ISMAR 2020

Generative Modeling in Spatial Computing

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XR Lab @ Berkeley

Berkeley UNIVERSITY OF CALIFORNIA

IMG: Angry Birds AR


actual footage shot
through HoloLens
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www.microsoft.com/en-us/research/project/holoportation-3

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SceneGen: Generative Contextual Scene Augmentation using Scene Graph Priors; Keshavarzi, Parikh, Zhai, Mao, Caldas and Yang. 2020

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Contextual Spatial Computing

Content Augmentation

Mutual Space

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Content Augmentation

Mutual Space

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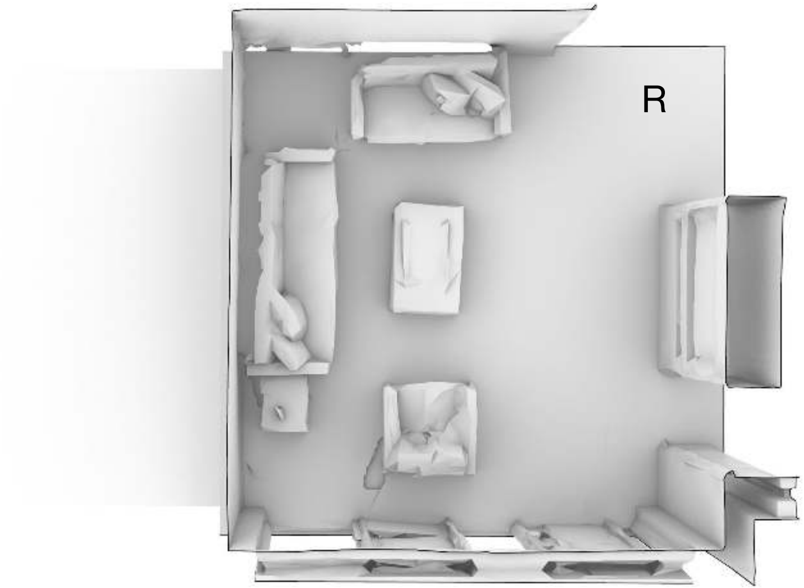
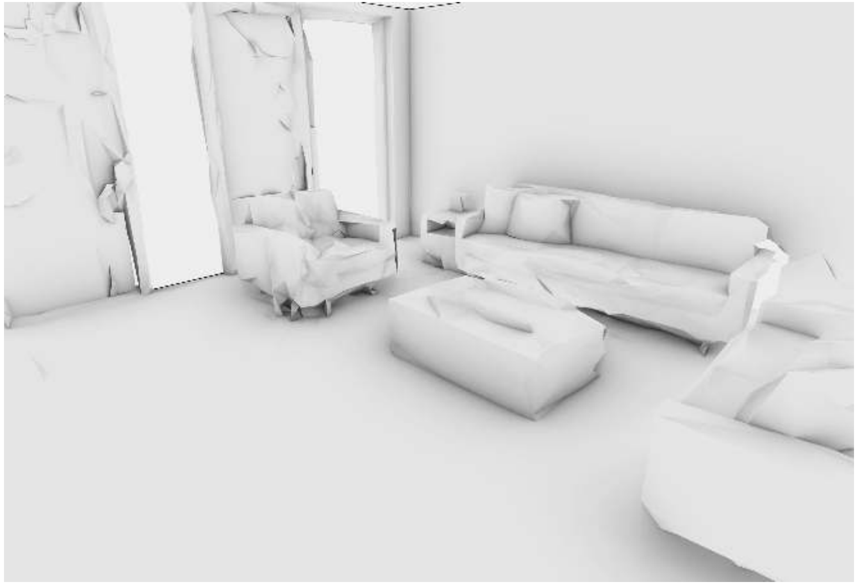
Content Augmentation

Constrained Placement



Target Scene Input



Constrained Placement

Target Scene Input

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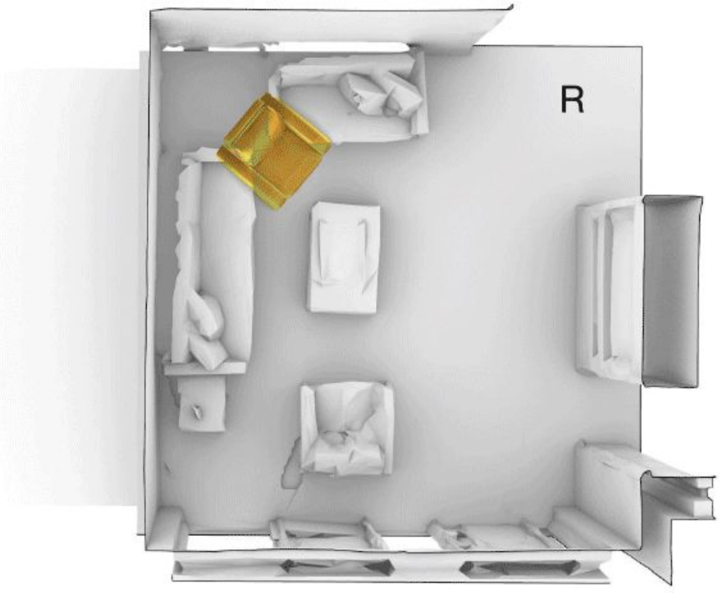
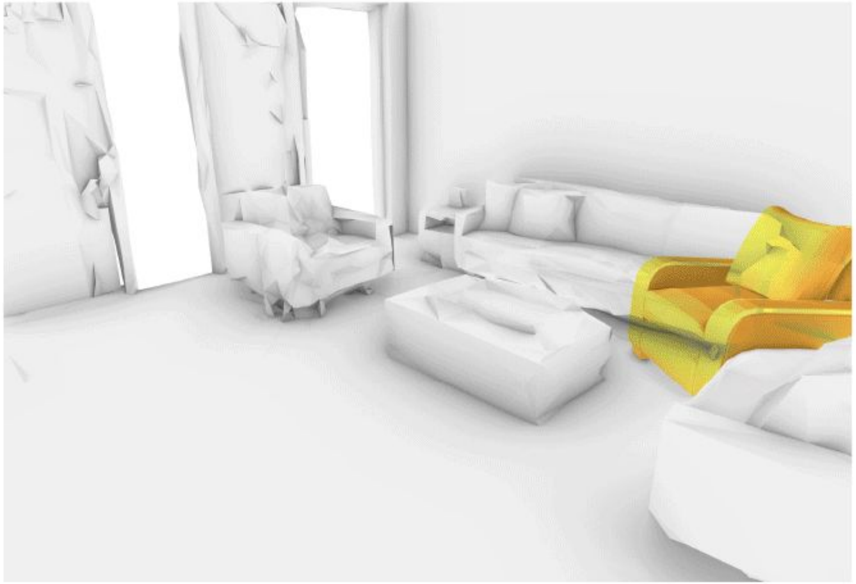
Constrained Placement





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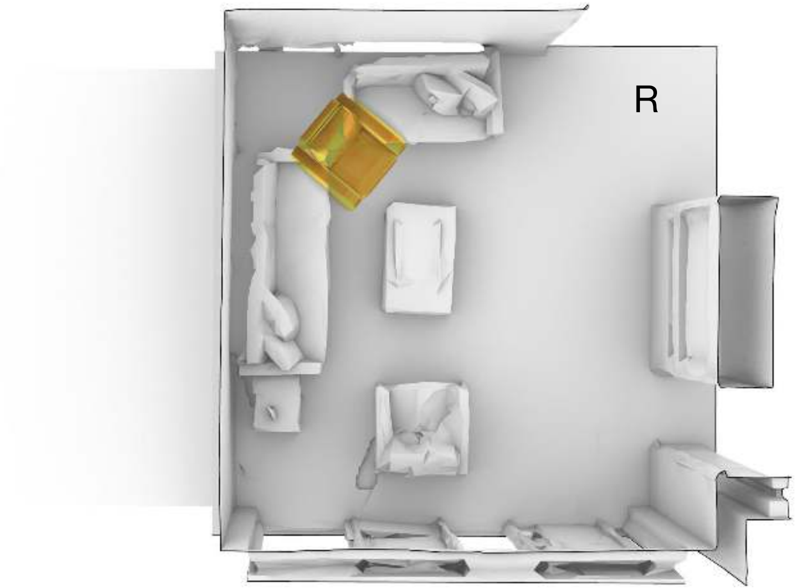
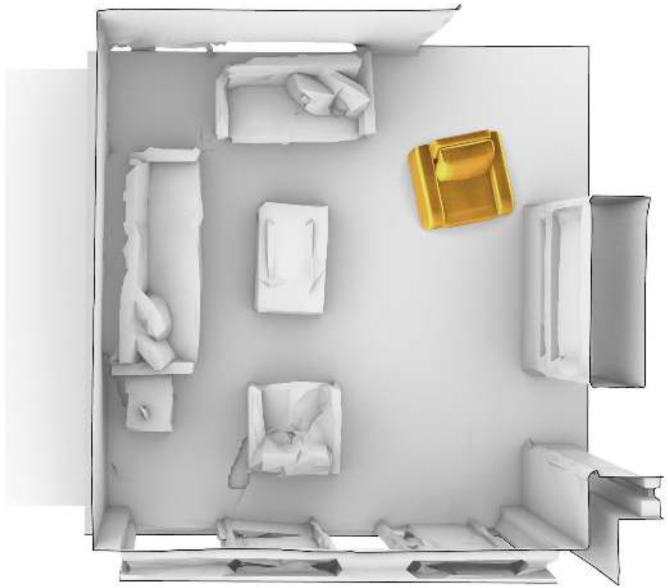
Constrained Placement



Conflicting Placement



Inconsistent with context

SceneGen: Generative Contextual Scene Augmentation using Scene Graph Priors; Keshavarzi, Parikh, Zhai, Mao, Caldas and Yang. 2020

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Background

Procedural Modeling

Example-based Modeling

Procedural Modeling

Example-based Modeling

Procedural Modeling

RoboRaid, Microsoft Hololens Demo

Procedural Modeling

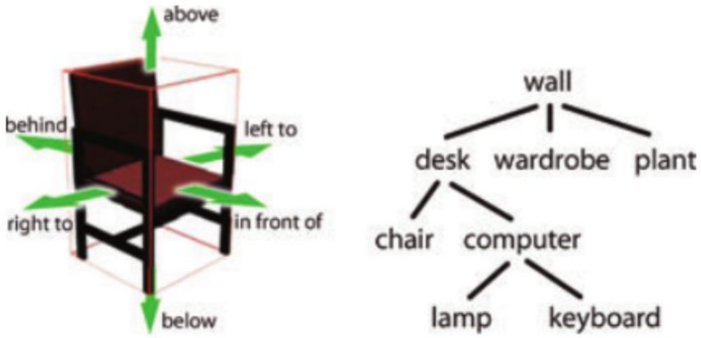
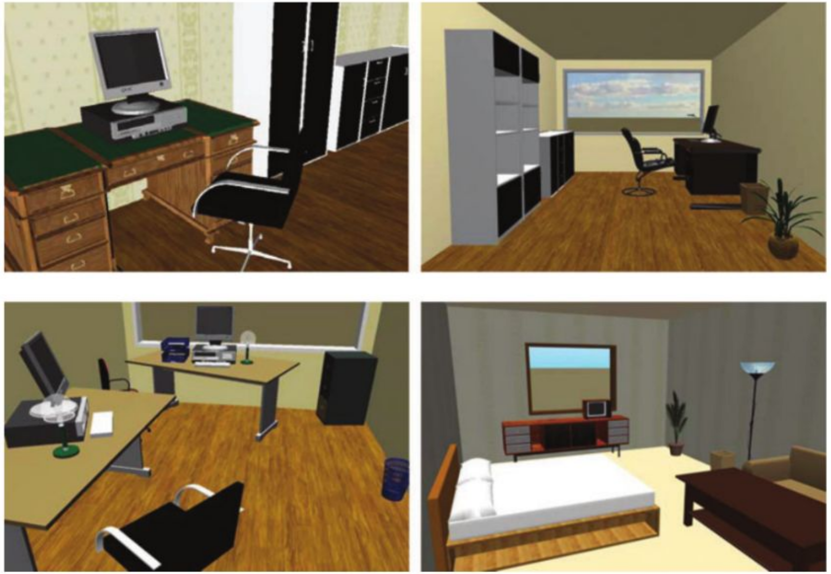


Figure 1: *Left: Objects are arranged based on their oriented bounding boxes (red) and their spatial relations (green). Right: Example of a hierarchy build by the agents.*



Germer, Tobias, and Martin Schwarz. "Procedural Arrangement of Furniture for Real-Time Walkthroughs." In *Computer Graphics Forum*, vol. 28, no. 8, pp. 2068-2078. Oxford, UK: Blackwell Publishing Ltd, 2009.

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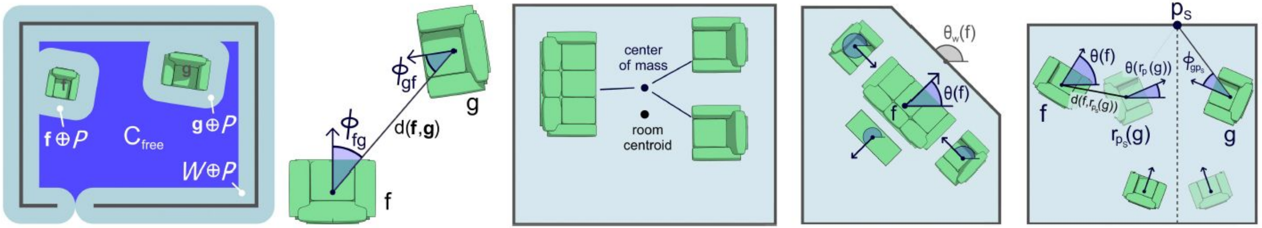
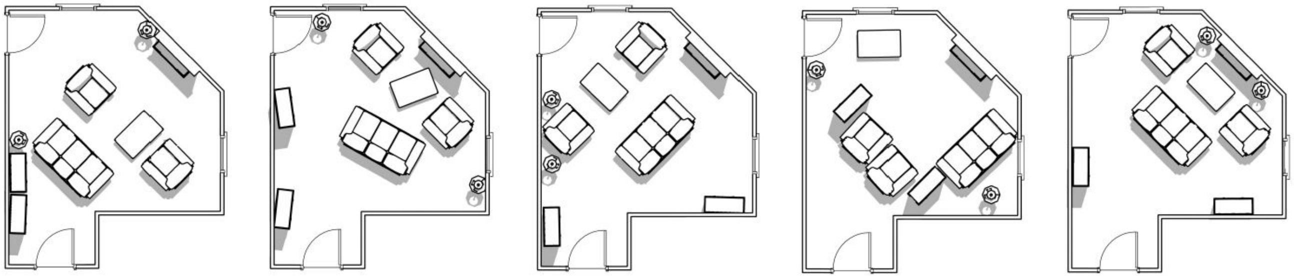
Procedural Modeling



(a) circulation (b) conversation (c) visual balance (d) alignment (e) emphasis



(a) Clearance and reachability term excluded (b) Alignment term excluded (c) Emphasis term excluded (d) Conversation and pairwise terms excluded (e) All terms included

Merrell, Paul, Eric Schkufza, Zeyang Li, Maneesh Agrawala, and Vladlen Koltun. "Interactive furniture layout using interior design guidelines." *ACM transactions on graphics (TOG)* 30, no. 4 (2011): 1-10.

Procedural Modeling

Example-based Modeling

Example-based Scene Synthesis

Fisher, Matthew, Daniel Ritchie, Manolis Savva, Thomas Funkhouser, and Pat Hanrahan. "Example-based synthesis of 3D object arrangements." *ACM Transactions on Graphics (TOG)* 31, no. 6 (2012): 1-11.

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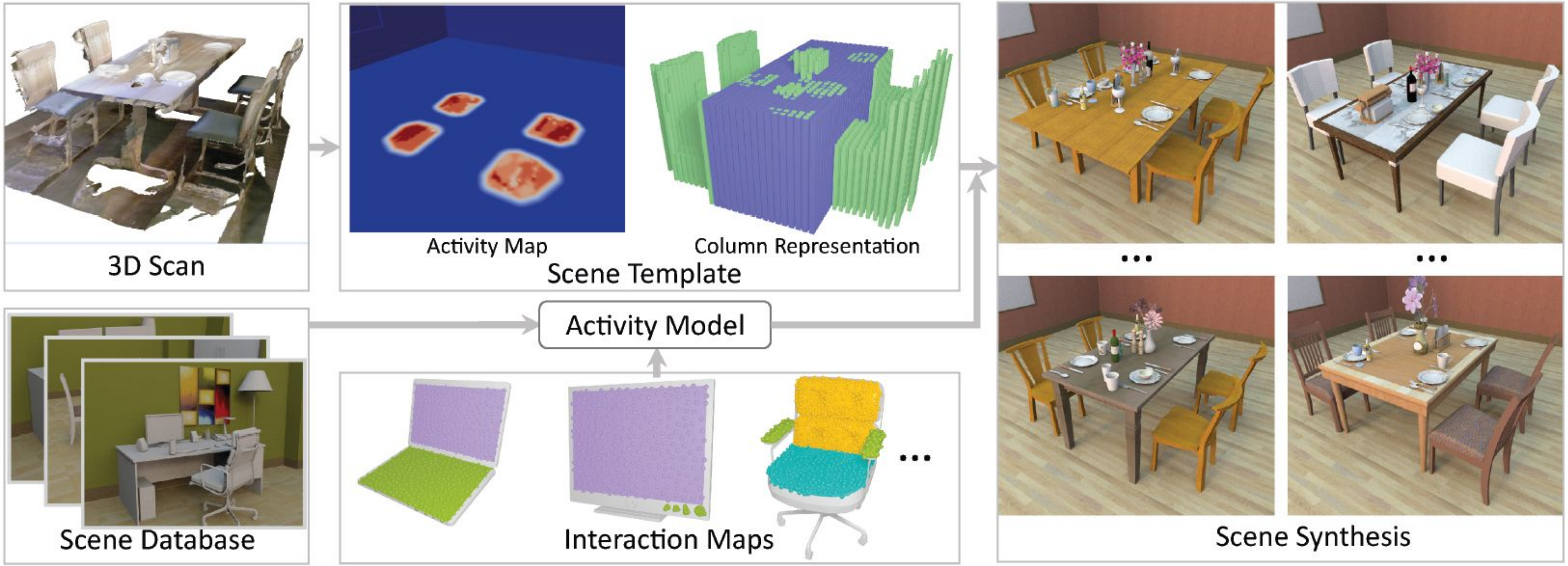
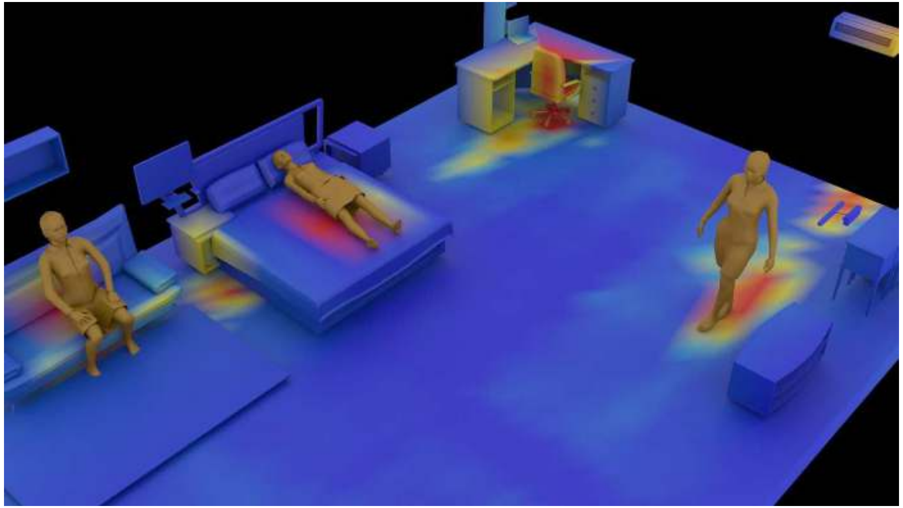
Example-based Scene Synthesis



Fisher, Matthew, Manolis Savva, Yangyan Li, Pat Hanrahan, and Matthias Nießner. "Activity-centric scene synthesis for functional 3D scene modeling." *ACM Transactions on Graphics (TOG)* 34, no. 6 (2015): 1-13.

