the other columns.

Most the the displacements are in the upper beam elements where there is only one core. Since there is only one core taking all the lateral forces compared to the other end where the structure is more stable due to the two cores most displacements are happening here. Maybe adding a shear wall on this side will make the structure more stable. The maximum displacement is only 0.55cm.

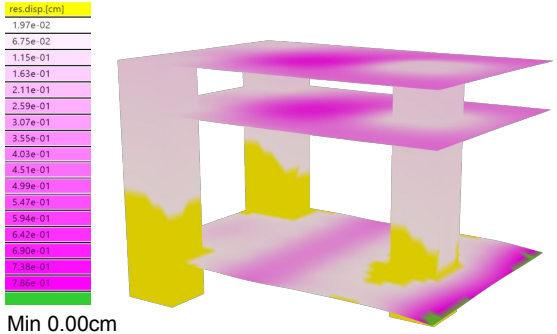
INITIAL STRUCTURE

ALL SHELL ELEMENT DISPLACEMENT



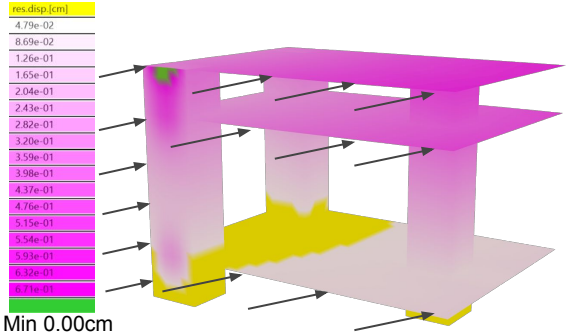
Min 0.00cm
Max 1.52cm

GRAVITY LOAD



Min 0.00cm
Max 0.98cm

SELF LOAD



Min 0.00cm
Max 0.95cm

WIND LOAD

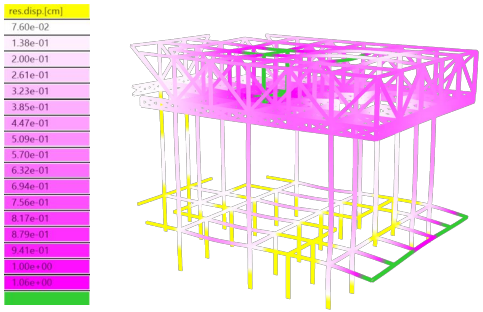
CONCLUSION

For both gravity and self load, the cantilevered part of the lower floors and the middle area of the upper floor and roof are being displaced the most, hence, would need additional support or to increase the size of the support members. There is little or no displacement in the cores for both the gravity and self load, specially at the bottom.

For the wind load the displacements are more in the upper region of the structure, the upper floors and the top part of the cores. The structure here is trying to resist the lateral movement caused by the wind. In other words, it is trying to stop twisting from the top in anti clock direction.

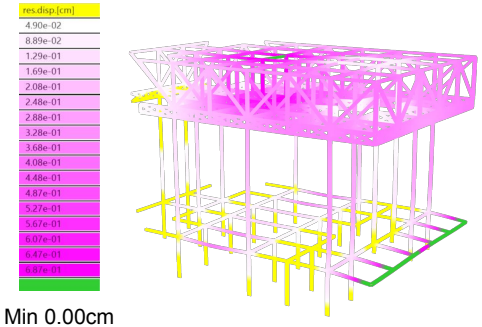
INITIAL STRUCTURE

ALL BEAM ELEMENT DISPLACEMENT



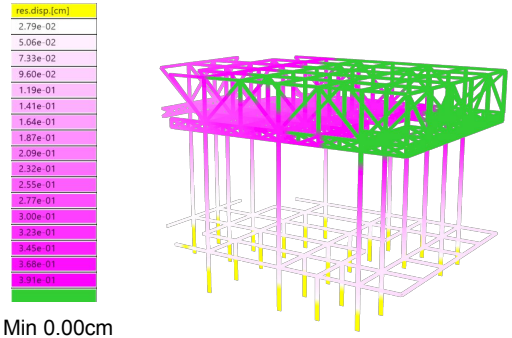
Min 0.00cm
Max 1.52cm

GRAVITY LOAD



Min 0.00cm
Max 0.98cm

SELF LOAD



Min 0.00cm
Max 0.55cm

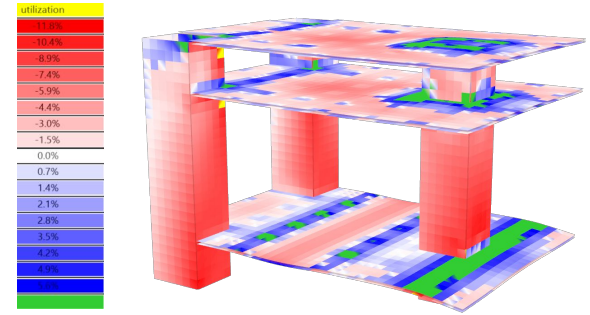
WIND LOAD

CONCLUSION

Similar to the floors and cores the area where the beam elements are being displaced the most are the same, the cantilevered areas and the upper floor. Here, we can see that the columns at the bottom are being displaced the least and are very stable, where as the upper areas are being displaced more.

