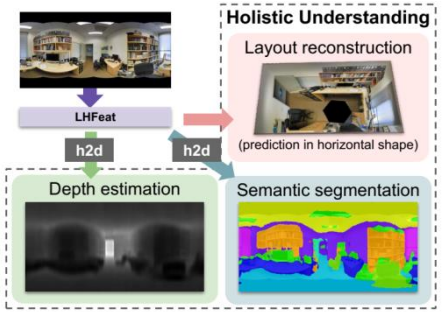
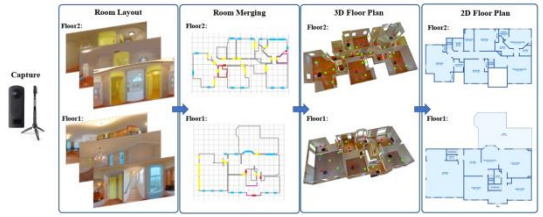
Integrated indoor model

Introduction

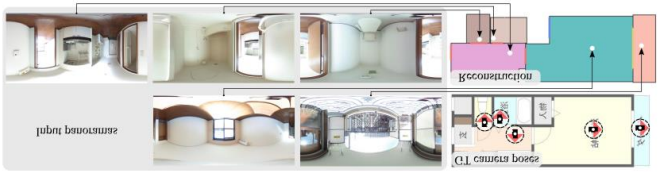
- Input: single and multi-view information
  - 3D room model and/or pixel-wise information
  - Camera positions and/or multi-view features
- Output: permanent structure scene
  - Single or multi-room scene
  - Structured floorplan with registered panoramas
  - Objects: not covered in this course…
    - Total scene understanding is a topic itself
- Pre-requisite: images registration
  - Not strictly



HoHoNet - Sun CVPR2021



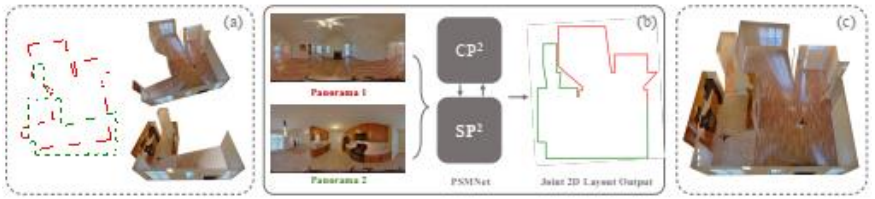
ZInD – Cruz CVPR2021



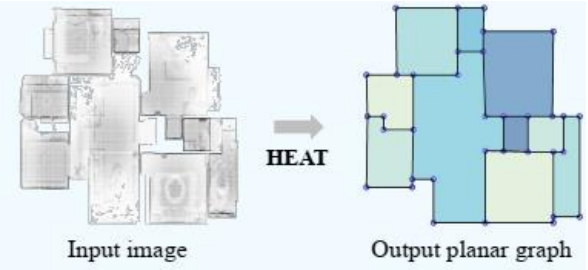
Shabani et al. ICCV2021

Common tasks

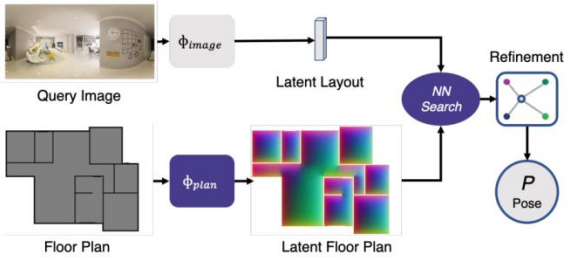
- **Multi-view layout estimation**
  - Integrating multiple single-view analysis
  - Sparse input: common case
  - Single or multi-room target
- **Structured floorplan reconstruction**
  - Multi-room segmentation
  - Dense input: professional capture
  - Walls, door, etc. identification
- **3D scene reconstruction and view localization**
  - Sparse and dense input: specific cases
  - Combining multi-modal data for a 3D model



PSMNet - Wang CVPR *2022*



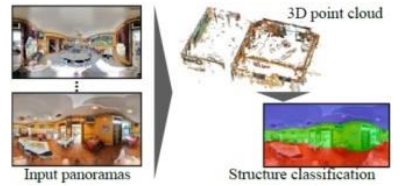
HEAT – Chen CVPR *2022*



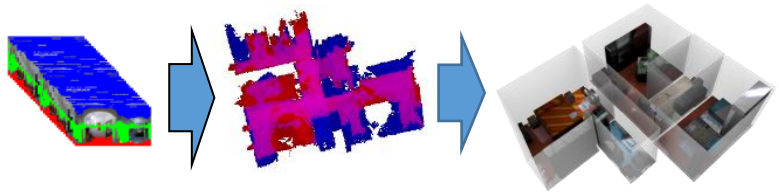
LalaLoc++ - Howard *ECCV 2022*

Multi-view layout estimation

- **Early approaches**
  - Exploiting multi-view registration
    - World reference frames
    - Sparse 3D information
  - Cabral 14: panorama analysis to complete 3D data
    - Externally calculated point cloud from MW-MVS
    - Labeled superpixels
  - Pintore 18: 3D facets from multiple panoramas
    - Assuming VW (vertical walls): less restrictive than MW
    - E2P transform locally applied to each super-pixel
      - 2D super-pixel +sparse MV features -> 3D facet
      - 3D facets from multiple images joined to identify layout