Example-based Scene Synthesis

(g) kitchen (h) living room (i) office



Qi, Siyuan, Yixin Zhu, Siyuan Huang, Chenfanfu Jiang, and Song-Chun Zhu. "Human-centric indoor scene synthesis using stochastic grammar." In *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*, pp. 5899-5908. 2018.

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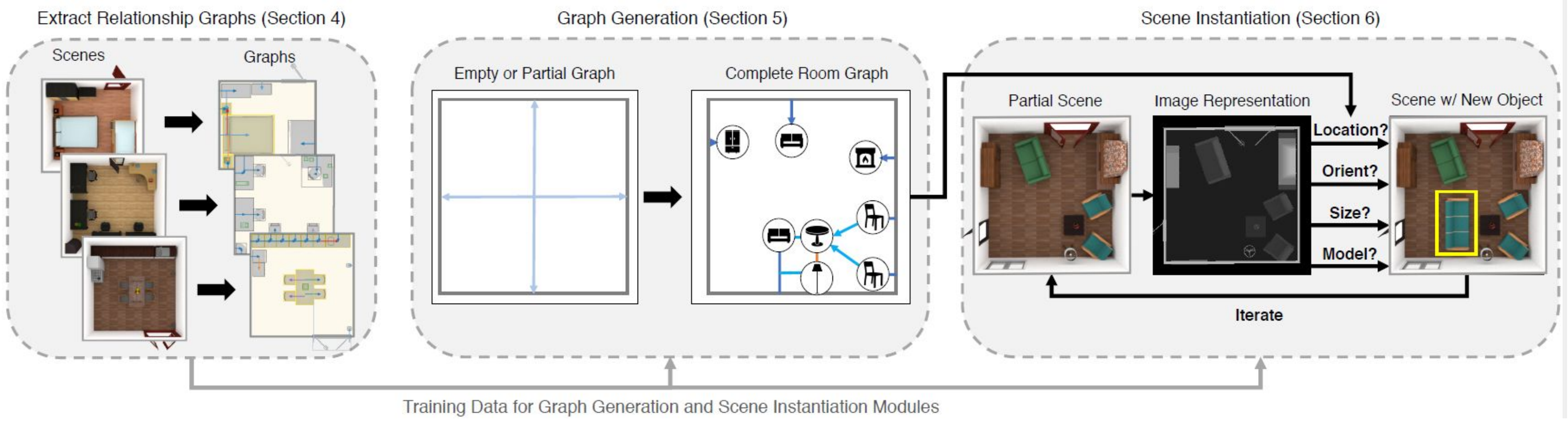
Example-based Scene Synthesis



Planit: Planning and instantiating indoor scenes with relation graph and spatial prior networks; Wang, Kai, Yu-An Lin, Ben Weissmann, Manolis Savva, Angel X. Chang, and Daniel Ritchie. *ACM Transactions on Graphics (TOG)* 38, no. 4 (2019): 1-15.

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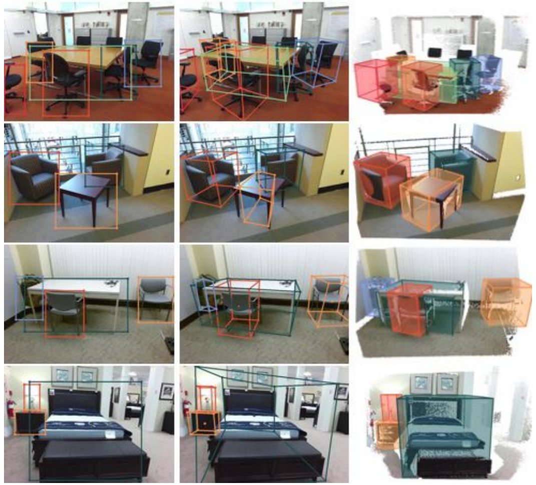
Datasets

Synthetic Data (SUNCG)

Scanned Data (MatterPort3D)

3D Object Detection (PerspectiveNet)



SceneGen: Generative Contextual Scene Augmentation using Scene Graph Priors; Keshavarzi, Parikh, Zhai, Mao, Caldas and Yang. 2020

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SceneGen:

Generative Contextual Scene Augmentation using Scene Graph Priors

Mohammad Keshavarzi, Aakash Parikh, Xiyu Zhai, Melody Mao, Luisa Caldas, Allen Y. Yang

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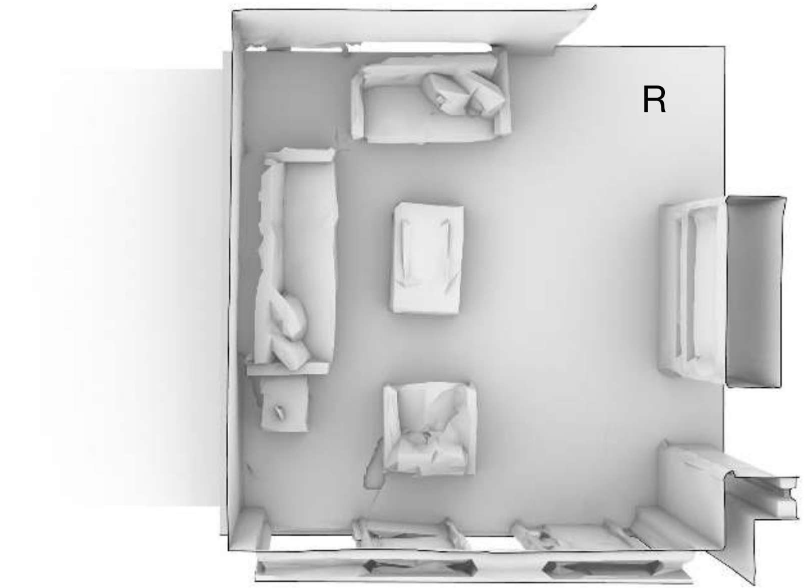
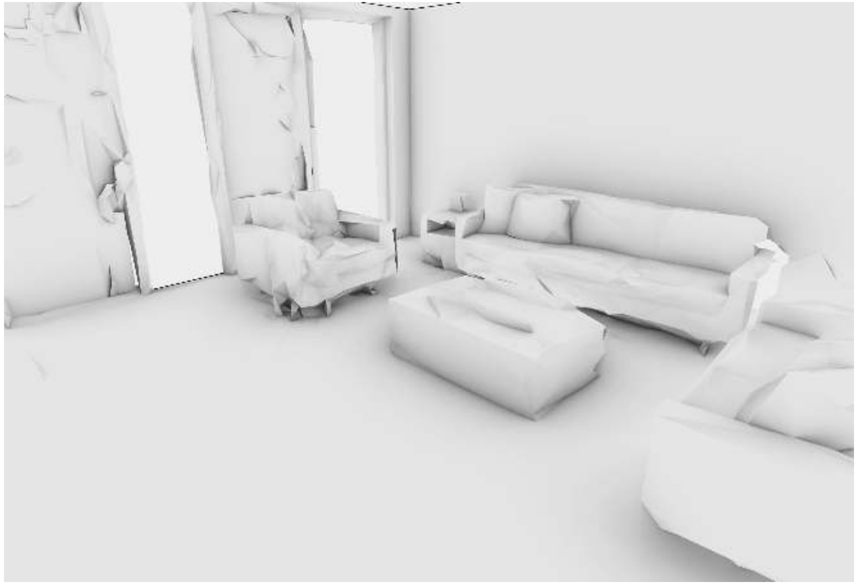
Spatial Scene Representation



Target Scene Input



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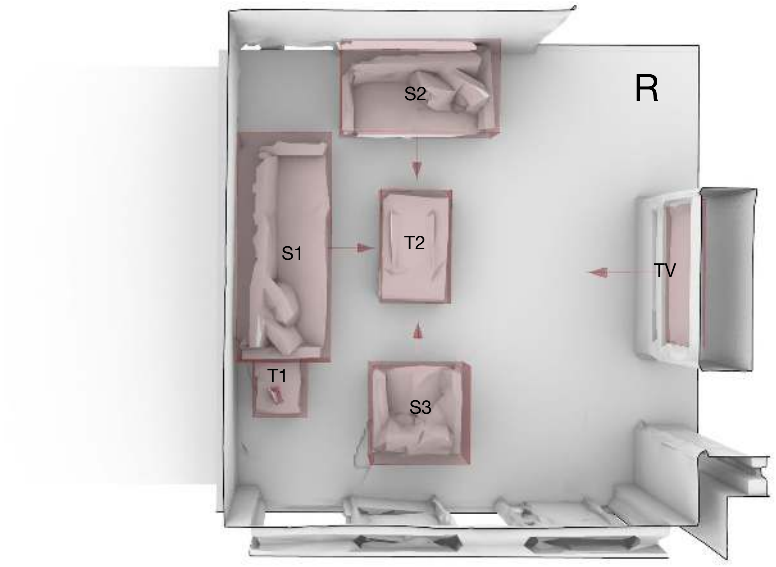
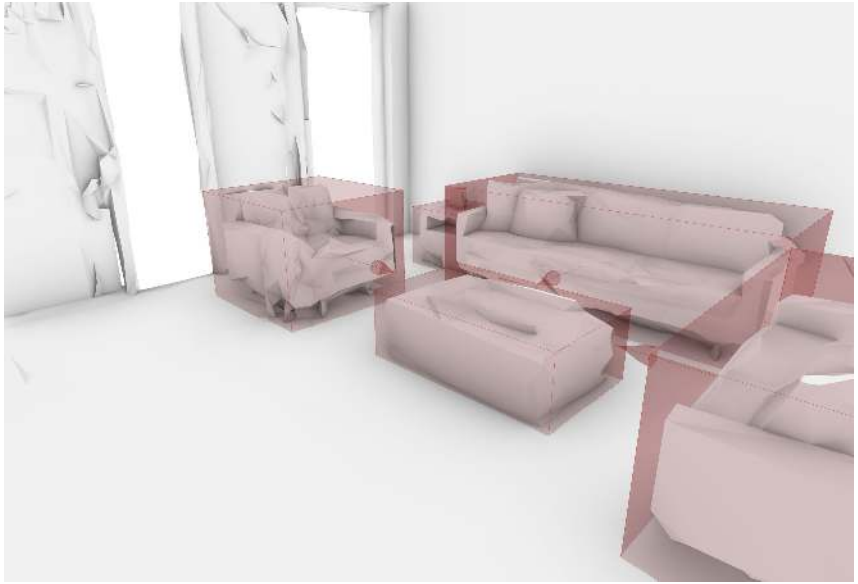


Target Scene Input



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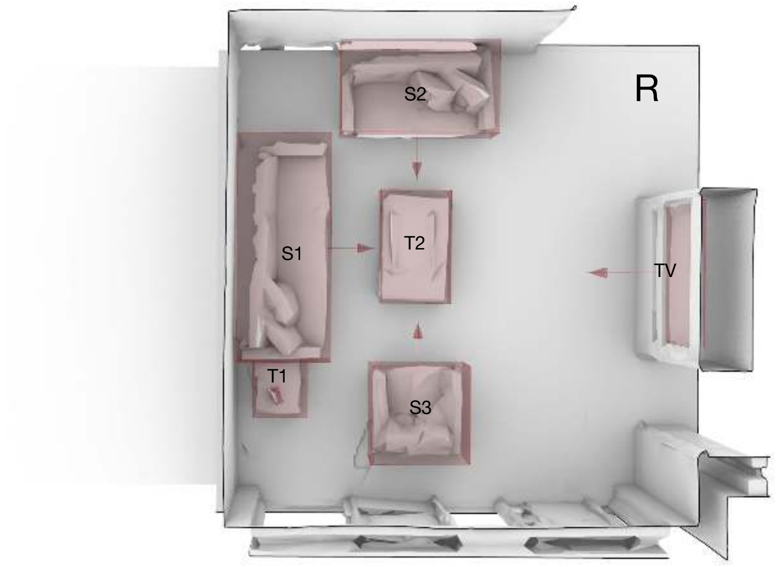

Target Scene Input

- S1 SOFA 1
- S2 SOFA 2
- S3 SOFA 3
- T1 TABLE 1
- T2 TABLE 2
- TV TV

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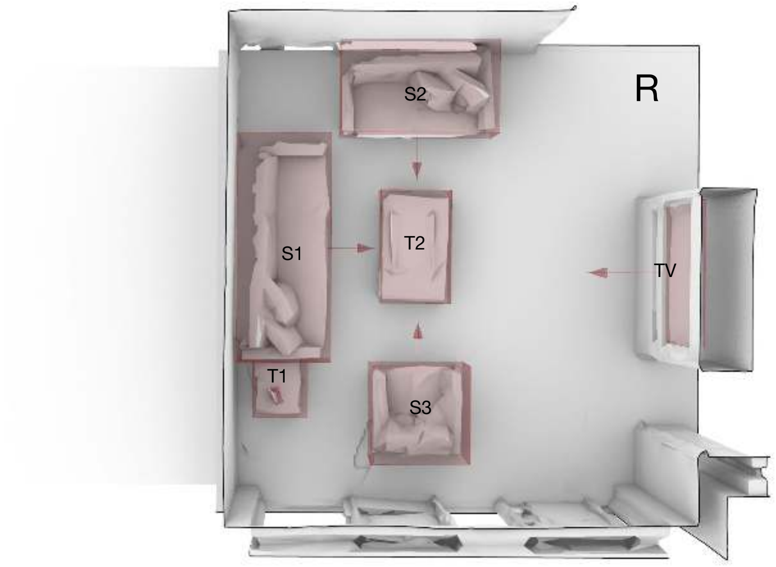
Spatial Scene Representation



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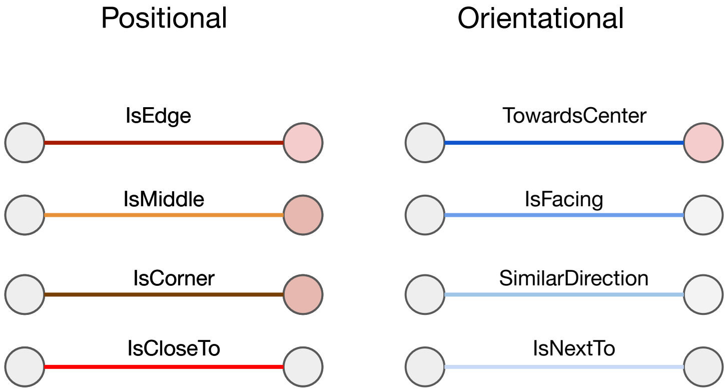

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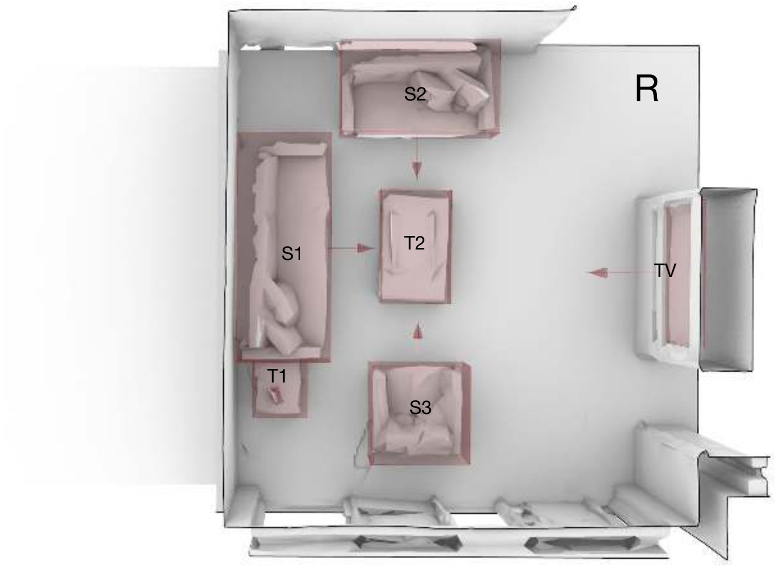

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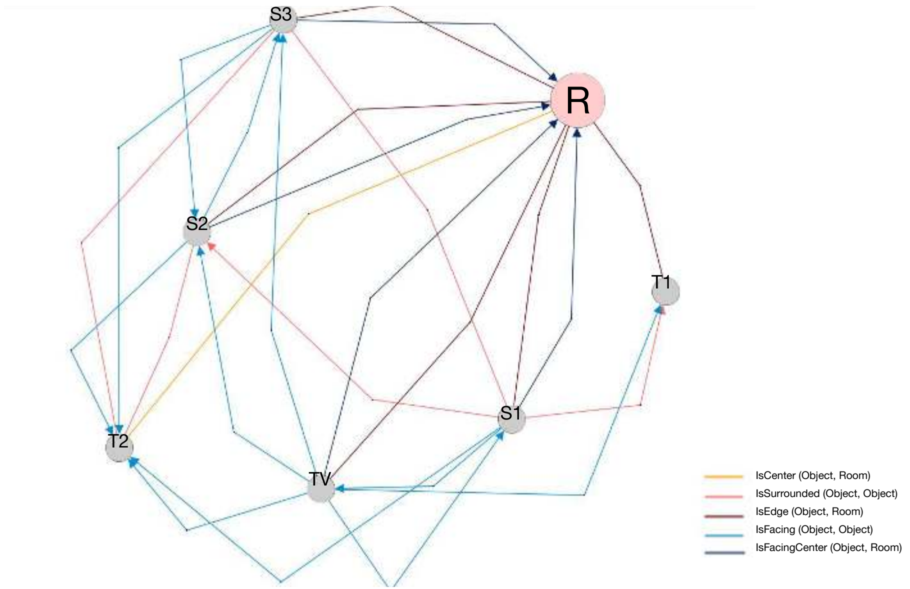