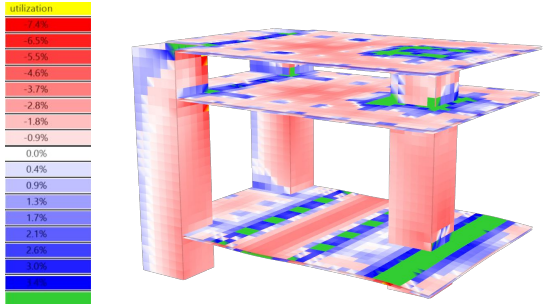
INITIAL STRUCTURE

ALL SHELL ELEMENT UTILIZATION



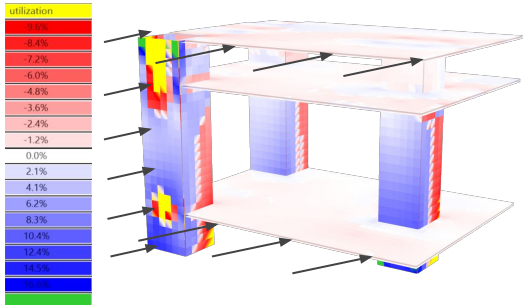
Min -29.3%
Max 20.6%

GRAVITY LOAD



Min -18.2%
Max 12.7%

SELF LOAD



Min -35.8%
Max 39.0%

WIND LOAD

CONCLUSION

The cores for the gravity and self load are not being utilized much **except the top left corner for gravity load and the left side for self load.** This is happening because the cores are taking all the loads of the floor and trying to prevent bending inwards so the outer side of the cores are working more than the other parts.

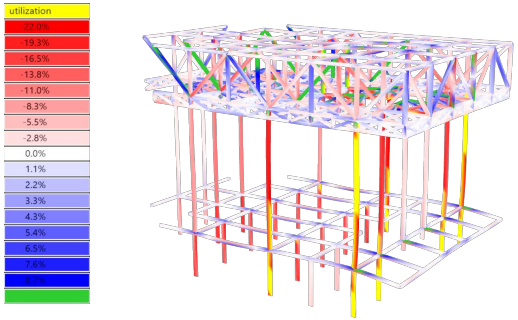
The areas where the floor intersect the cores or the columns are working the most as seen in green here. The start of the cantilevered floor is also being utilized the most.

For the wind load, the core are being utilized much more than for the other two loads at a maximum of 39% compared to only 20% and 12%.

The cores in the wind load are preventing lateral movement. We can see the direct relationship between the with the displacement and the utilization of the shell elements.

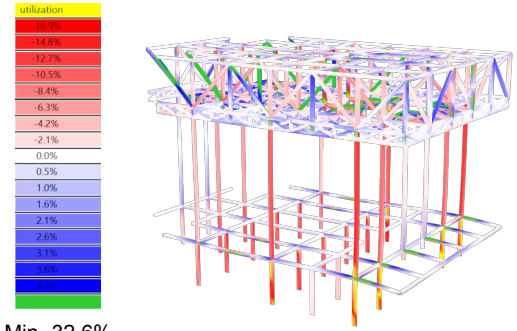
INITIAL STRUCTURE

ALL BEAM ELEMENT UTILIZATION



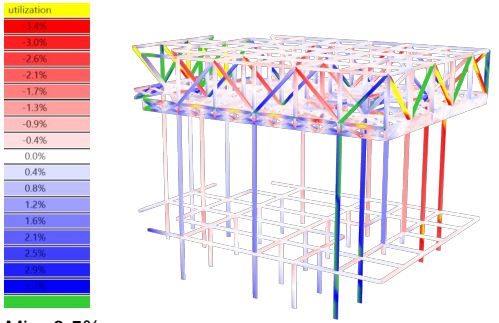
Min -52.7%
Max 35.0%

GRAVITY LOAD



Min -32.6%
Max 19.9%

SELF LOAD



Min -8.5%
Max 8.3%

WIND LOAD

CONCLUSION

The columns on the bottom half of the structure are not being utilized much for gravity and self load. Only the beams in lower half are being utilized to hold up the floor mass.

The upper floor seems to be doing most of the work here. This could be the case as the mass here is more as well. Among the upper beam elements the diagonal members are being utilized the most.

In the case for wind load, the columns closest to the facade where the wind is applied are working the most.

The utilization for the beam elements on the upper floor are not concentrated in one area but rather scattered all around.