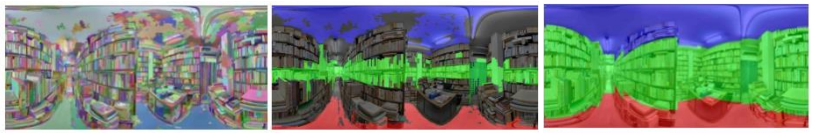
Cabral et al. CVPR2014



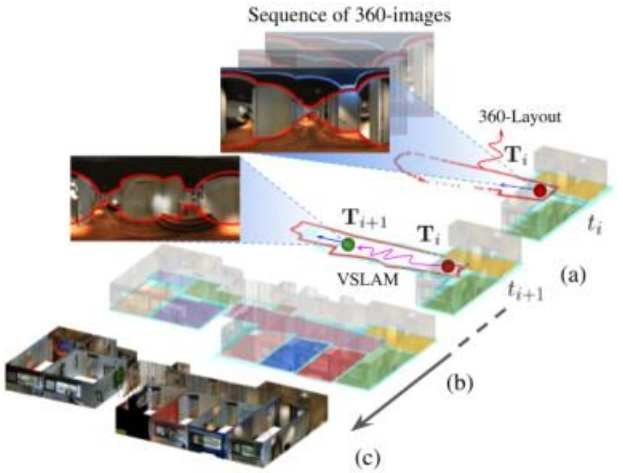
Pintore et al. CGF 2019

Multi-view layout estimation

- Early approaches limitations
  - Image segmentation not robust
    - Hand-crafted features
    - Empirical criteria and thresholds
  - 3D data quality leads reconstruction
    - Dense images coverage needed
- **Data-driven techniques**
  - Boosted the computer vision approaches
  - Effective with sparse images coverage
  - Single-view predictions fusion



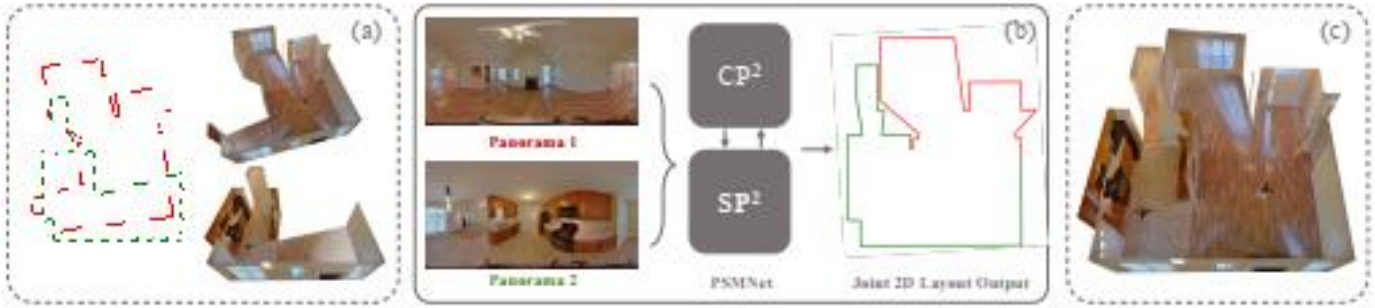
Cabral 2014: labeling propagation



360DFPE Solarte RAL 2022

Multi-view layout estimation

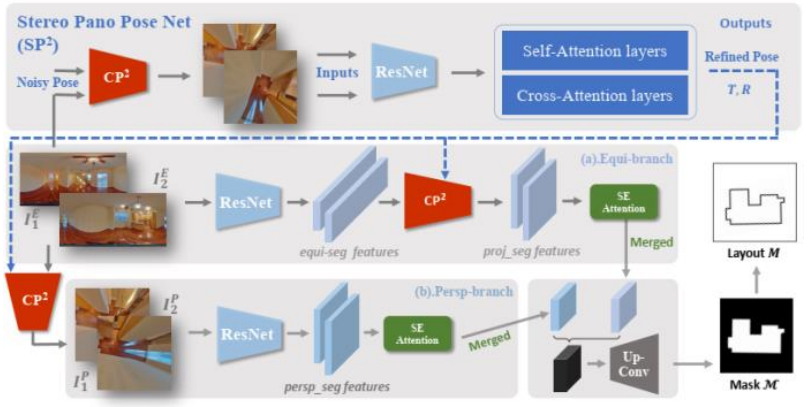
- Single image limits
  - > 10 corners – multi-purpose environments
- End-to-end joint layout-pose estimator
  - Input: pair of panoramic images
    - **Usually wide baseline, noisy alignment – incomplete layouts**
- NB. Single image layouts usually have different scale
  - Common using same camera height as scale factor