Spatial Representation Graph

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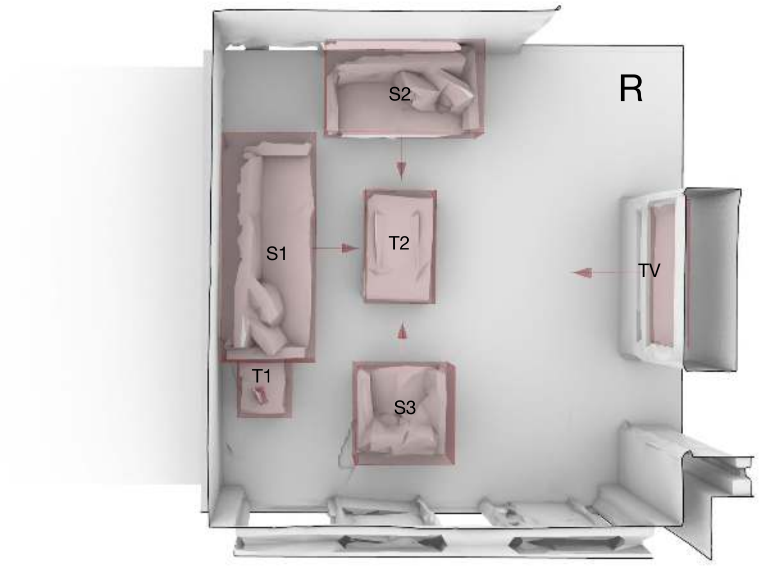
Spatial Scene Representation



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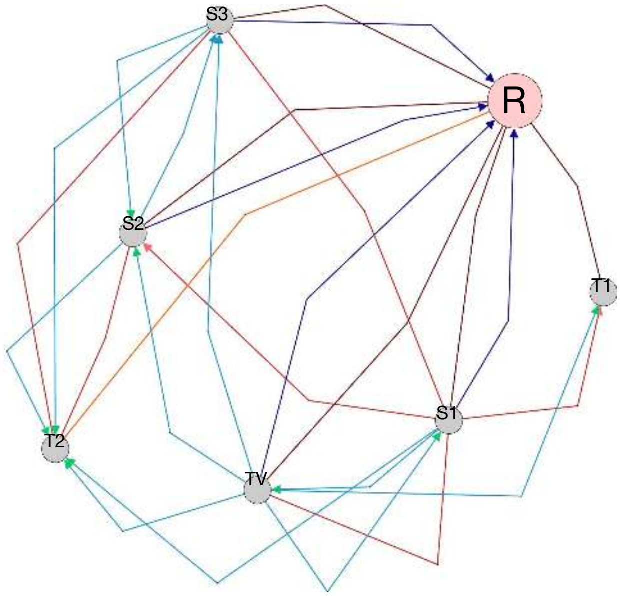

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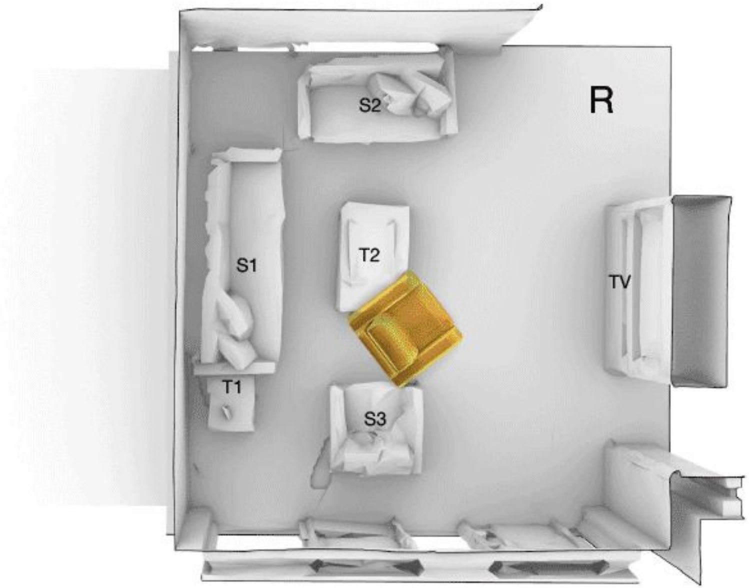
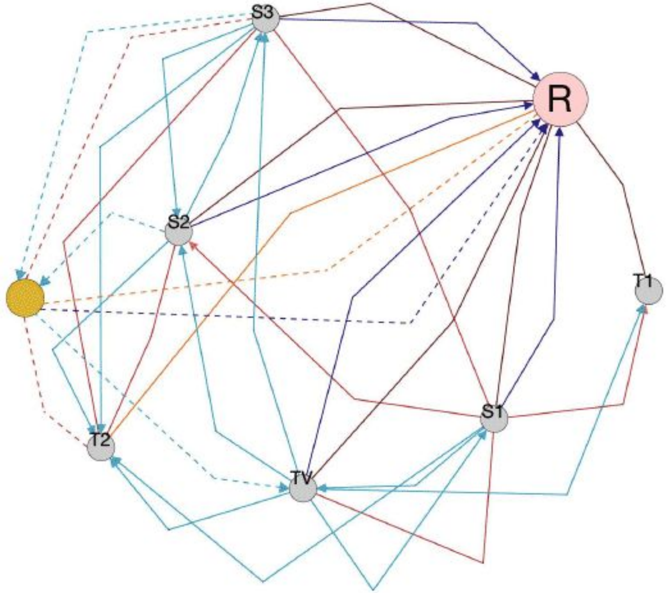


Target Scene Input



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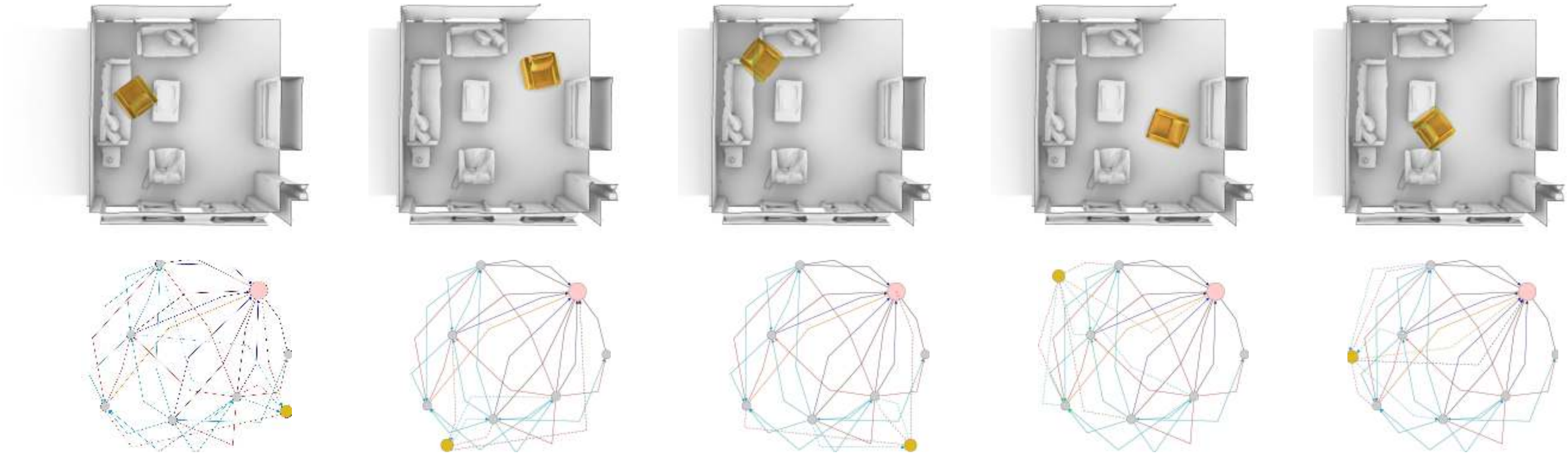

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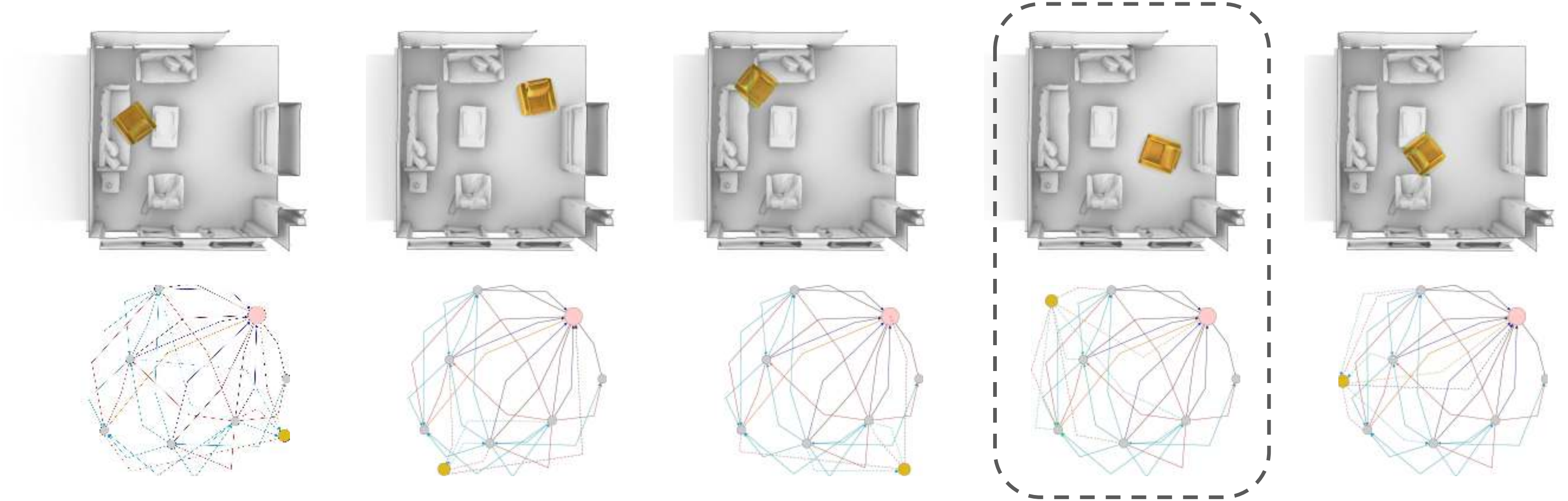

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Knowledge Model

Dataset

Datasets

Synthetic Data (SUNCG)

Scanned Data (MatterPort3D)

3D Object Detection (PerspectiveNet)

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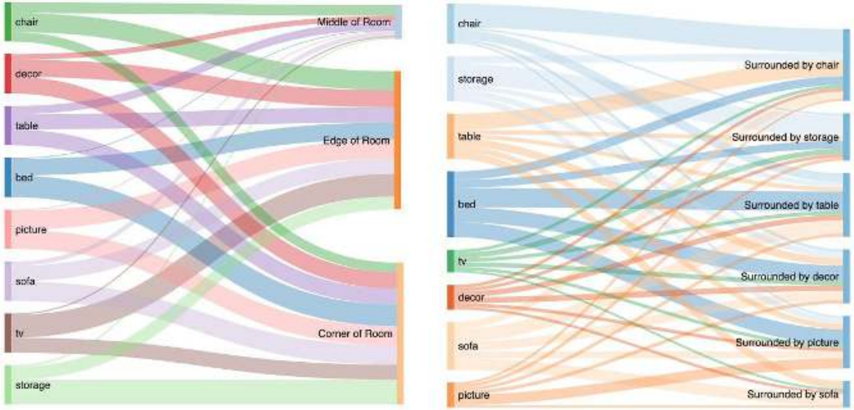
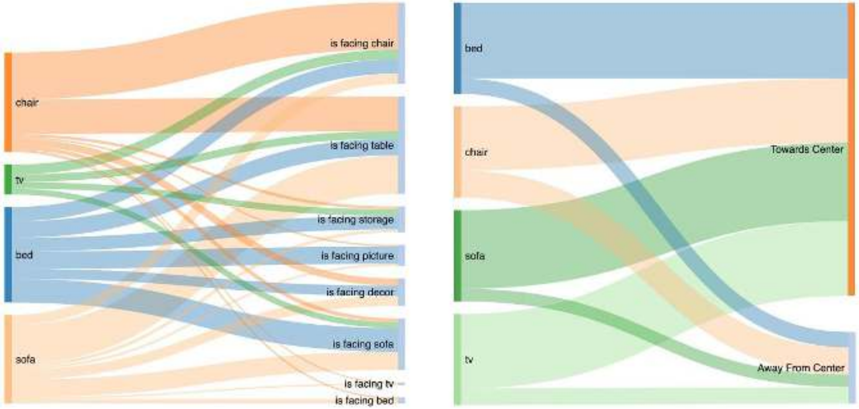
Knowledge Model



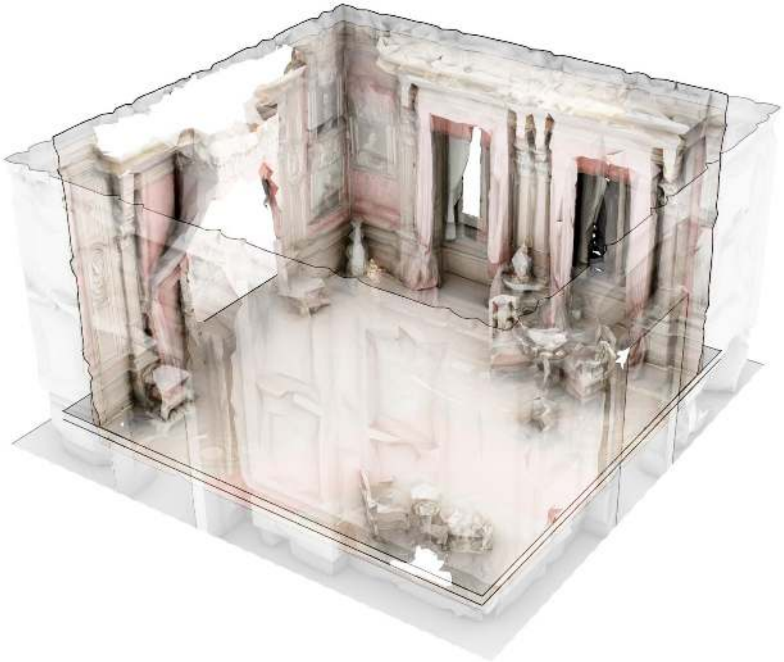
Positional Relationships



Orientational Relationships

Experiments

Object Placement

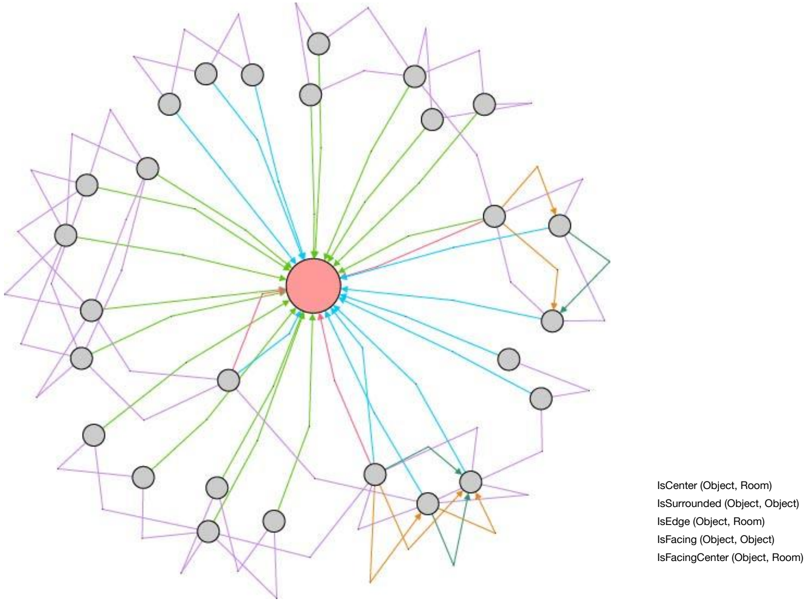


Object Placement

SceneGen: Generative Contextual Scene Augmentation using Scene Graph Priors; Keshavarzi, Parikh, Zhai, Mao, Caldas and Yang. 2020

Object Placement

Target Scene



Spatial Representation Graph

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Object Placement

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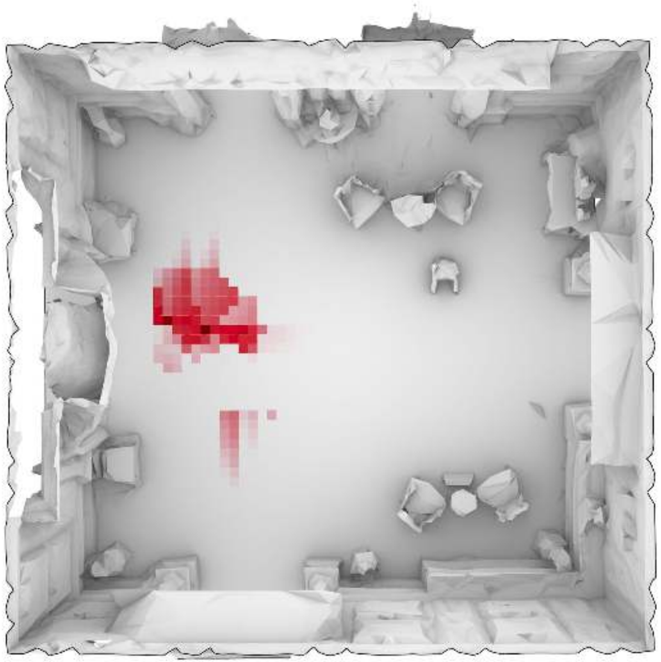

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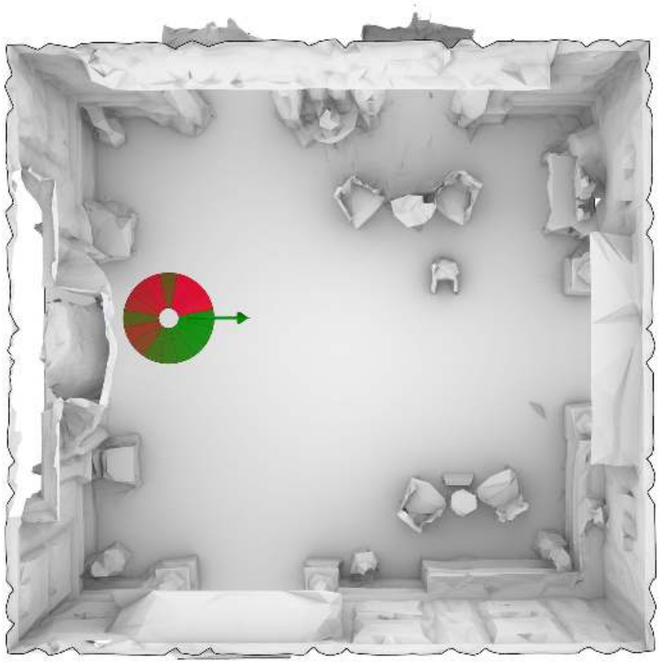

