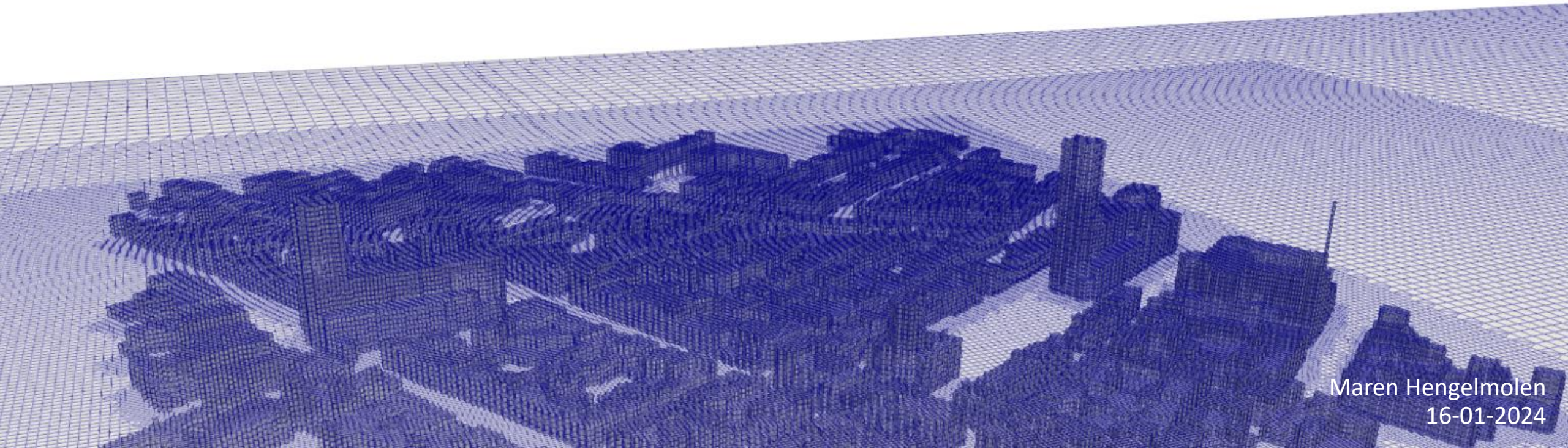
Urban CFD simulations set-up validations

Final presentation



Maren Hengelmolen
16-01-2024

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Life in the city

https://www.green.earth/blog/the-top-10-green-cities-in-the-world

Challenges

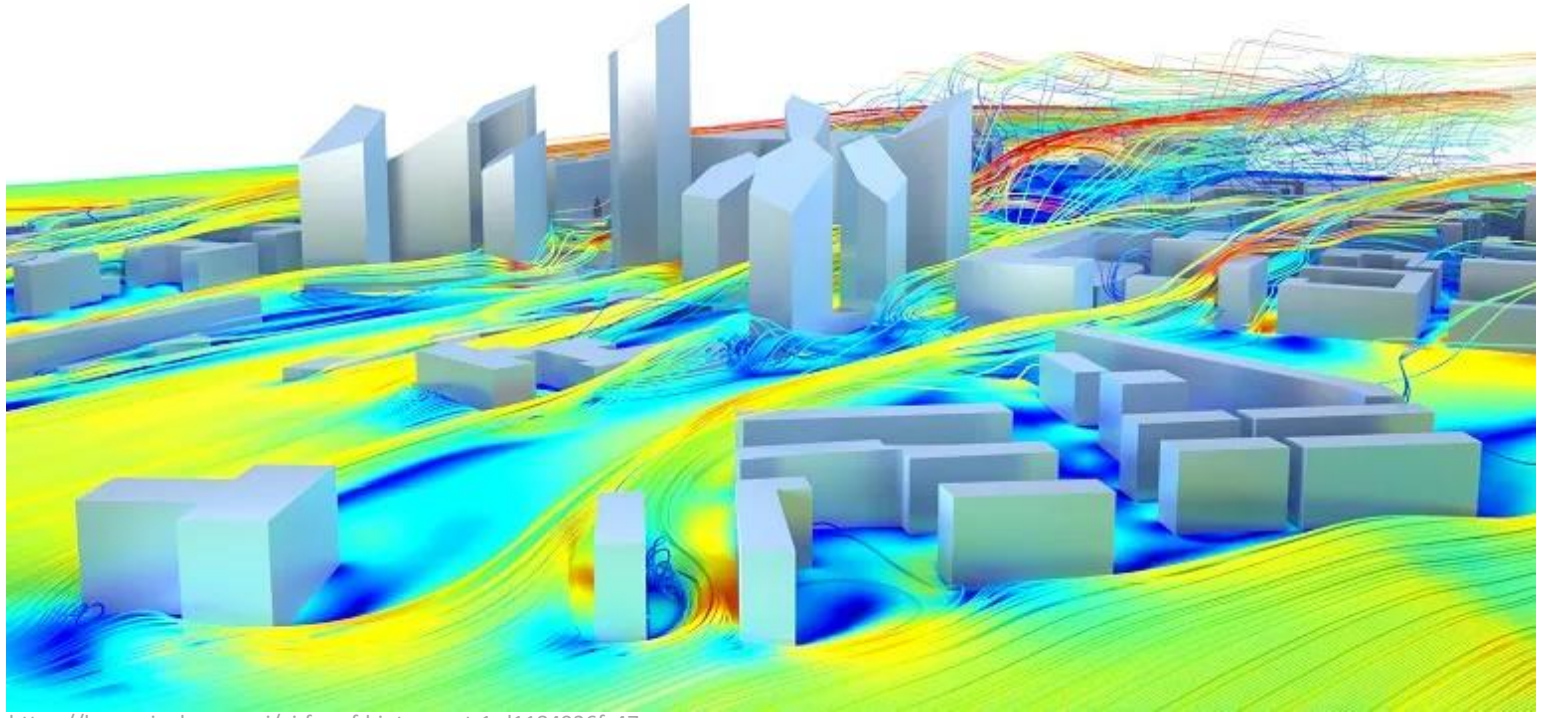
https://news.miami.edu/stories/2022/07/medical,-scientific-advances-help-boost-world-population-to-8-billion.html

https://www.downtoearth.org.in/news/climate-change/global-warming-to-raise-frequency-of-heat-waves-study-64453

https://www.iqair.com/us/newsroom/does-air-pollution-cause-climate-change

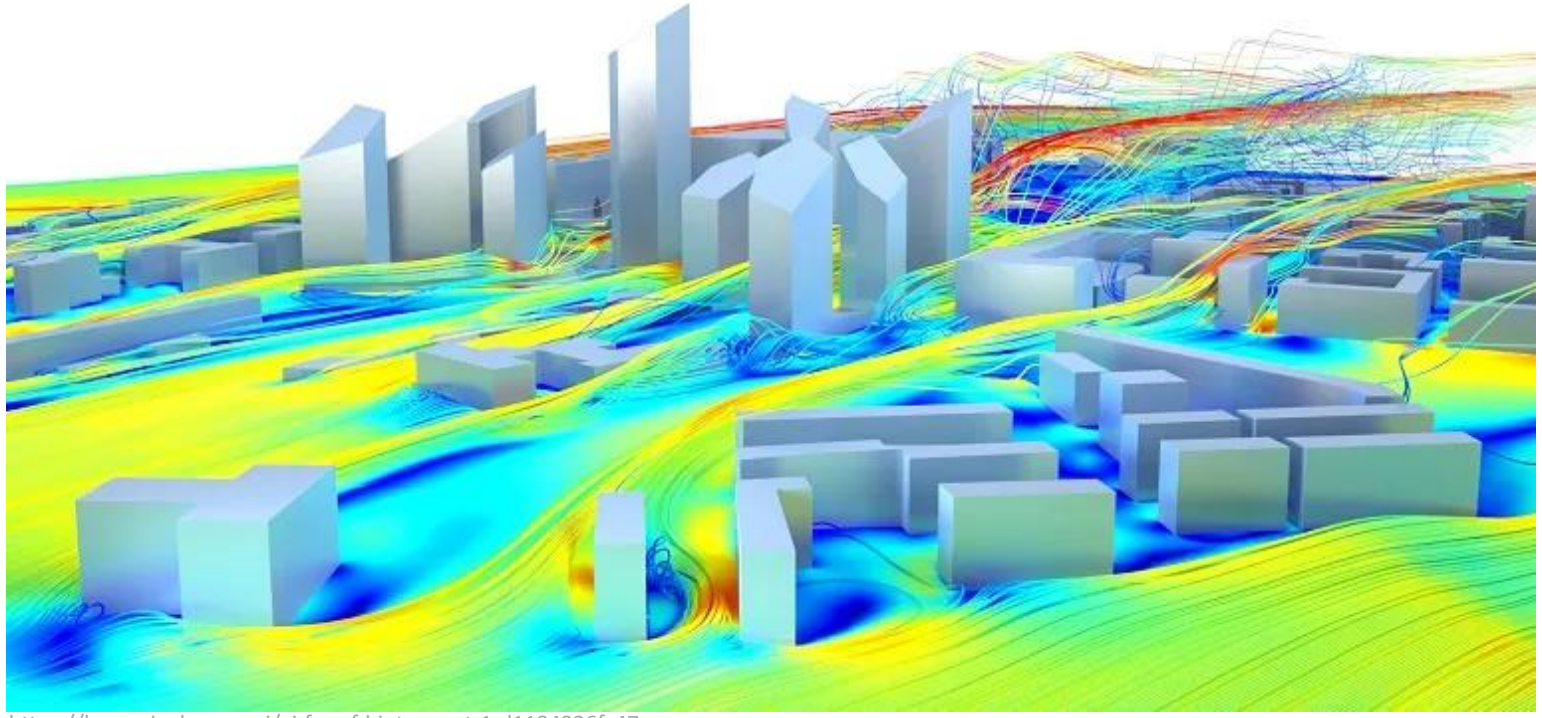
https://dundalk.ie/news/14022020/storm-dennis-to-bring-heavy-rain

Future cities



https://becominghuman.ai/ai-for-cfd-intro-part-1-d1184936fc47

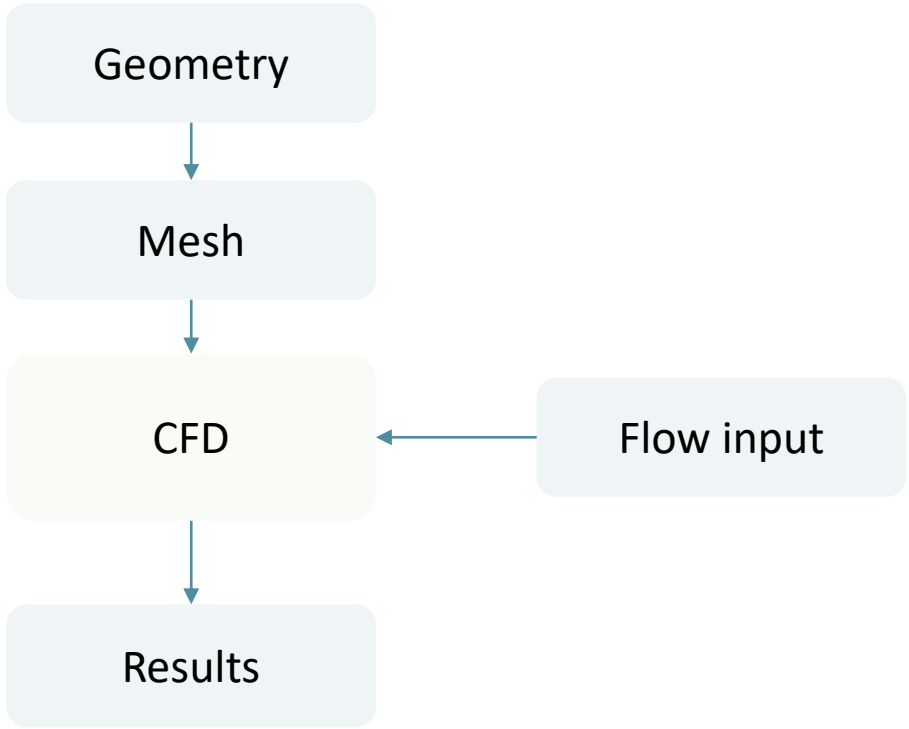
Future cities



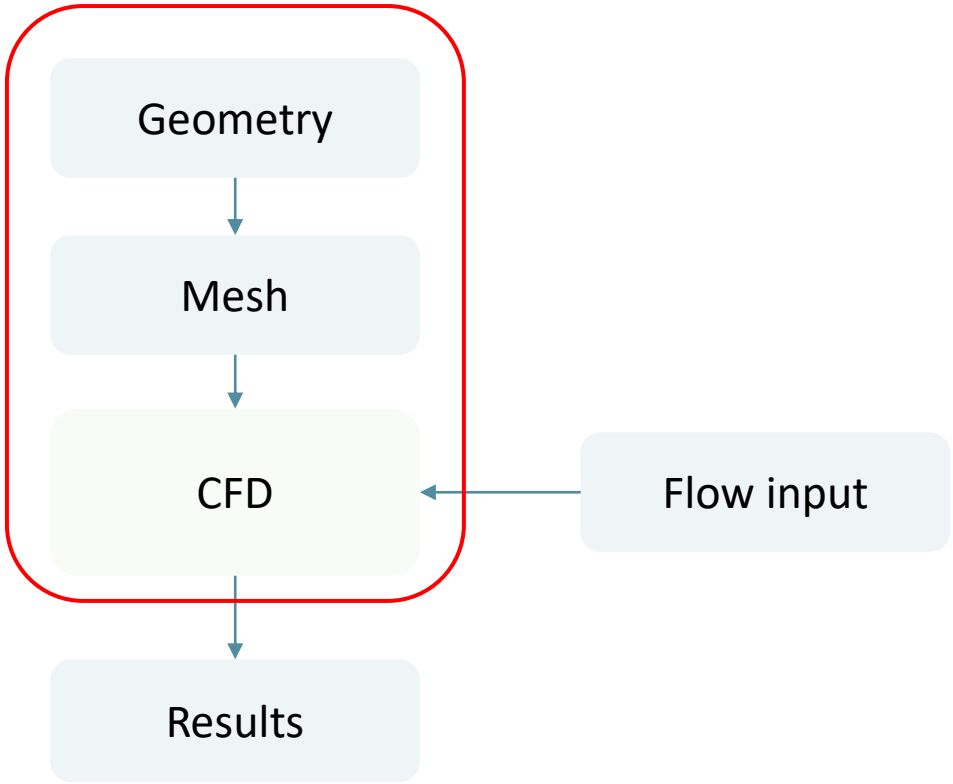
https://becominghuman.ai/ai-for-cfd-intro-part-1-d1184936fc47