PSMNet - Wang CVPR *2022*

End-to-end joint layout-pose estimator 1

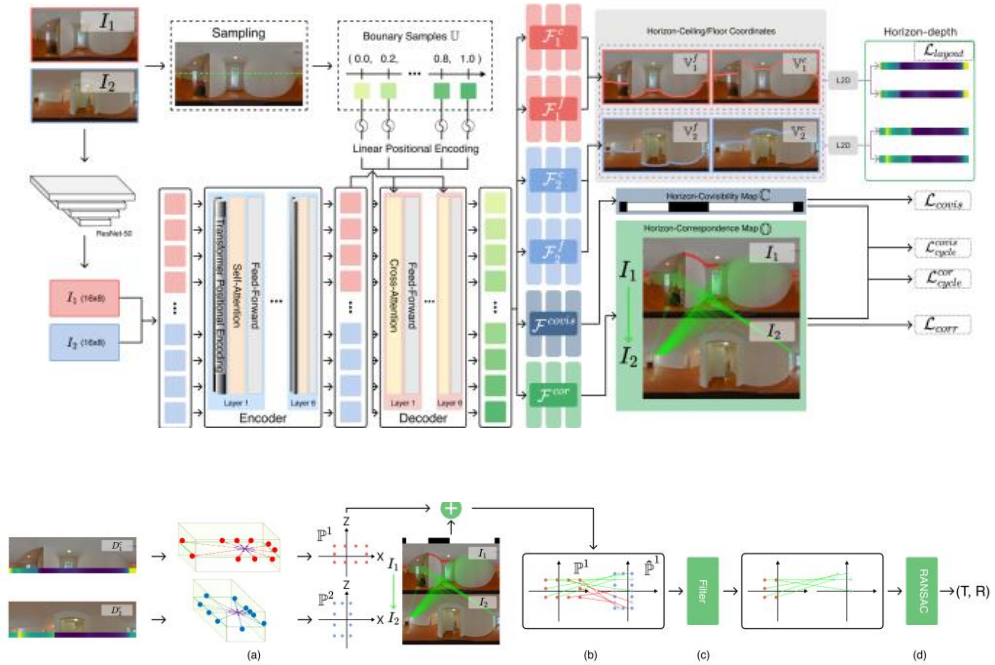
- Stereo pose network: Img1 and Img2 mutual pose
  - Computed in E2P space (**AtlantaNet, Dula-Net**)
- Equirectangular branch
  - ResNet on E1 and E2 to extract features
  - E2 features projected to E1 + cross-attention joining
  - E2P on equi feats: output floorplan space
- E2P branch
  - Images projection P1 and P2, P2 image projected to P1
  - ResNet on P1 and P2 to extract features
  - Cross-attention joining
- Cross attention joining: equi + E2P
- Decoding all to merged footprint mask



PSMNet - Wang CVPR *2022*

End-to-end joint layout-pose estimator 2

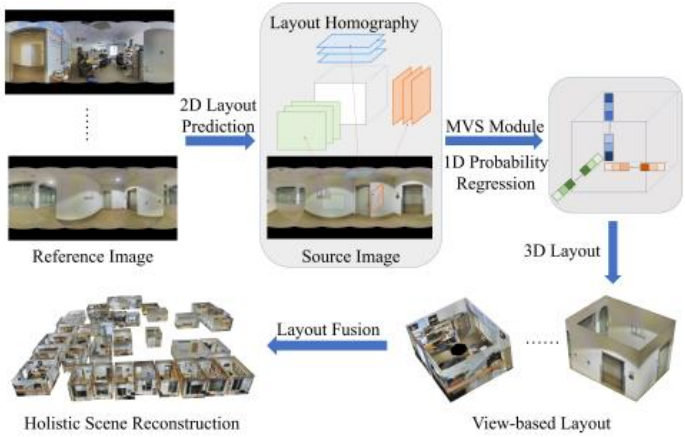
- Single equirectangular branch
  - ResNet features from I1 and I2
  - Single transformer – multihead output
    - Horizon ceiling/floor coordinates
      - 2 layouts (Led2Net – Wang CVPR2021)
    - Horizon covisibility and correspondences maps
- Geometry-aware registration
  - Covisibility and correspondences maps
  - Registration pipeline (RANSAC)
- Layout direct fusion