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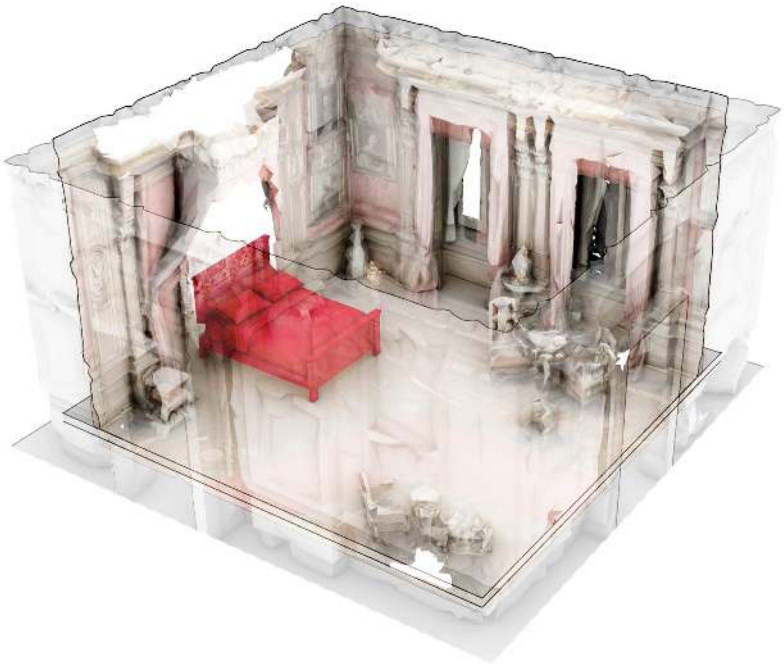

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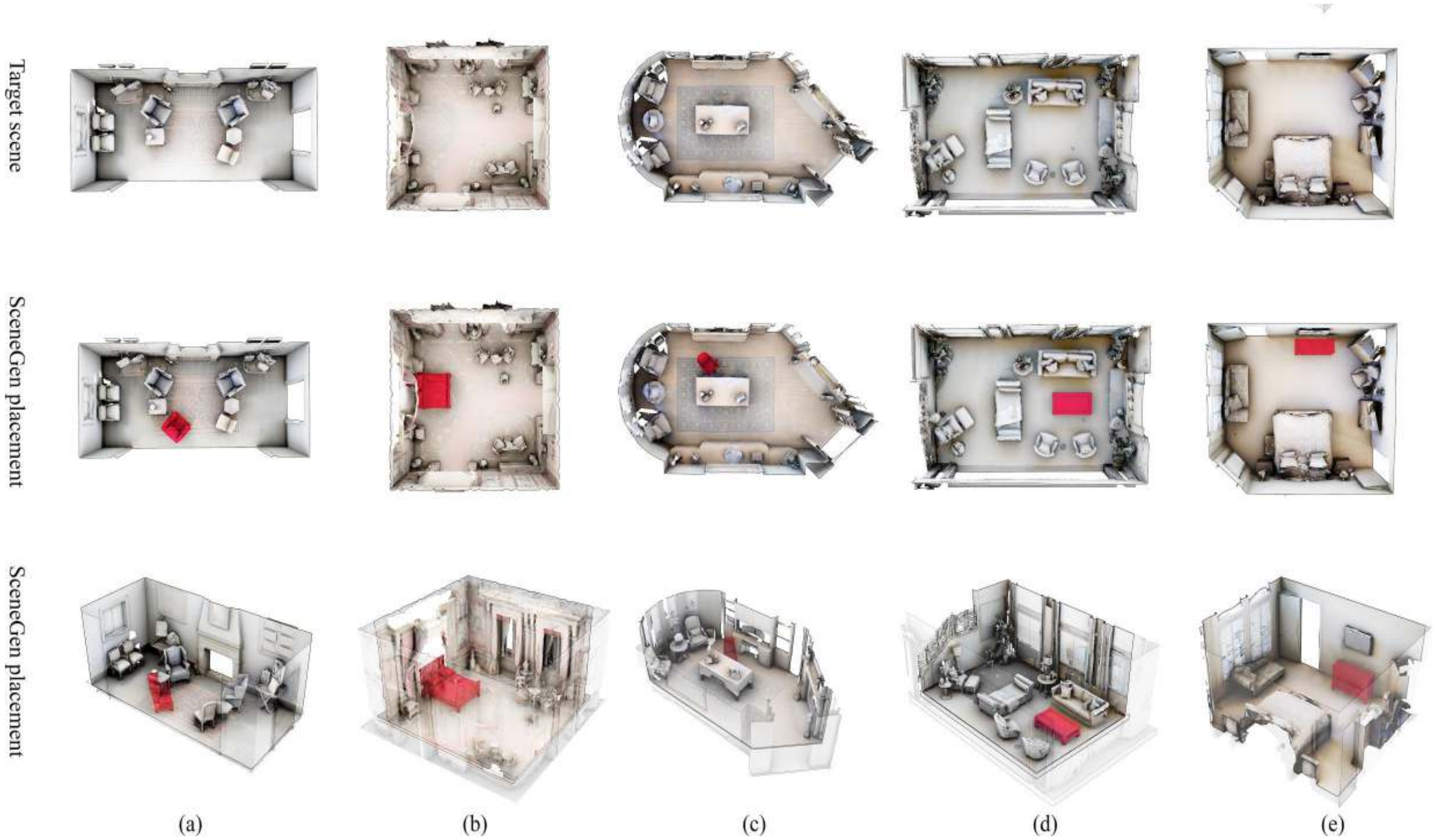

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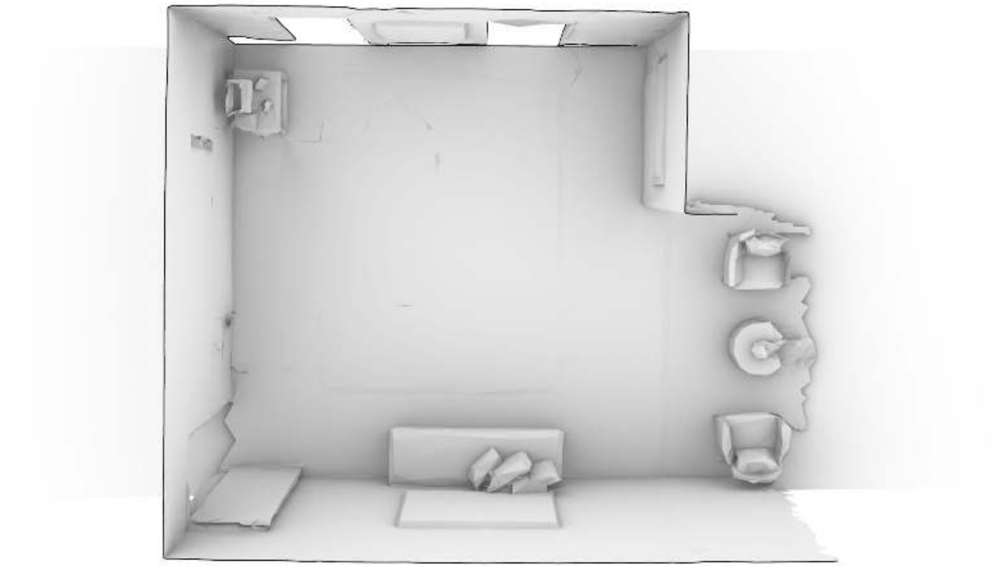
Multi-object Placement



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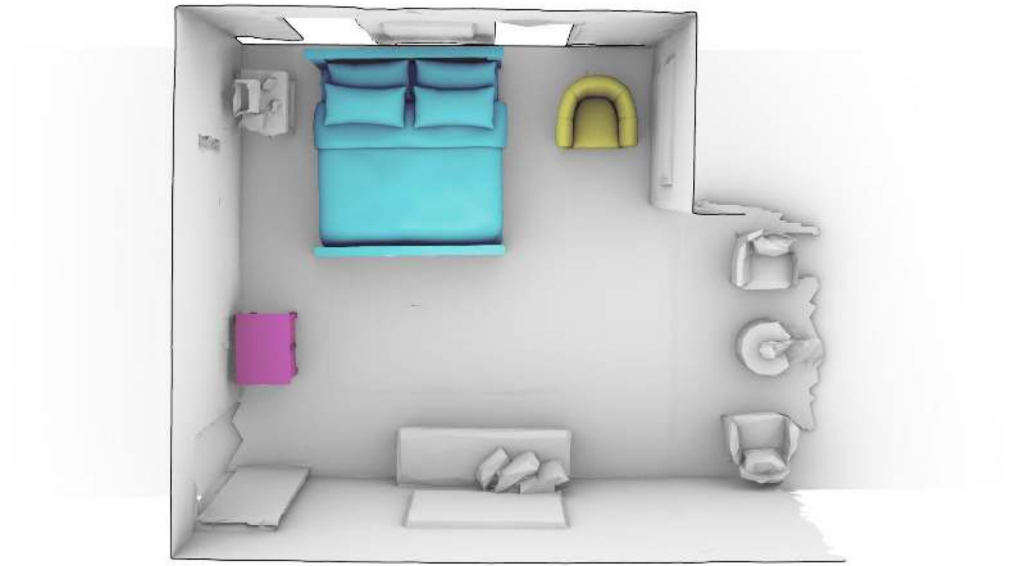

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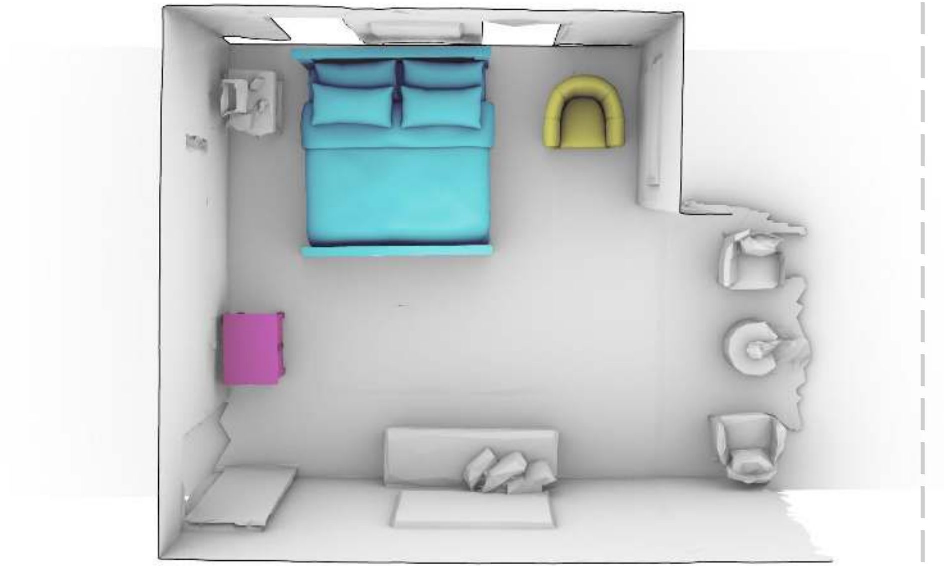
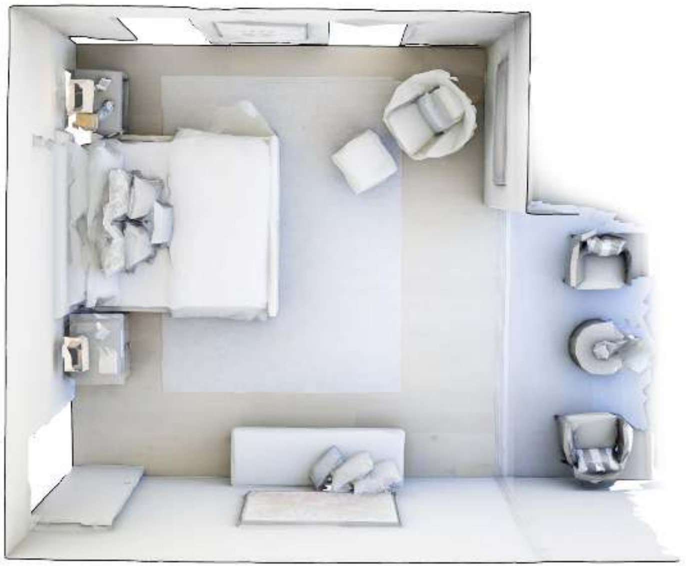


SceneGen



GroundTruth

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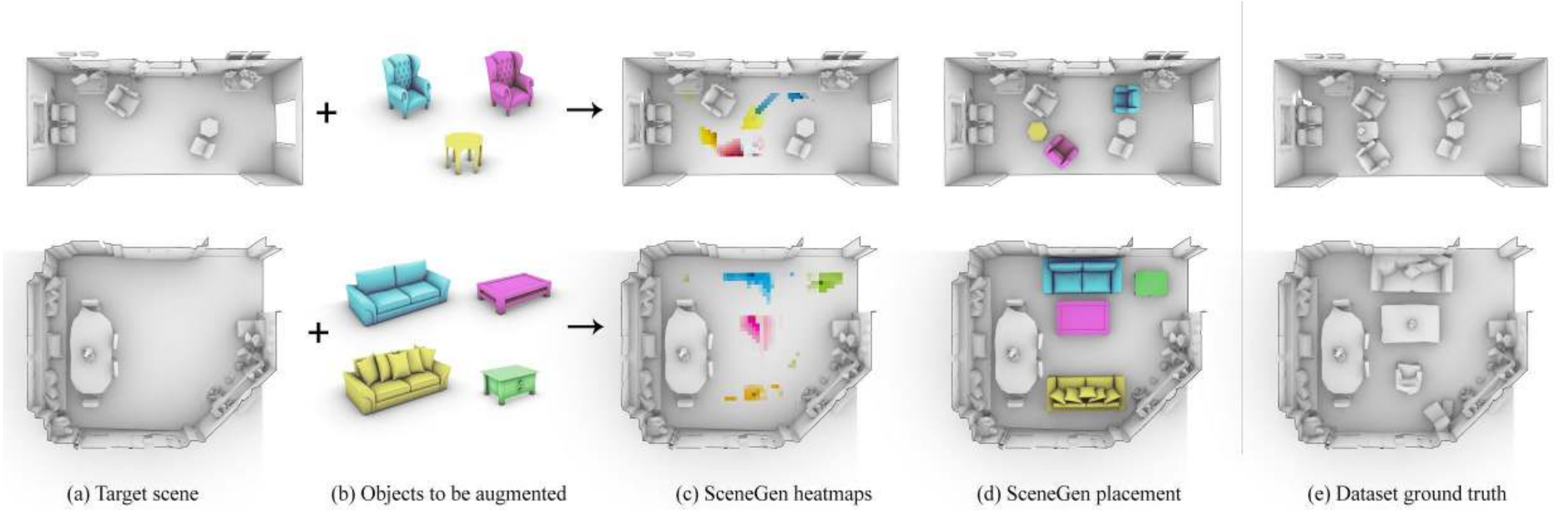
Multi-object Placement



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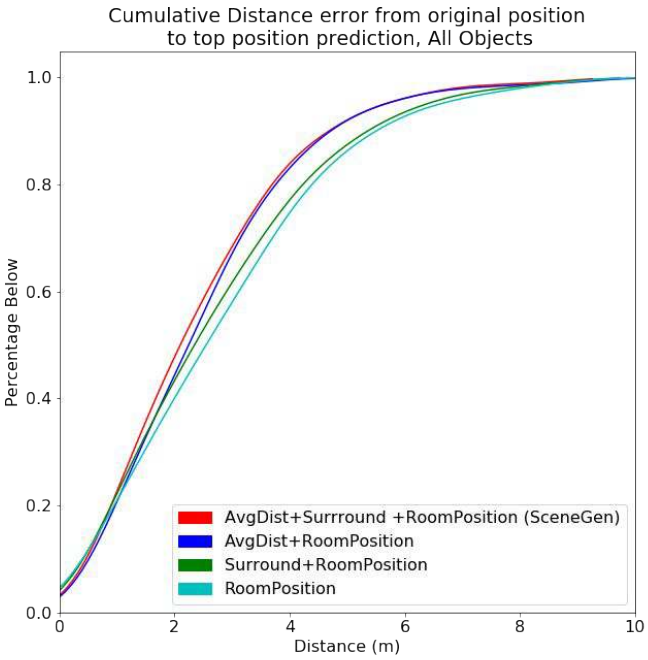
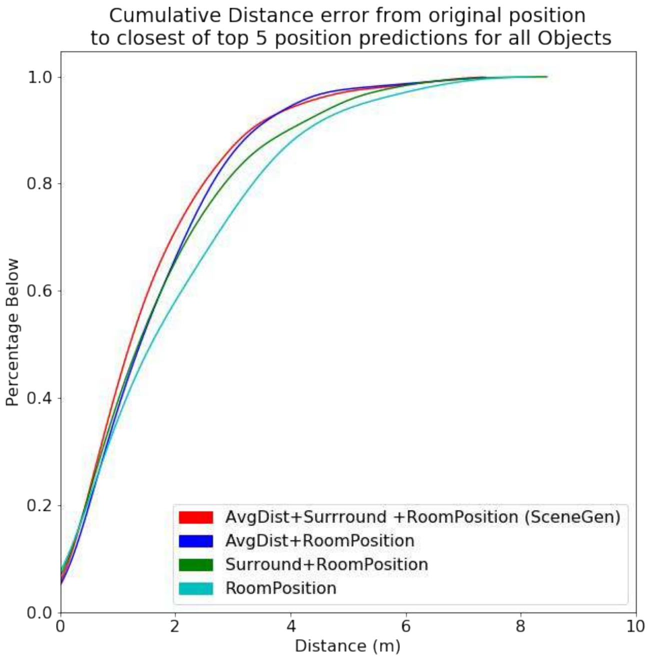
Numerical Experiments

