Mini Project Review 1

STUDYING THE VENTILATION PATTERNS IN A COVID-19 MULTI-PATIENT WARD USING CFD

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1. PROBLEM STATEMENT

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The Covid-19 pandemic forced hospitals to accommodate more infected patients per ward than their initial capacity.

The existing ventilation mechanisms in hospitals are designed for 3 to 4 patients per ward.

Improper ventilation leads to spread of infectious diseases.

Laboratory equipments used to estimate indoor air quality for designing ventilation system are expensive.

Ventilation systems designed using CFD are mostly done by closed source licensed softwares.

2. BACKGROUND

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Hospitals are required to implement containment strategies to prevent their staff and visitors from spreading the disease, usually through isolation wards.

By studying the natural ventilation patterns inside a hospital ward, we can try to curb the spread of airborne pathogens.

In India, the National Centre for Disease Control (NCDC) publishes guidelines addressing the setting up of isolation wards in hospitals.

We propose to design an isolation ward using FreeCAD in accordance with the NCDC guidelines for COVID 19, and use OpenFOAM to study the ventilation patterns in the room.

3. LITERATURE SURVEY

3.1 General CFD Papers

[1] Application of open-source CFD software to the indoor airflow simulation

Wang, C., Sadrizadeh, S., Holmberg, H., 38th AIVC Conference, **2017**

[2] Thermo-ventilation study by OpenFOAM

Limane, A., Fellouah, H., Galanis, N., *Build. Simul.* 8, **2015**

[3] Natural Ventilation for agriculture buildings

Hong, S., Exadaktylos, V,. Lee, I., Amon, T., Youssef, A., Norton, T., Berckmans, D., *Computers and Electronics in Agriculture*, Volume 138, **2017**

3.1 General CFD Papers

[4] Comparison of OpenFOAM and ANSYS Fluent

Welahettige, P., Vaagsaether, K., 9th EUROSIM Conference, **2016**

[5] OpenFOAM simulation of the natural ventilation system in a university chemical laboratory

Córdova-Suárez, M., Tene-Salazar, O., Tigre-Ortega, F., et al., E3S Web Conf. Volume 167, **2020**

3.2 Hospital Related Papers

[6] Optimisation of Hospital Room by means of CFD for more efficient ventilation

Méndez, C., San José J.F., Villafruela J.M., Castro, F., *Energy and Buildings*, Volume 40, Issue 5, **2008**

[7] The ventilation of multiple-bed hospital wards: Review and analysis

Beggs, C., Kerr, K., Noakes, C., Hathway, A., Sleigh, A., *American Journal of Infection Control*, **2008**

[8] Dynamic airflow simulation within an isolation room

Shih, Y., Chiu, C., Wang, O., *Building and Environment*, Volume 42, Issue 9, **2007**

3.2 Hospital Related Papers

[9] Development of ventilation design strategy for effective removal of pollutant in the isolation room of a hospital

K.W.D. Cheong, S.Y. Phua, *Building and Environment*, Volume 41, Issue 9, **2006**

[10] Numerical Study of Three Ventilation Strategies in a prefabricated COVID-19 inpatient ward

Juan Ren, Yue Wang, Qibo Liu, Yu Liu, *Building and Environment*, Volume 188, Issue 9, **2007**

[11] Role of ventilation in airborne transmission of infectious agents in the built environment – a multidisciplinary systematic review

Y. Li, G. M. Leung, J. W. Tang, X. Yang, et al., *International Journal of Indoor Environment and Health*, **2007**

3.3 Viri Modelling Papers

[12] Virions and respiratory droplets in air: Diffusion, drift, and contact with the epithelium

Vladimir P. Zhdanov, Bengt Kasemo, *Biosystems*, Volume 198, **2020**

[13] A physicist view of COVID-19 airborne infection through convective airflow in indoor spaces