GPR-Net - Su CoRR *2022*

Multi-view layout estimation with MVS

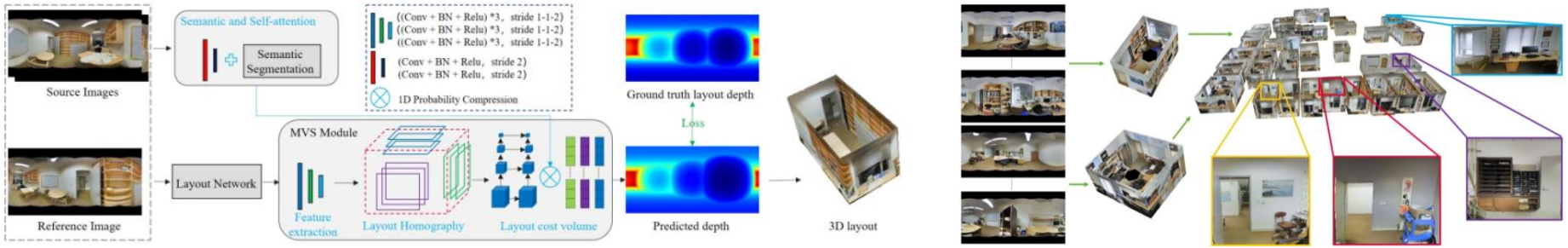
- Combining single image layout and multi-view stereo (MVS)
  - Each panorama treated as reference view with a set of associated source views
  - Layout as a set of 3D planar elements
  - Semantics and self-attention to enforce structural analysis



MVlayoutNet – Hu ACM MM2022

Multi-view layout estimation with MVS

- 2D boudaries prediction for reference and source images
  - 3D elements fitting into 2D layout and aggregated as cost volumes
    - 1 D probability map for each layout element
      - Depth of the reference layout image
- Fusion on each reference room layout at the same scale



MVlayoutNet – Hu ACM MM2022

Layout estimation from sparse images

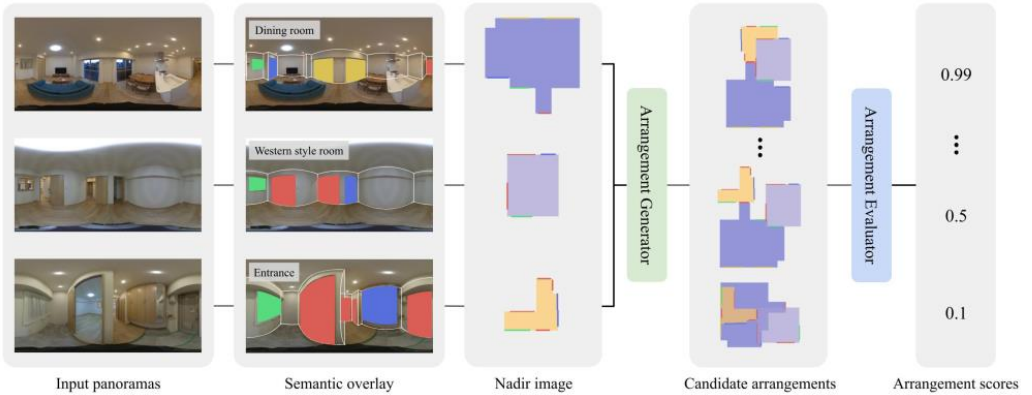
- Previous: 2<= images per room
  - Professional capture (eg. Zillow indoor dataset)
  - Easy-moderate challenge
- More common
  - Non-professional capturing
  - Very wide baseline
  - Sparse coverage
  - Hard registration and reconstruction

ZInD - Cruz CVPR *2022*

Shabani et al. ICCV 2021

Floorplan estimation from wide baseline

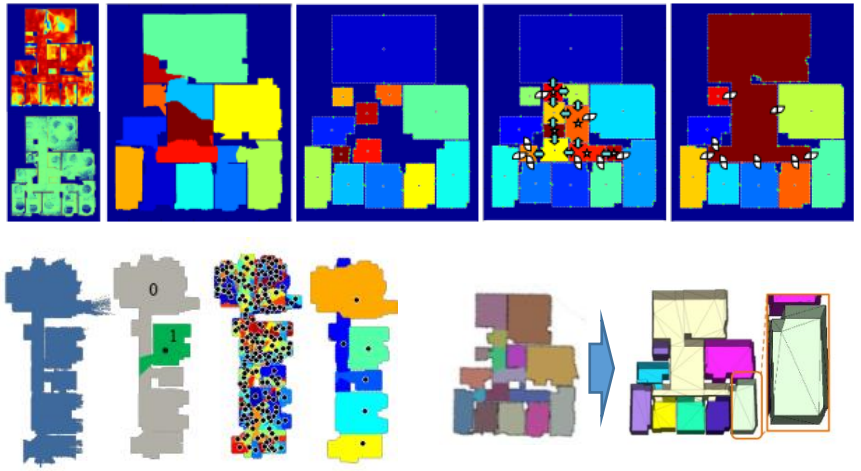
- Input: indoor panoramas with little to no visual overlaps
- Pipeline
  - For each panorama
    - Layout estimation
    - doors/windows detection
    - Top-down nadir view (256x256 16 channels)
  - Arrangement generator
    - Floorplan candidates
    - Graph of nadir images
  - Arrangement evaluator
    - Output: 2D relative camera pose for each panorama