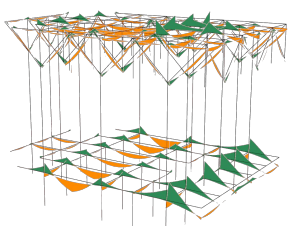
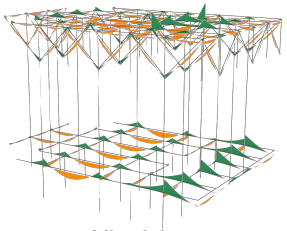
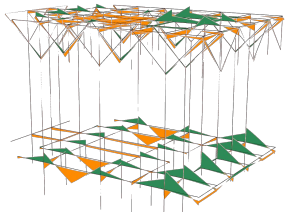
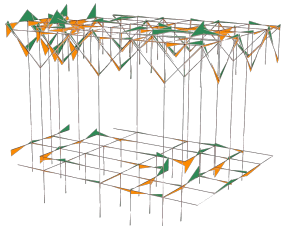
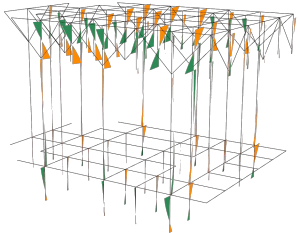
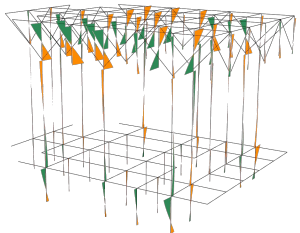
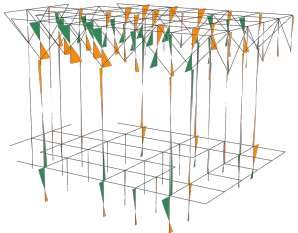
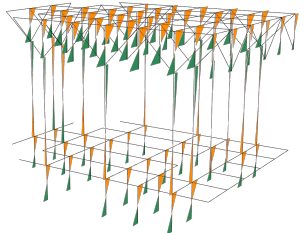
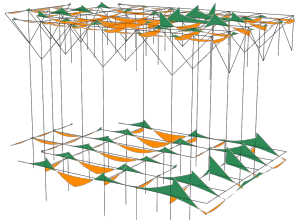
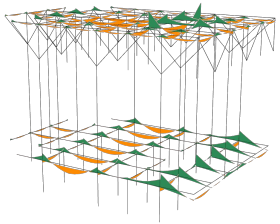
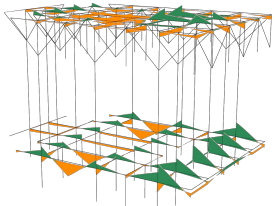
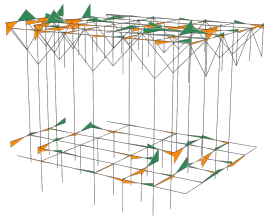
INITIAL STRUCTURE

BEAMS FORCES, My (kN)

Bending

CONCLUSION

Bending for both columns and beams seem to be equally distributed in both direction for gravity and self load. **In the case of wind load there are areas where bending is unevenly distributed for the beams**, with peaks in certain area and little or no bending in other areas.

	ALL LOADS	GRAVITY	SELF LOADS	WIND LOADS
ALL BEAMS	 Min -6.345 Max 10.735	 Min -6.345 Max 10.735	 Min -4.252 Max 5.397	 Min -1.474 Max 1.914
COLUMNS ONLY	 Min -0.405 Max 0.403	 Min -0.405 Max 0.403	 Min -0.286 Max 0.287	 Min -0.126 Max 0.127
BEAMS ONLY	 Min -3.892 Max 10.735	 Min -3.892 Max 10.892	 Min -3.756 Max 4.611	 Min -0.926 Max 0.883

INITIAL STRUCTURE

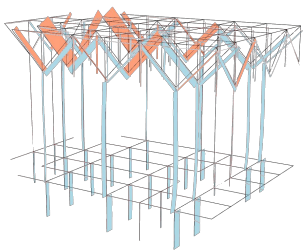
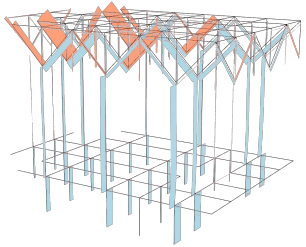
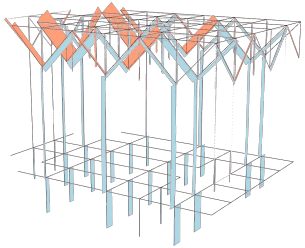
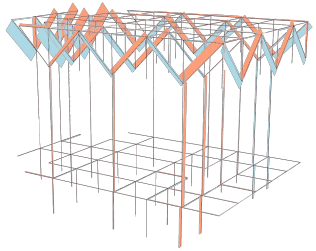
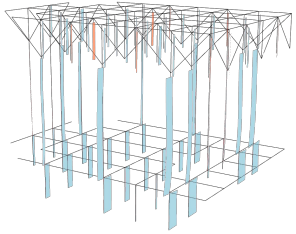
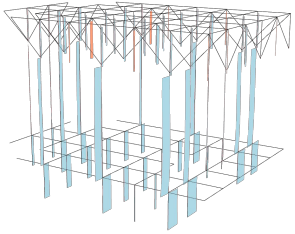
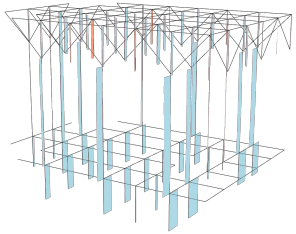
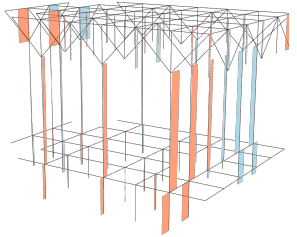
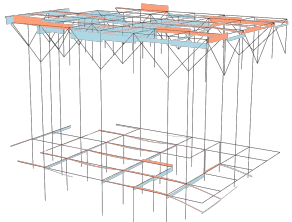
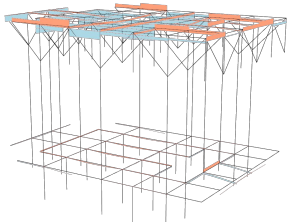
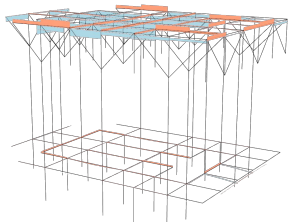
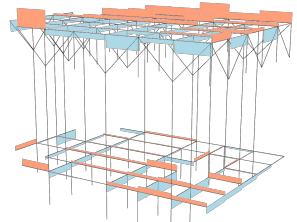
BEAMS FORCES, Nx (kN)