Luis A. Anchordoqui and Eugene M. Chudnovsky, *ArXiv*, **2020**

4. METHODOLOGY

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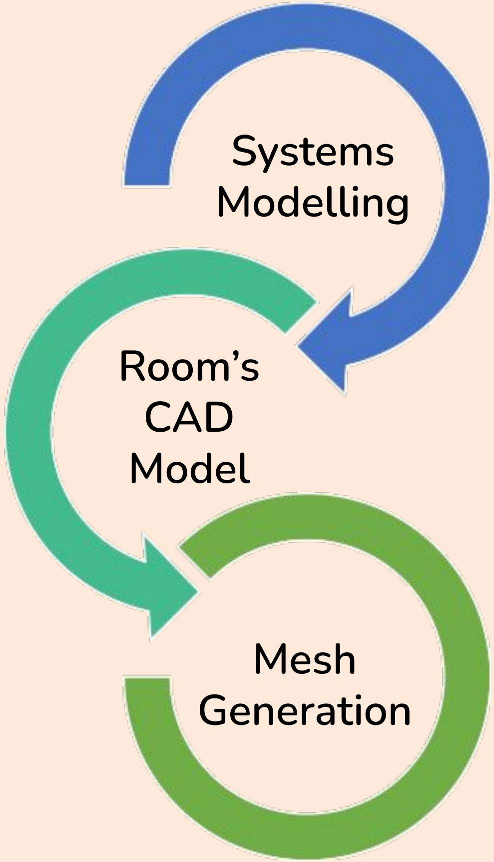
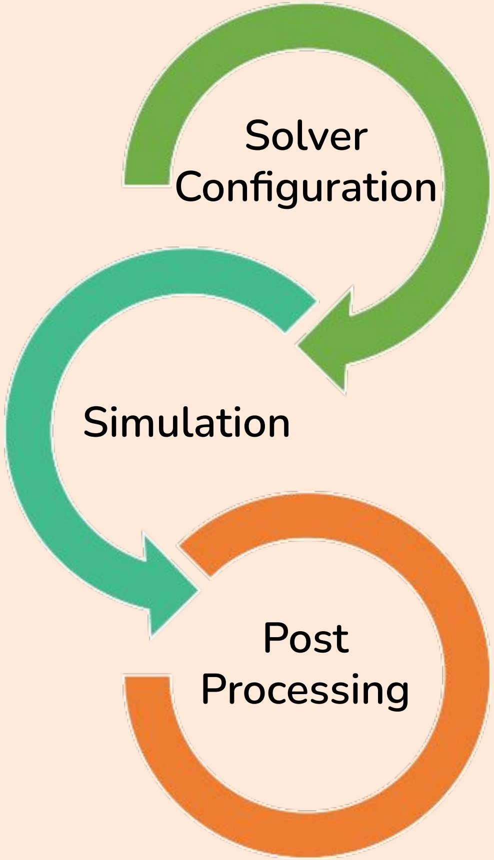


Calculate the size of ventilation ducts for the ward.
Derive governing equations for the motion of viri particles.

Design the room's floor plan according to NCDC guidelines.
Export the model as an STL file for meshing.

Generate the mesh using Gmsh.

4. METHODOLOGY



Select the Finite Volume solver in OpenFOAM.
Define boundary conditions for the flow field.

Run the OpenFOAM case to simulate the flow field.

Visualize the simulation results in ParaView.

Progress To Date

- We have completed the first three parts (Systems modelling, Room's CAD model and Mesh generation).
- We are working on the remaining three parts (Solver configuration, Simulation and Post Processing).