Computational Fluid Dynamics (CFD) simulations

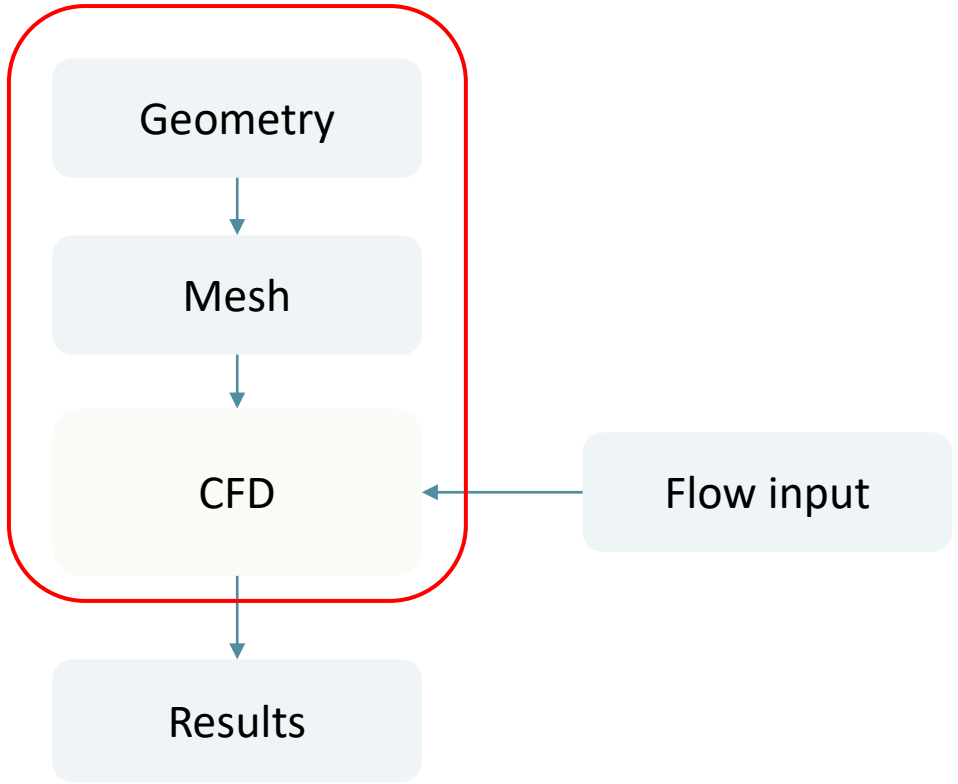
Computational Fluid Dynamics



Computational Fluid Dynamics

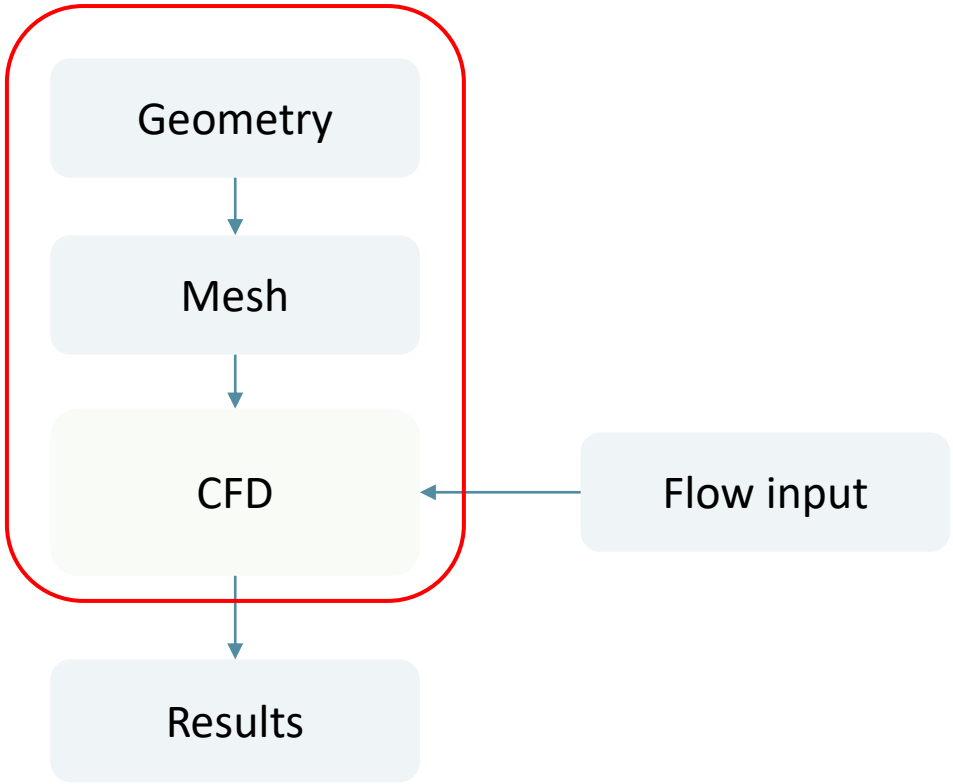


Computational Fluid Dynamics



Standards and guidelines

Computational Fluid Dynamics

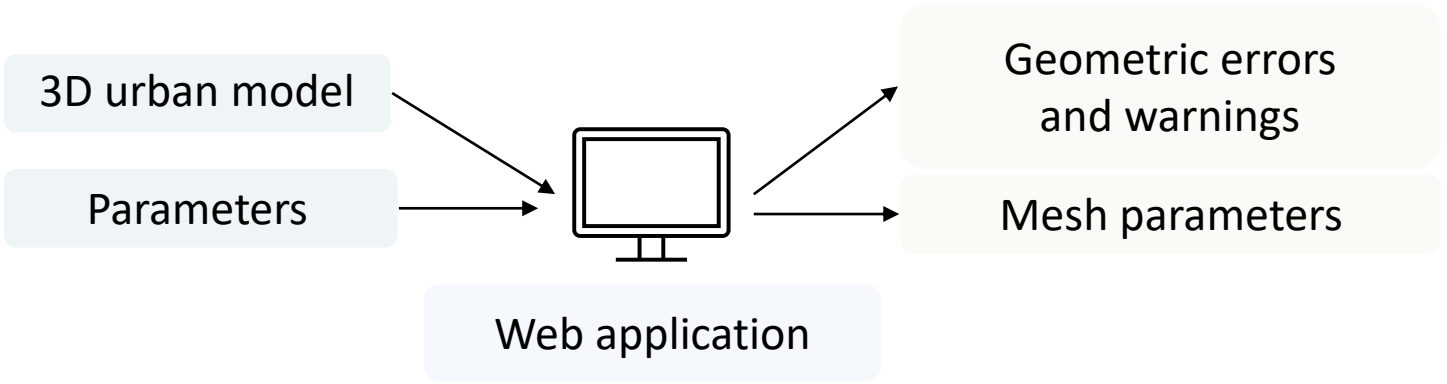


Standards and guidelines

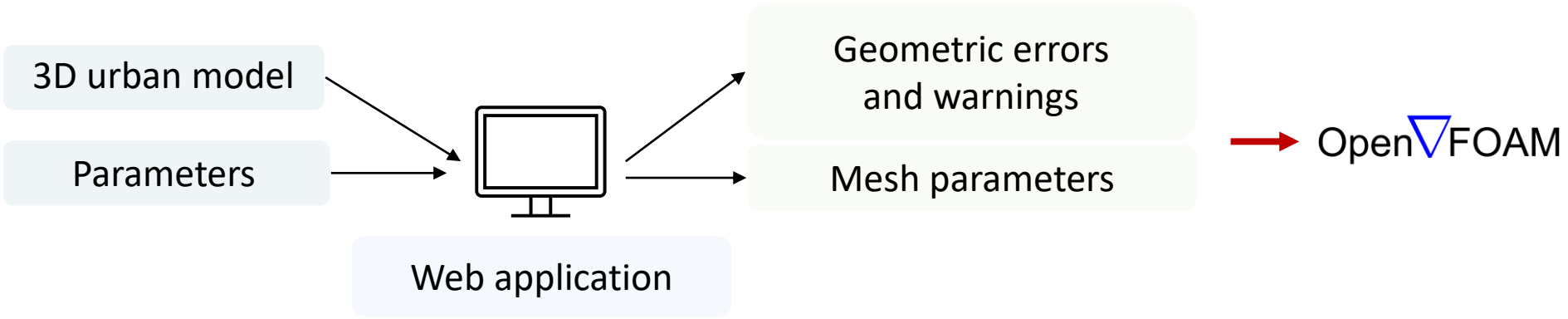
→ Time consuming
→ Require expertise to implement

Develop a **method**
that **validates geometries**
and **defines mesh parameters**
to **simplify the use of**
CFD simulation in urban areas.

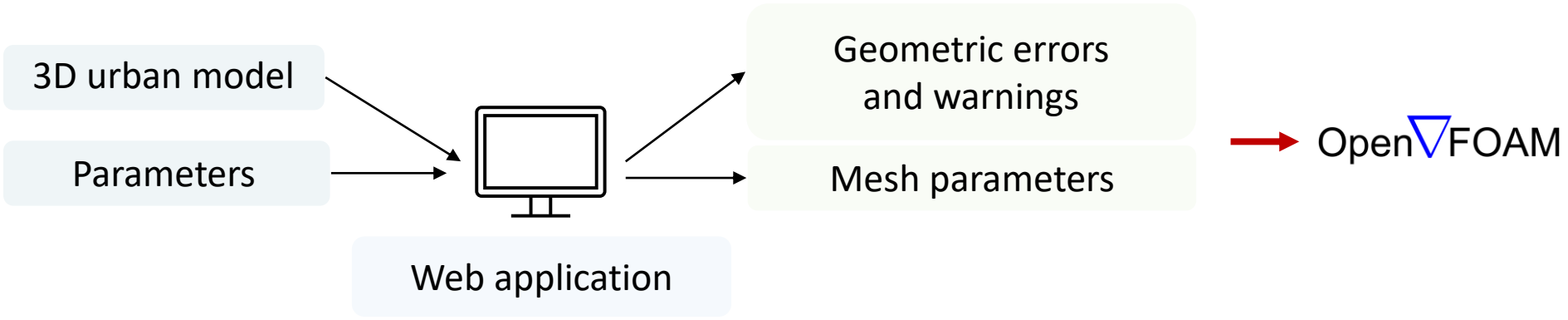
Approach


3D urban model
Parameters
Web application
Geometric errors and warnings
Mesh parameters

Approach

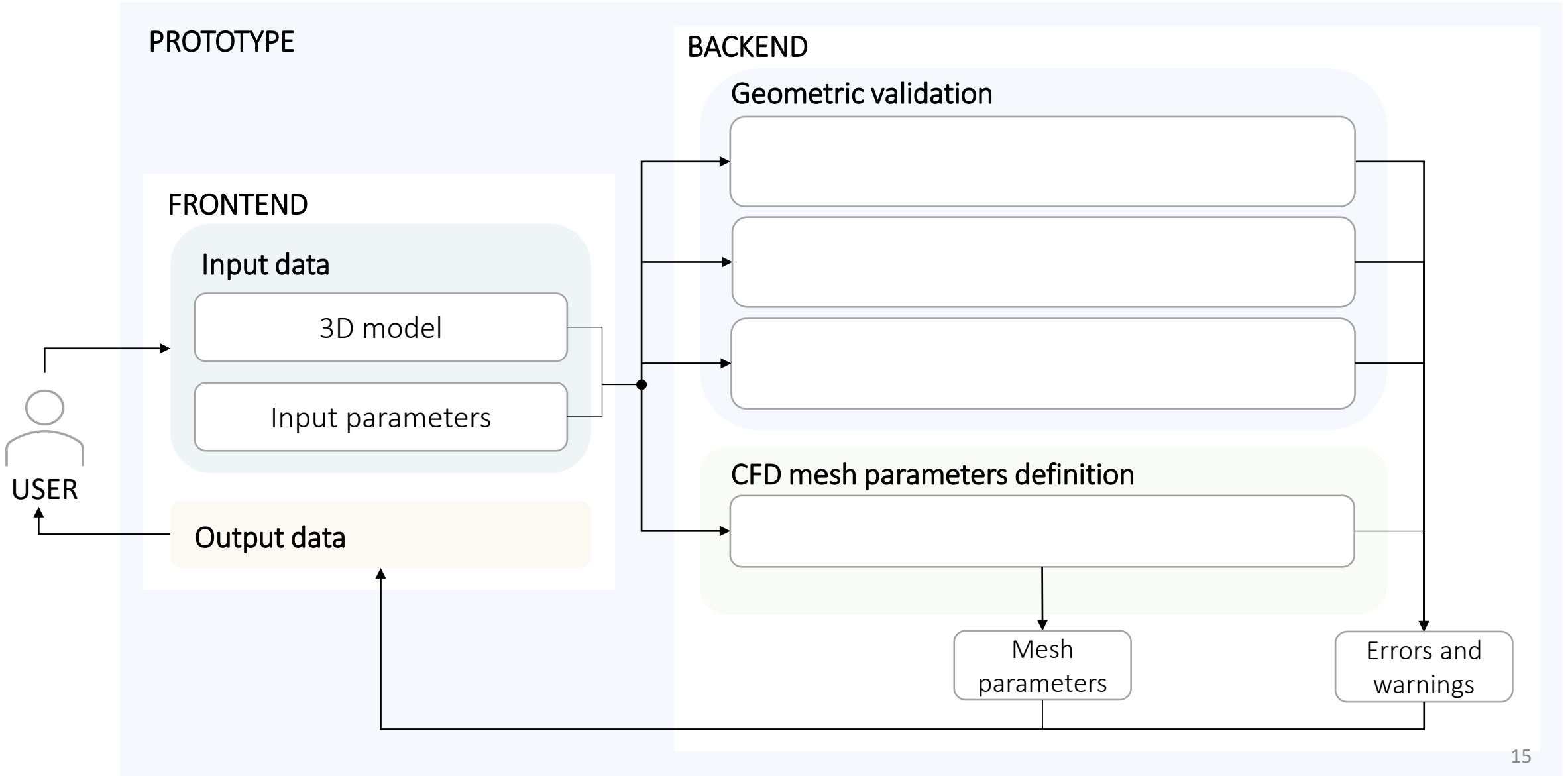

3D urban model
Parameters
Web application
Geometric errors and warnings
Mesh parameters
OpenFOAM

Approach

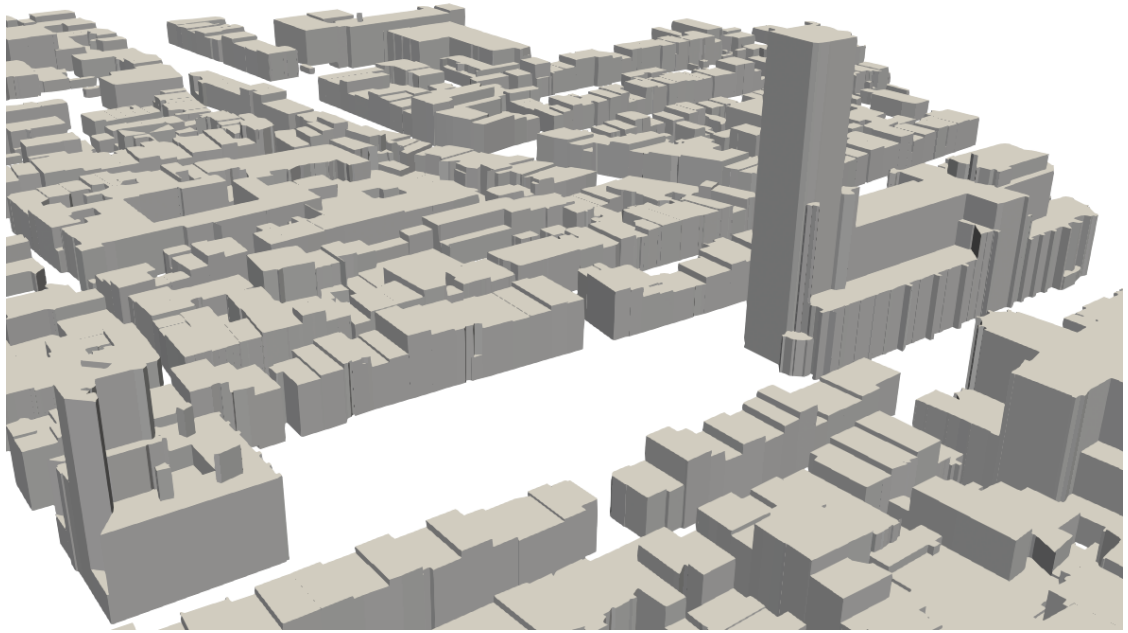


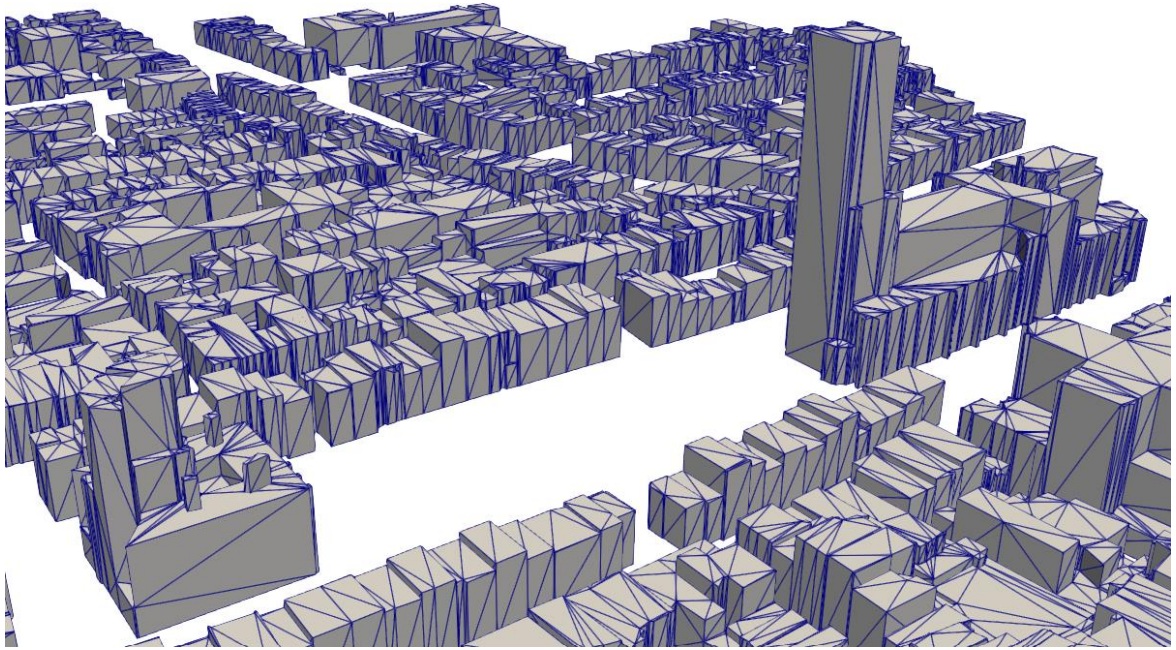
Prototype of the web application

Architecture

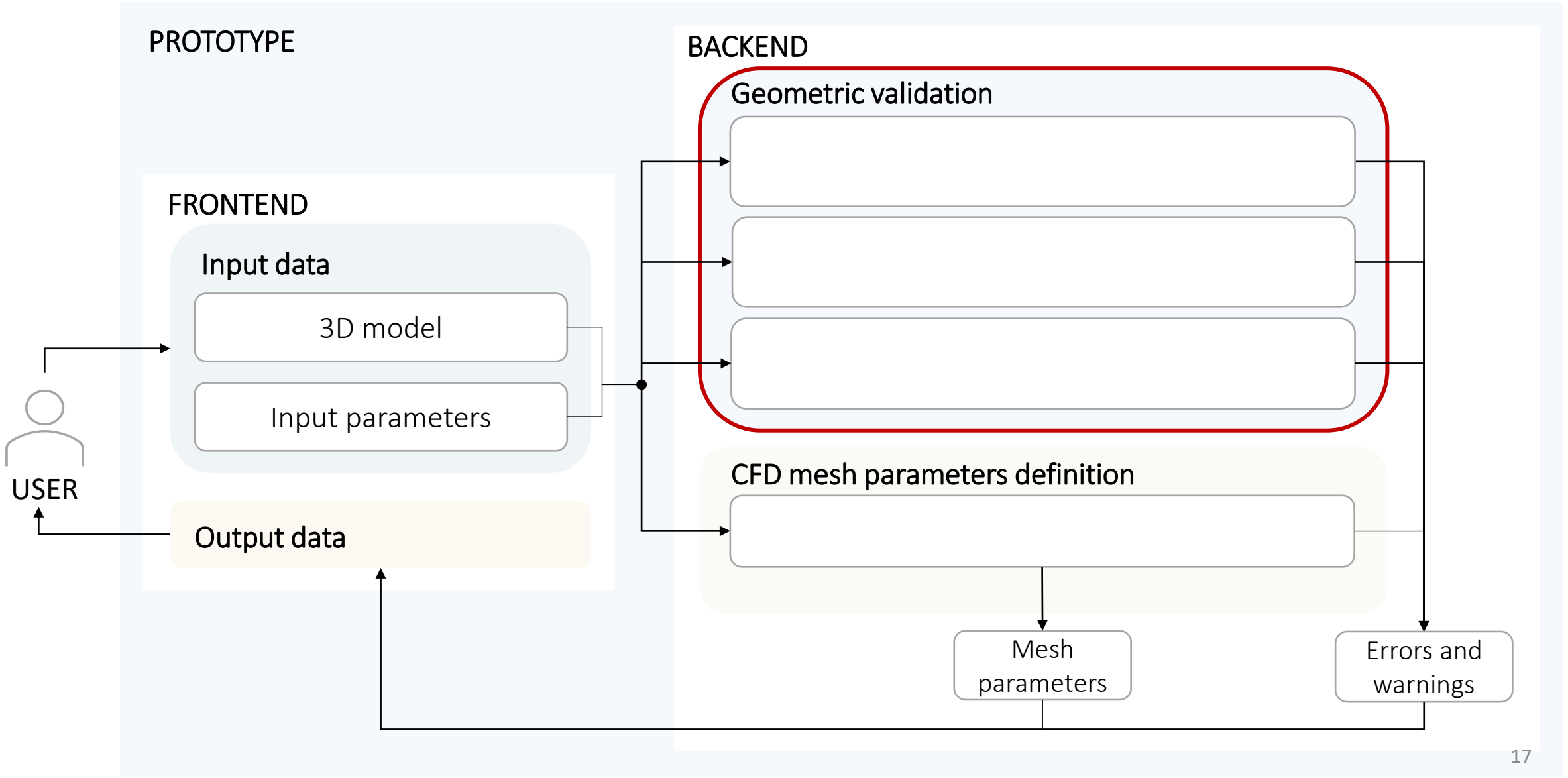


Input model





Architecture



Separate building and terrain validation

ISO19107 standard

- Basic primitive definition

Separate building and terrain validation

ISO19107 standard

- Basic primitive definition

→ Can be difficult to interpret
→ Can be challenging to implement
→ Can be difficult to identify errors