Tension and compression

CONCLUSION

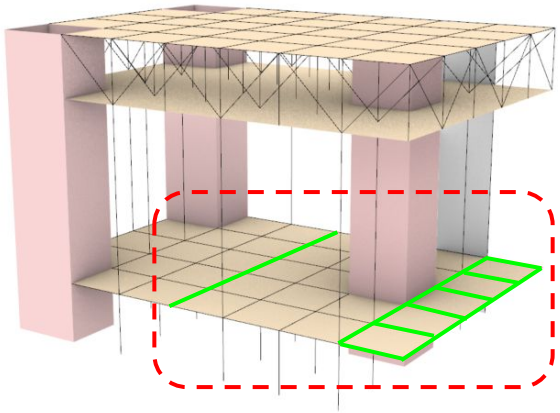
Taking a closer look at the beam forces we noticed that the columns are in more compression than in tension for gravity and self load whereas in the wind load they are more in tension towards the facade where the wind load is applied. We will have to add diagonal members to adjust the columns.

For the beams, most of the tension and compression are in the upper elements except for the wind load where it is evenly distributed.

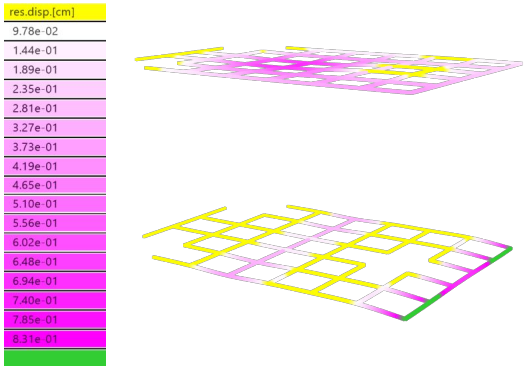
	ALL LOADS	GRAVITY	SELF LOADS	WIND LOADS
ALL BEAMS				
	Min -274.5 Max 307.13	Min -274.5 Max 307.13	Min -166.56 Max 187.08	Min -86.98 Max 85.39
COLUMNS				
	Min -211.32 Max 56.29	Min -211.32 Max 56.29	Min -127.99 Max 30.18	Min -28.83 Max 29.51
BEAMS				
	Min -20.646 Max 9.478	Min -20.646 Max 9.478	Min -13.062 Max 4.769	Min -7.129 Max 9.478

ADJUSTMENTS TO INITIAL STRUCTURE

ADDING ADDITIONAL SUPPORTS BASED ON INITIAL ANALYSIS

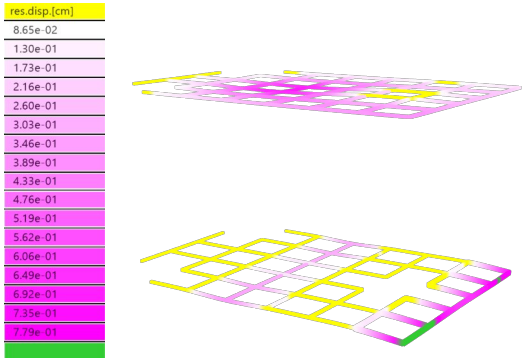


SELF LOAD
BEAM HEIGHT AT CANTILEVERED PART
30 cm



Min 0.00cm
Max 0.97cm

SELF LOAD
BEAM HEIGHT AT CANTILEVERED PART
50 cm

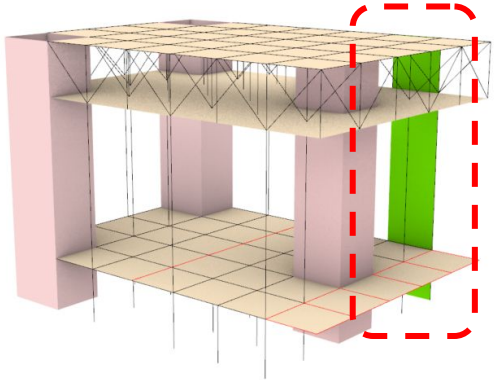


Min 0.00cm
Max 0.86cm

Adding beams to support the floor and increasing the size of the beams where the floor is cantilevered.

By adding and increasing the beam size in the relevant part, the displacement is reduced.

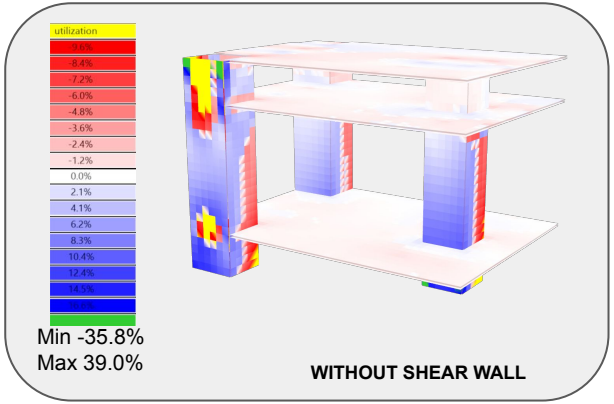
ADDING ADDITIONAL SHEAR WALL ADDED BASED ON INITIAL ANALYSIS



Adding additional shear wall to prevent lateral movement from wind loads.