4.1.1 Main Duct Design

1. IS 659 (1964) safety code for air conditioning lays down the guidelines for designing an AC system for hospitals.
2. The NCDC guidelines mandate the number of Air Changes Per Hour to be at least 12.

$$ACPH = \frac{60Q}{Volume}$$

$$\Rightarrow 12 = \frac{60Q}{24000}$$

$$\Rightarrow Q = 4800CFM$$

4.1.1 Main Duct Design

IS : 659 - 1964

TABLE 1 MINIMUM FRESH AIR REQUIREMENTS

(Clauses 3.2 and 3.2.1)

SL No.	APPLICATION	SMOKING	m^3/min PER PERSON: Recom-mended	m^3/min PER PERSON: Mini-mum	m^3/min PER m^2 OF FLOOR AREA
(1)	(2)	(3)	(4)	(5)	(6)
i)	Apartments	Some	0.56	0.28	—
ii)	Banking space	Occasional	0.28	0.21	—
iii)	Board rooms	Very heavy	1.40	0.56	—
iv)	Department stores	None	0.21	0.14	0.015
v)	Directors' rooms	Very heavy	1.40	0.84	—
vi)	Drug stores*	Considerable	0.28	0.21	—
vii)	Factories†	None	0.28	0.21	0.03
viii)	Oarages	—	—	—	0.30
ix)	Hospitals:				
	a) Operating rooms (all fresh air)	None			0.60
	b) Private rooms	None	0.84	0.70	0.10
	c) Wards	None	0.56	0.28	—
x)	Hotel rooms	Heavy	0.84	0.70	0.10

IS 659 (1964)

- Ensure that appropriate hand washing facilities and hand-hygiene supplies are available. Stock the sink area with suitable supplies for hand washing, and with alcohol-based hand rub near the point of care and the room door.
- Ensure adequate room ventilation. If room is air-conditioned, ensure 12 air changes/ hour and filtering of exhaust air. A negative pressure in isolation rooms is desirable for patients requiring aerosolization procedures (intubation, suction nebulisation). These rooms may have standalone air-conditioning. These areas should not be a part of the central air-conditioning.
- If air-conditioning is not available negative pressure could also be created through putting up 3-4 exhaust fans driving air out of the room.

NCDC Guidelines

4.1.1 Main Duct Design

$$Area = \frac{Q}{V}$$

$$A_{max} = \frac{4800}{1000} = 4.8sqft$$

$$A_{min} = \frac{4800}{1500} = 3.2sqft$$

Hence, we fix the duct parameters as

- Velocity : 1000 fpm
- Dimensions : 3 ft x 1.6 ft

4.1.1 Main Duct Design

5.2 Velocity Reduction Method

This method sizes the duct by varying the velocity in the main and branch ducts. The various steps involved are:

a. Select suitable velocities in the main and branch ducts. The table below indicates commonly used velocity limits:

Type of Duct	Comfort Systems Velocity (fpm)	Industrial Systems Velocity (fpm)	High Speed Systems Velocity (fpm)
Main duct	1000 - 1500	1500 - 2400	2000 - 3600
Main branch duct	700 - 1000	1000 - 1600	1200 - 2400
Runout duct	400 - 600	600 - 800	800 - 1000

b. Find the diameters of the main and branch ducts from air flow rates and velocities. The velocity in duct can be expressed as:

$$A = Q / v$$

Where,

- A = duct area (ft^2)
- Q = air flow rate (cfm)
- v = air speed (fpm)

(HVAC - How to Size and Design Ducts)

4.1.2 Virus Particle Modelling

$$v = v_0 e^{\frac{-t}{\alpha m}}$$

$$D = max(D_0, D^*)$$

$$m = \frac{4\pi}{3} R^3 \rho$$

$$D^* = \frac{k_B T}{6\pi\eta R}$$

$$\alpha = \frac{D}{k_B T}$$

$$D_0 = \frac{3(k_B T)^{1.5}}{(8\pi m)^{0.5} P R^2}$$

4.1.2 Virus Particle Modelling

is the virus mobility in the fluid, and where $\eta = 1.8 \times 10^{-5}$ kg/(ms) is the dynamic viscosity of air [13]. Substituting (2) into (1) we find that the downward terminal speed of the virus in dry air is indeed negligible, $v_{\text{down}} \sim 8 \times 10^{-8}$ m/s. It is therefore clear that gravity plays no role in the motion of an isolated virus through the air. Rather it follows a convection pattern in a manner similar to how smelly substances move through the air. The survival probability of the virus in the dry air is then given by the likelihood of survival outside its natural environment. The half-life of SARS-CoV-2 in aerosols has been found to be about 1.1 hours [5].