Shabani et al. ICCV 2021

Floorplan segmentation with small baseline

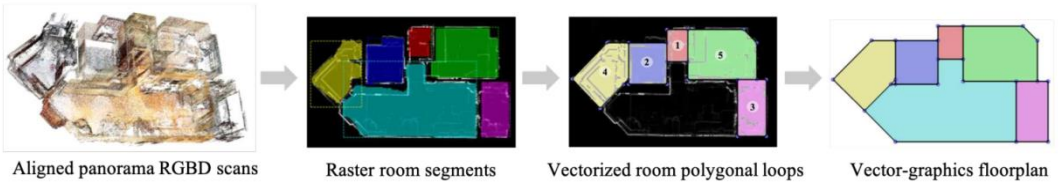
- Input: Registered RGBD panoramas-> point cloud -> density map
  - RGB+dense depth: from instruments, MWS or direct prediction
  - Smaller baseline: SfM or IPC allowed
- Ouput: top-down maps of interior space
  - 3D rooms can be extruded
  - **Base for indoor structured graph**
    - Walls, objects, connections as nodes
- Early heuristic approaches
  - Room segmentation as space clustering
    - Free space evidence

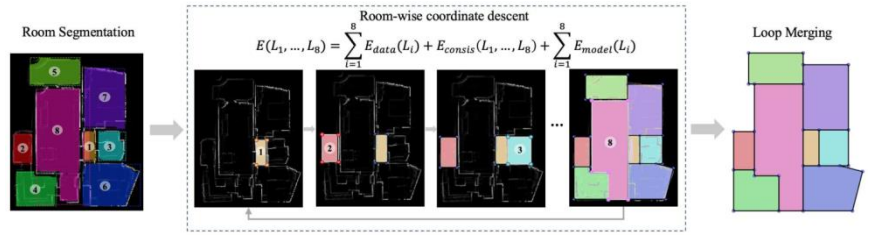


Ikheata et al. ICCV 2015

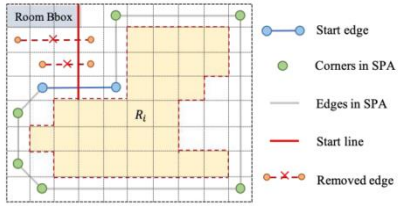
Data-driven floorplan segmentation

- **Hybrid approach: example 1**
  - Input: 4 channels density map
    - Density+average 3D normal
  - Instance semantic segmentation technique
    - Mask-RCNN
  - Floorplan graph inference
    - Reconstruction of multiple polygonal loops
    - Room-wise coordinate descent
  - Loop merging