Separate building and terrain validation

ISO19107 standard

- Basic primitive definition

→ Can be difficult to interpret
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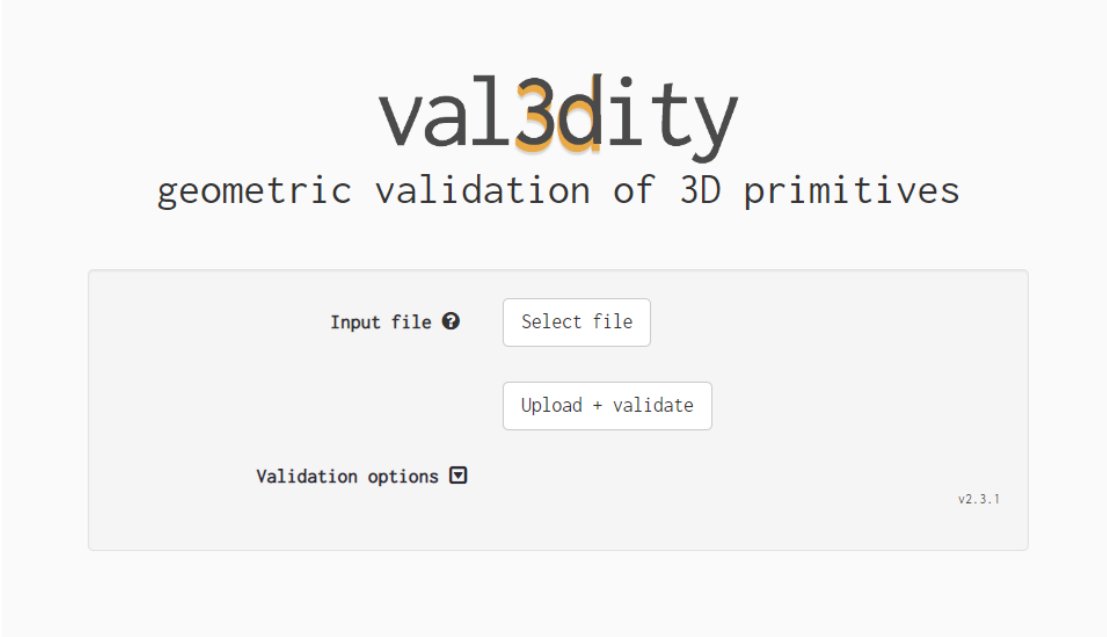
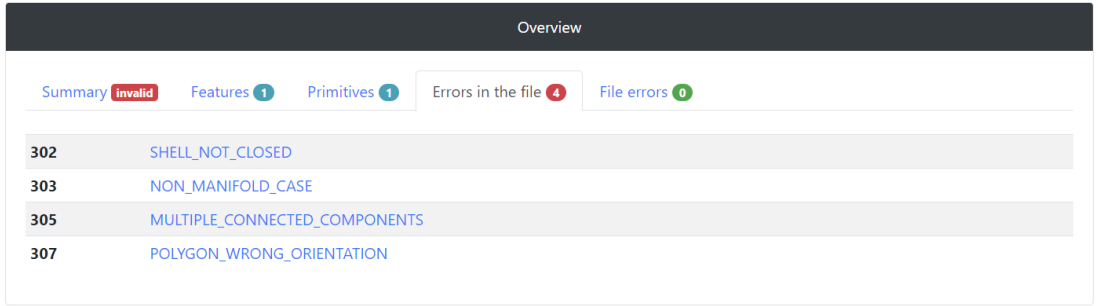
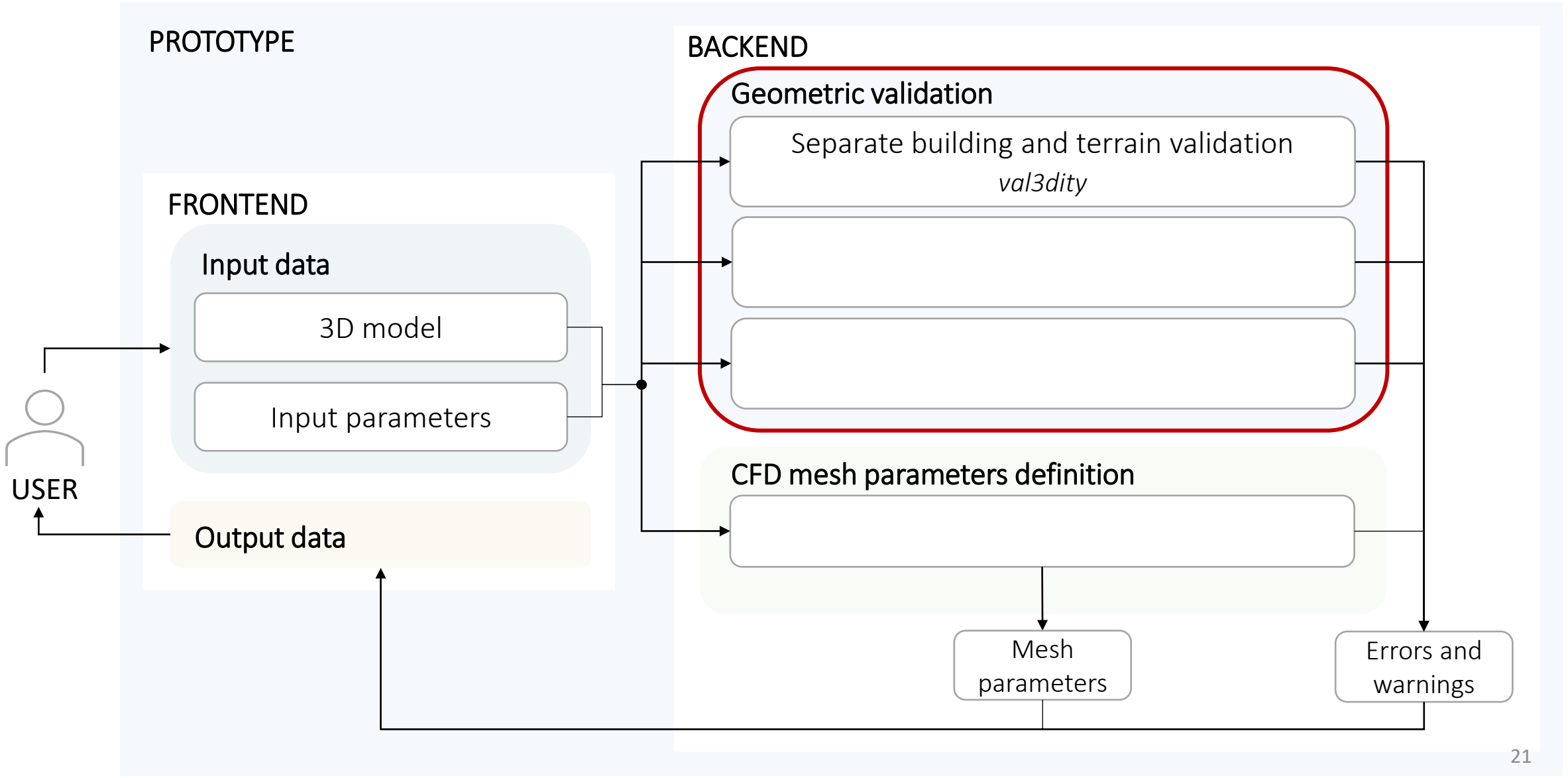
Val3dity software

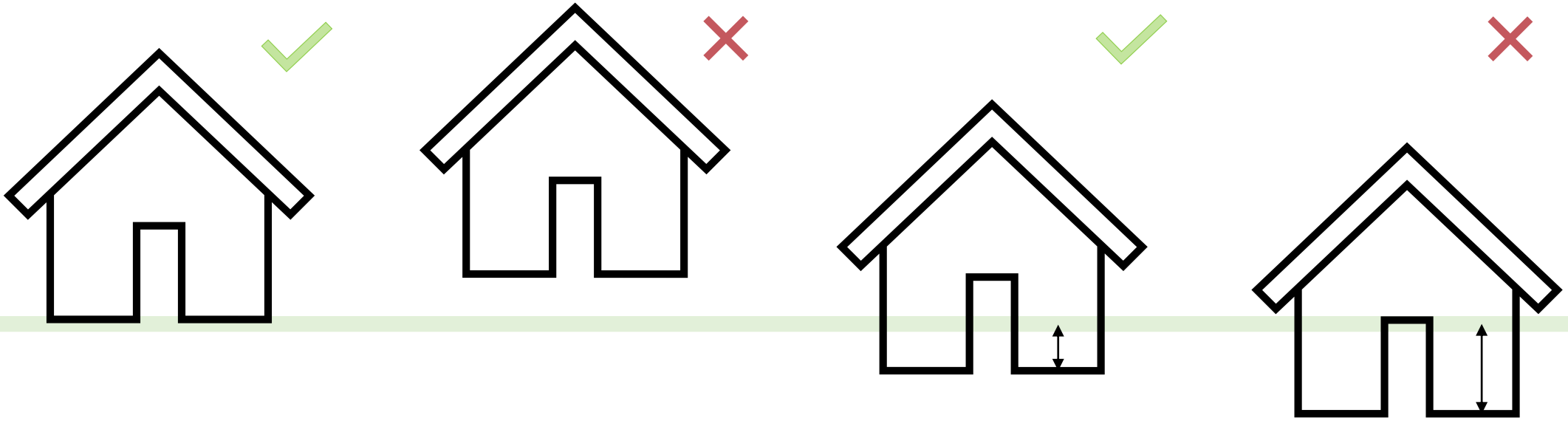




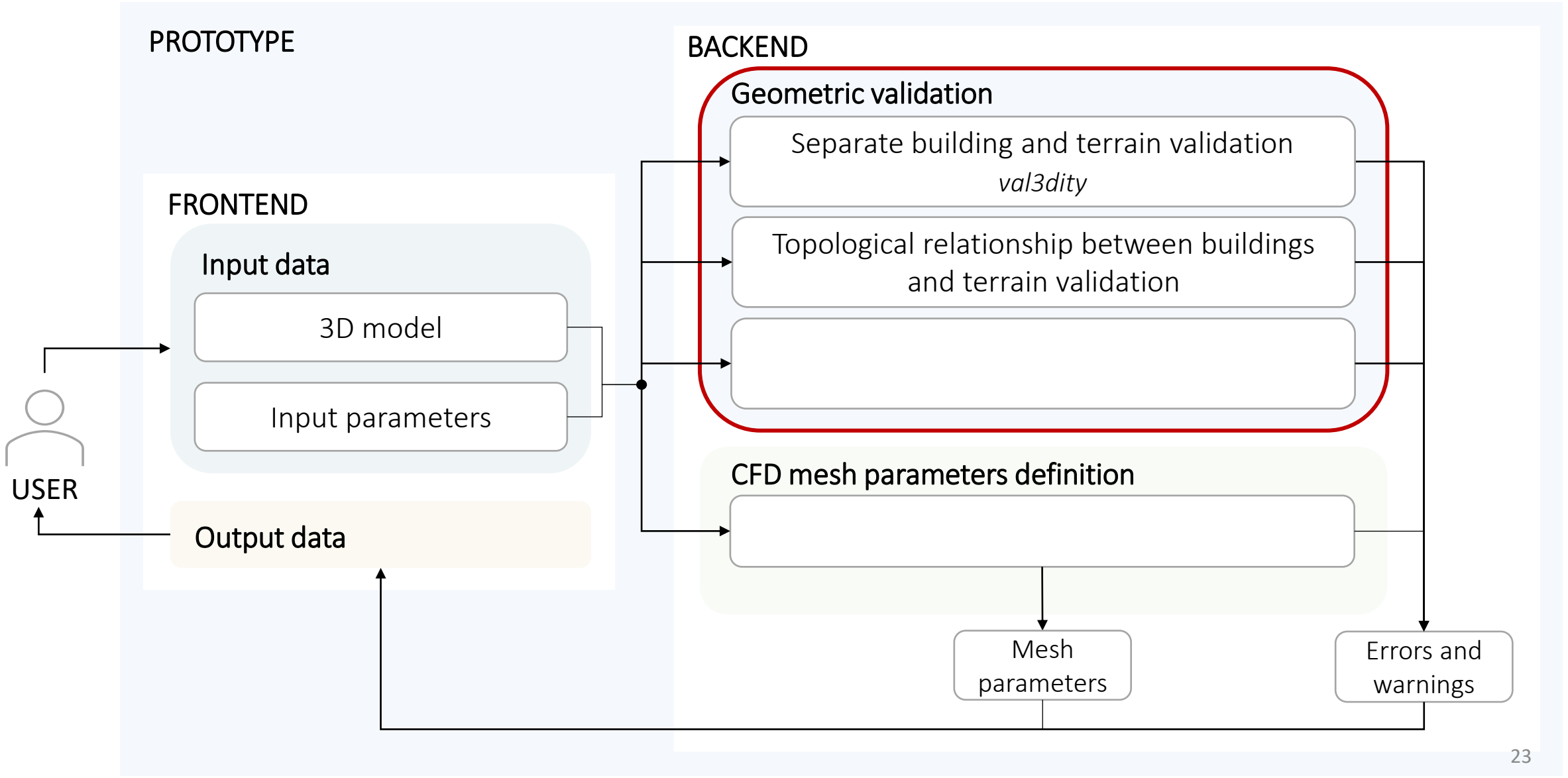
Architecture



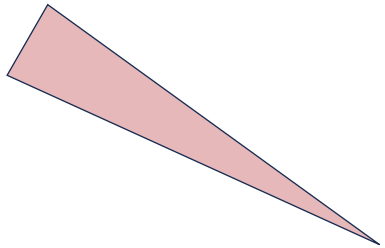
Topological relationships between buildings and terrain



Architecture

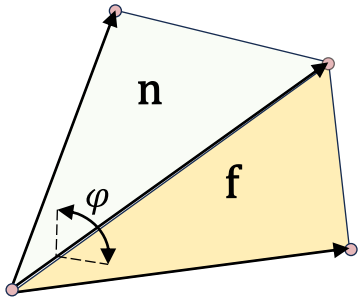


Required validations for the meshing process

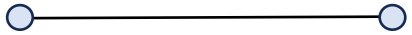


Sliver triangles
when SP $\leq \sigma$

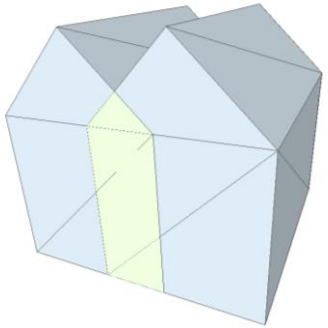
$$\mathrm{SP} = \frac{2 \times area}{perimeter}$$