We have seen that the coronavirus can go airborne staying suspended in the air. However, the virus is transmitted through respiratory droplets and droplet nuclei produced mostly while sneezing and coughing. Then to ascertain whether airborne transmissible SARS-CoV-2 can survive and stay infectious in aerosols we

A physicist view of COVID-19 airborne infection through convective airflow in indoor spaces

4.2 Room CAD Model

According to the NCDC,

- At District level, a minimum of 10 bed isolation ward should be established.
- COVID - 19 patients should be housed in single rooms
- However, if sufficient single rooms are not available, beds could be put with a spatial separation of at least 1 meter (3 feet) from other.
- To create a 10 bed facility, a minimum space of 2000 sq feet area clearly segregated from other patient care areas is required.

4.2 Room CAD Model

B. Setting up isolation facility/ward

An isolation facility aims to control the airflow in the room so that the number of airborne infectious particles is reduced to a level that ensures cross-infection of other people within a healthcare facility is highly unlikely.

- At State level, a minimum of **50** bed isolation ward should be established.
- At District level, a minimum of **10** bed isolation ward should be established.
  - Post signages on the door indicating that the space is an isolation area.
  - Remove all non-essential furniture and ensure that the remaining furniture is easy to clean, and does not conceal or retain dirt or moisture within or around it.
  - COVID-19 patients should be housed in single rooms.
  - However, if sufficient single rooms are not available, beds could be put with a spatial separation of at least 1 meter (3 feet) from one another.
  - To create a 10 bed facility, a minimum space of 2000 sq. feet area clearly segregated from other patientcare areas is required.
  - Preferably the isolation ward should have a separate entry/exit and should not be co-located with post-surgical wards/dialysis unit/SNCU/labour room etc.
  - It should be in a segregated area which is not frequented by outsiders.
  - The access to isolation ward should be through dedicated lift/guarded stairs.