Numerical Experiments





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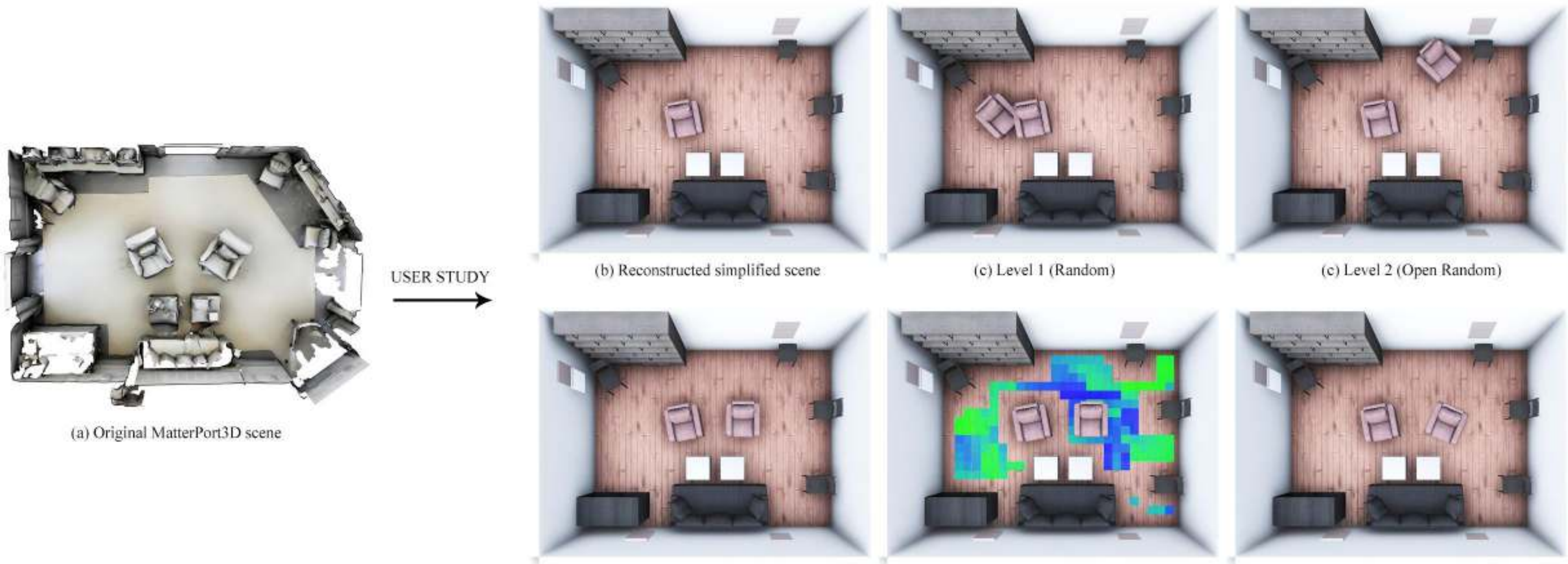
User Experiments

User Experiments



(a) Original MatterPort3D scene
(b) Reconstructed simplified scene
(c) Level 1 (Random)
(c) Level 2 (Open Random)
(e) Level 3 (SceneGen)
(f) Level 4 (SceneGen + heatmap)
(g) Level 5 (Ground Truth)

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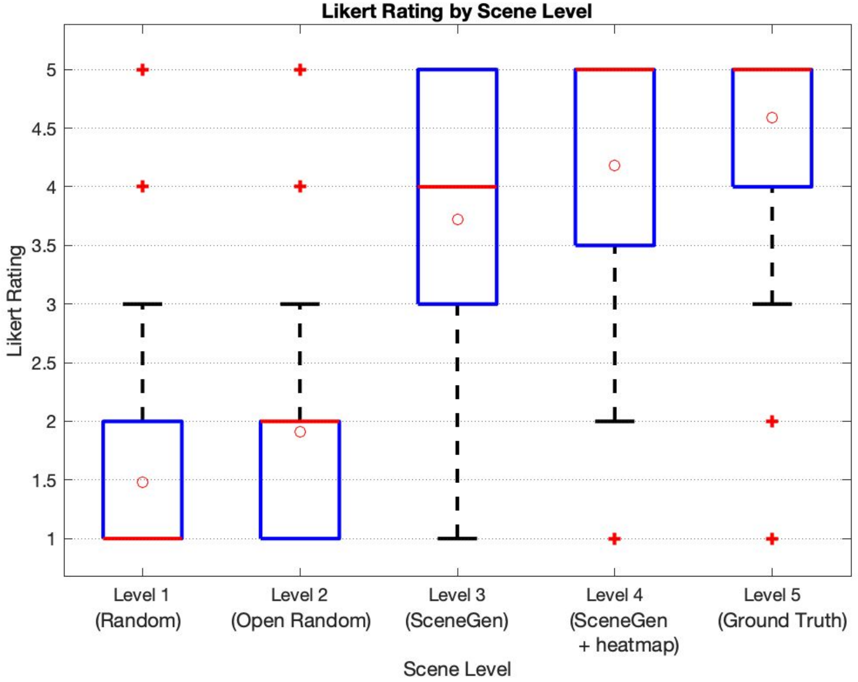
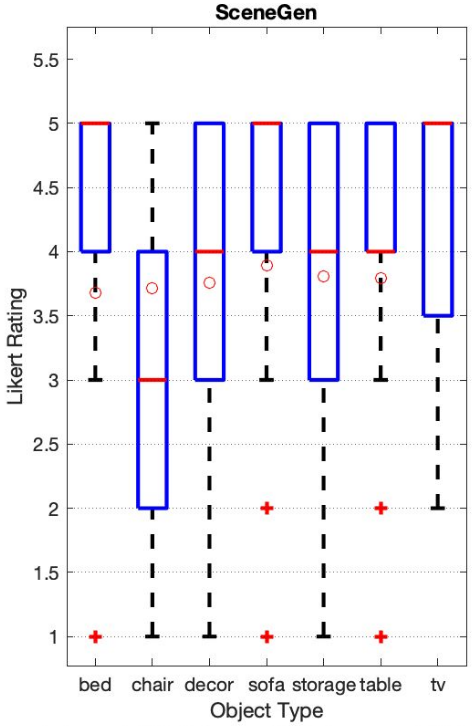
User Experiments

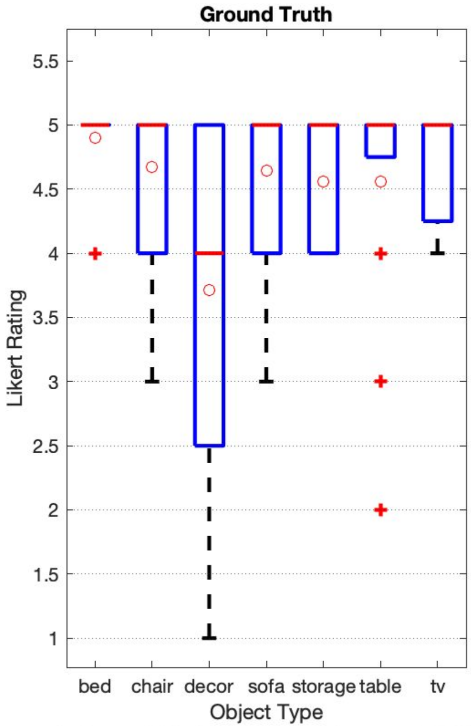


Level 1 mean=1.48, Level 2 mean=1.91, Level 3 mean=3.72, Level 4 mean=4.185, Level 5 mean=4.5887

User Experiments

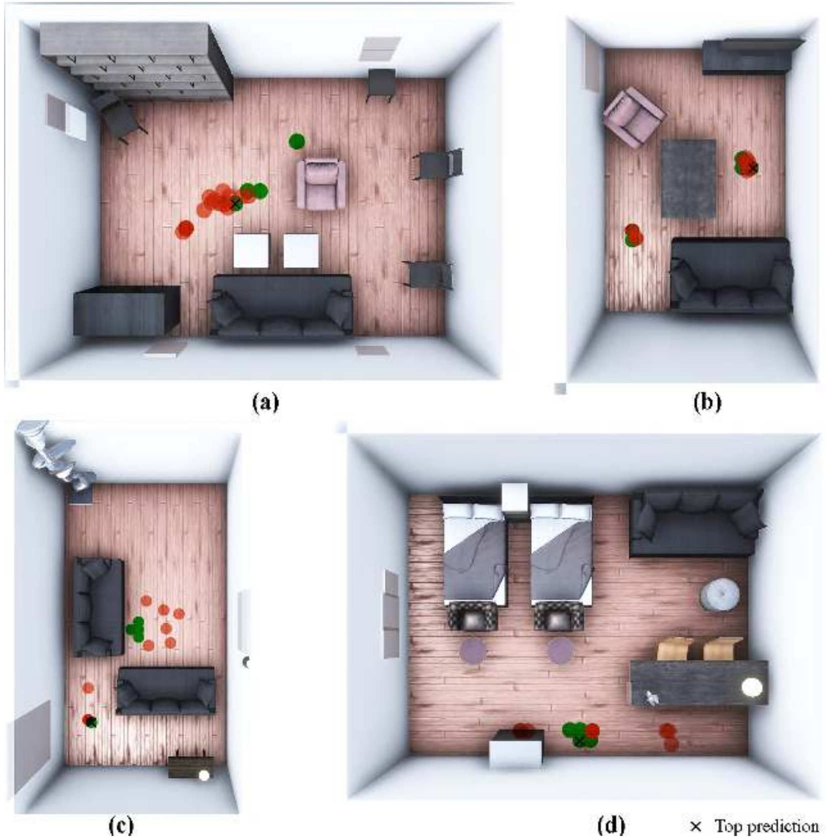


bed mean=3.6827, chair mean=3.7136, decor mean=3.7604,
sofa mean=3.8893, storage mean=3.8095, table mean=3.7925



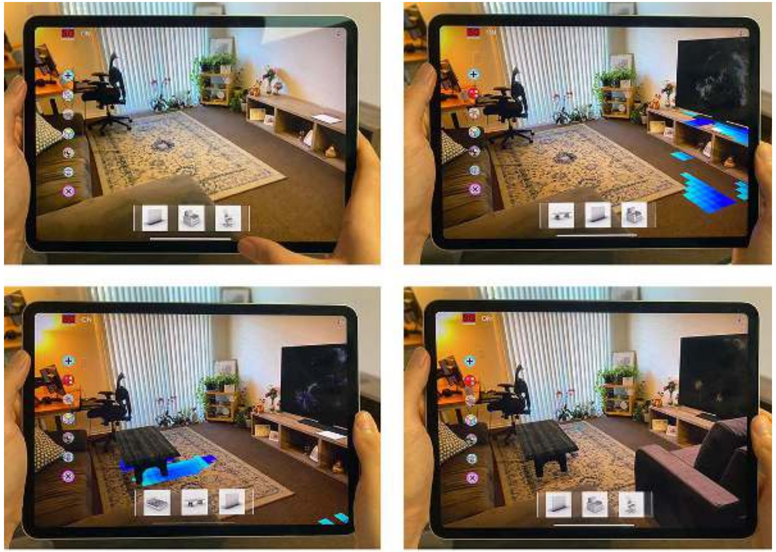
bed mean=4.902, chair mean=4.6711, decor mean=3.7143,
sofa mean=4.6452, storage mean=4.5556, table mean=4.56

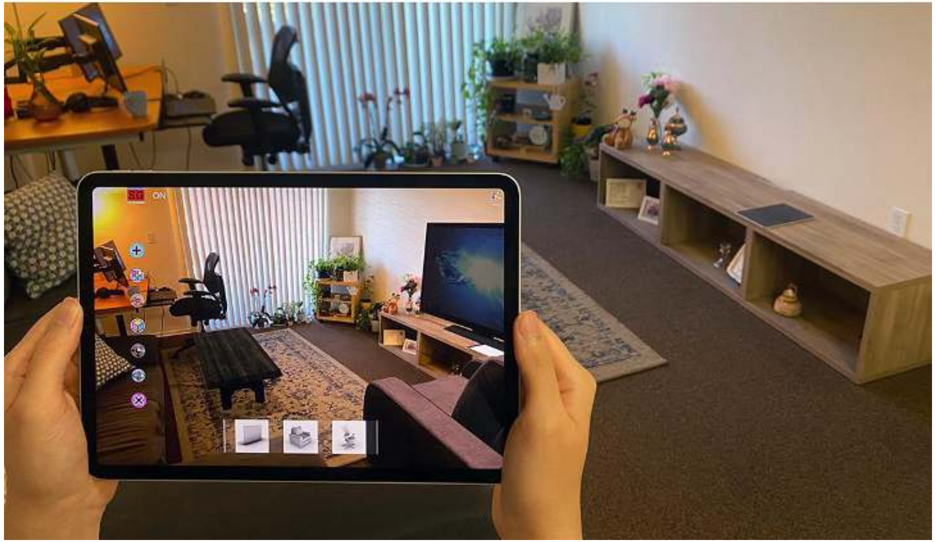
User Experiments



SceneGen: Generative Contextual Scene Augmentation using Scene Graph Priors; Keshavarzi, Parikh, Zhai, Mao, Caldas and Yang. 2020

Augmented Reality Application





SceneGen: Generative Contextual Scene Augmentation using Scene Graph Priors; Keshavarzi, Parikh, Zhai, Mao, Caldas and Yang. 2020

Content Augmentation

Mutual Space

Content Augmentation

Mutual Space

www.microsoft.com/en-us/research/project/holoportation-3

www.microsoft.com/en-us/research/project/holoportation-3

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www.microsoft.com/en-us/research/project/holoportation-3

Spatial Computing

has

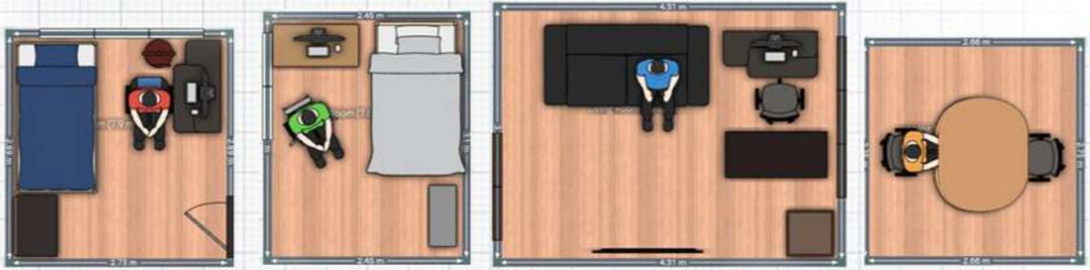
Spatial Limitations

How we address this challenge?

Goal I

Locate the maximum mutual space

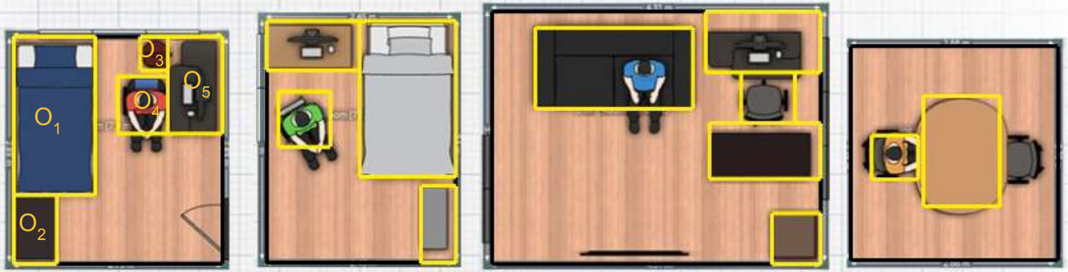
Input Data



R_1 R_2 R_3 R_4

Input Data

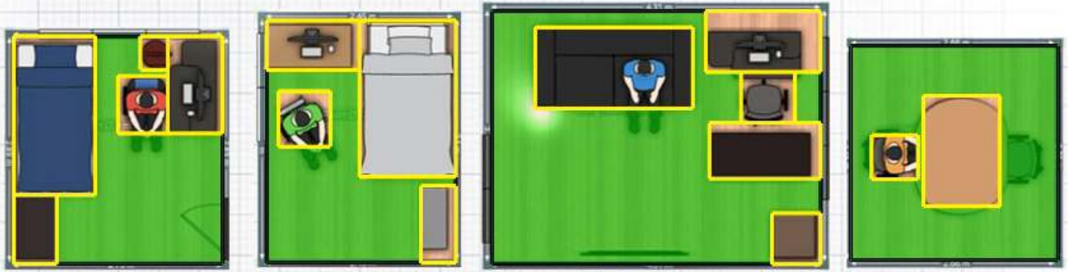
Semantic Segmentation



R_1 R_2 R_3 R_4

Open Spaces

Standable Spaces



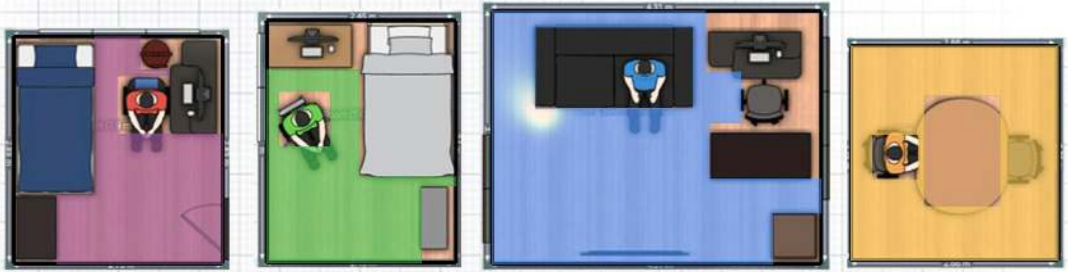
R_1 R_2 R_3 R_4

$$S_i = R_i - \bigcup_{k=1}^{n_i} O_{i,k}.$$

Optimization and Manipulation of Contextual Mutual Spaces for Multi-User Virtual and Augmented Reality Interaction; Keshavarzi et al.

Open Spaces

Standable Spaces



R_1 R_2 R_3 R_4

$$S_i = R_i - \bigcup_{k=1}^{n_i} O_{i,k}.$$

$$S_i = R_i - \bigcup_{k=1}^{n_i} O_{i,k}.$$

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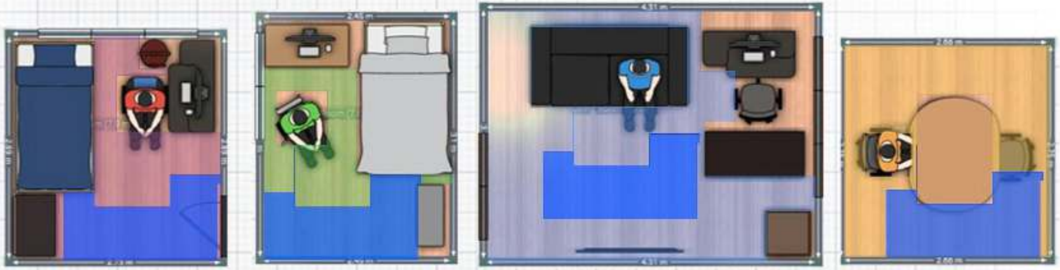
Mutual Boundary Search

Standable Spaces



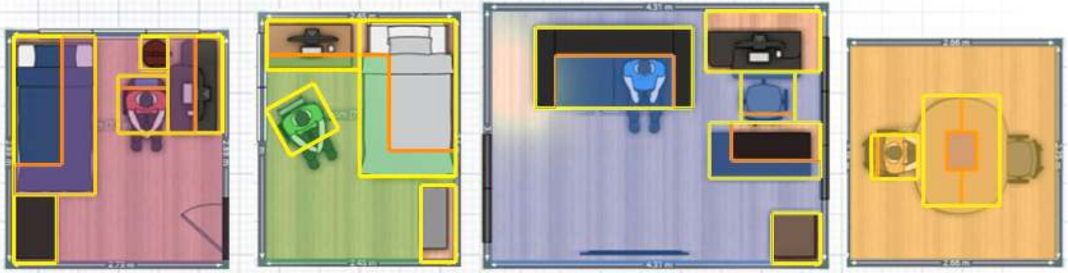
R_1 R_2 R_3 R_4

$$M_S(R_1, \cdots, R_m)$$

Optimization and Manipulation of Contextual Mutual Spaces for Multi-User Virtual and Augmented Reality Interaction; Keshavarzi et al.