FloorSP ICCV 2019



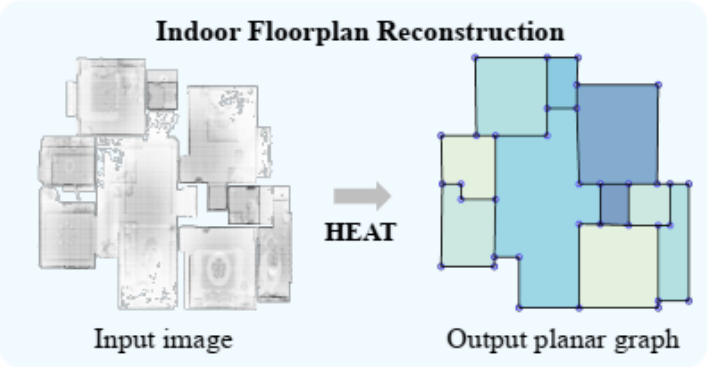
Data-driven floorplan segmentation

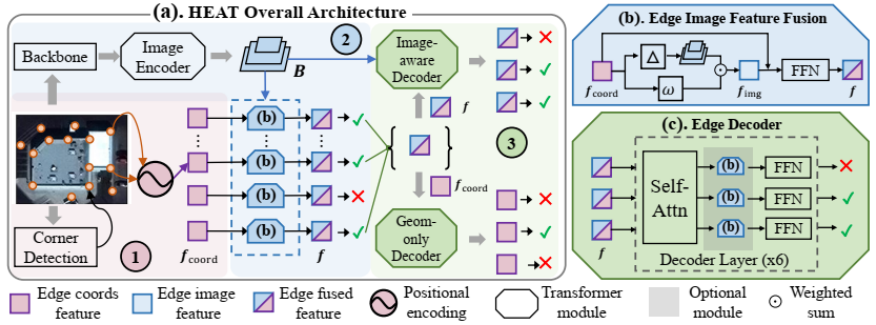
- **Hybrid approach: example 2**
  - Input: Mask-RCNN room proposals
  - Room shapes *jointly* while adjusting their locations
    - Monte Carlo Tree Search (MCTS) algorithm
      - guided by a learned scoring function
        - Density map and proposed shape image
  - Differentiable refinement step

MonteFloor ICCV 2021

Data-driven floorplan segmentation

- Fully data-driven
  - End-to-end, simplest pipeline
  - Es. Holistic edge attention transformer (HEAT)
    - Input: intensity map (same of MonteFloor, etc.)
    - DETR corner detector
      - Edges are nodes
    - 64x64 feature candidates-> 256x256confidence map
    - Transformers
    - End-to-end training data generated on the fly
      - From detected edges vs. GT
      - Output: floorplan edges

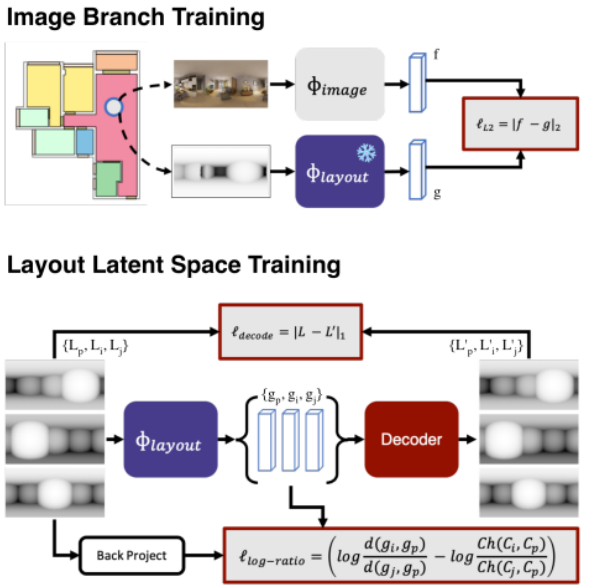


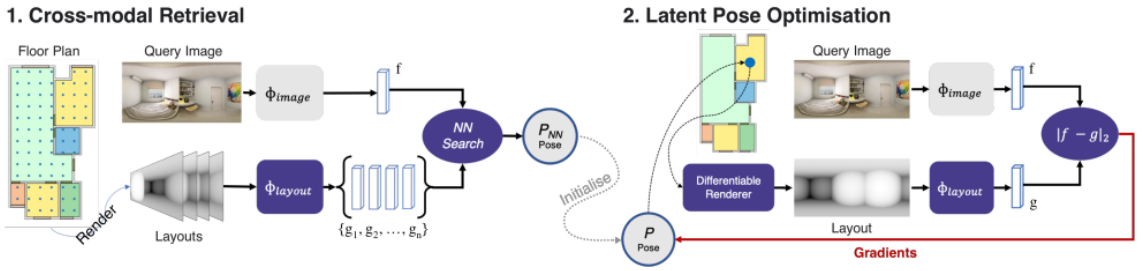


HEAT CVPR 2021

Reconstruction and localization

- Enhanced panoramic image integration
  - Exploiting latent features
- Hybrid example 1: align the floor plan to a panorama
  - 2D sampled positions – rotation in assumed known
  - 3D floor plan extrusion
  - rendering of 3D rooms as panoramic layout
  - Floorplan latent representation
  - Single image latent representation
  - NN search and refinement