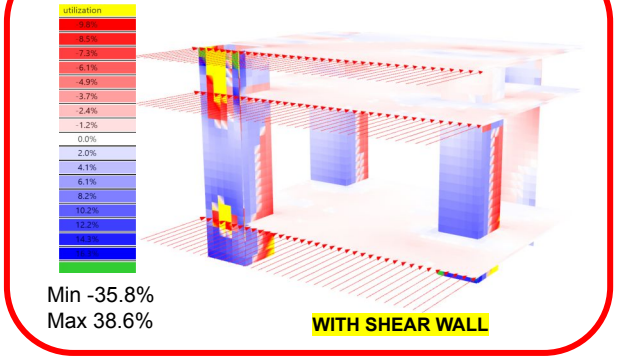
By adding an additional shear wall the utilization of the shell elements reduce by only 1% and there is little change to the displacement. It seems like the additional wall is not doing much to the overall core structure here. However, once we start stacking and hanging spaces, it could help in supporting the additional loads.

WIND LOAD
UTILIZATION (FLOOR & CORE)



Min -35.8%
Max 39.0%

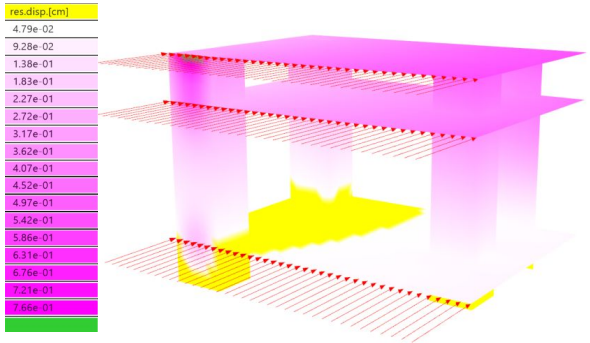
WITHOUT SHEAR WALL



Min -35.8%
Max 38.6%

WITH SHEAR WALL

WIND LOAD
DISPLACEMENT (FLOOR & CORE)

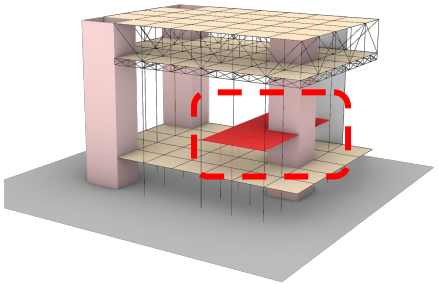


Min 0.00c
Max 0.95cm

PLUG IN - STACKING AND HANGING ADDITIONAL SPACES

SECOND GOAL

Stacking 1 & Hanging (self load only)

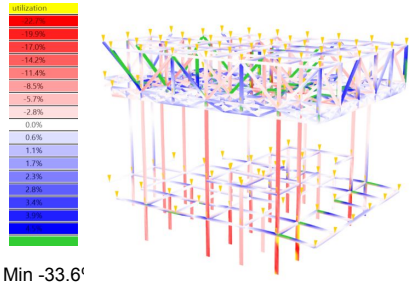


The overall structure is still stable after adding floors to the existing structure. There is little displacement to both the beam and shell elements and the utilization is at a maximum of 20% only.

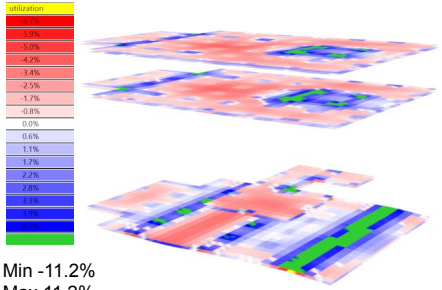
Hence, we can add more loads to this existing structure.