Mutual Boundary Search

Sittable Space



$$A(R_i) = \bigcup_{k=1}^{n_i} A(O_{i,k}) + A(S_i).$$

R_1 R_2 R_3 R_4

$$A(R_i) = \bigcup_{k=1}^{n_i} A(O_{i,k}) - A(S_i).$$

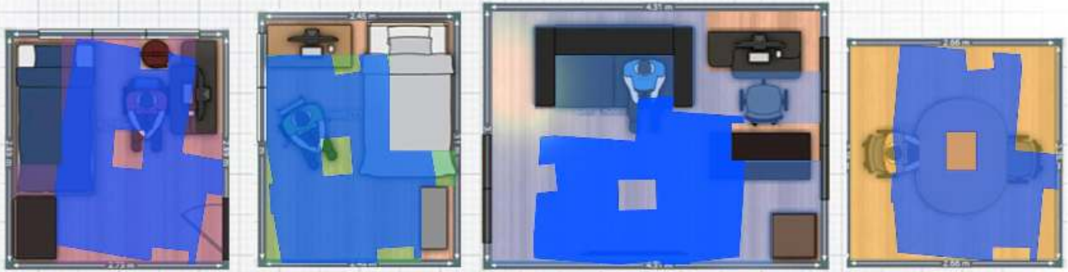
$$A(R_i) = \bigcup_{k=1}^{n_i} A(O_{i,k}) - A(S_i).$$

$$A(R_i) = \bigcup_{k=1}^{n_i} A(O_{i,k}) - A(S_i).$$

$$A(R_i) = \bigcup_{k=1}^{n_i} A(O_{i,k}) - A(S_i).$$

Mutual Boundary Search

Sittable Space



R_1 R_2 R_3 R_4

$$M_S(R_1, \cdots, R_m)$$

Implementation

on

Real-world Datasets

familyroom_1pXnuDYAj8r

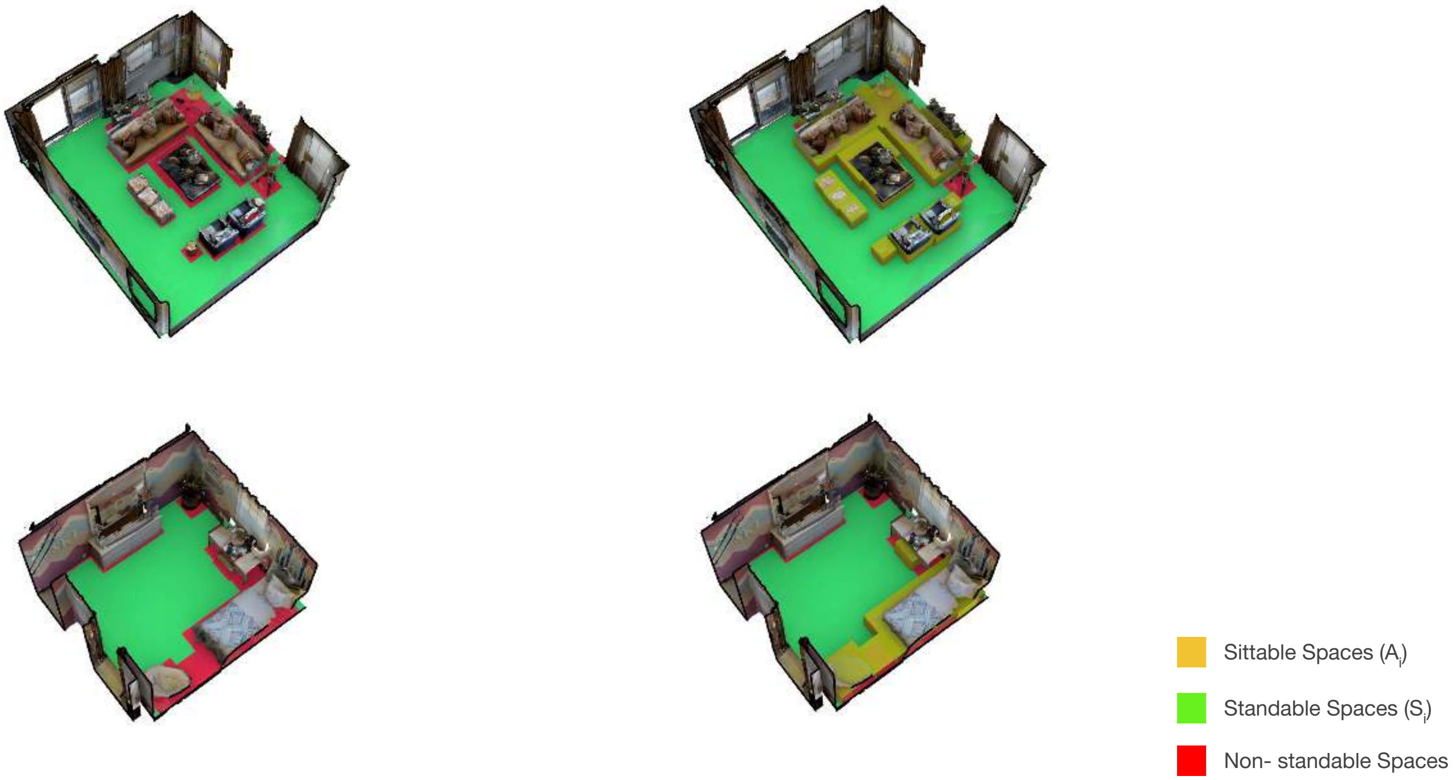
kitchen_1pXnuDYAj8r

9_familyroom_1pXnuDYAj8r

bedroom_1pXnuDYAj8r

Standable Spaces (S_i)

Non- standable Spaces



Standables Only

Standables + Sitables

Mutual Boundary Search

14Far

familyroom_1pX
nuDYAj8r

bedroom_1pXnu
DYAj8r

bedroom_1pXnu
DYAj8r

- Mutual Spaces (M_S)
- Standable Spaces (S_i)
- Non- standable Spaces

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What if we need more mutual space?

Goal II
Rearrange Furniture so that:

Mutual Space

$M_S(R_1, \cdots, R_m)$

$$E(R_i, \Theta_i) = \sum_{k=1}^{n_i} w_k \|G(O_{i,k}, \theta_{i,k})\|_t,$$

Effort

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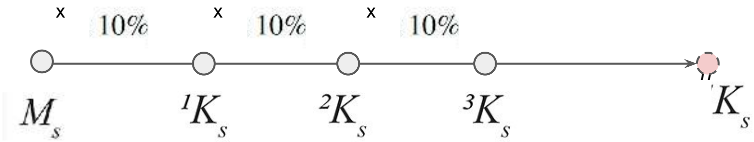
Increase Step

$$\min \sum_{i=1}^{m} E(R_i, \Theta_i^s) \quad \text{subj. to} \quad K^s\Big(\bigcap_{i=1}^{m} G(S_i, \theta_i^s)\Big) \text{ increases } 10\%,$$

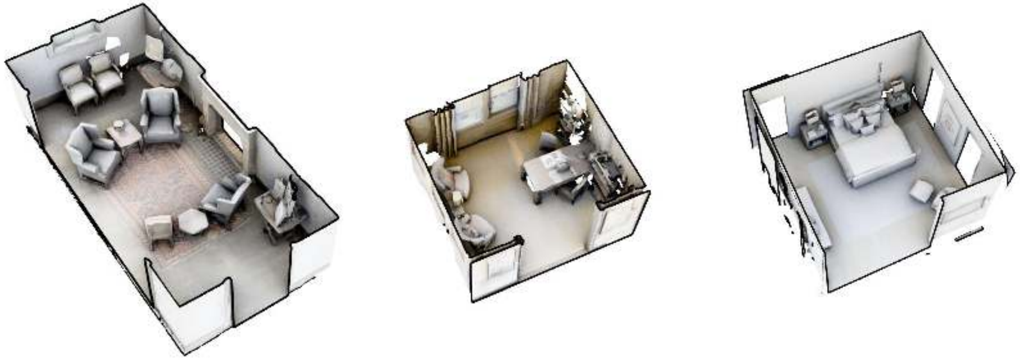
Increase Step

$$\min \sum_{i=1}^{m} E(R_i, \Theta_i^s) \quad \text{subj. to} \quad K^s\left(\bigcap_{i=1}^{m} G(S_i, \theta_i^s)\right) \text{ increases } 10\%,$$



$K_{\text{(Area)}}$

Furniture Layout Optimization

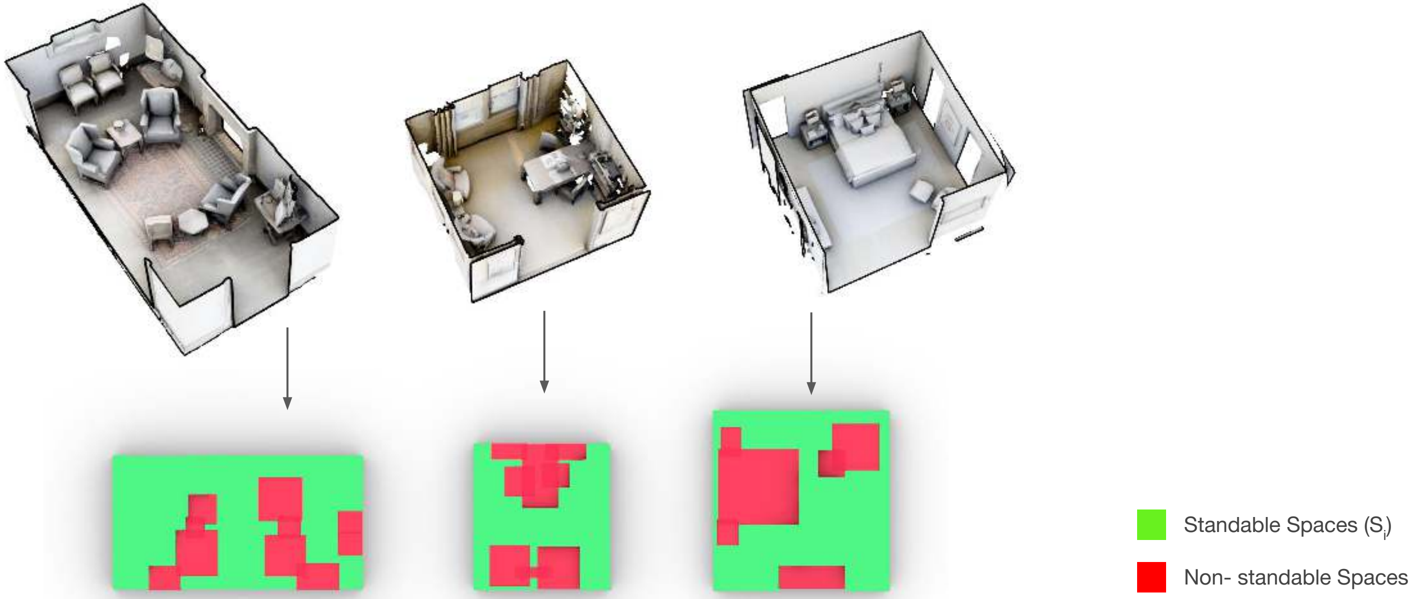


FamilyRoom
Area: 34.32 m^2
Objects: 10

Office
Area: 34.32 m^2
Objects: 8

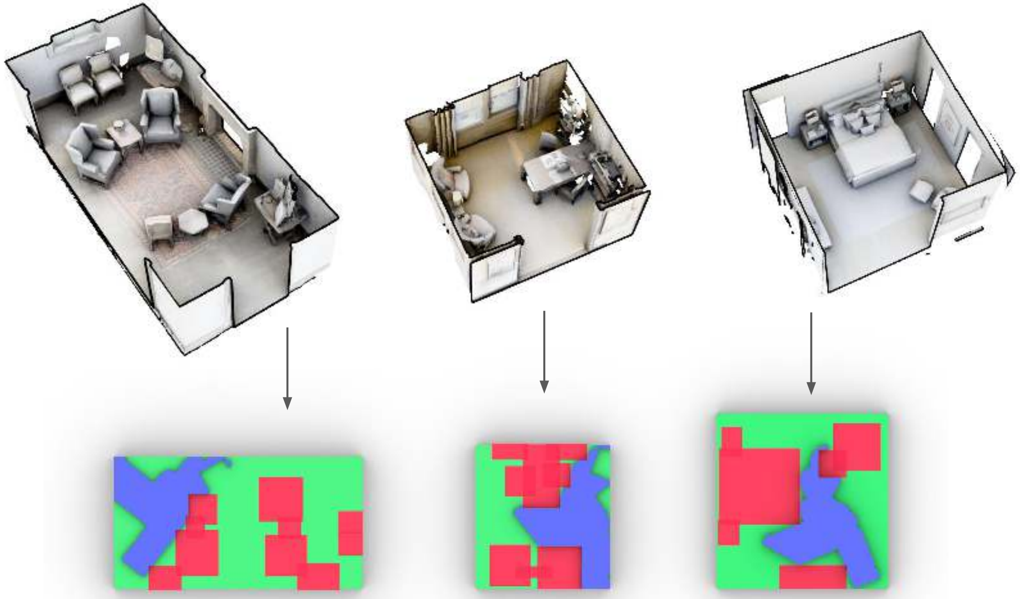
Bedroom
Area: 50.31 m^2
Objects: 6

Furniture Layout Optimization



Optimization and Manipulation of Contextual Mutual Spaces for Multi-User Virtual and Augmented Reality Interaction; Keshavarzi et al.

Furniture Layout Optimization



$M_s = 10.88$

- Mutual Spaces (M_S)
- Standable Spaces (S_i)
- Non- standable Spaces

Optimization and Manipulation of Contextual Mutual Spaces for Multi-User Virtual and Augmented Reality Interaction; Keshavarzi et al.

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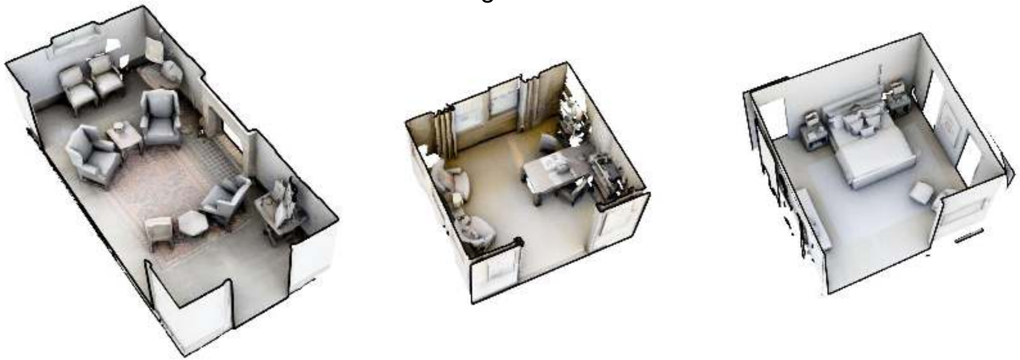
Furniture Layout Optimization

Rearrange Furniture so that:



$$E(R_i, \Theta_i) = \sum_{k=1}^{n_i} w_k \| G(O_{i,k}, \theta_{i,k}) \|_t ,$$

Effort

Mutual Space

$$M_S(R_1, \cdots, R_m)$$

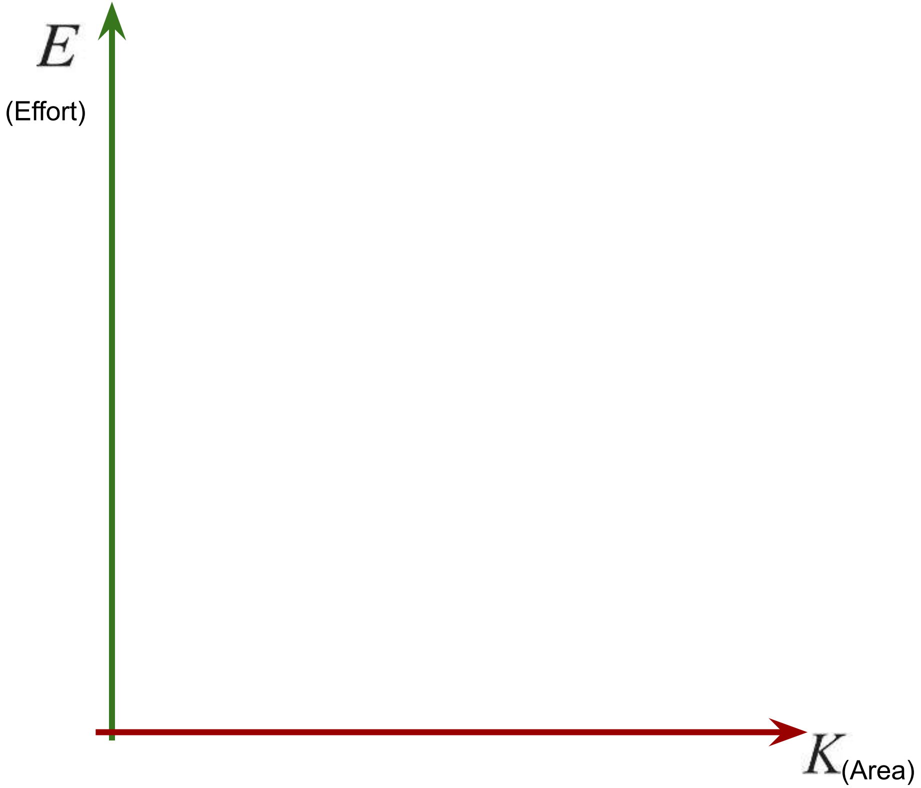
Optimization and Manipulation of Contextual Mutual Spaces for Multi-User Virtual and Augmented Reality Interaction; Keshavarzi et al.