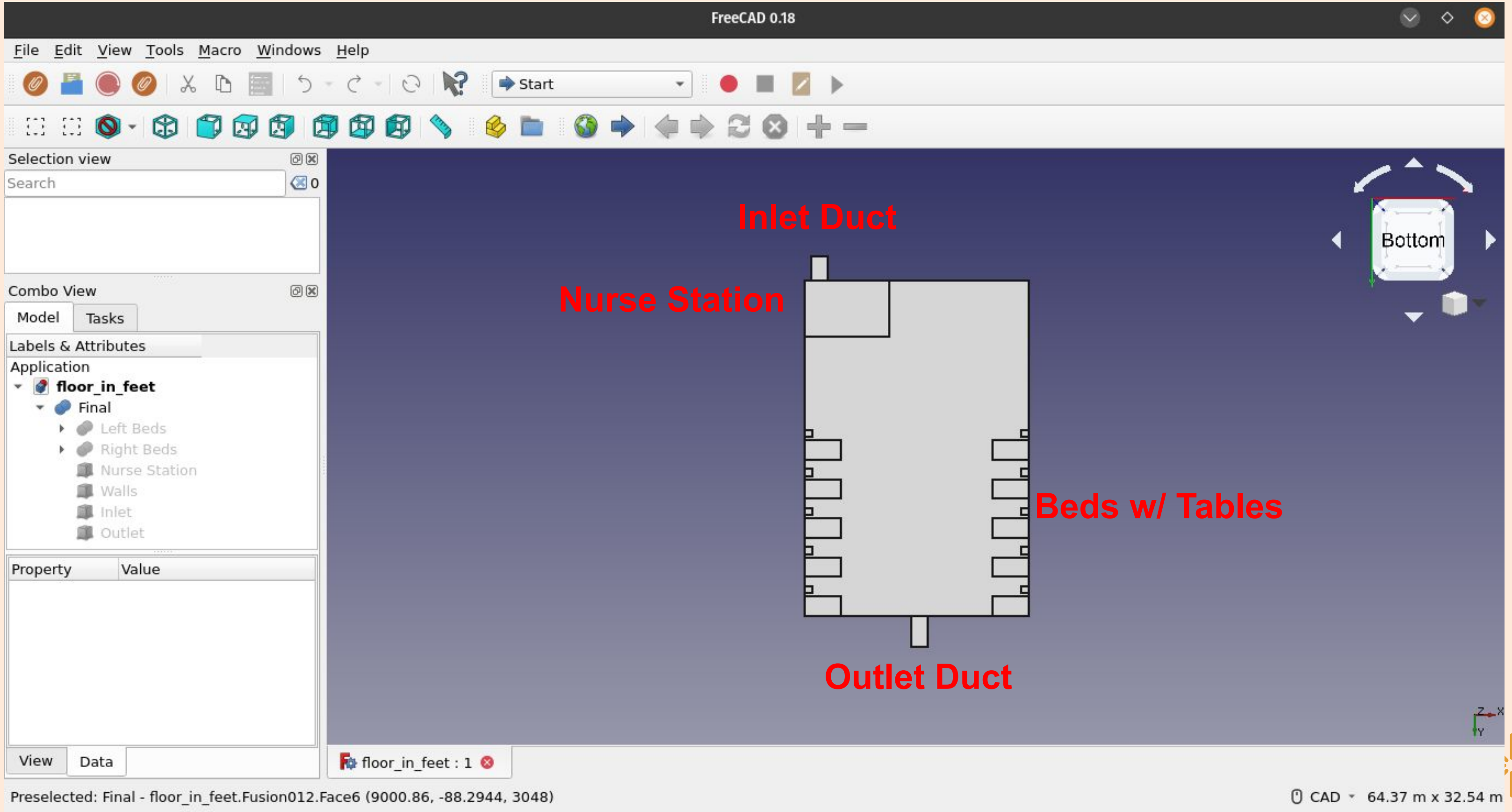
NCDC Guidelines for the handling of the COVID 19 pandemic

4.2 Room CAD Model

Our Dimensions:

- Room : 60 ft x 40 ft x 10 ft
- Patient Bed : 6.5 ft x 3.5 ft x 2.5 ft
- Patient Bedside Table : 1.3 ft x 1.3 ft x 2.62 ft
- Nurse Station : 15 ft x 10 ft x 4 ft
- Ventilation Duct : 3 ft x 8 ft x 1.6 ft