BEAM ELEMENTS | FLOOR | CORE

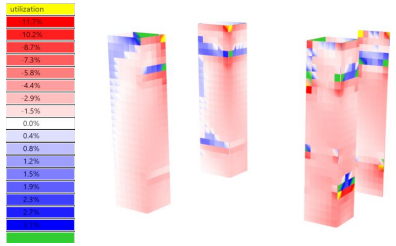
UTILIZATION



Min -33.6%
Max 20.8%

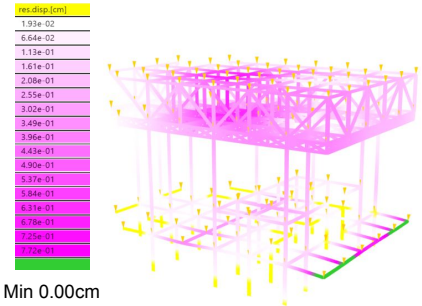


Min -11.2%
Max 11.2%

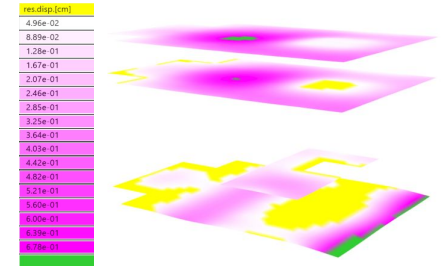


Min -17.6%
Max 12.0%

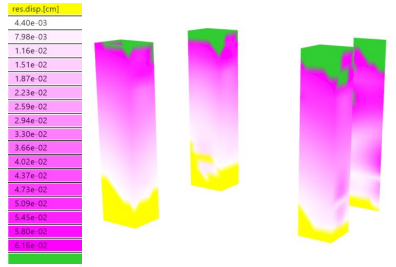
DISPLACEMENT



Min 0.00cm
Max 0.66cm



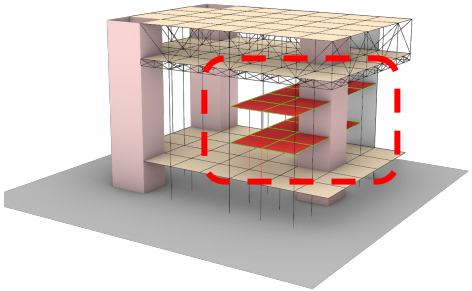
Min 0.003cm
Max 0.968cm



Min 0.000cm
Max 0.088cm

SECOND GOAL

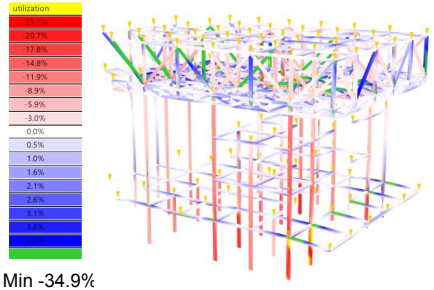
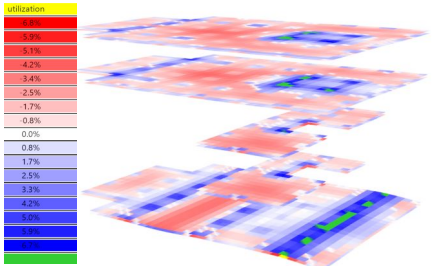
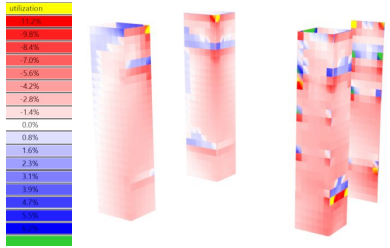
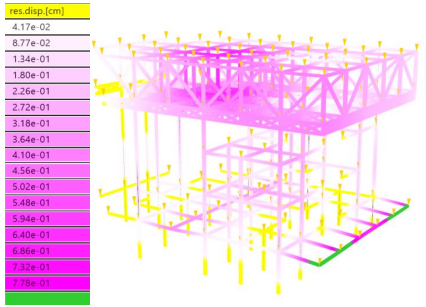
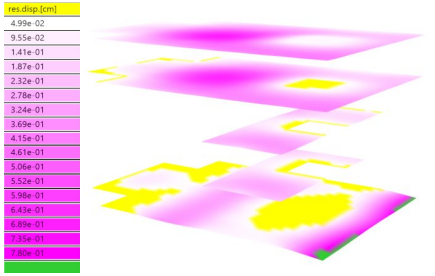
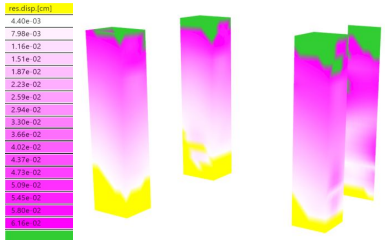
Stacking 2 & Hanging (self load only)



We added more floor on top of the same area to see if the utilization and displacements change. The results show very little change in displacement for all the elements. (beam, floor and core)

Maybe, we have over specified the size of the structural elements and can start looking at reducing the size of the elements so they are being used efficiently.

Also, looking at all the load case instead of just self load.

	BEAM ELEMENTS	FLOOR	CORE
UTILIZATION	 Min -34.9% Max 20.9%	 Min -11.0% Max 12.1%	 Min -17.0% Max 12.1%
DISPLACEMENT	 Min 0.041cm Max 0.778m	 Min 0.011cm Max 0.975cm	 Min 0.00cm Max 0.086cm

SECOND GOAL

Stacking & Hanging (all loads)

Before we started reducing the size of the structural elements we wanted to test hanging floors from the truss to see how it affects the structure.

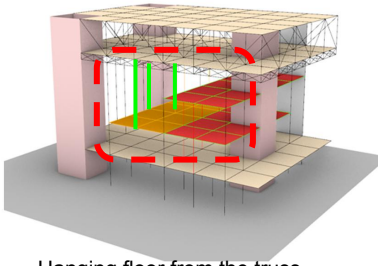
Here, we decided to look at all the load cases but isolating only those elements that would be affected by the hanging loads.

The initial results showed displacement where the distance between the hanging cables were more than 10m. We changed it to 5 meters and this helped reduce the deformation from 2.43cm to 1.97cm.

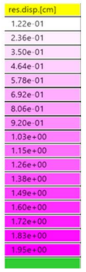
We also see here that the beam and truss are not under utilised and working at 40%.

DISPLACEMENT
(BEAMS AND TRUSS)

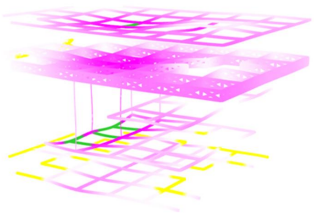
UTILIZATION
(BEAMS AND TRUSS)