Sharp angles
when φ $\leq \theta$

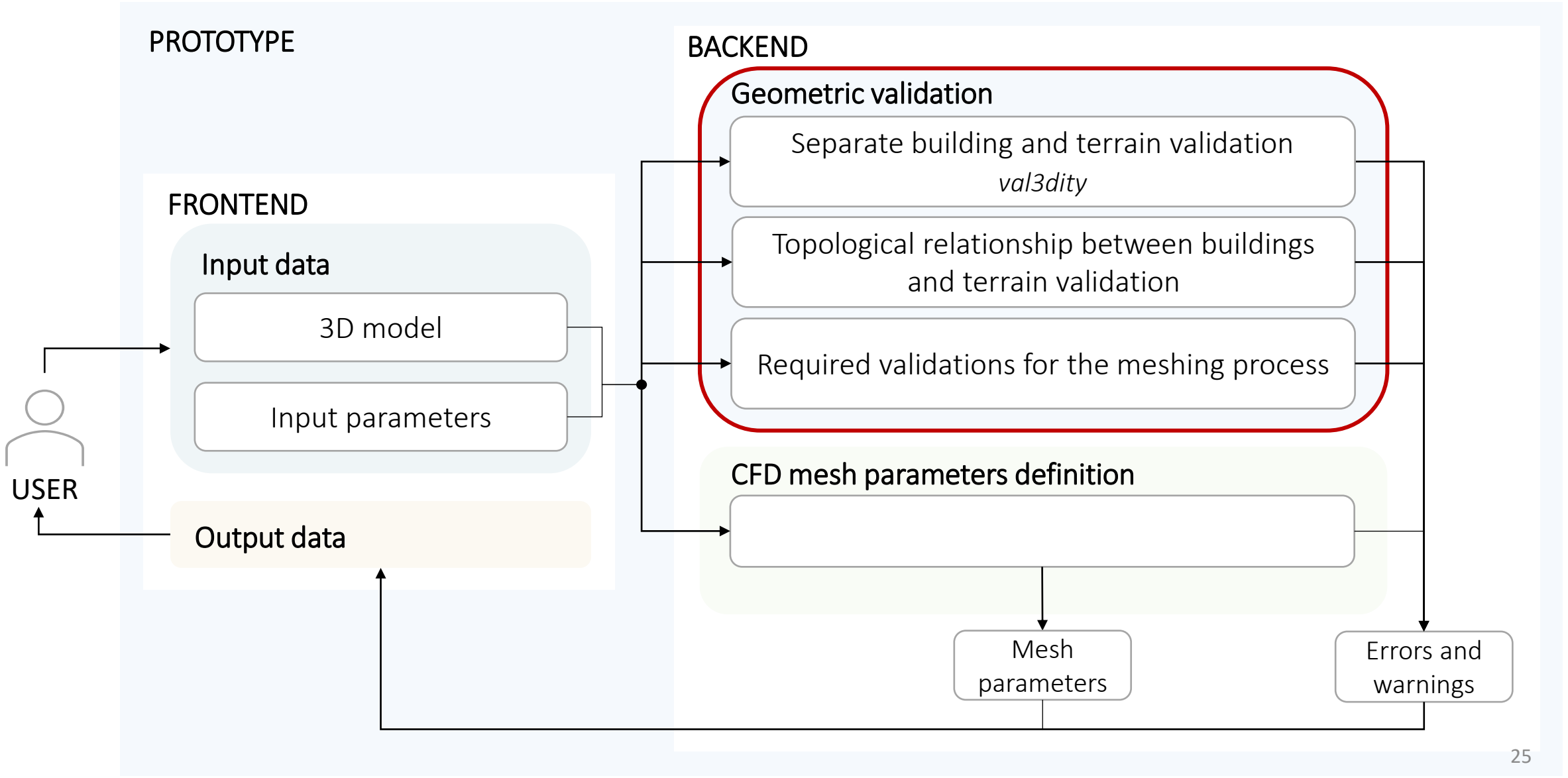


Short edges
when l $\leq \lambda$

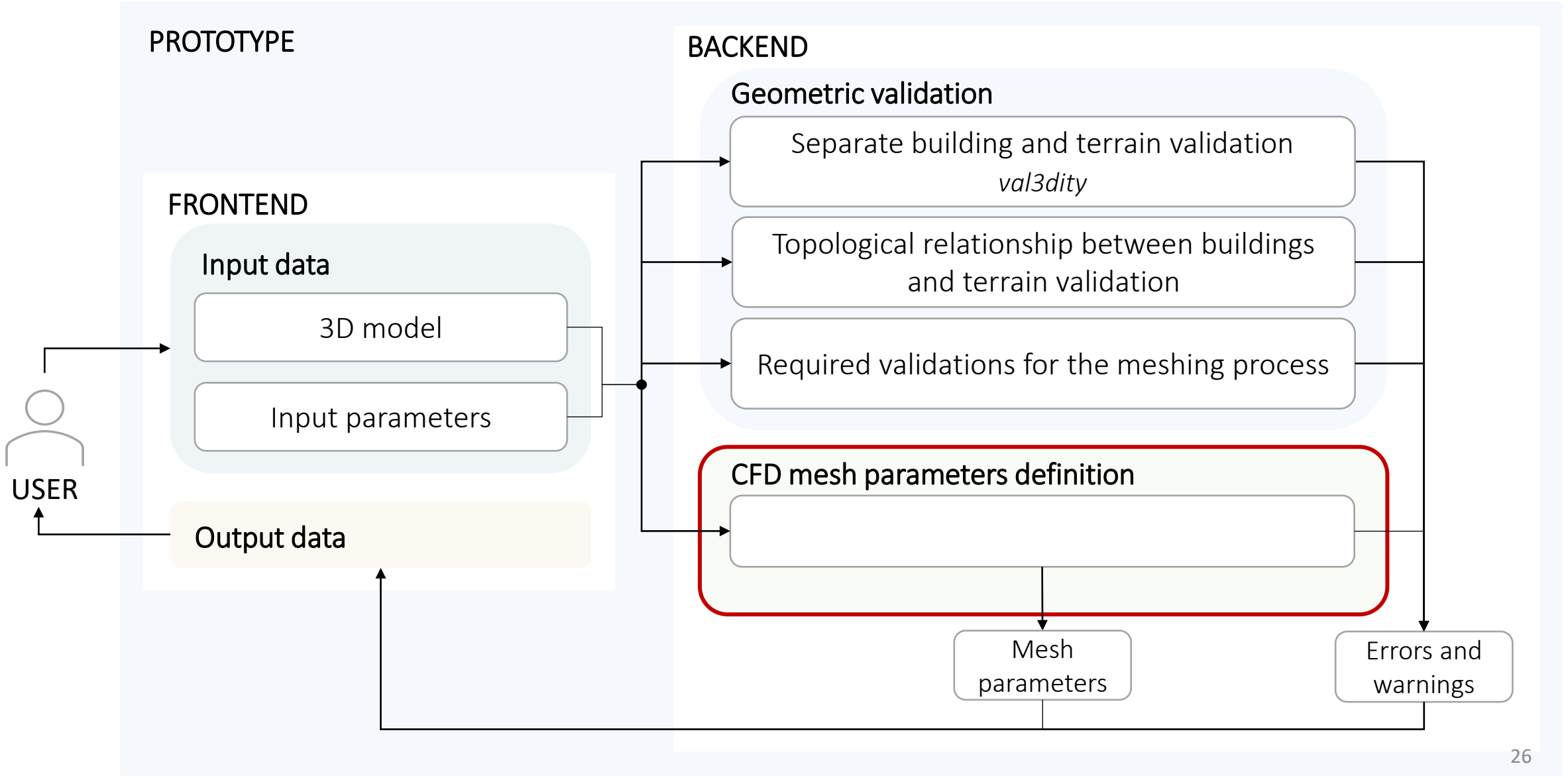


Overlapping
buildings

Architecture

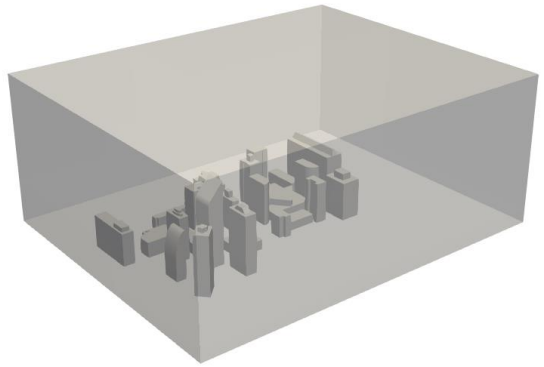


Architecture

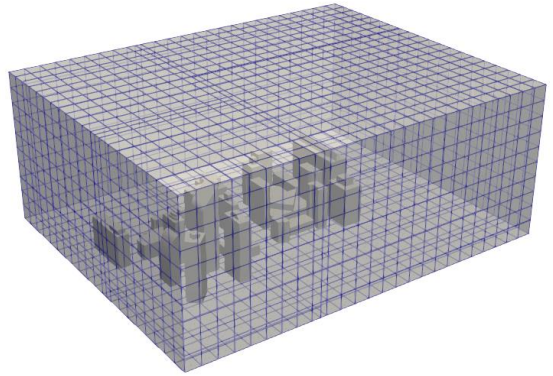


Mesh generation

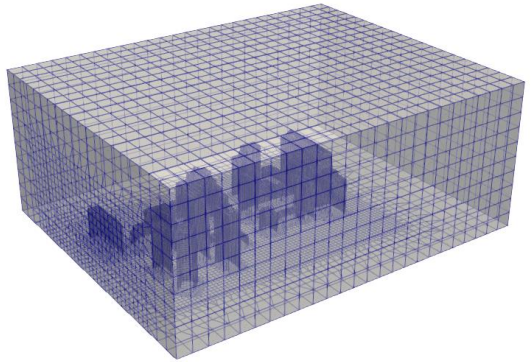
1) 3D urban model



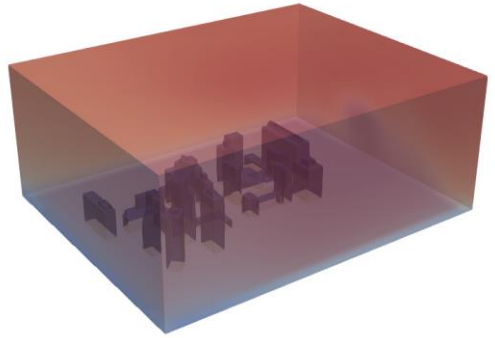
2) Computational domain



3) Background mesh



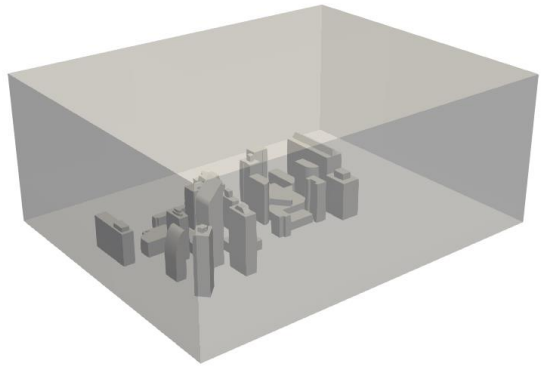
4) Refined mesh



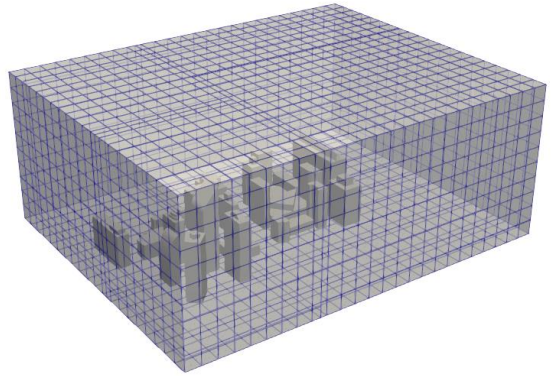
CFD simulation

Mesh generation

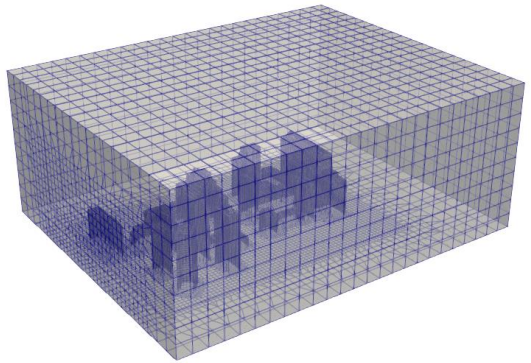
1) 3D urban model



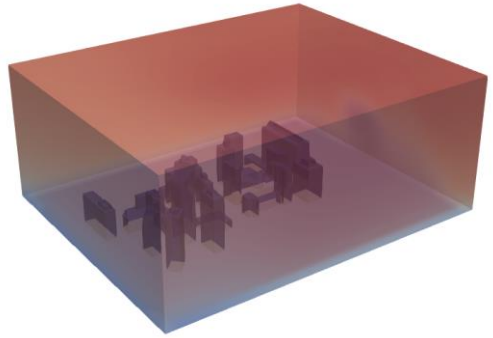
2) Computational domain



3) Background mesh

