Gaussian Scenes: Pose-Free Sparse-View Scene Reconstruction using Depth-Enhanced Diffusion Priors

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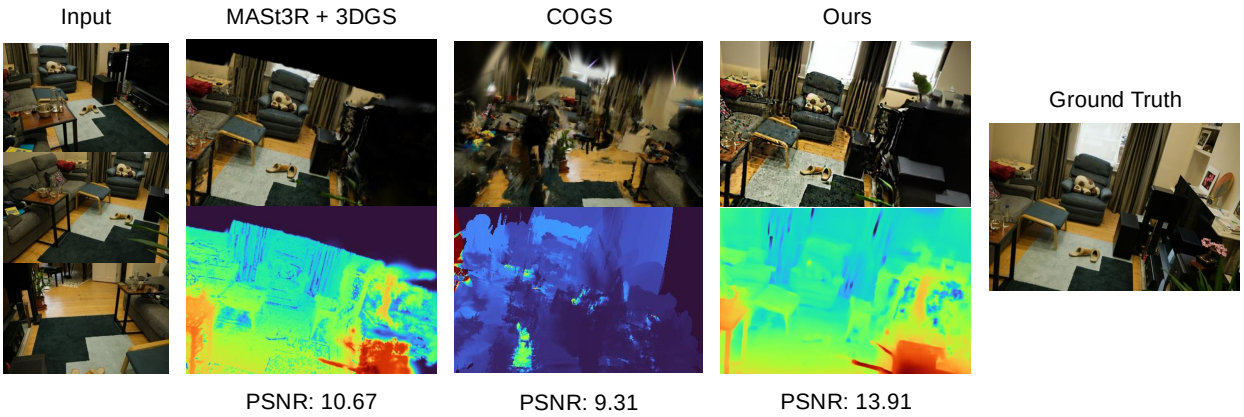

Figure 1: Given sparse *pose-free* images as input, *GScenes* reconstructs a 3D scene in 5 minutes by iteratively fusing novel view renders and depth maps with an underlying 3D Gaussian representation. Typical pose-free baselines built with geometric priors struggle with reconstructing 360°scenes from sparse inputs due to the absence of generative priors. *GScenes* comprises a latent diffusion model capable of inpainting missing details and removing Gaussian artifacts in novel view renders, thereby enabling generation of full 360°scenes.

Abstract

In this work, we introduce a generative approach for *pose-free* (without camera parameters) reconstruction of 360°scenes from a sparse set of 2D images. Pose-free scene reconstruction from incomplete, pose-free observations is usually regularized with depth estimation or 3D foundational priors. While recent advances have enabled sparse-view reconstruction of large complex scenes (with high degree of foreground and background detail) with known camera poses using view-conditioned generative priors, these methods cannot be directly adapted for the pose-free setting when ground-truth poses are not available during evaluation. To address this, we propose an image-to-image generative model designed to inpaint missing details and remove artifacts in novel view renders and depth maps of a 3D scene. We introduce context and geometry conditioning using Feature-wise Linear Modulation (FiLM) modulation layers as a lightweight alternative to cross-attention and also propose a novel confidence measure for 3D Gaussian splat representations to allow for better detection of these artifacts. By progressively integrating these novel views in a Gaussian-SLAM-inspired process, we achieve a multi-view-consistent 3D representation. Evaluations on the MipNeRF360 and DL3DV-10K benchmark dataset demonstrate that our method surpasses existing pose-free techniques and performs competitively with state-of-the-art *posed* (precomputed camera parameters are given) reconstruction methods in complex 360°scenes. Our code and datasets will be open-sourced upon acceptance.

1 Introduction

Reconstructing high-quality 3D scenes from sparse images remains a fundamental challenge in computer vision. While recent methods employ various priors to stabilize NeRFs (Mildenhall et al., 2020) or Gaussian splats (3DGS) (Kerbl et al., 2023) in under-constrained scenarios, they typically require accurate camera parameters derived from dense observations—a restrictive assumption for real-world applications. Pose estimation from sparse views is inherently challenging; both traditional Structure from Motion and recent foundational models (Wang et al., 2024; Leroy et al., 2024) struggle with insufficient matching features. Current pose-free 3DGS approaches integrate monocular depth (Ranftl et al., 2020), semantic segmentation (Kirillov et al., 2023), or 3D priors (Wang et al., 2024), but fail on complex 360°scenes with sparse coverage, highlighting the need for additional generative regularization.