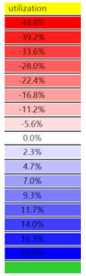


Hanging floor from the truss
with steel cables 3cm diameter

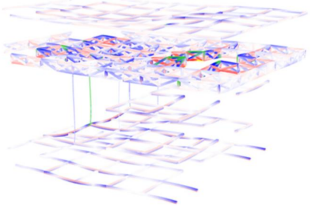


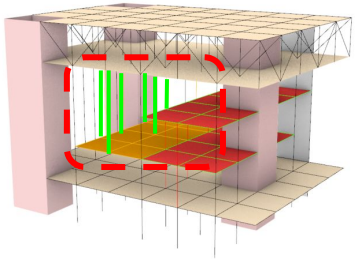
Min 0.00cm
Max 2.43cm



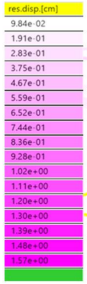


Min -66.0%
Max 39.8%

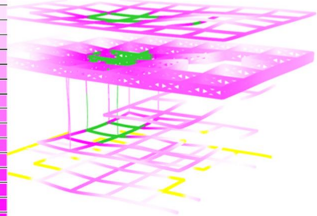


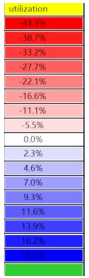


Adding 2 more cables to support the hanging floor since there is displacement where the distance between cables span 10 meters

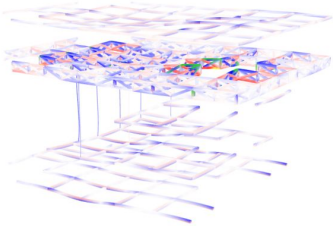


Min 0.00cm
Max 1.97cm



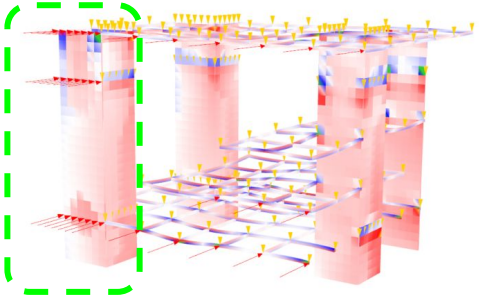


Min -65.2%
Max 39.5%

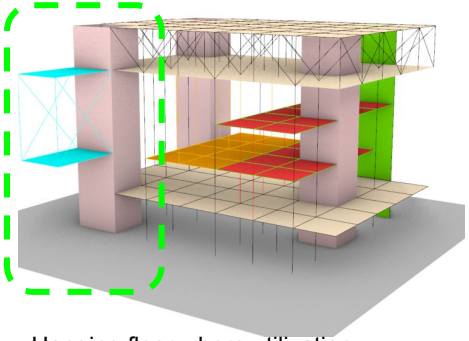


SECOND GOAL

Stacking & Hanging (all loads)



Utilization before hanging floor from core



Hanging floor where utilization is the least in the core

CORES & BEAMS

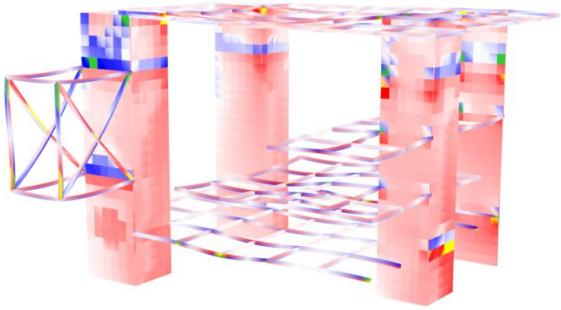
CORES



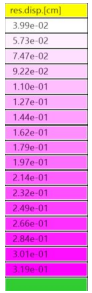
Min -49.9%
Max 32.2%

BEAMS

Min -21.0%
Max 21.9%

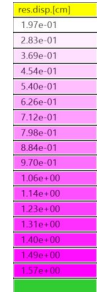


CORES

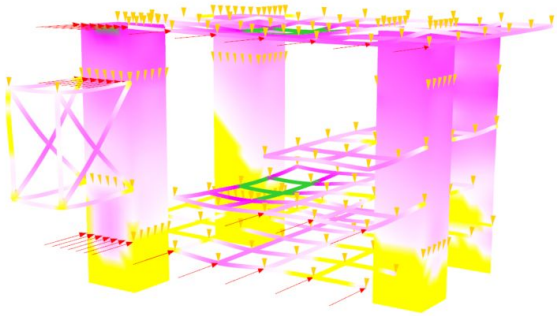


Min 0.00cm
Max 0.39cm

BEAMS



Min 0.00cm
Max 1.97cm



From the initial analysis we also noticed that the cores were being under-utilized so we saw this as an opportunity to hang floors from areas where they were being utilised the least.

Here, we've attached a cantilevered floor to the core. The utilization of the core increases but is still stable and not deforming too much.

The beams supporting the additional floor show little deformation and are also stable.

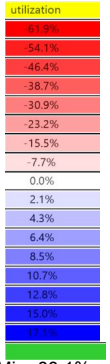
REDUCING BEAM SIZES
(all loads)

We then went through the process of incrementally reducing the cross section of the columns and analysing the results to the columns and beams. The columns were chosen as they are the structural elements that are being underutilized the most.

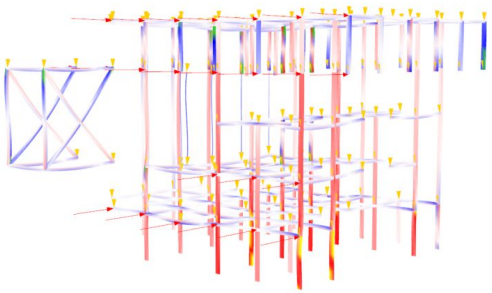
We first reduced all the columns from 50x50cm to 30x30, then reduced only the bottom half to 20x20cm and got a utilization of 32.1%. We felt that we could reduced the amount of columns on the ground floor as they were the ones not being used efficiently.