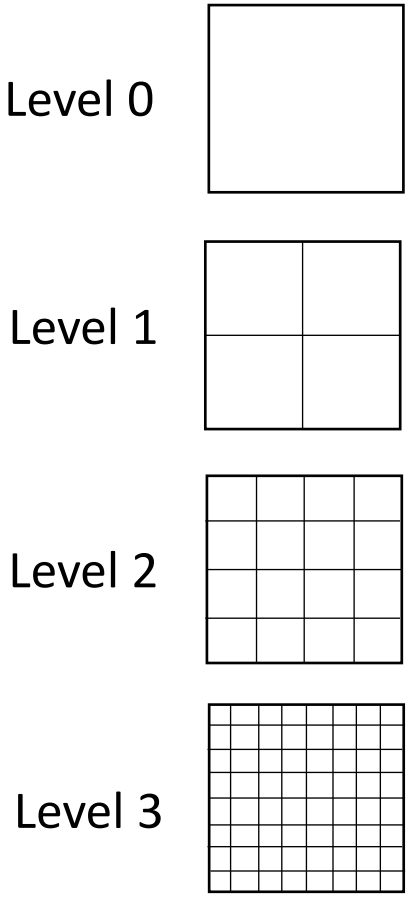


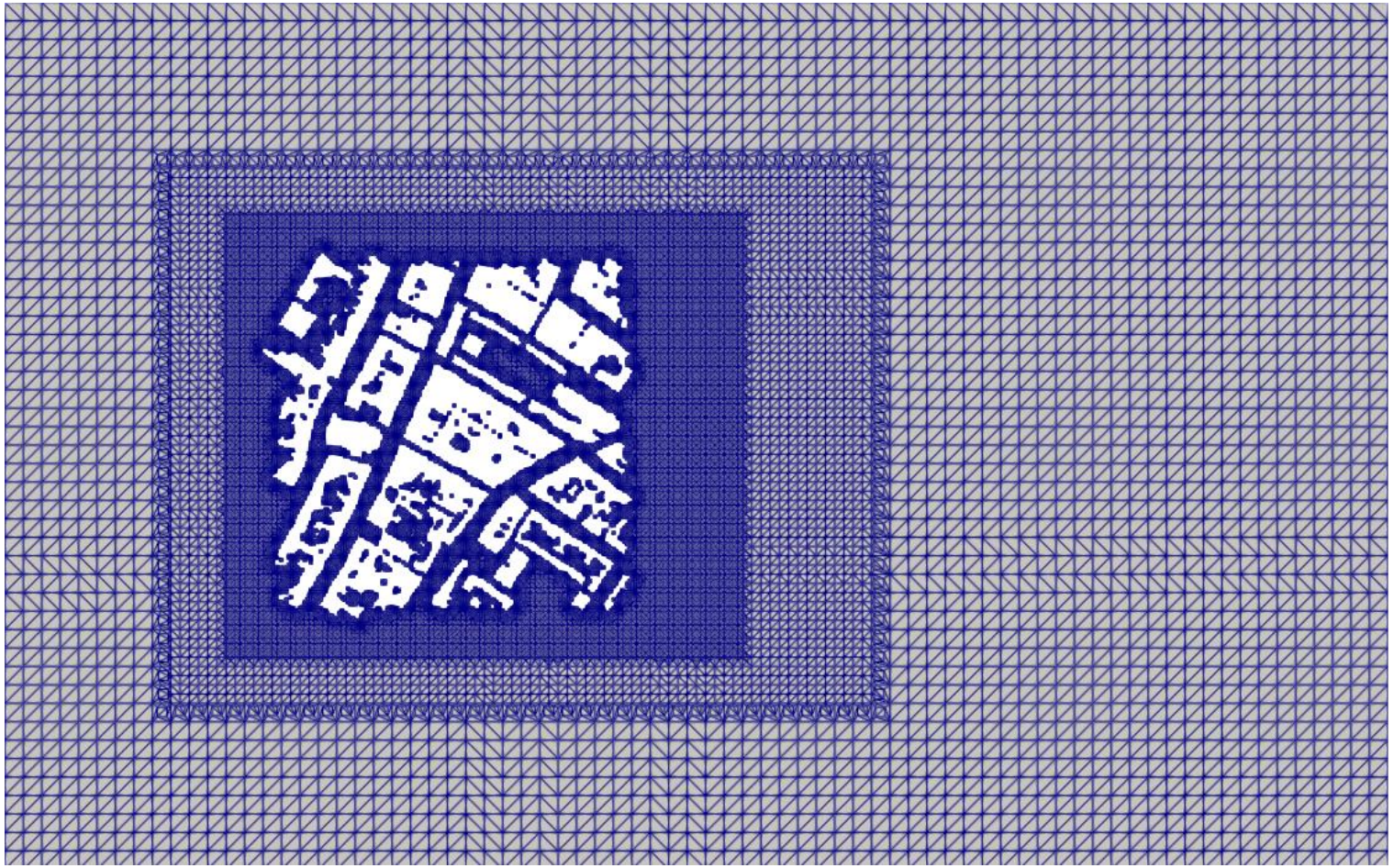
4) Refined mesh



CFD simulation

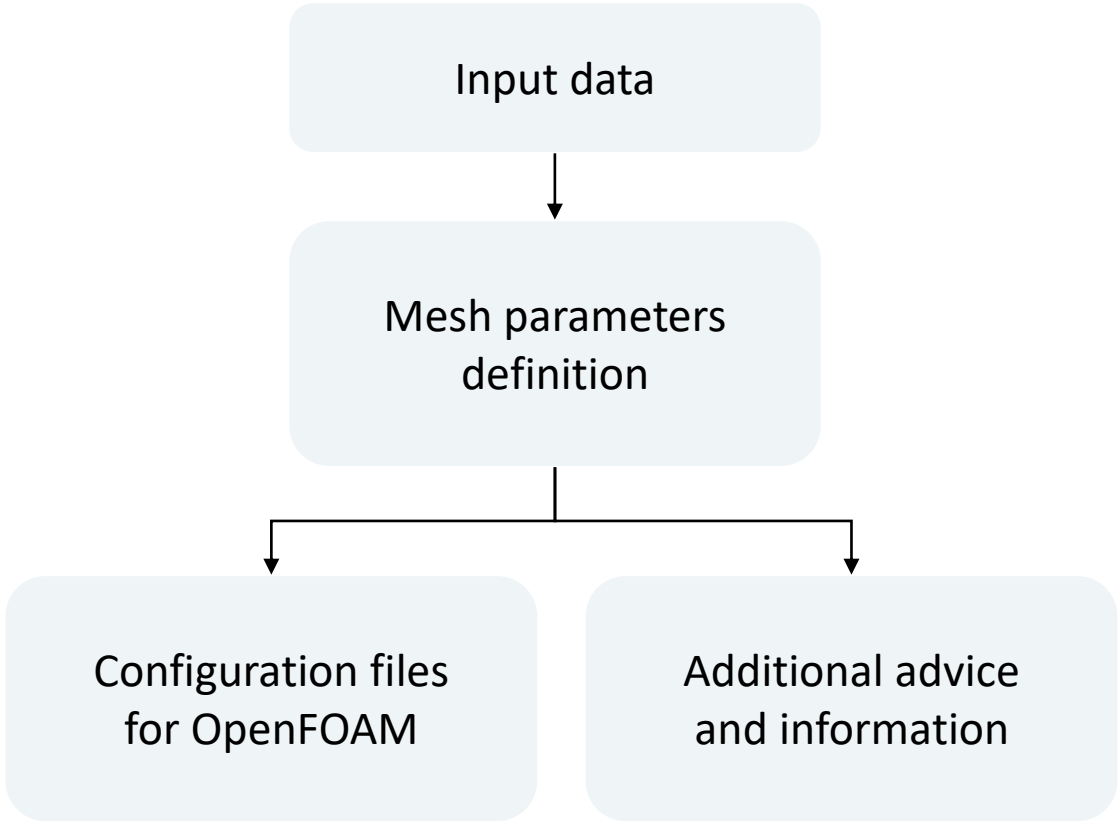
Refined mesh





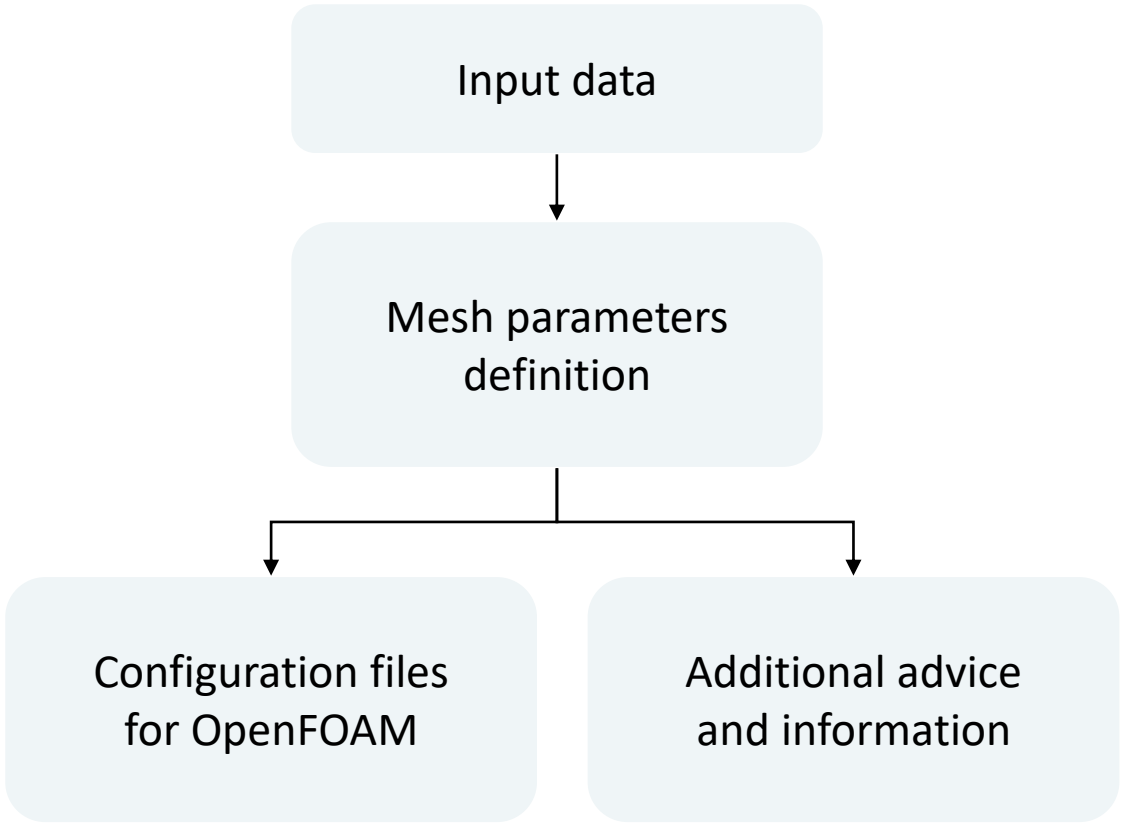
CFD mesh parameters definition

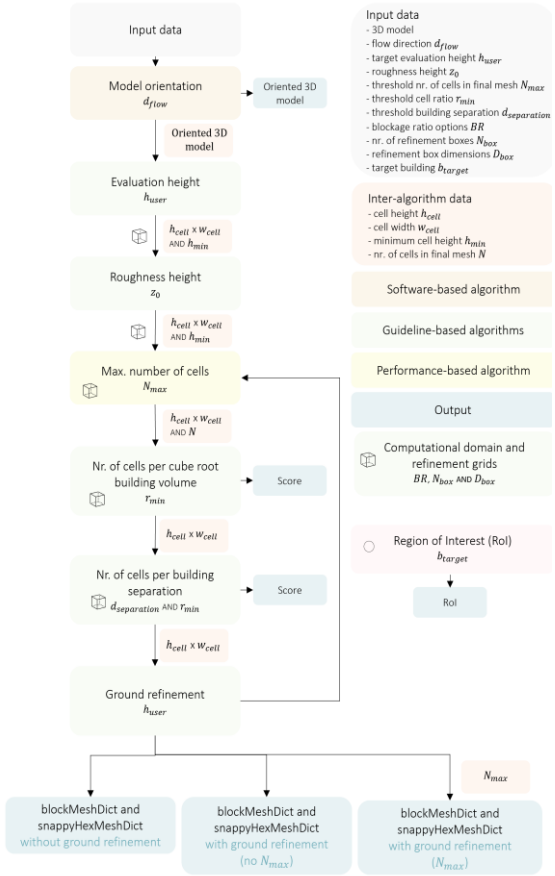
Based on recent CFD guidelines



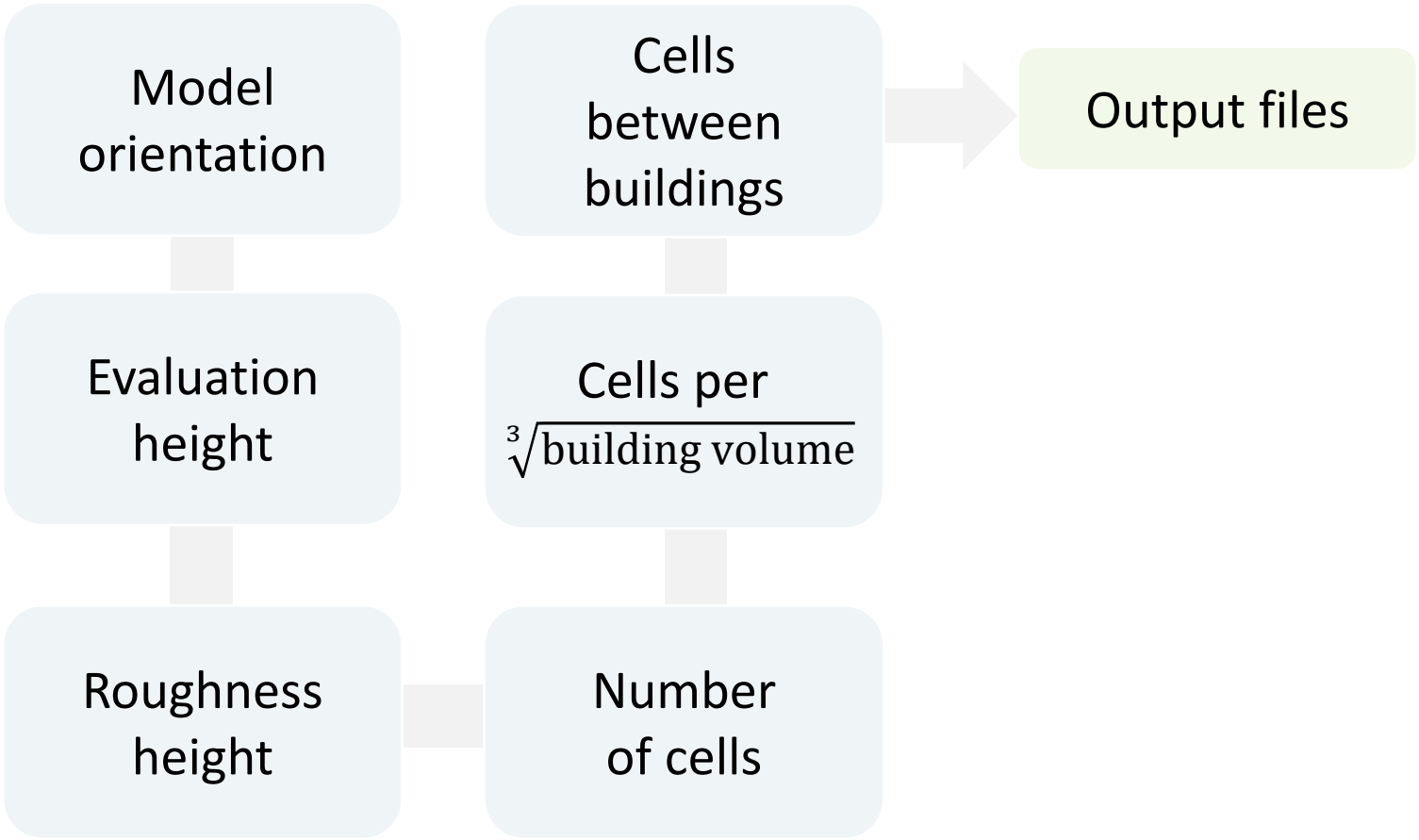
CFD mesh parameters definition

Based on recent CFD guidelines

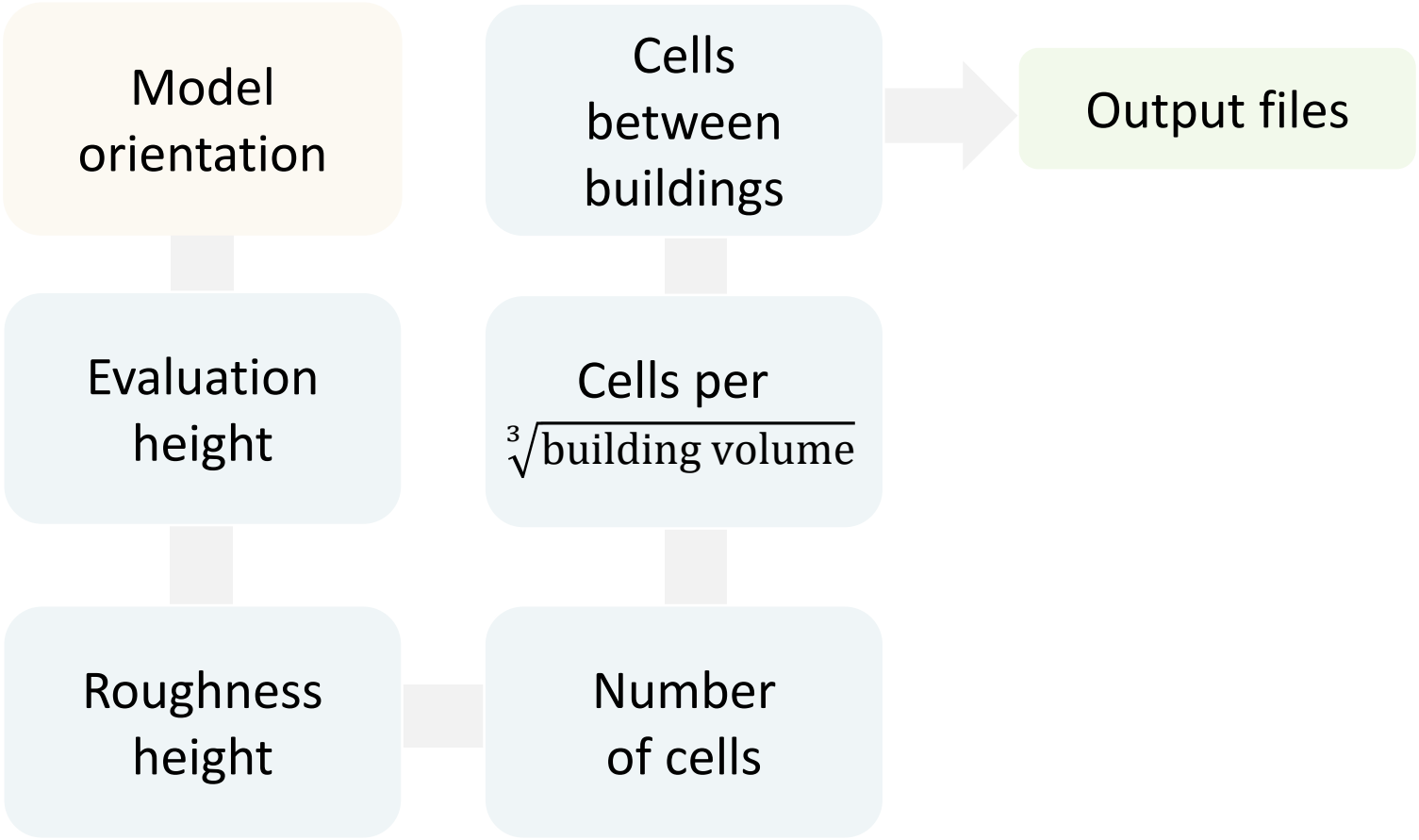




Workflow


Model orientation
Evaluation height
Roughness height
Number of cells
Cells per $\sqrt[3]{\text{building volume}}$
Cells between buildings
Output files

Workflow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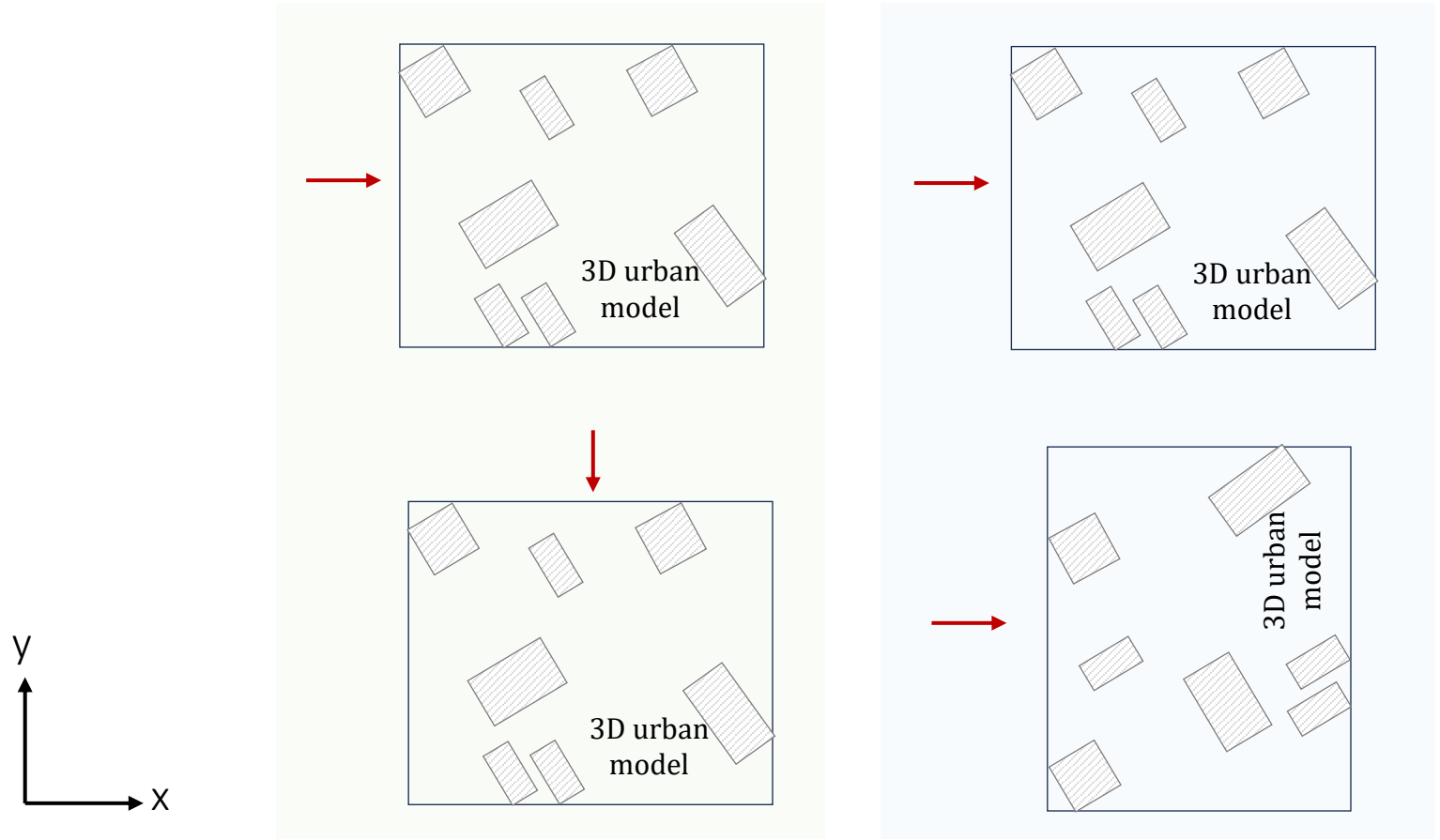
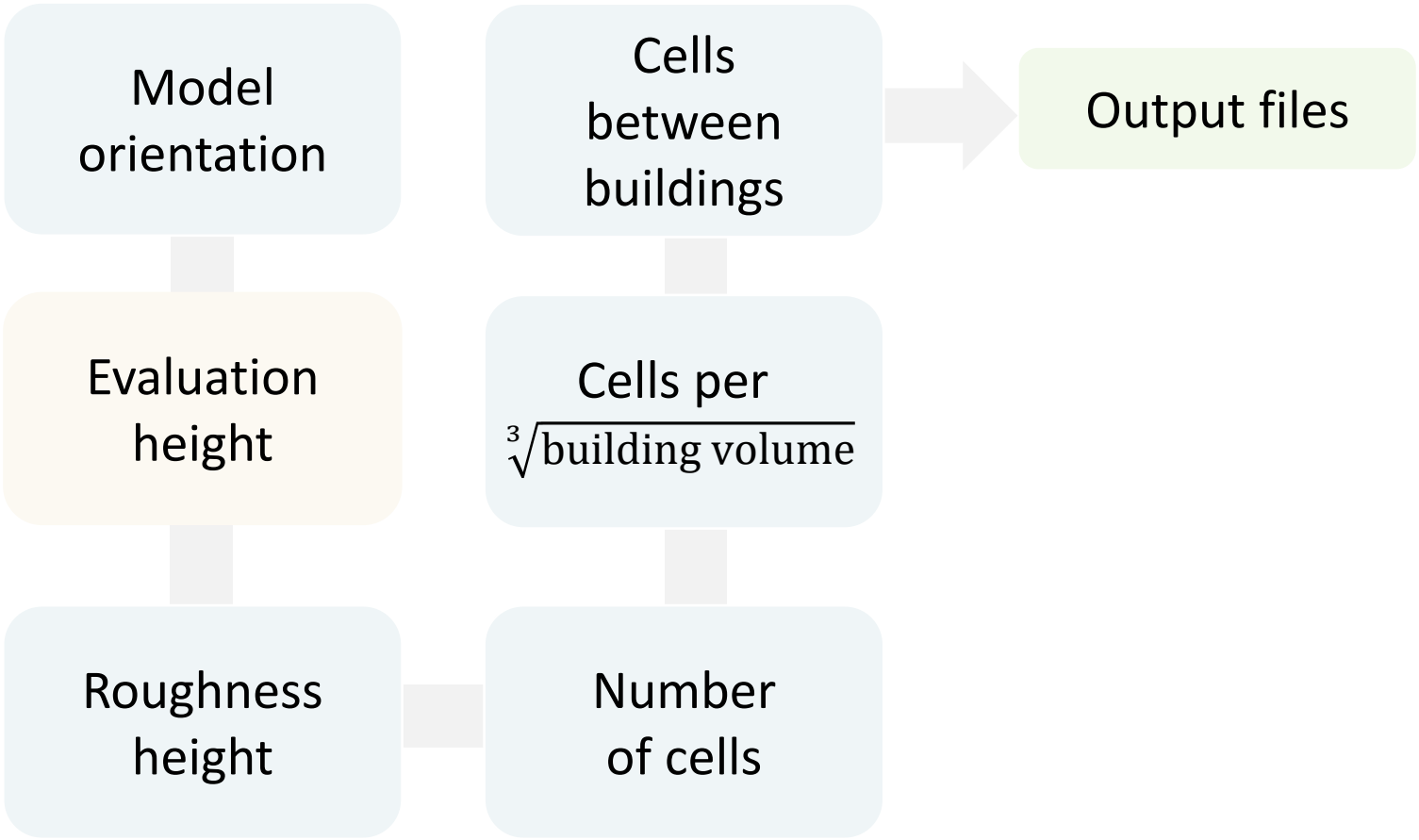