4.2 Room CAD Model



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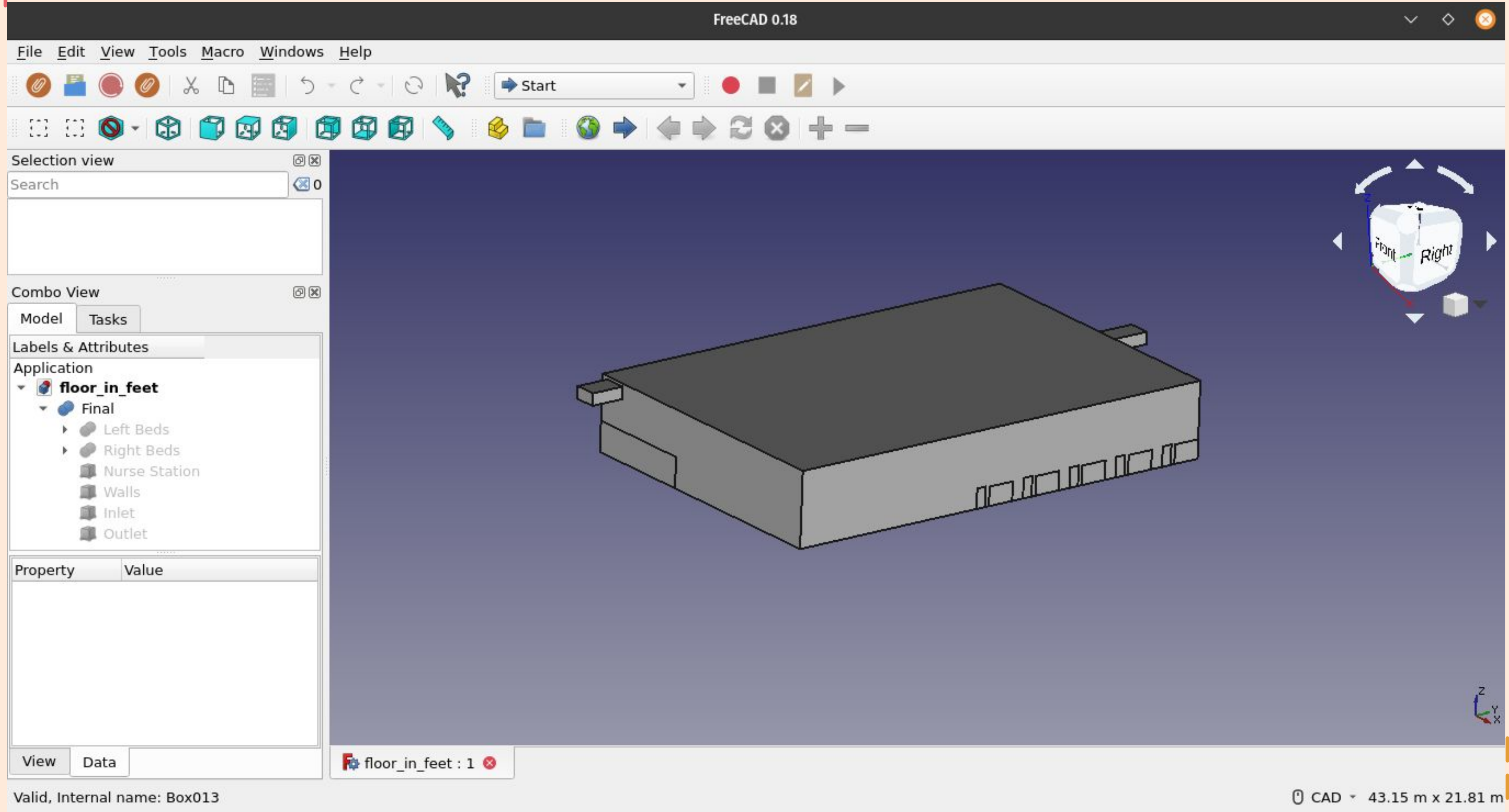