We reduced the amount of columns on the ground floor and also reduced the size of all the columns to 20x20cm.

1.

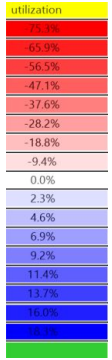


Min -88.1%
Max 30.2%

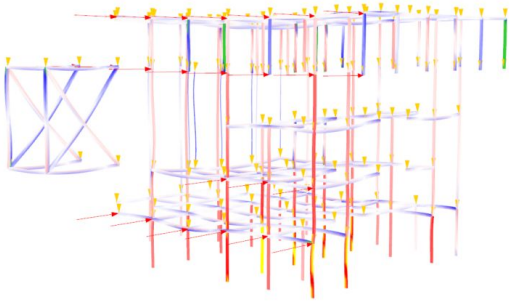


All column size 50x50cm
Beam size 30 x 30cm

2.

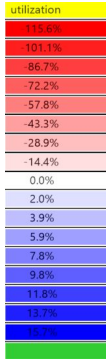


Min -102.0%
Max 31.7%

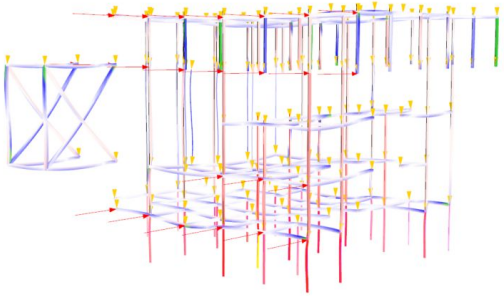


All column size 30x30cm
Beam size 30 x 30cm

3.

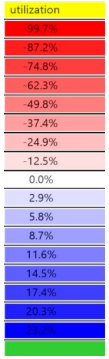


Min -132.0%
Max 32.1%

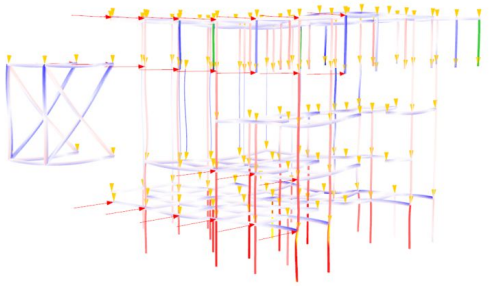


Upper columns 30x30cm
Bottom columns size 20x20cm
Beam size 30 x 30cm

4.



Min -115.1%
Max 38.6%

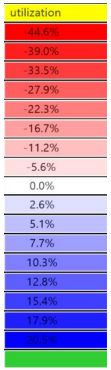


Upper columns 20x20cm
Bottom columns size 20x20cm
(AMOUNT REDUCED)
Beam size 30 x 30cm

OVERALL RESULTS
(all loads)

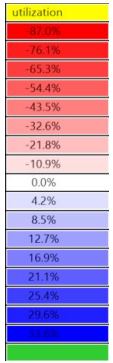
UTILIZATION,
ALL LOAD CASES, ALL ELEMENTS

SHELL

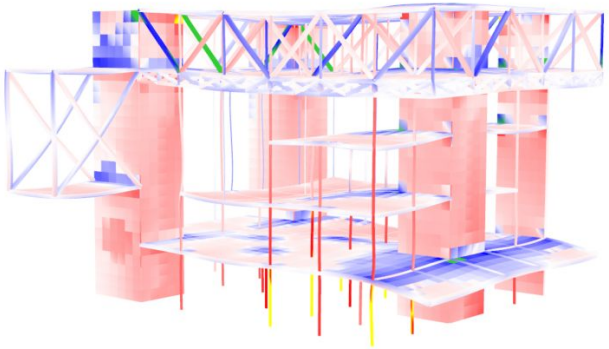


Min -59.6%
Max 40.6%

BEAM

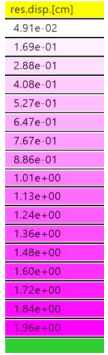


Min -114.9%
Max 71.0%



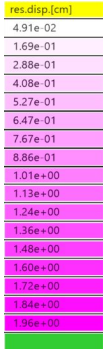
DISPLACEMENT,
ALL LOAD CASES, ALL ELEMENTS

SHELL

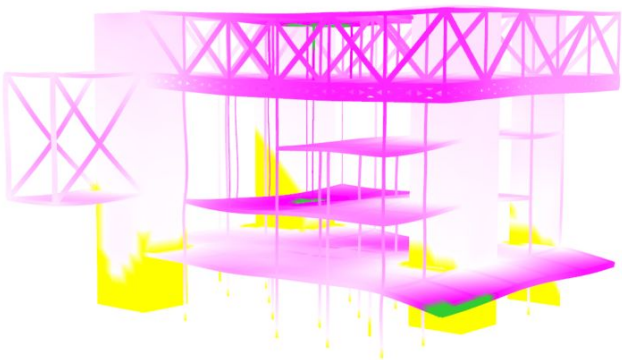


Min 0.00cm
Max 2.45cm

BEAM



Min 0.00cm
Max 2.45cm



CONCLUSION

From the final analysis on the entire model we can see that some parts of the structure are still not being utilized efficiently and we can still stack or hang more spaces if needed.

With this we can conclude that this structural strategy of creating a big truss system on top and a very stable bottom structure to have maximum open floor area allows us to plug in more loads in the future if and when needed.

THANK YOU