Workflow


Model orientation
Evaluation height
Roughness height
Number of cells
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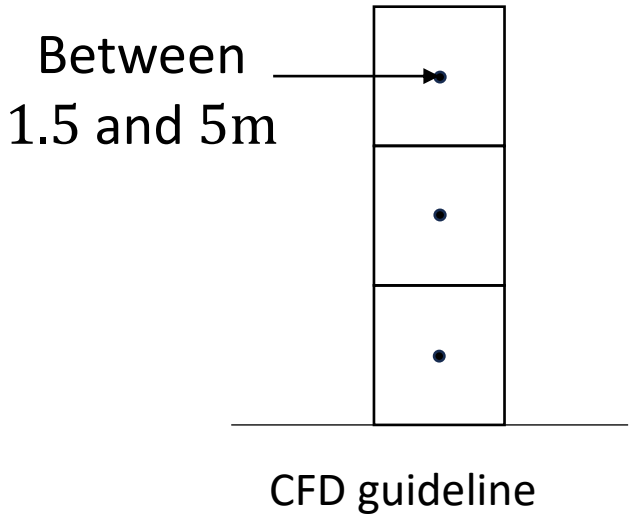
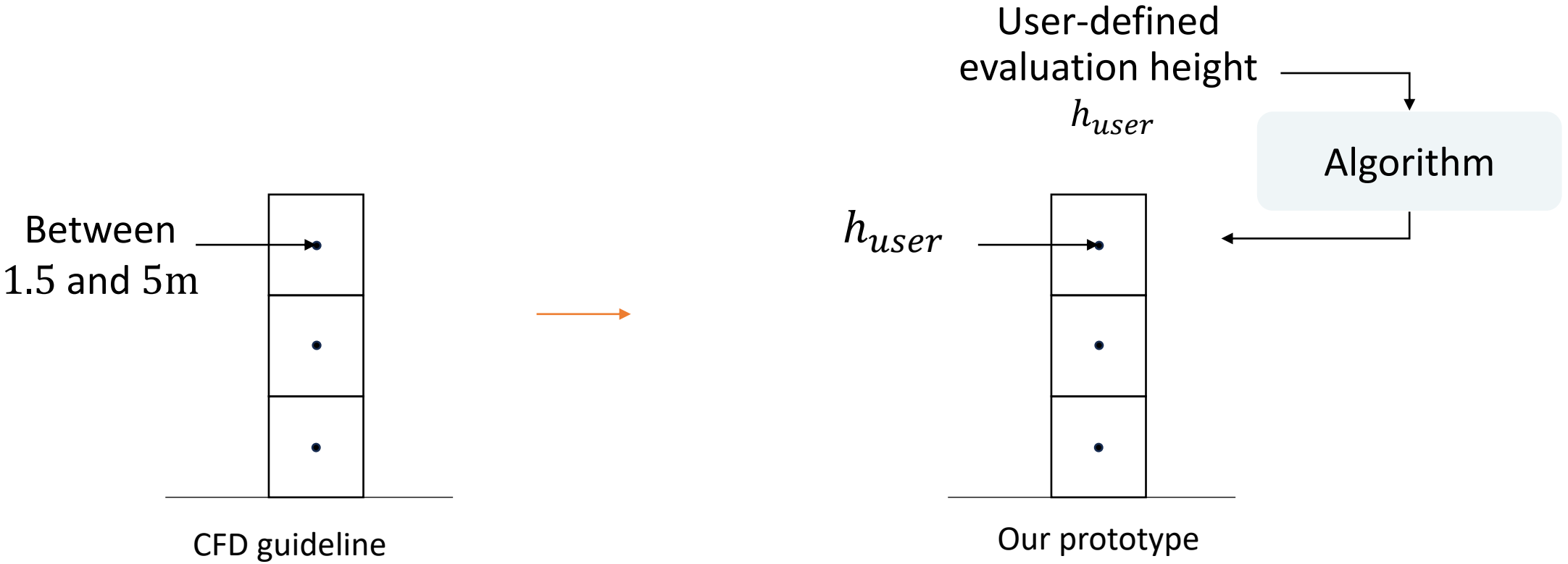
Cells between buildings
Output files

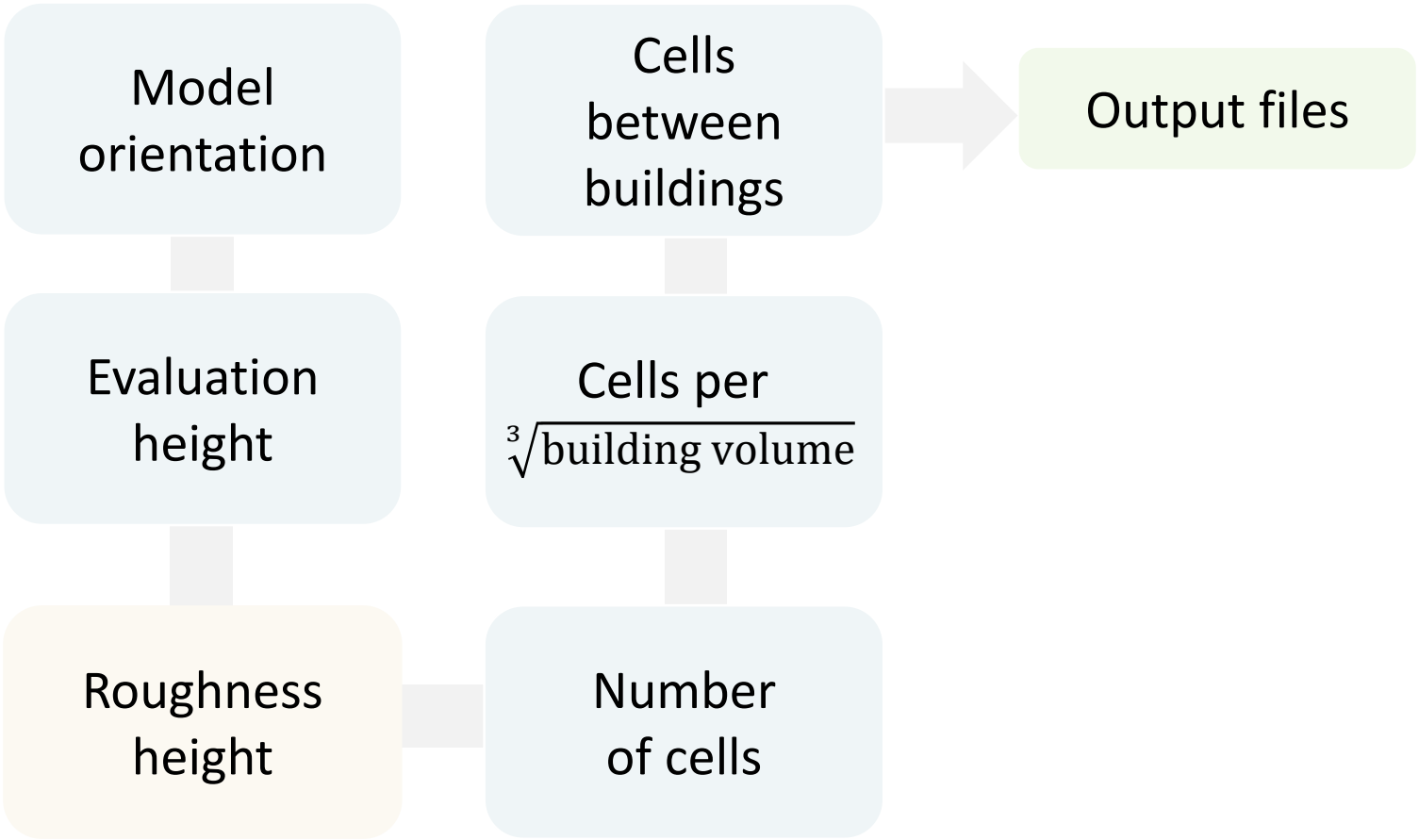
Evaluation height



Evaluation height

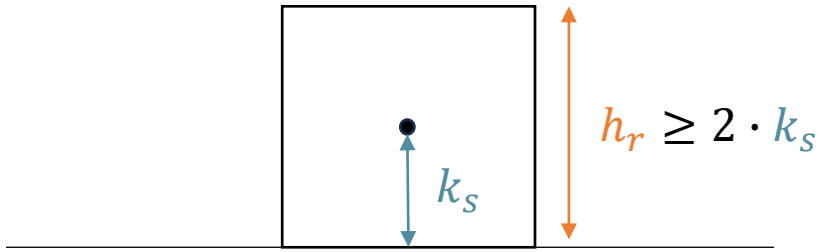


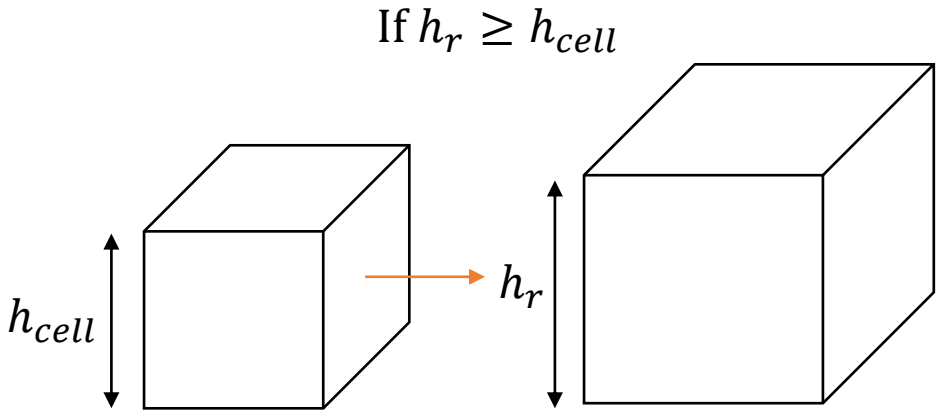
Workflow


Model orientation
Evaluation height
Roughness height
Number of cells
Cells per $\sqrt[3]{\text{building volume}}$
Cells between buildings
Output files

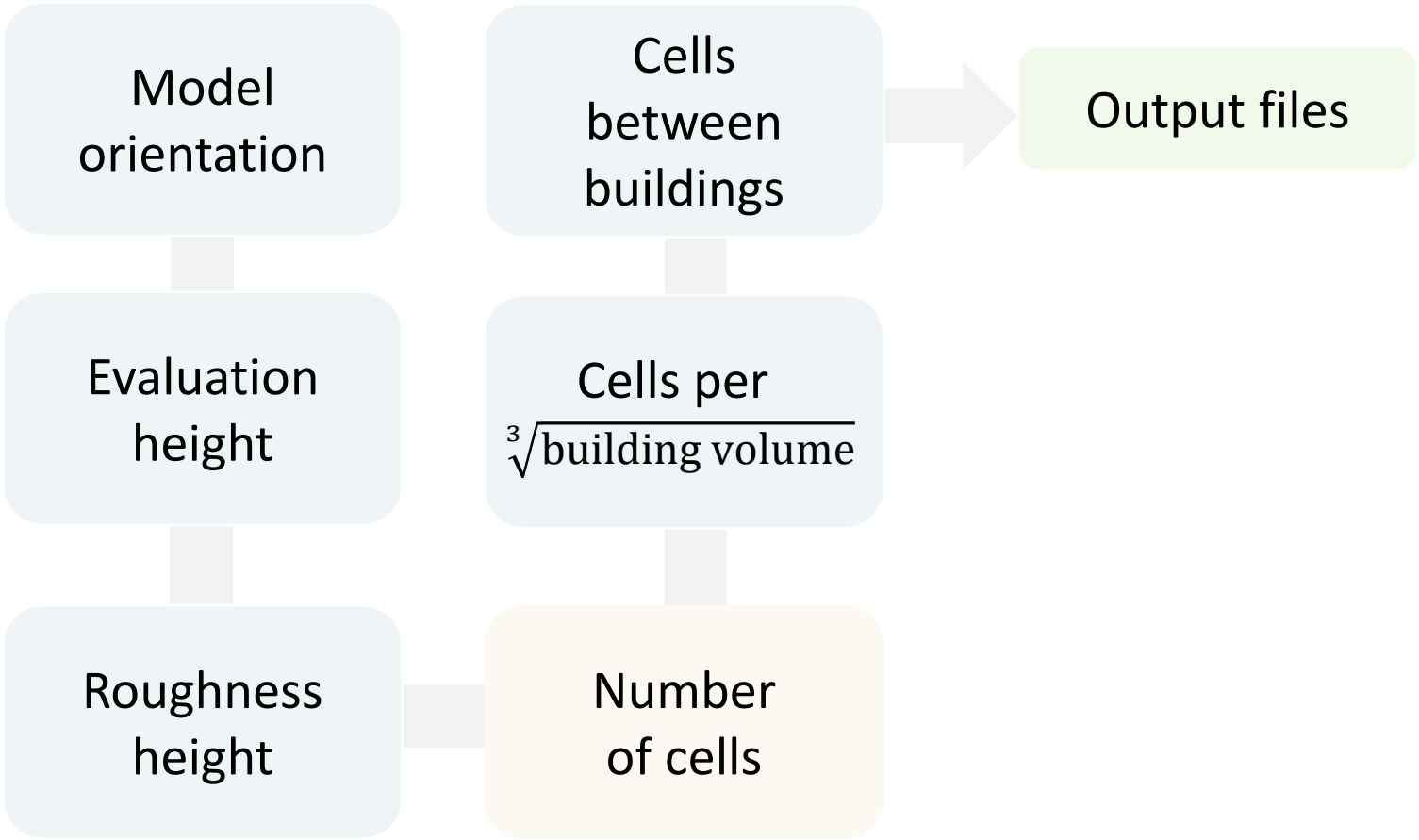
Roughness height

User-defined roughness height k_s





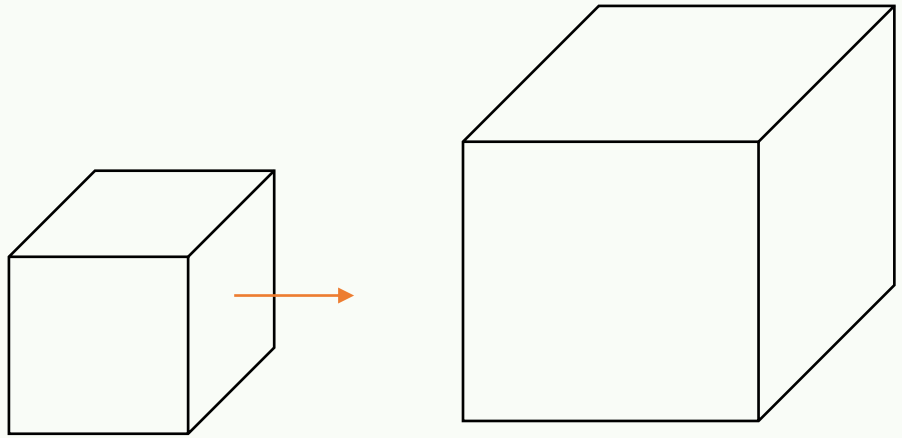
Workflow


Model orientation
Evaluation height
Roughness height
Number of cells
Cells per $\sqrt[3]{\text{building volume}}$
Cells between buildings
Output files

