SPATIAL REASONING AI PLACEMENT SYSTEM

This report decribes an AI system capable of placing objects inside arbitrary 3d indoor environments.

The system combines geometry-based reasoning with a local Large Language Model(LLM) to generate explainable placements.

SYSTEM ARCHITECTURE

1. Scene Parsing: Extract meshes and compute room bounds.

2. Semantic Tagging: Identify walls, furniture, obstacles.

3. LLM Planning: Convert user intent into structured placement rules.

4. Geometry Solver: Generate collision-free candidate positions.

5. Optimization: Score candidates based on constraints.

6. Grounded Explanation: LLM verbalizes measured spatial metrics

PIPELINE PHASES

Phase 1 - 3D Scene understanding & bounding boxes

Phase 1.5 – Semantic tagging of obstacles & structures

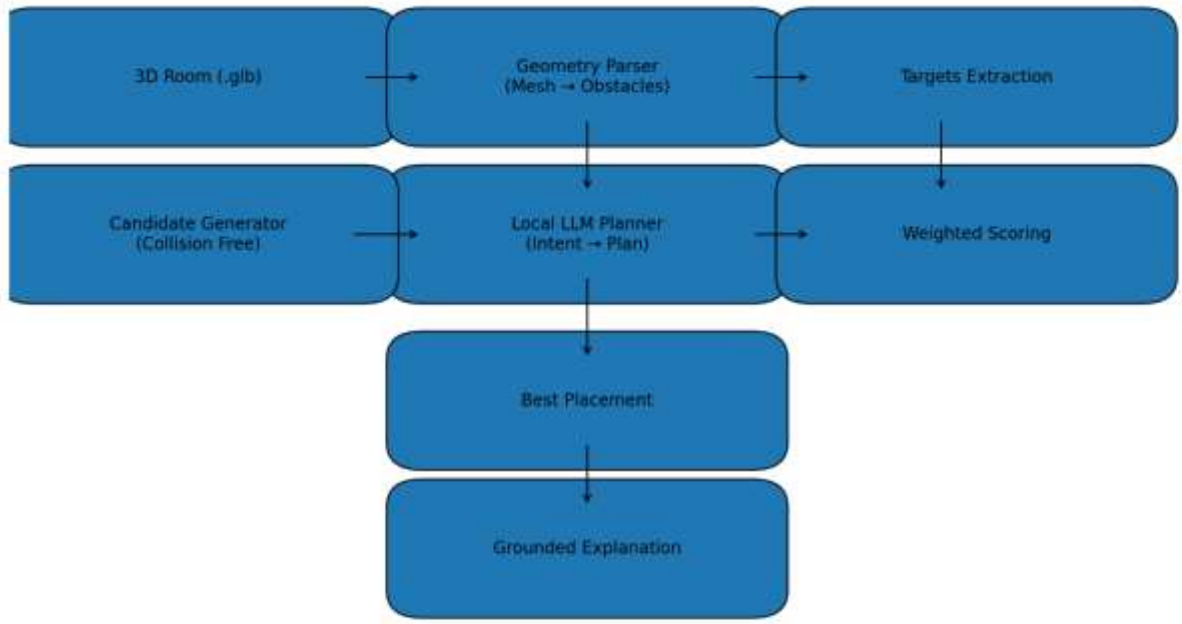
Phase 2 – Candidate generation in free space

Phase 3 – Weighted scoring optimization

Phase 4 – LLM intent interpretation

Phase 5 – Grounded Explanation Generation

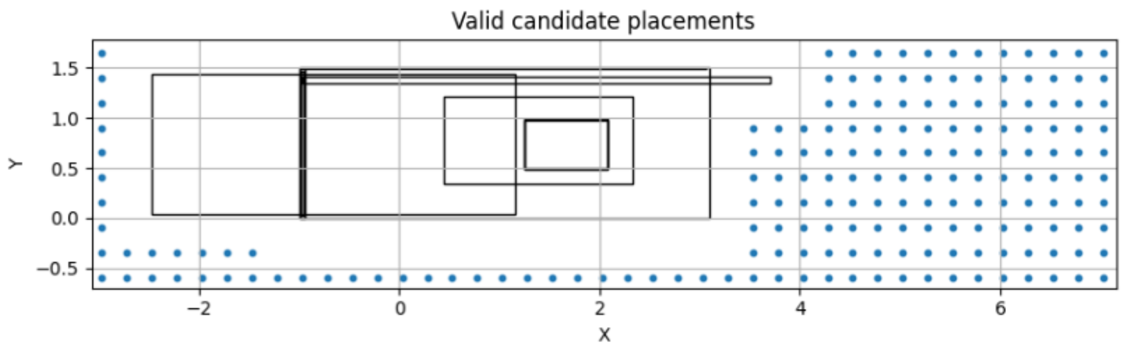
FLOWCHART



RESULTS

Example Output: -

```
Obstacles count used for grid: 10
Grid: OK | cell: 0.25
Grid Shape: [10, 41]
Candidates meta: {'step': 0.25, 'clearance': 0.35, 'boundary_margin': 0.1, 'num_valid': 18
2, 'num_blocked': 228, 'num_obstacles': 10}
Wrote: outputs\candidates.json
```




```
Wrote: outputs\scene_graph.json
Room bounds: {'min': [-3.072100089727104, -0.6975192089530289, -3.644868236094374], 'max':
[7.158818006515503, 1.7766119499656021, 1.0000006481999293]}
Floor z: -1.734517626987245
Objects: 84
Tag COunts: Counter({'clutter': 71, 'obstacle': 10, 'structure': 3})
```

Detected targets: ['window', 'tv', 'shelf']

LLM PLAN: {'object_type': 'chair', 'object_dims': {'width': 0.6, 'depth': 0.6}, 'target': {'name': None}, 'weights': {'near_target': 0.4210526315789474, 'max_clearance':

0.10526315789473685, 'near_wall': 0.4736842105263158}, 'constraints': {'min_clearance': 0.3, 'boundary_margin': 0.1}, 'wall_pref': 'near'}

Valid placements: 130

Best placement: [7.027899910272897, -0.5975192089530289, -1.734517626987245] score: 0.5789473684210527

===== EXPLANATION =====

This placement is suitable for a chair as it is located 0.09999999999999998 meters from the wall, ensuring the chair is near the wall while maintaining walking space. The clearance distance of 3.9730876892422757 meters from any obstacle is more than the required maximum clearance of 1.0 meter. The chair's dimensions, with a width and depth of 0.6 meters each, will not encroach upon the walking space. The 'near_wall' component, which prioritizes placing the chair near the wall, has a score of 1.0, indicating a strong preference for this placement. The overall score of 0.5789473684210527 reflects the balance between the 'near_target', 'max_clearance', and 'near_wall' components, making this placement an optimal solution for the user request.

CONCLUSION

This project demonstrates hybrid AI reasoning: LLM provides semantic understanding, while geometry guarantees correctness. This combination enables generalizable spatial reasoning across unseen rooms.

LIMITATIONS:

1.LLM only decides the preferences: for ex:near wall,open space,etc

It does not handle feasibility, it is handled by geometric engine.

2.No Human Navigation Simulation

The planner approximates walking space using clearance radius.So a placement may be collision free but still it can be awkard to move around.

The system prioritizes reliability over generative freedom: geometric correctness is guaranteed first, and language reasoning is layered on top. This trade-off intentionally prevents hallucinated spatial decisions while maintaining generalization across unseen rooms.

Also, there is a lot future improvements can be done on this.