Furniture Layout Optimization

E

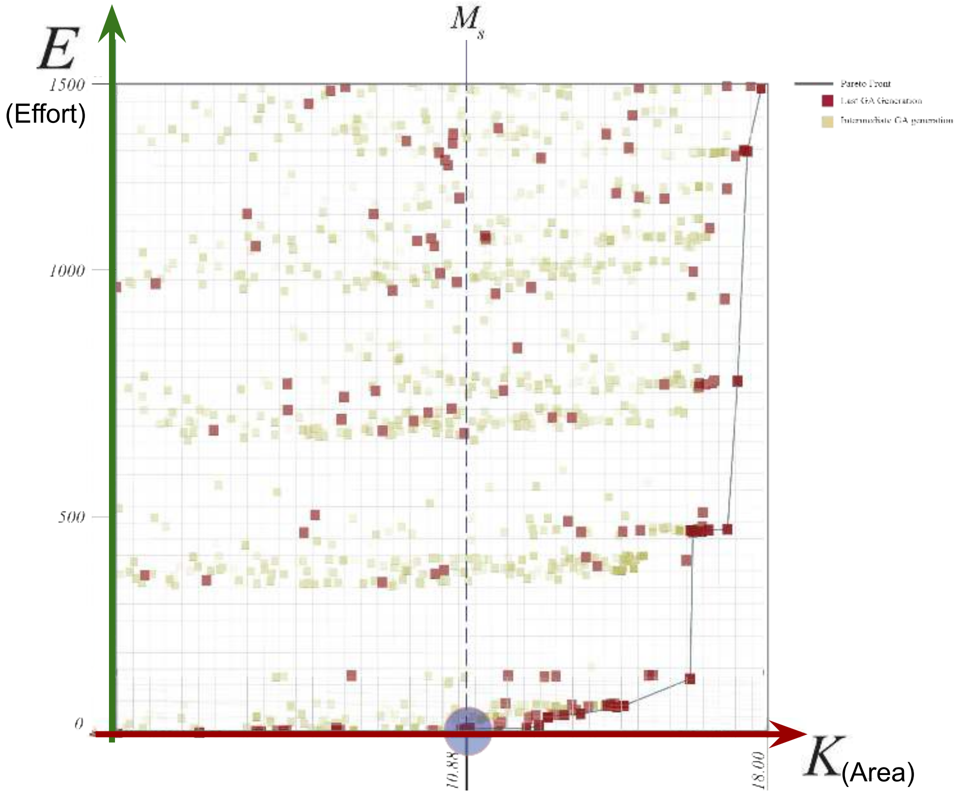
(Effort)

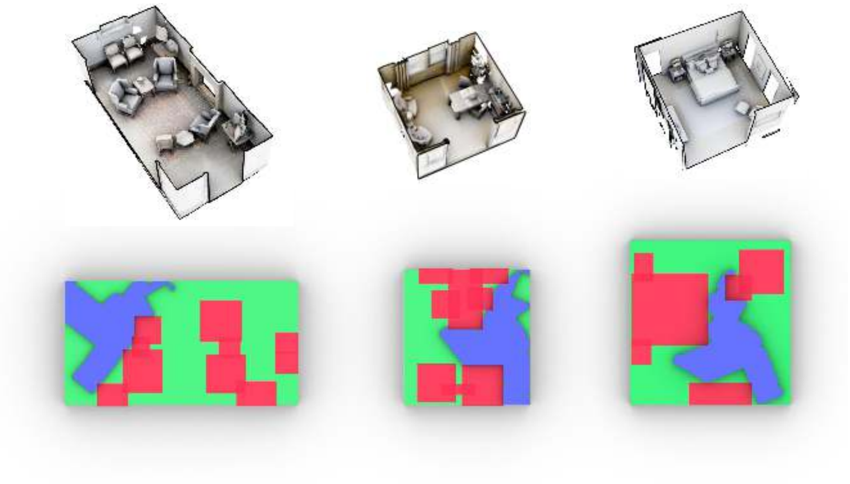
Furniture Layout Optimization



Optimization and Manipulation of Contextual Mutual Spaces for Multi-User Virtual and Augmented Reality Interaction; Keshavarzi et al.

Furniture Layout Optimization



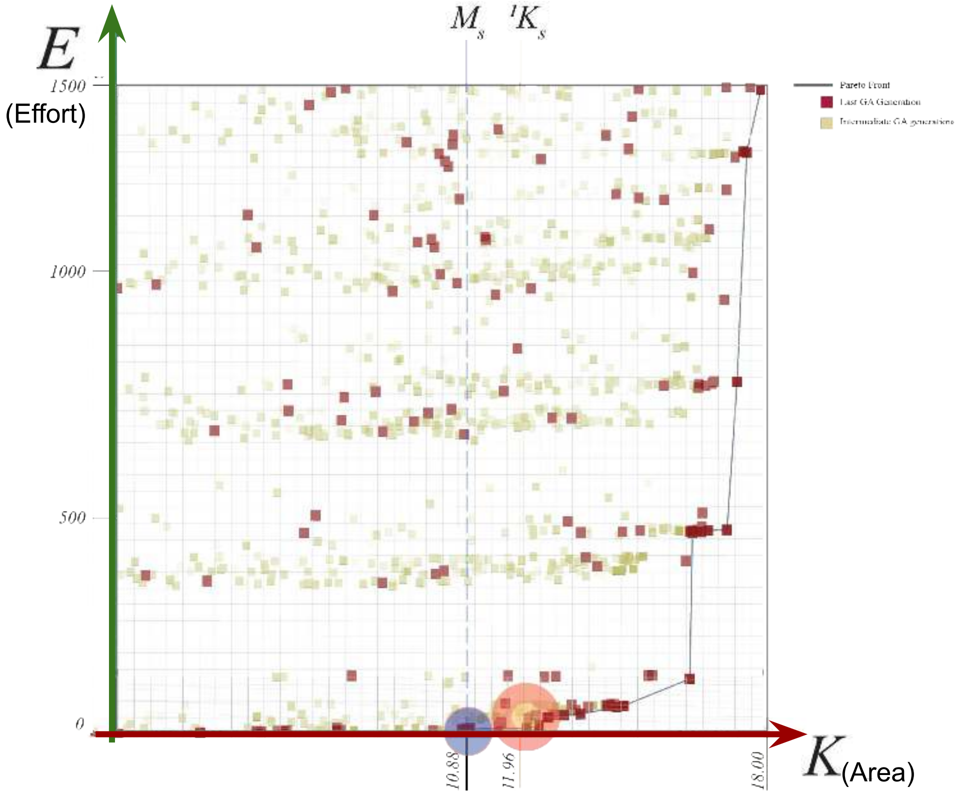


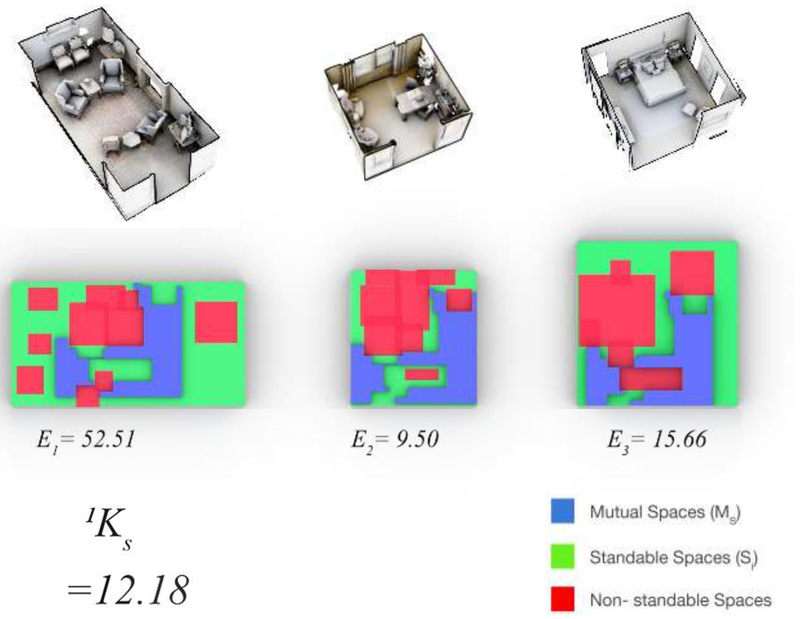
M_s
$=10.88$

Mutual Spaces (M_s)
Standable Spaces (S)
Non- standable Spaces

Optimization and Manipulation of Contextual Mutual Spaces for Multi-User Virtual and Augmented Reality Interaction; Keshavarzi et al.

Furniture Layout Optimization





$$\min \sum_{i=1}^{m} E(R_i, \Theta_i^s) \quad \text{subj. to} \quad K^s\left(\bigcap_{i=1}^{m} G(S_i, \theta_i^s)\right) \text{ increases } 10\%,$$

Optimization and Manipulation of Contextual Mutual Spaces for Multi-User Virtual and Augmented Reality Interaction; Keshavarzi et al.

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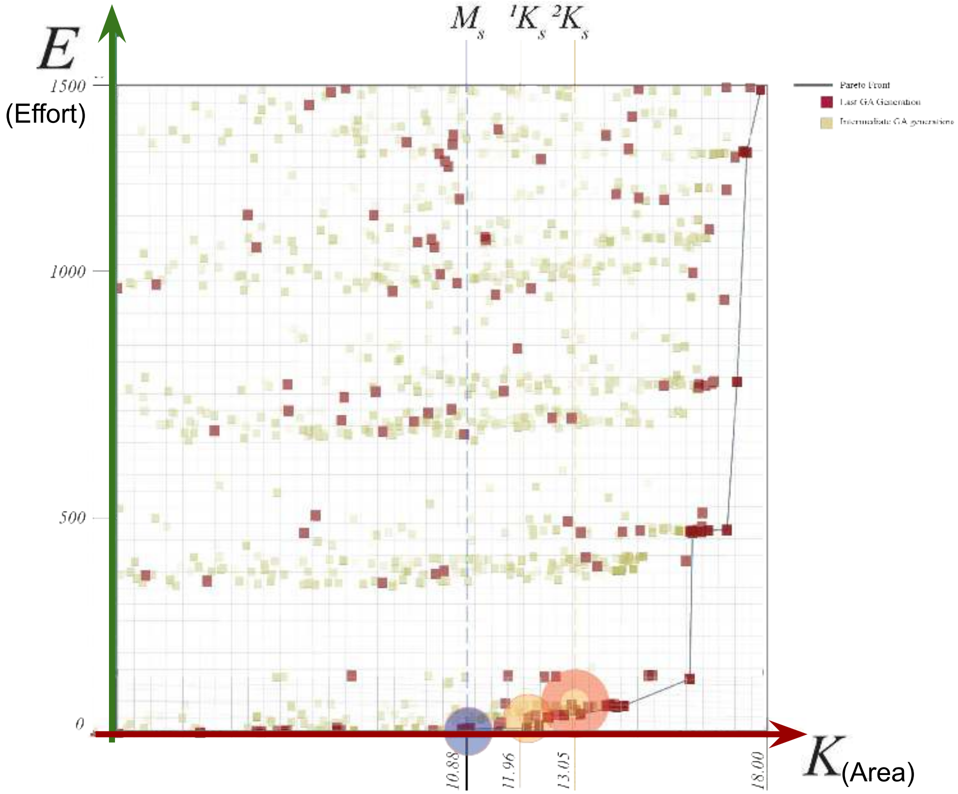
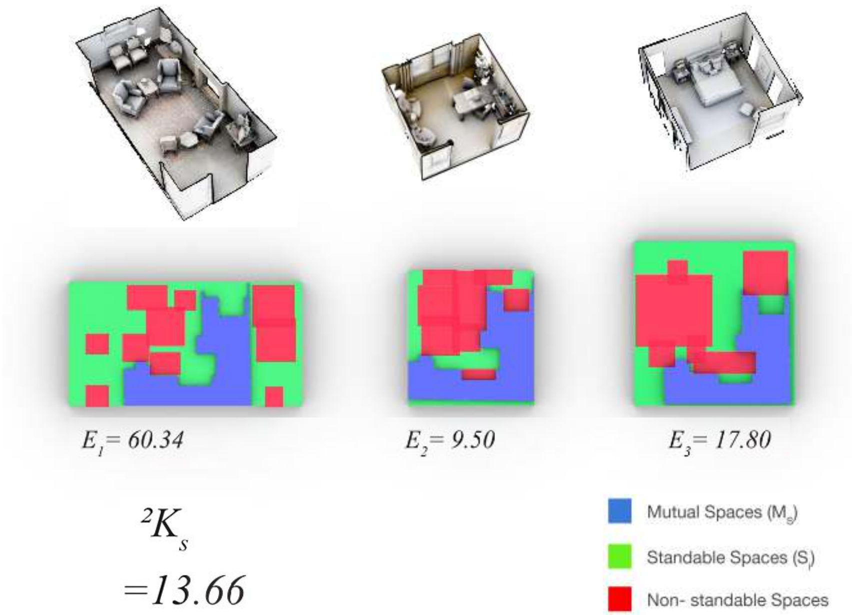
Furniture Layout Optimization





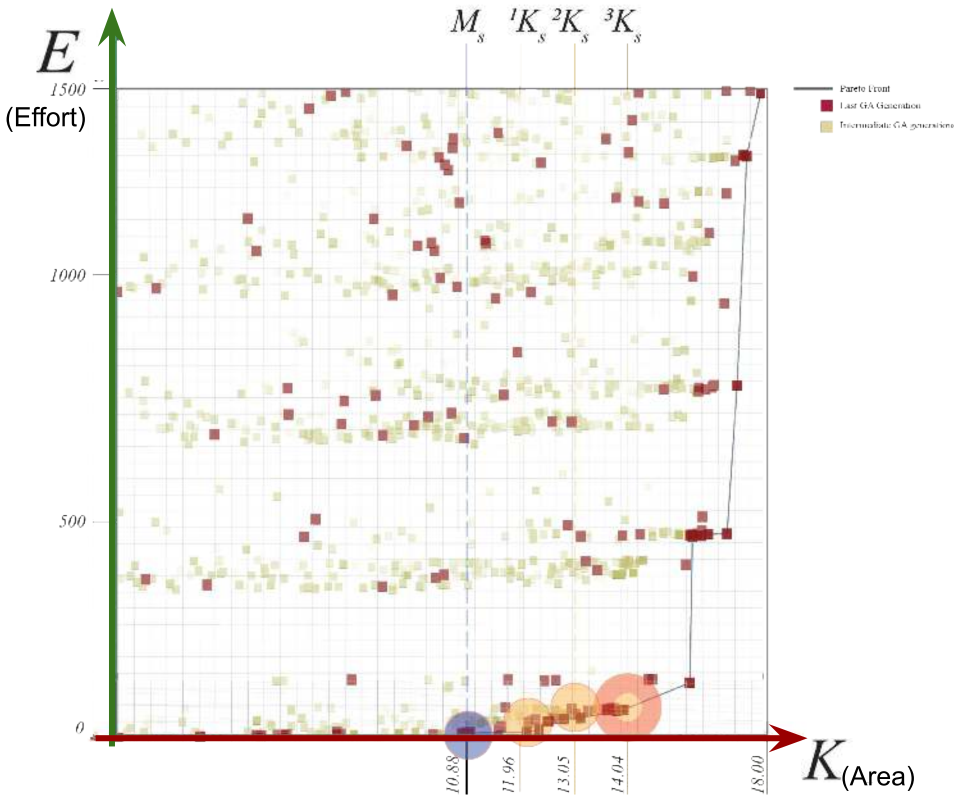
^2K_s

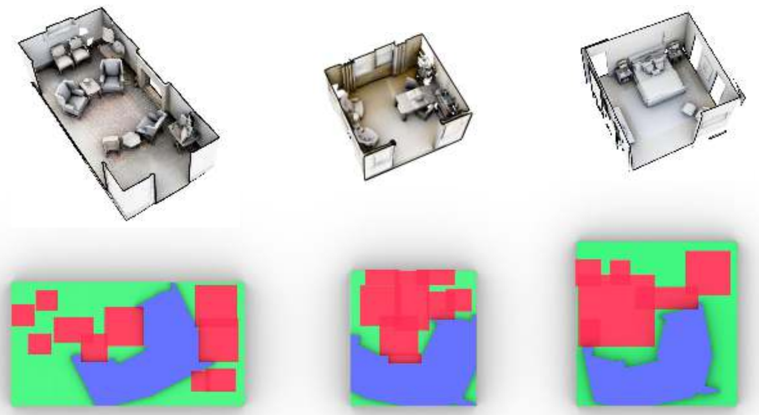
$=13.66$

$$\min \sum_{i=1}^{m} E(R_i, \Theta_i^s) \quad \text{subj. to} \quad K^s\Big(\bigcap_{i=1}^{m} G(S_i, \theta_i^s)\Big) \text{ increases } 10\%,$$

Optimization and Manipulation of Contextual Mutual Spaces for Multi-User Virtual and Augmented Reality Interaction; Keshavarzi et al.

Furniture Layout Optimization





$E_1 = 74.86$ $E_2 = 10.43$ $E_3 = 17.96$

Mutual Spaces (M_s)

Standable Spaces (S_i)

Non- standable Spaces

$${}^3K_s = 14.33$$

$$\min \sum_{i=1}^{m} E(R_i, \Theta_i^s) \quad \text{subj. to} \quad K^s\left(\bigcap_{i=1}^{m} G(S_i, \theta_i^s)\right) \text{ increases } 10\%,$$

Optimization and Manipulation of Contextual Mutual Spaces for Multi-User Virtual and Augmented Reality Interaction; Keshavarzi et al.