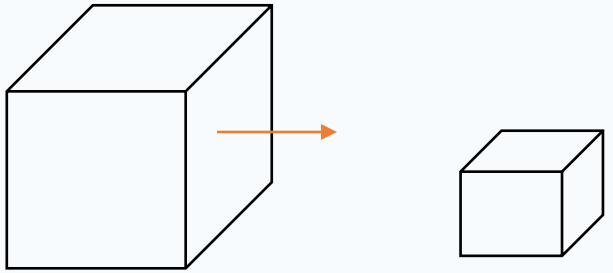
Number of cells

Maximum number of cells N_{max}

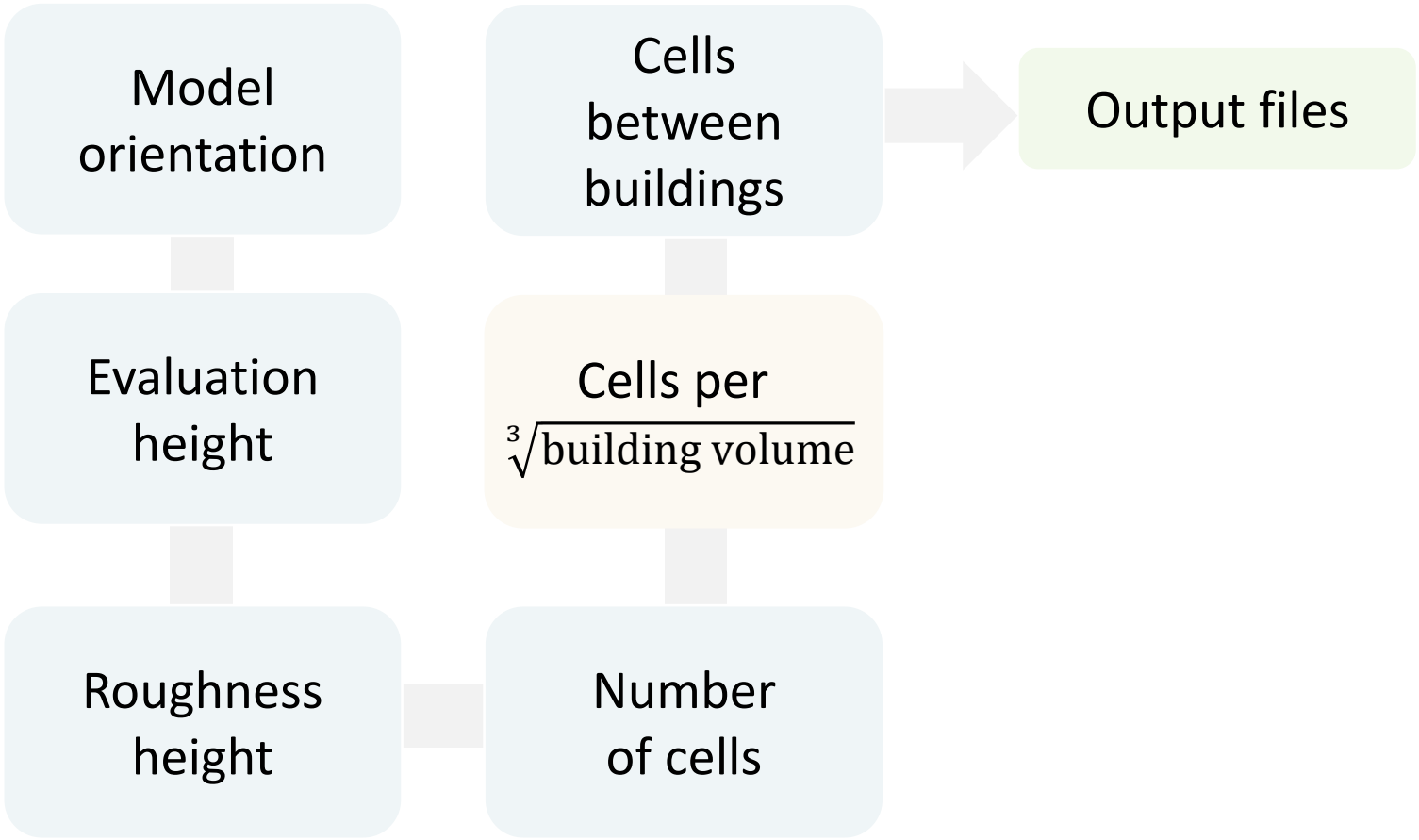
$N > N_{max}$



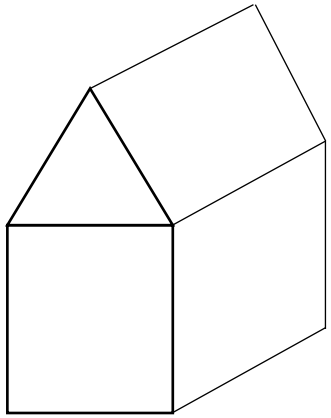
$N \leq N_{max}$



Workflow

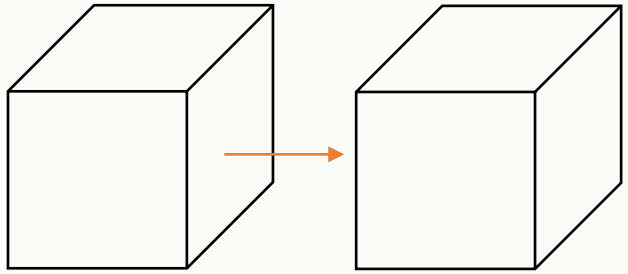

Model orientation
Evaluation height
Roughness height
Number of cells
Cells per $\sqrt[3]{\text{building volume}}$
Cells between buildings
Output files

Cells per cube root building volume

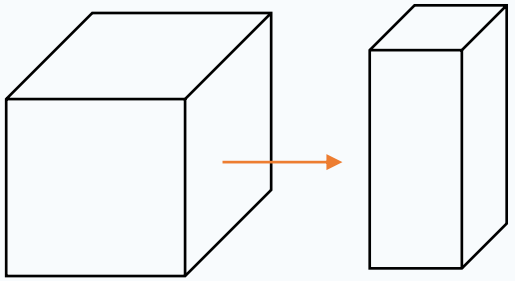


$\sqrt[3]{\text{building volume}}$ → more 10 cells?

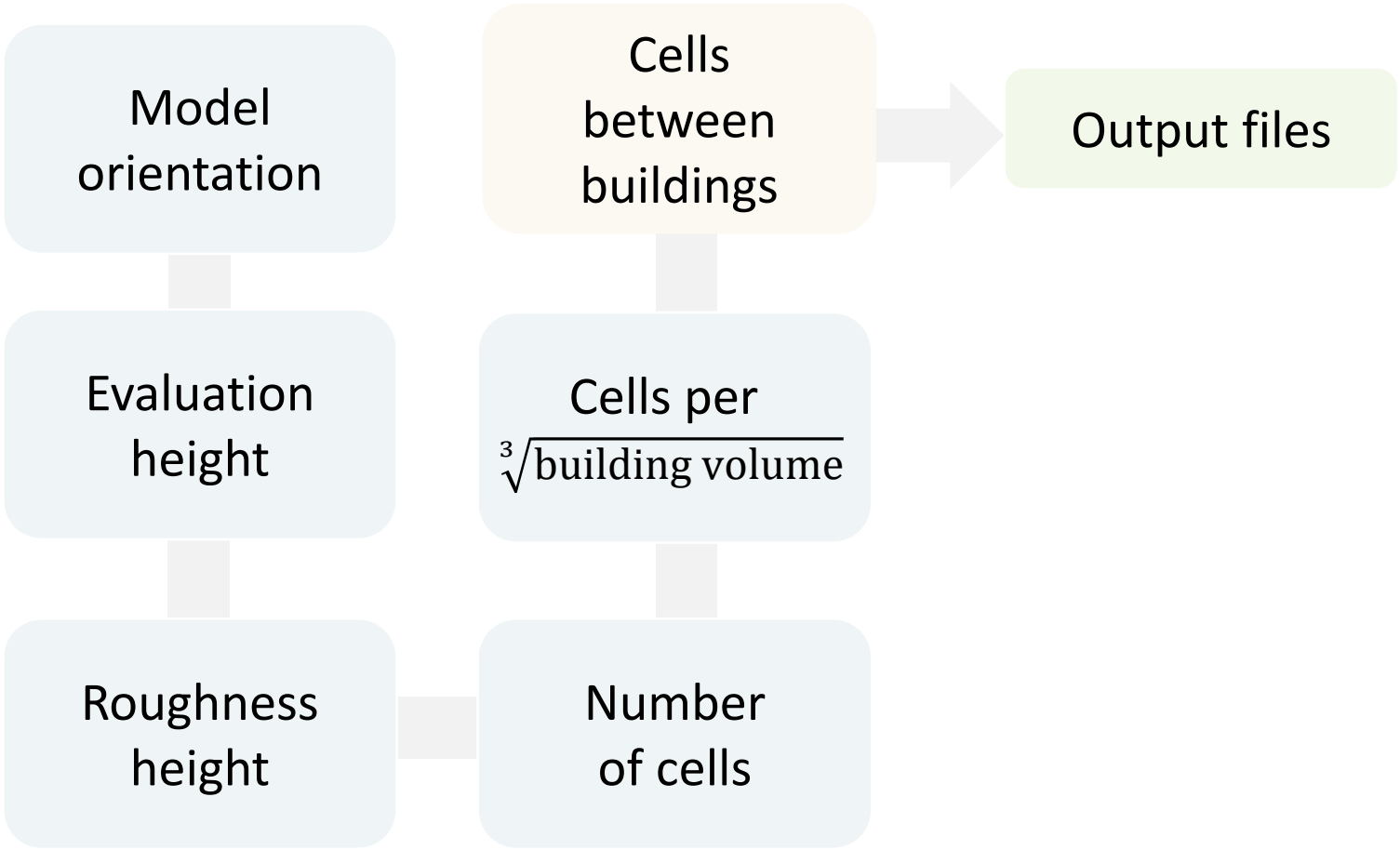
Yes



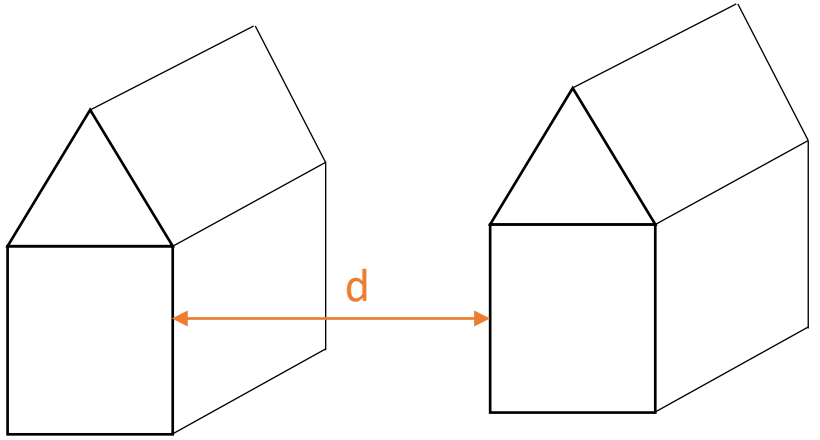
No



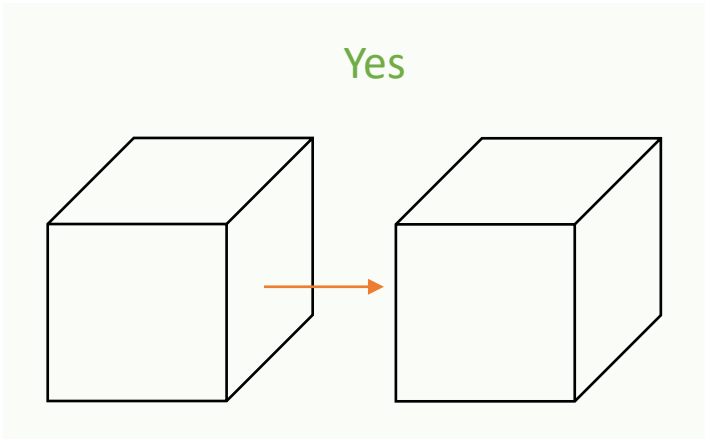
Workflow

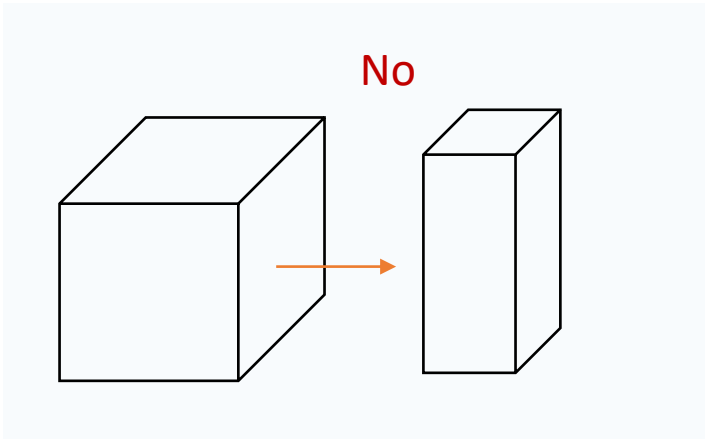

Model orientation
Evaluation height
Roughness height
Number of cells
Cells per $\sqrt[3]{\text{building volume}}$
Cells between buildings
Output files

Cells per building separation

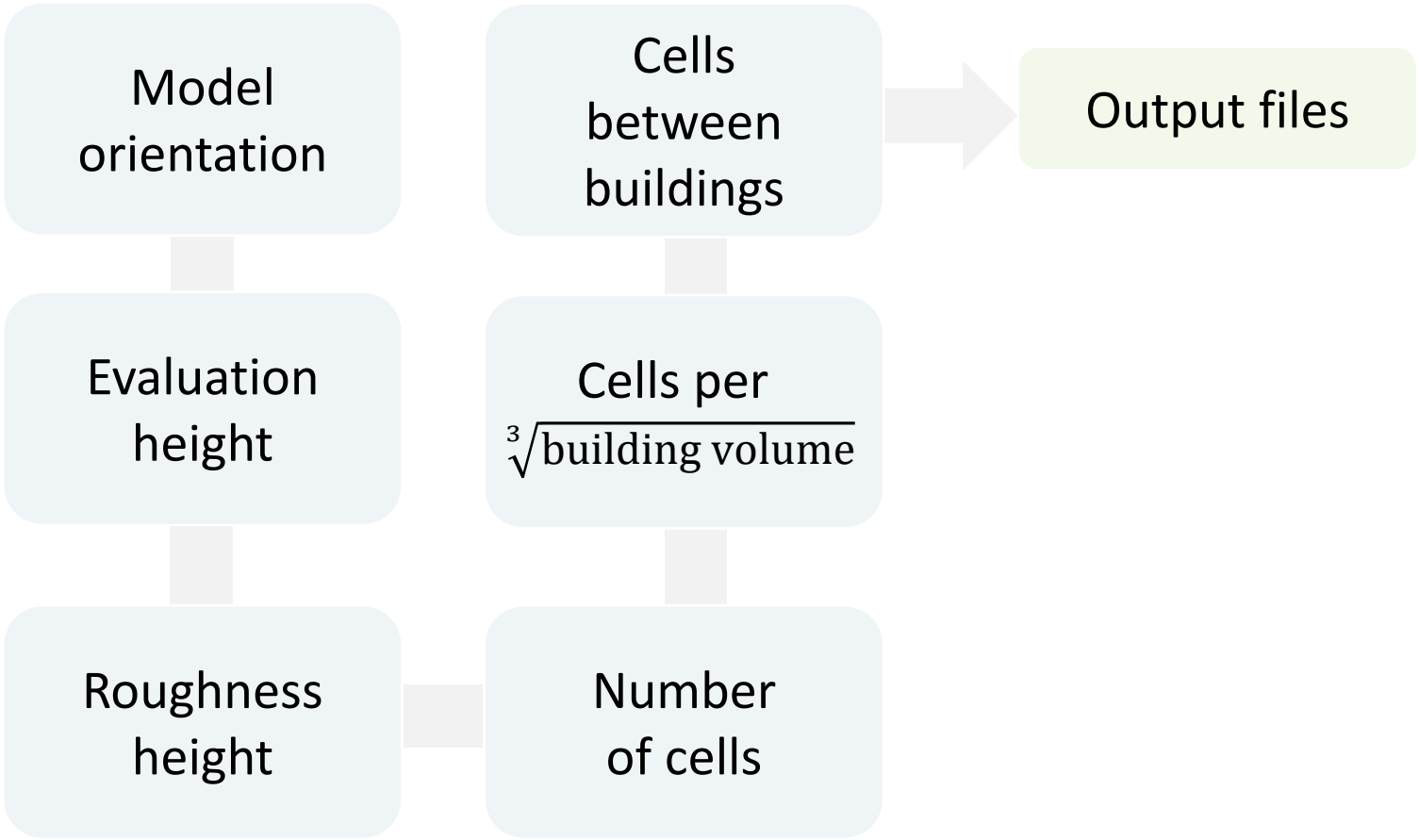


more 10 cells?