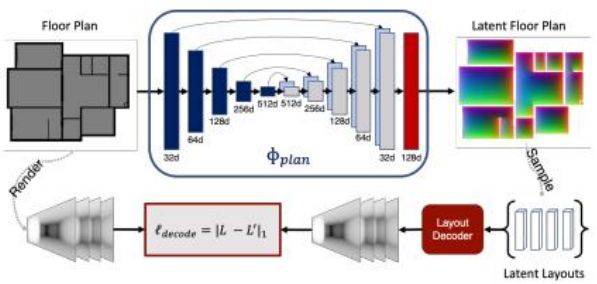


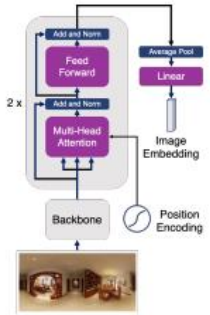


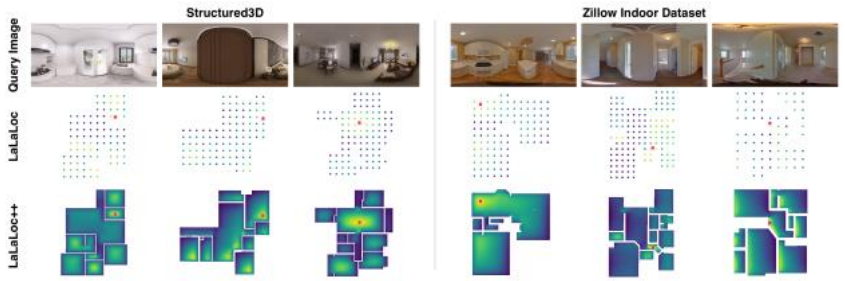
LaLaLoc ICCV 2021

Reconstruction and localization

- Full data-drive example 2: LaLaLoc++
  - Full data-driven
  - Latent floorplan instead of individual rooms
    - Rendering only to train latent floorplan estimator
    - Prediction directly in latent space
    - Recovered position not only in a fixed grid
  - Shared latent space between image and floorplan
    - image layout similar to latent floorplan sampled layouts
  - Gradient refinement for sub-pixel refinement
  - Rotation can be estimated



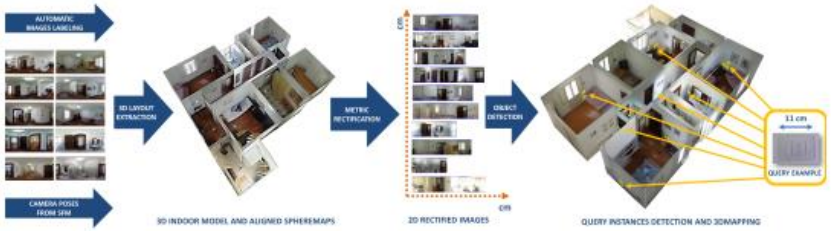




LaLaLoc++ ECCV 2022

3D floorplan reconstruction

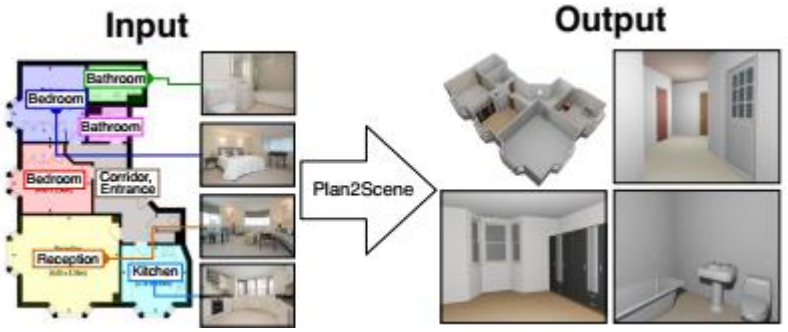
- Input: single room or floorplan layout and associated panoramas
- Early approaches
  - SfM + super-pixels + geometric reasoning
    - Recovering floorplan and registered images
  - Simple texturing by splatting input images
  - Problems
    - Low adaptability and robustness
    - Cluttered images are splatted on walls
      - Many visual artifacts

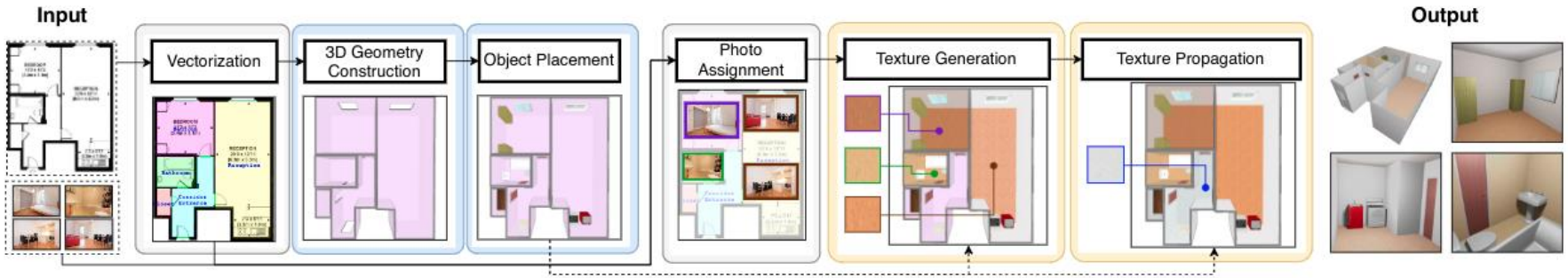


Pintore et al. CAG 2018

3D floorplan reconstruction

- Data-driven solutions
  - Floorplan to 3D scene becomes a specific task
  - Layout from reconstruction or CAD blueprint
  - Objects from recovery or CAD atlas
  - Photo assignment: fine alignment not necessary