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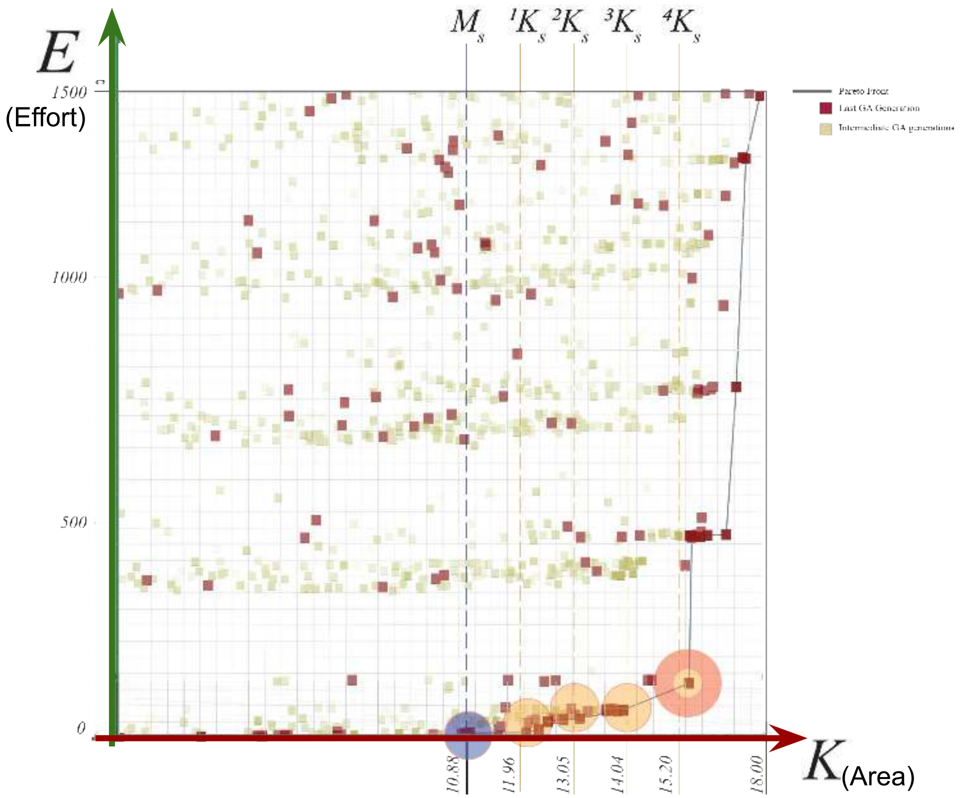
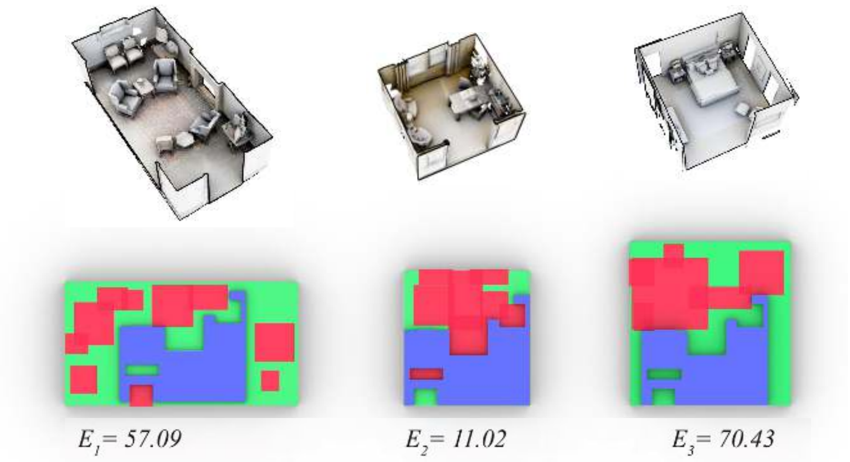
Furniture Layout Optimization





^4K_s

$= 15.99$

Mutual Spaces (M_s)

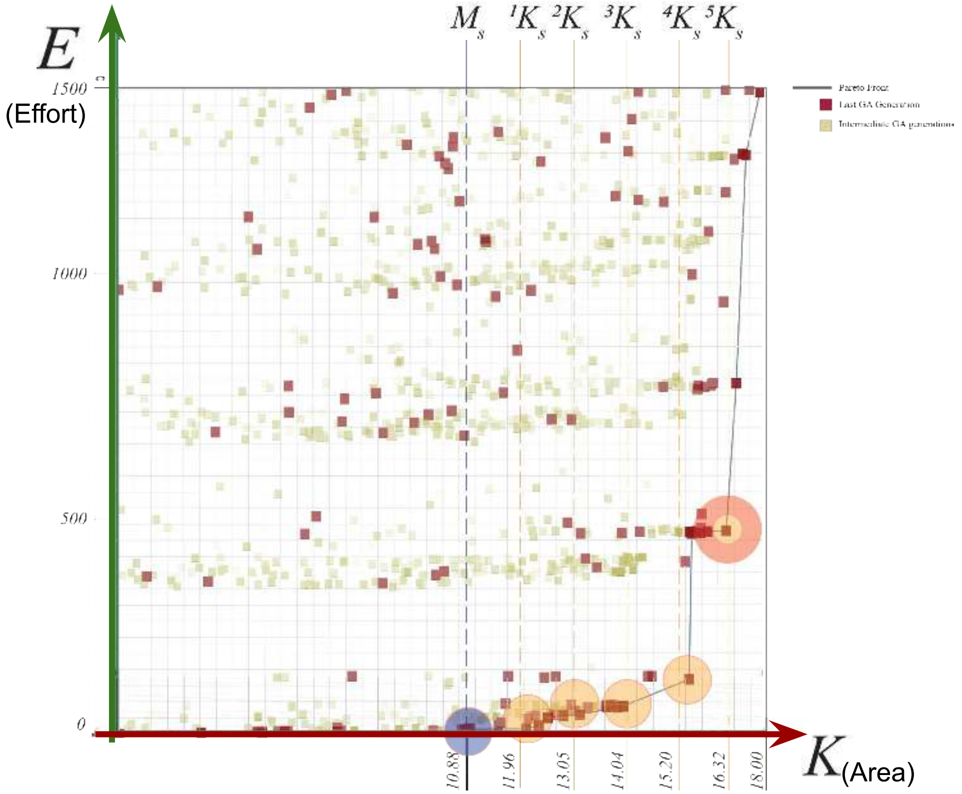
Standable Spaces (S_i)

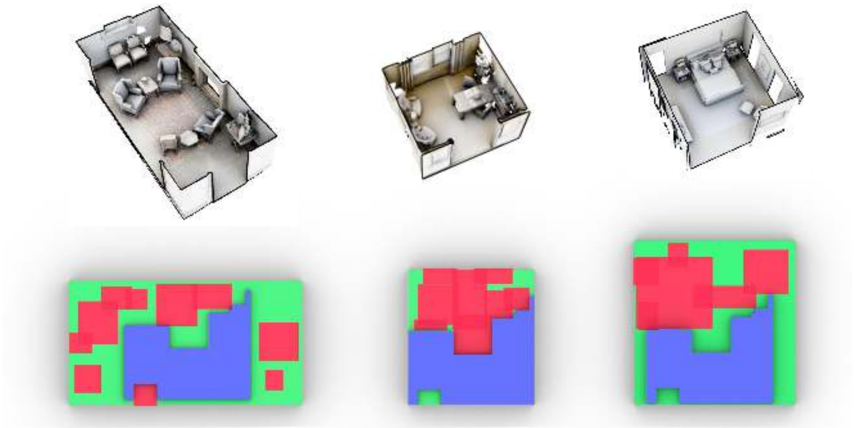
Non- standable Spaces

$$\min \sum_{i=1}^{m} E(R_i, \Theta_i^s) \quad \text{subj. to} \quad K^s\left(\bigcap_{i=1}^{m} G(S_i, \theta_i^s)\right) \text{ increases } 10\%,$$

Optimization and Manipulation of Contextual Mutual Spaces for Multi-User Virtual and Augmented Reality Interaction; Keshavarzi et al.

Furniture Layout Optimization





$E_1 = 57.09$ $E_2 = 212.90$ $E_3 = 70.43$

Mutual Spaces (M_s)

Standable Spaces (S_i)

Non- standable Spaces

^5K_s

$=17.05$

$$\min \sum_{i=1}^{m} E(R_i, \Theta_i^s) \quad \text{subj. to} \quad K^s\Big(\bigcap_{i=1}^{m} G(S_i, \theta_i^s)\Big) \text{ increases } 10\%,$$

Optimization and Manipulation of Contextual Mutual Spaces for Multi-User Virtual and Augmented Reality Interaction; Keshavarzi et al.

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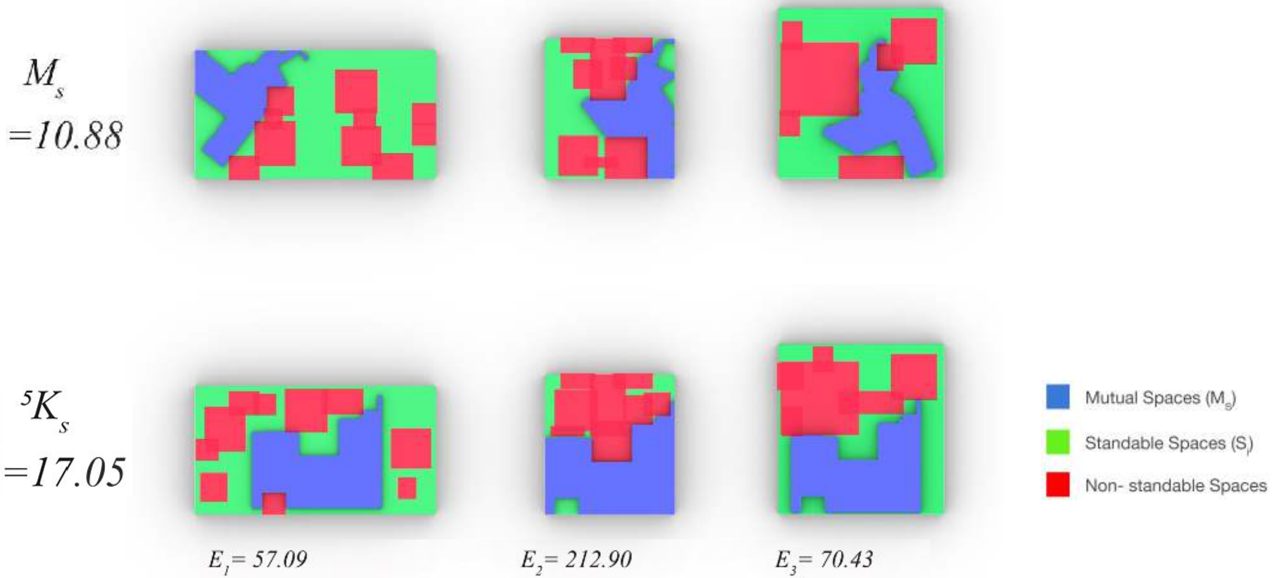
Furniture Layout Optimization

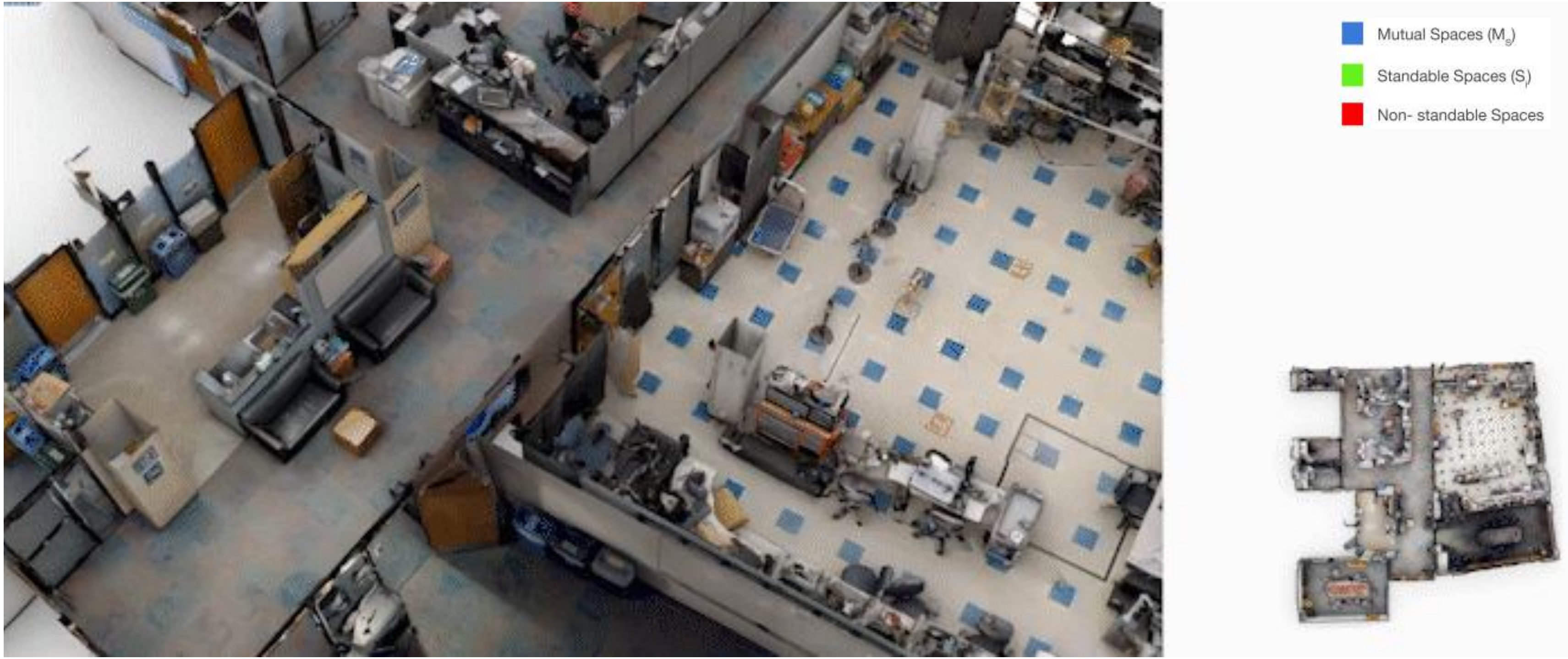
Initial Setting

Furniture Rearrangement



Hololens Visualization

Hololens Visualization



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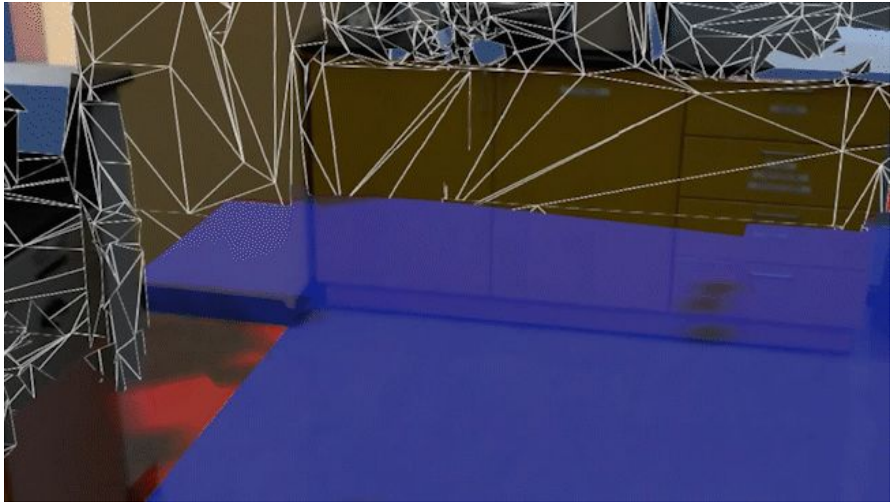
Hololens Visualization



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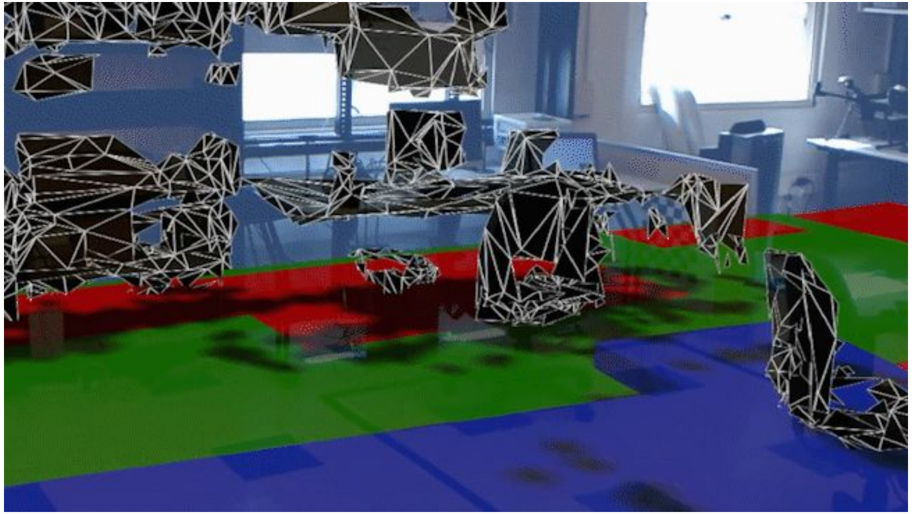

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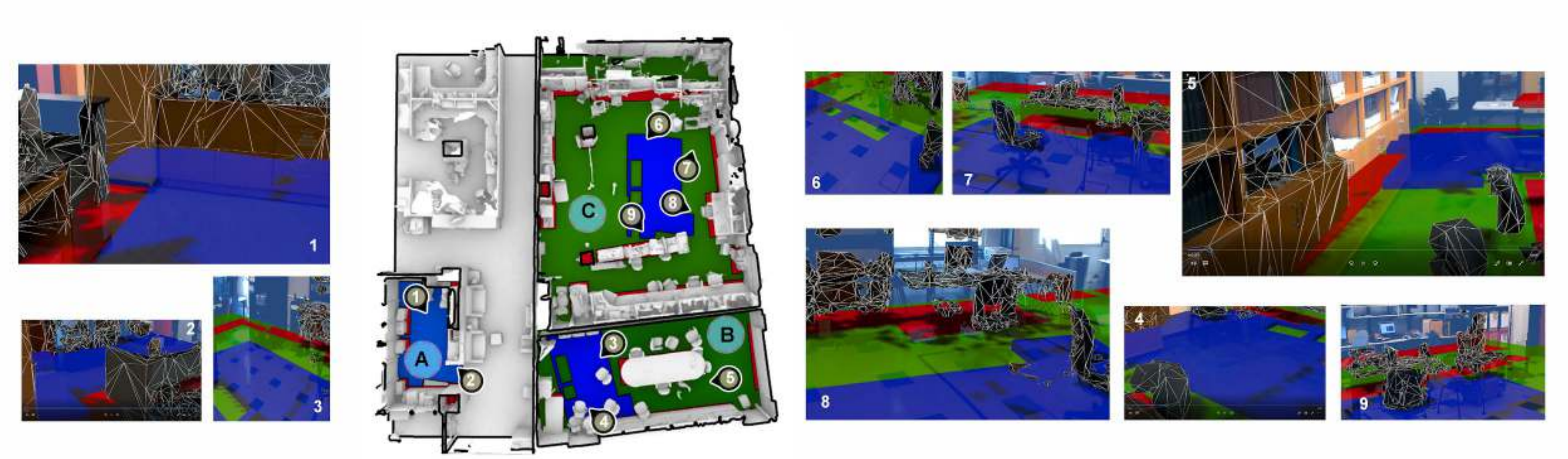
Hololens Visualization



Limitations

Limitations

- Furniture manipulation does not have continuous transformation in each increasing step
- Furniture with fixed positions are not automatically detected
- Weight is calculated based on standard assumptions.

Future Steps

Future Work

- Usability studies can be conducted on how to improve the visualization strategies so participants can experience the required tele-communication functionalities while preserving the mutual spatial ground.

- Cross-platform integration between various AR/VR platforms (mobiles, standalone, etc)

- Utilize robust floorplanning methods for furniture manipulation

Thank you!

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