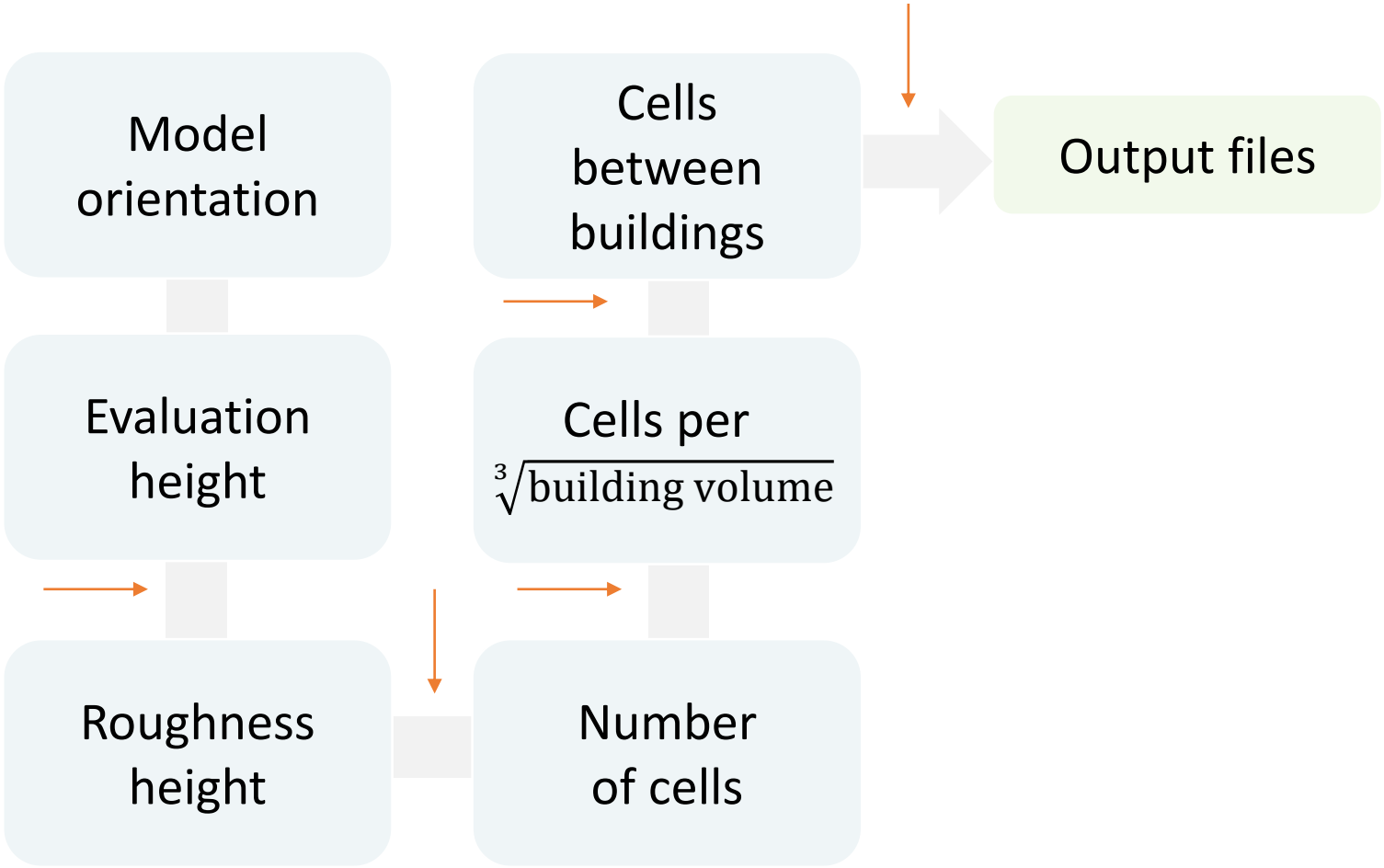




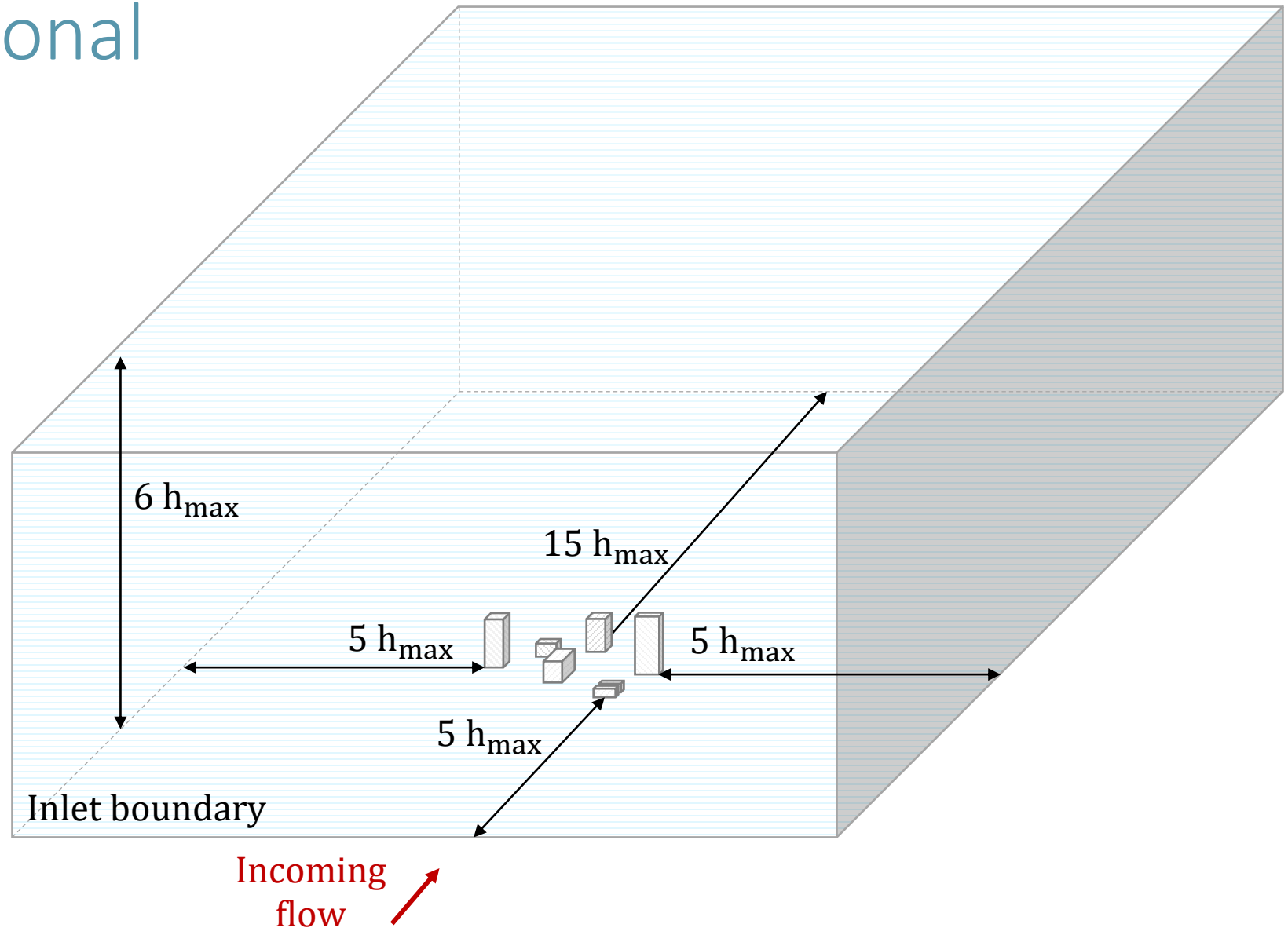
Workflow


Model orientation
Evaluation height
Roughness height
Number of cells
Cells per $\sqrt[3]{\text{building volume}}$
Cells between buildings
Output files

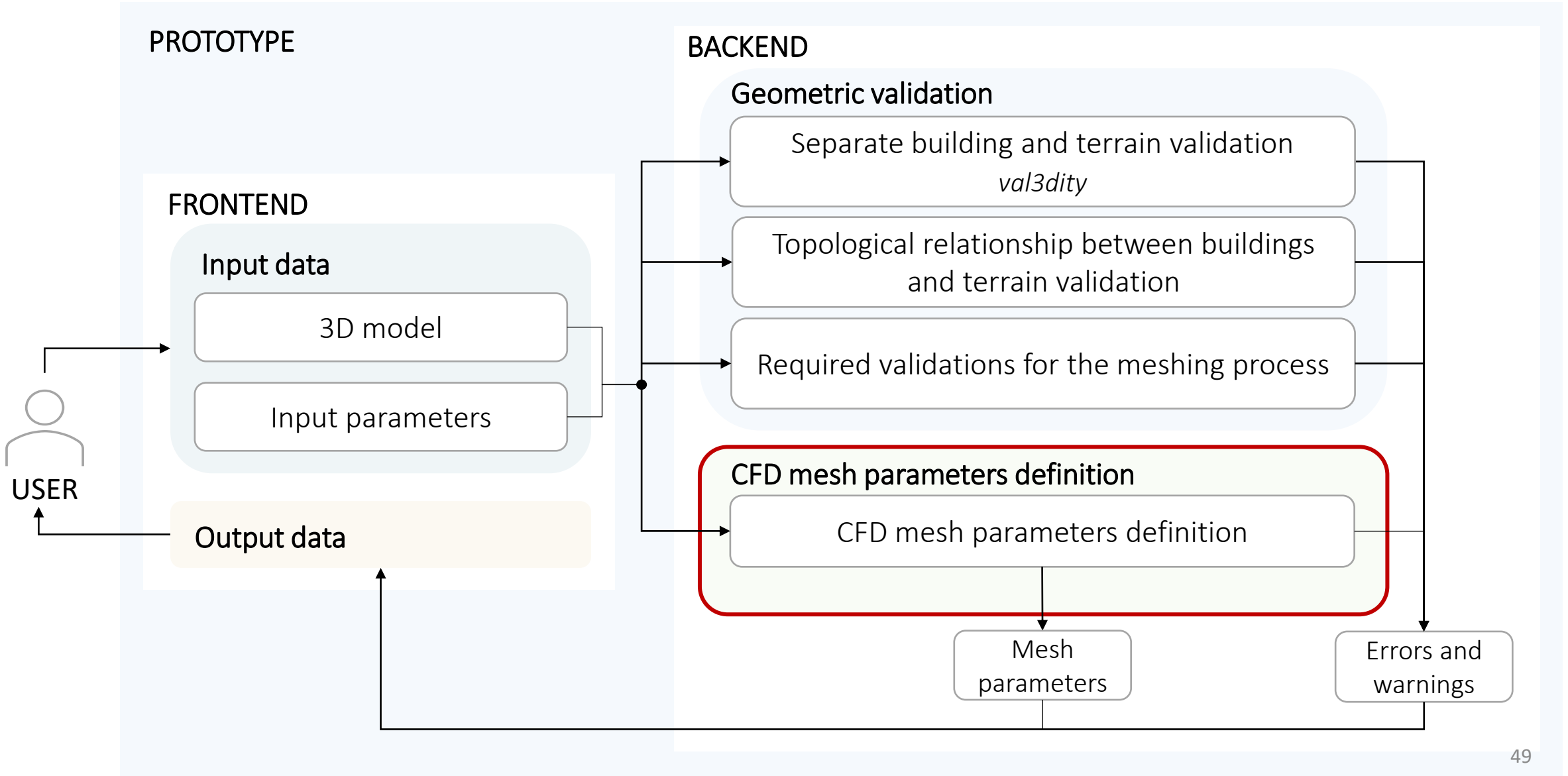
Workflow


Model orientation
Cells between buildings
Output files
Evaluation height
Cells per $\sqrt[3]{\text{building volume}}$
Roughness height
Number of cells

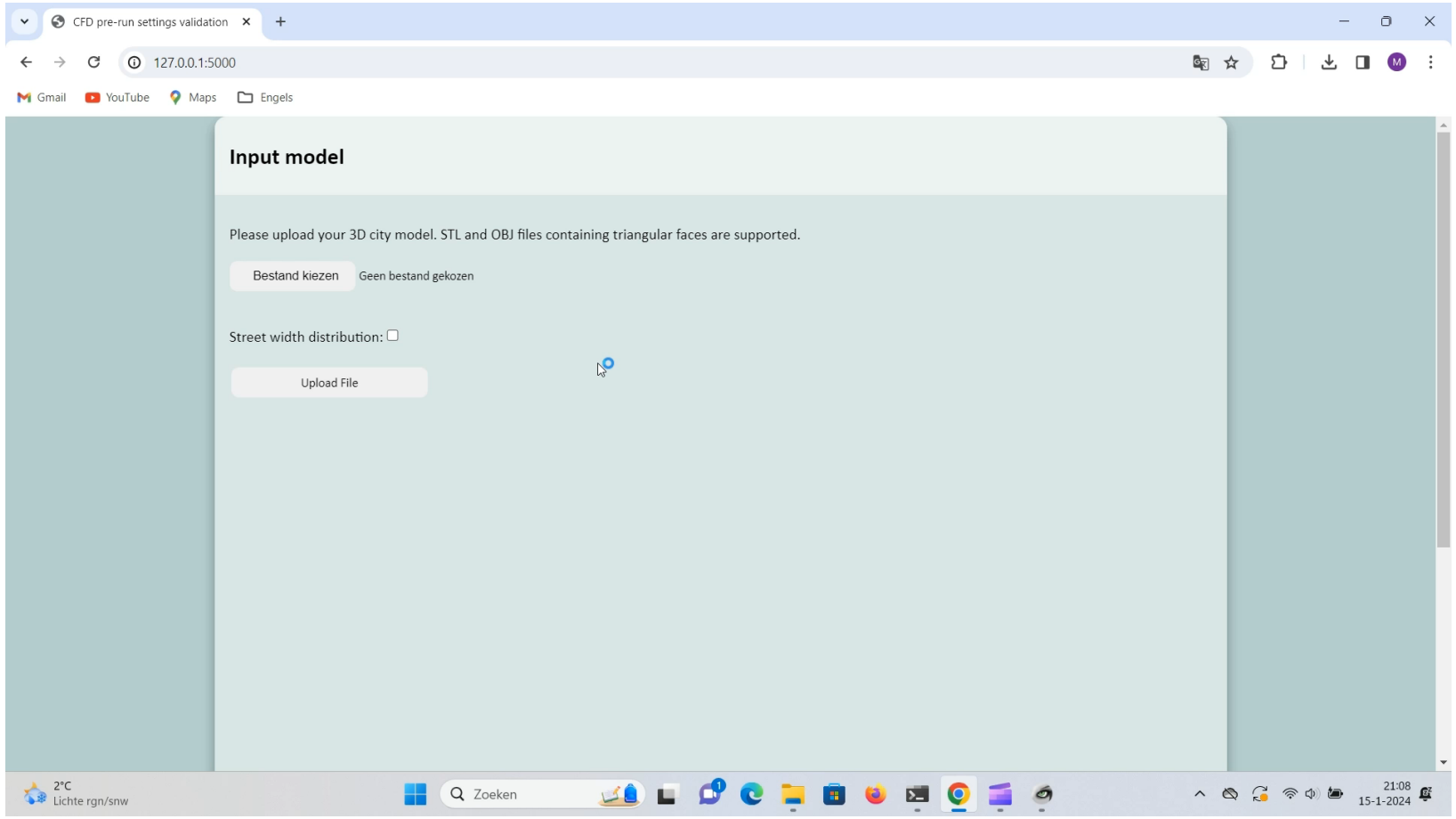
Computational domain



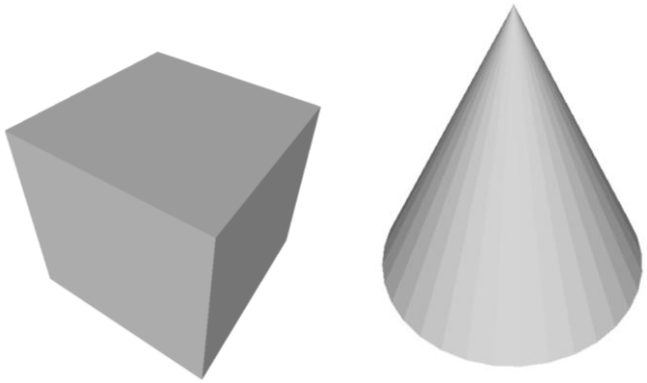
Architecture



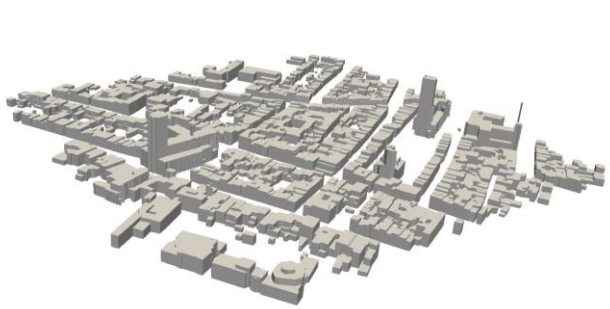
Results

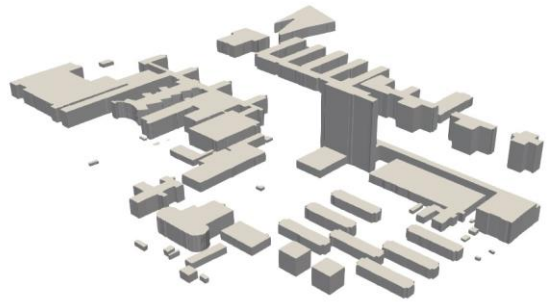

CFD pre-run settings validation
127.0.0.1:5000
Gmail
YouTube
Maps
Engels
Input model
Please upload your 3D city model. STL and OBJ files containing triangular faces are supported.
Bestand kiezen
Geen bestand gekozen
Street width distribution:
Upload File
2°C
Lichte rgn/snw
Zoeken
21:08
15-1-2024

Validation

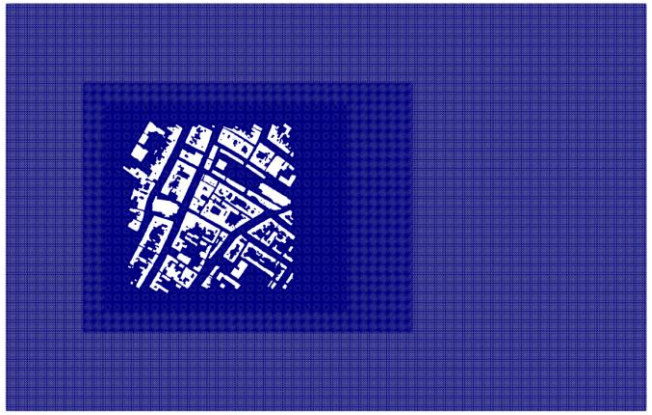


Basic shapes





Real-world data



Mesh generation
in OpenFOAM

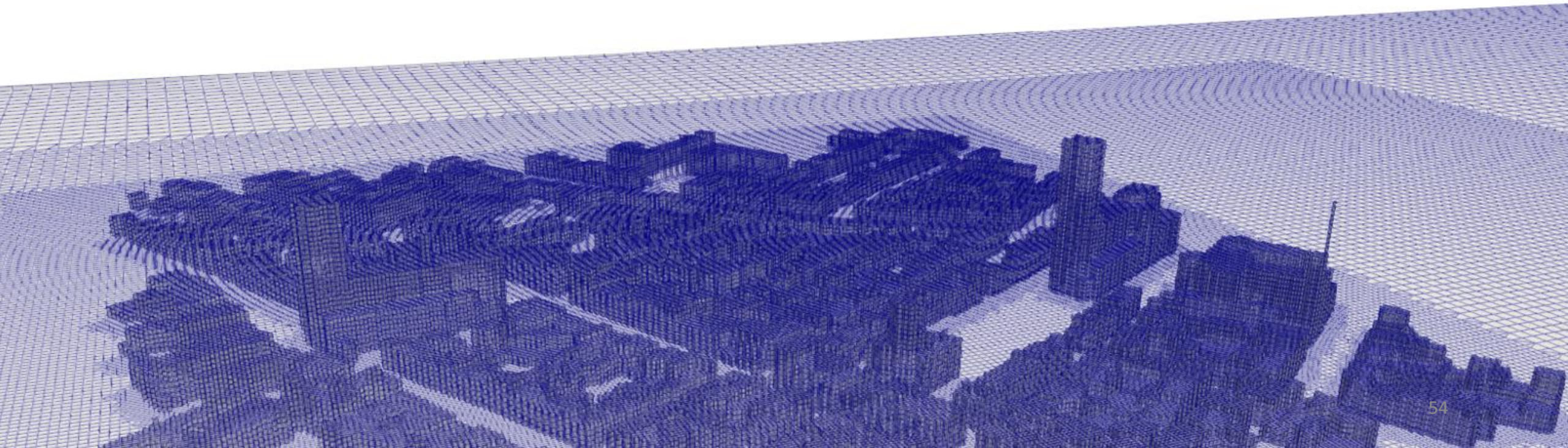
Main limitations/recommendations

- Dimensions at which sliver triangles, short edges, and sharp angles are affecting the meshing process are unknown
- Method based on the evaluation height is not suitable for large evaluation heights
- Number of cells approximation differs approx. 12% from the actual number
- Not all CFD guidelines can be satisfied at the same time
- Further development of the prototype

Conclusions

- Prototype of a **web application**
- This method identifies **geometric errors** and suggests **mesh parameters**
- Follows **standards and guidelines**
- It simplifies **the ease of use** of CFD simulations for urban areas
- Warning: **expertise is needed** to set suitable input parameters

Questions



Literature

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