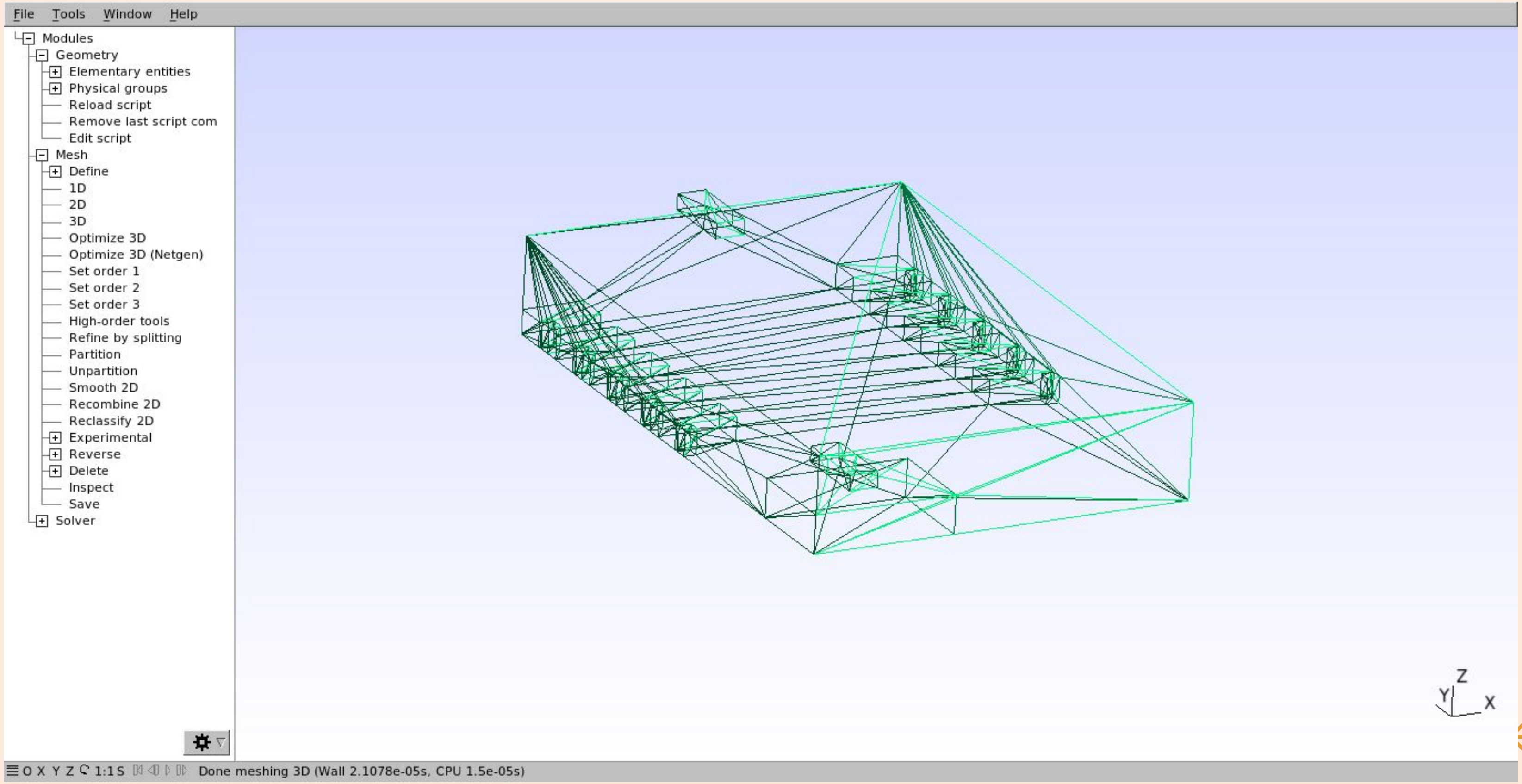
4.3 Mesh Generation

- First, we export the STL file from FreeCAD. Then, we import this into Gmsh and prepare it for OpenFOAM.