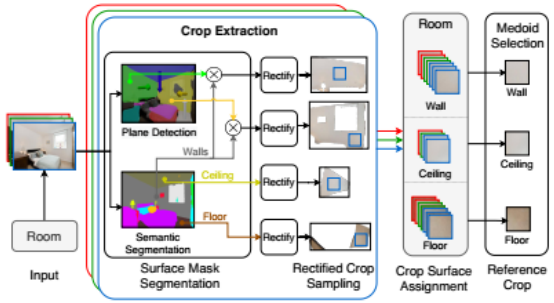


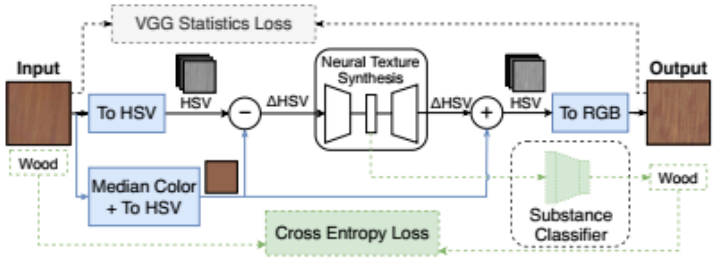


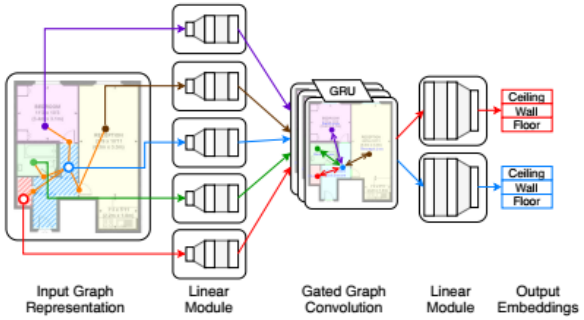
Plan2Scene CVPR 2021

3D floorplan reconstruction

- Main focus on:
  - Texture generation for observed surfaces
    - Semantic matching
    - Encoder-decoder network for synthesis
      - stationary statistics
  - Texture propagation for unobserved surfaces
    - Occlusion or missing images
    - Room-door-room connectivity to propagate
      - GCN network
        - rooms are nodes and edges are doors





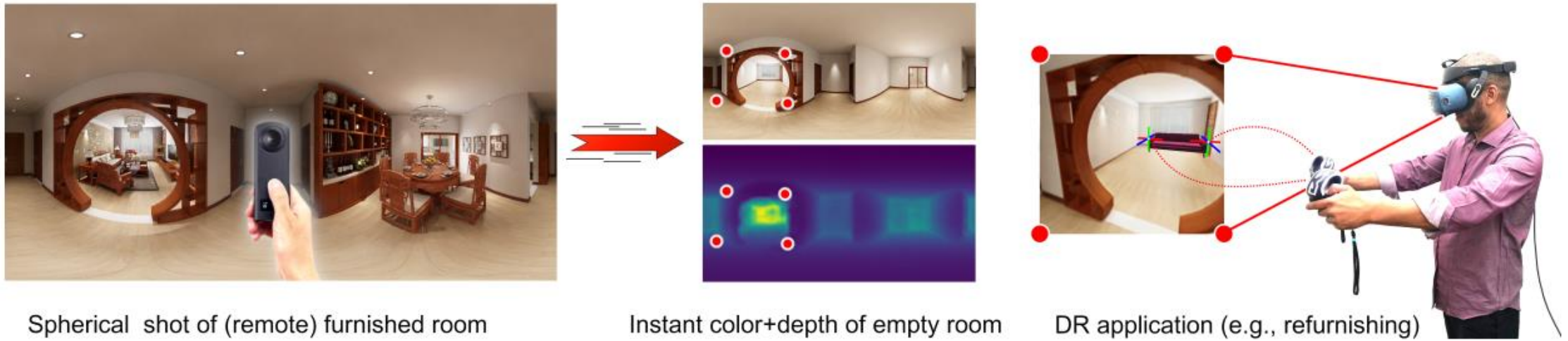


Plan2Scene CVPR 2021

Integrated indoor model: summary

- Target: permanent structure representation
  - Multi-view layout estimation
  - Multi-room segmentation
  - 3D scene reconstruction
- Open problems
  - Multi-room scenes are still limited by heavy priors
  - Multi-story buildings, pillars, stairs
  - 3D models lack geometric details or photorealism

HoHoNet - Sun CVPR2021



Spherical shot of (remote) furnished room

Instant color+depth of empty room

DR application (e.g., refurnishing)

Next session

Visual representation generation and exploration