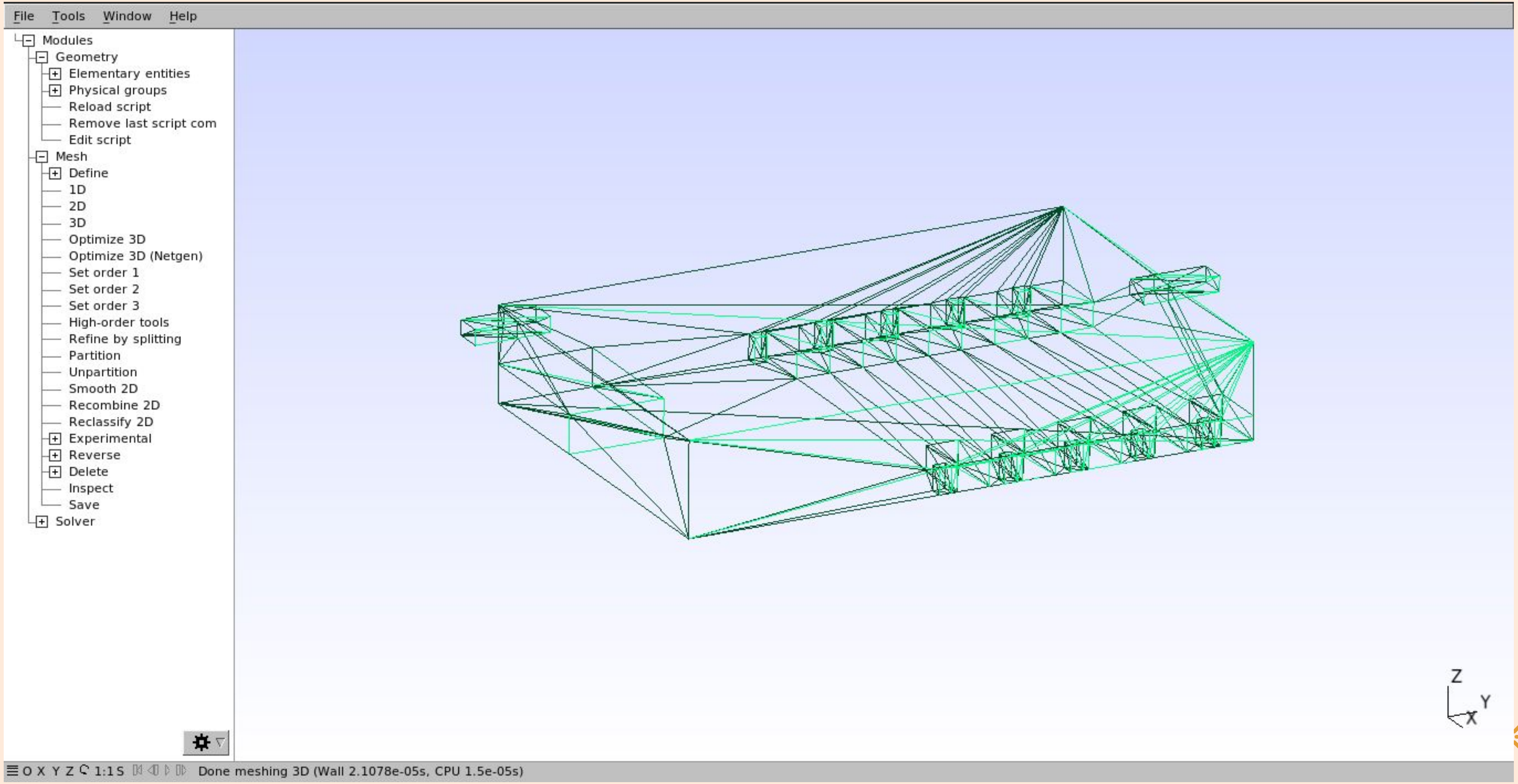
- We generated a triangular mesh from our model initially.

- We will shift to quad or hex mesh after design validation.

4.3 Mesh Generation



4.3 Mesh Generation



5. Next Steps

- Make the appropriate assumptions about the flow.
- Finalize the solver schema for the simulation.
- Run simulations and visualise the flow field in ParaView.
- Improve the CAD model by adding more vents.
- Try and accommodate the accumulation of virus particles on walls of the room.

QUESTIONS?

6. Other References

S. No	TOPIC	DESCRIPTION
1	NCDC Guidelines for Setting up Isolation Facility/Ward	List of guidelines recommended by the NCDC to combat COVID-19
2	BIS 659 (1964) : Safety Code for Air Conditioning	BIS safety code guidelines for setting up an AC system
3	HVAC - How to Size and Design Ducts	Course notes on HVAC system design approved by CED engineering.
4	Open Source Engineering Software recommended by Harvard	An OSS stack suggested by the Harvard School of Engineering and Applied Sciences using FreeCAD, Gmsh, OpenFOAM and Paraview
5	From design to mesh generation using FreeCAD and GMSH	Tutorial on exporting a FreeCAD model and generating its corresponding mesh using Gmsh
6	Water Filling Tank Example	A case walkthrough for filling a tank with water through FreeCAD, OpenFOAM and ParaView.
7	Triangular mesh vs Quad mesh	ResearchGate discussion thread comparing the tri and quad meshes
8	Hospital Bed Dimensions	Website where you can buy hospital beds and tables

THANK YOU!