Although most previous sparse view 3D scene reconstruction works are *posed* and require ground-truth camera poses (DSNeRF (Deng et al., 2022), DNGaussian (Li et al., 2024), SparseGS (Xiong et al., 2023), SparseNeRF (Wang et al., 2023a), DietNeRF (Jain et al., 2021), FreeNeRF (Yang et al., 2023), RegNeRF (Niemeyer et al., 2022), DiffusioNeRF (Wynn and Turmukhambetov, 2023)), recent works like COGS (Jiang et al., 2024) and InstantSplat (Fan et al., 2024) have found initial success in the *pose-free* sparse view reconstruction problem. Although they have been successful in reducing 3D reconstruction-related artifacts such as blur, floaters, color, and streak-like artifacts, they lack generative capabilities for a complete 360°reconstruction, which requires robust priors from powerful generative models (Saharia et al., 2022; Rombach et al., 2022). In addition, most of these methods lack mechanisms to robustly identify and locate these artifacts in the reconstructed scenes. Recent methods like ZeroNVS (Sargent et al., 2024), Reconfusion (Wu et al., 2024), and CAT3D (Gao* et al., 2024) incorporate 3D view conditioning for realistic extrapolation but depend on accurate poses and cannot be trivially extended to the pose-free problem. Gaussian Object (Yang et al., 2024), iFusion (Wu et al., 2023), and UpFusion (Nagoor Kani et al., 2024) do provide pose-free generative solutions, but remain limited to only object reconstruction rather than scene reconstruction. Other generative solutions like ZeroNVS, ReconFusion, and CAT3D use stronger priors over regularization-based techniques like FreeNeRF, RegNeRF, and DietNeRF but rely on large-scale 3D datasets, video datasets and compute resources not available to the average researcher. Furthermore, works like ReconFusion and CAT3D remain closed-source with no access to their models, data or other reproducibility data, which severely limits their usage for the community. We summarize such existing methods and their use cases and attributes in Fig 2.

Method	Pose-free	Open-source	Generative Priors	Scene Reconstruction
FreeNeRF, DietNeRF, RegNeRF, DN-Gaussian, SparseGS, SparseNeRF	✗	✓	✗	✓
DiffusioNeRF, ZeroNVS	✗	✓	✓	✓
ReconFusion, CAT3D	✗	✗	✓	✓
Gaussian Object, iFusion, UpFusion	✓	✓	✓	✗
InstantSplat, COGS	✓	✓	✗	✓
***GScenes* (Ours)**	✓	✓	✓	✓

Figure 2: **Comparison of sparse-view reconstruction methods.** Methods are grouped based on their requirement for accurate camera poses, open-source availability, need for generative priors, and applicability to large-scale scene reconstruction.

To alleviate these challenges, we present *GScenes*, an efficient approach using 3D foundational and RGBD (RGB image and depth) generative priors for pose-free sparse-view reconstruction of complex 360°scenes. We first estimate a point cloud and approximate camera parameters using MASt3R (Leroy et al., 2024), then jointly optimize Gaussians and cameras with 3DGS. Novel views generated from an elliptical trajectory fitted to the training views contain artifacts that our diffusion prior refines to further optimize the scene. We condition a Stable Diffusion UNet (Rombach et al., 2022) on estimated cameras, context, 3DGS renders, depth maps, and a confidence map capturing artifacts and missing details. Our proposed confidence measure is designed by combining per-pixel light transmittance with Gaussian density, which provides a reliable conditioning signal to the Stable Diffusion UNet on the presence of empty regions and Gaussian artifacts in novel view renders and depth maps. For training our diffusion prior, we create our own dataset of 171, 461 samples using scenes from open-source multiview datasets. Each sample is a pair of clean RGBD images and images with empty regions and Gaussian artifacts, along with other conditioning signals (confidence map,

clip features, etc). Augmented variants of both the Stable Diffusion VAE and UNet are finetuned using this synthetic dataset. Despite using weaker and cheaper generative priors than pose-dependent methods, we demonstrate competitive performance against closed source methods like ReconFusion (Wu et al., 2024) and CAT3D (Gao* et al., 2024) while outperforming other techniques without requiring million-scale multi-view or video data or extensive compute resources. Our contributions include:

- An image-to-image RGBD generative model for synthesizing plausible novel views from sparse pose-free images, using lightweight FiLM modulation (Perez et al., 2018) instead of cross-attention
- A confidence measure to detect artifacts in novel view renders, guiding our diffusion model toward effective novel view synthesis
- Integration of diffusion priors with MASt3R's geometry prior, enabling efficient scene reconstruction previously requiring 3D-aware video diffusion
- Superior performance compared to recent regularization and generative prior-based open-source methods for 3D scene reconstruction
- An open-source low-cost solution with lower data and compute requirements compared to state-of-the-art posed reconstruction methods.

See Appendix for further discussion and Related Works (Appendix B).

2 Method

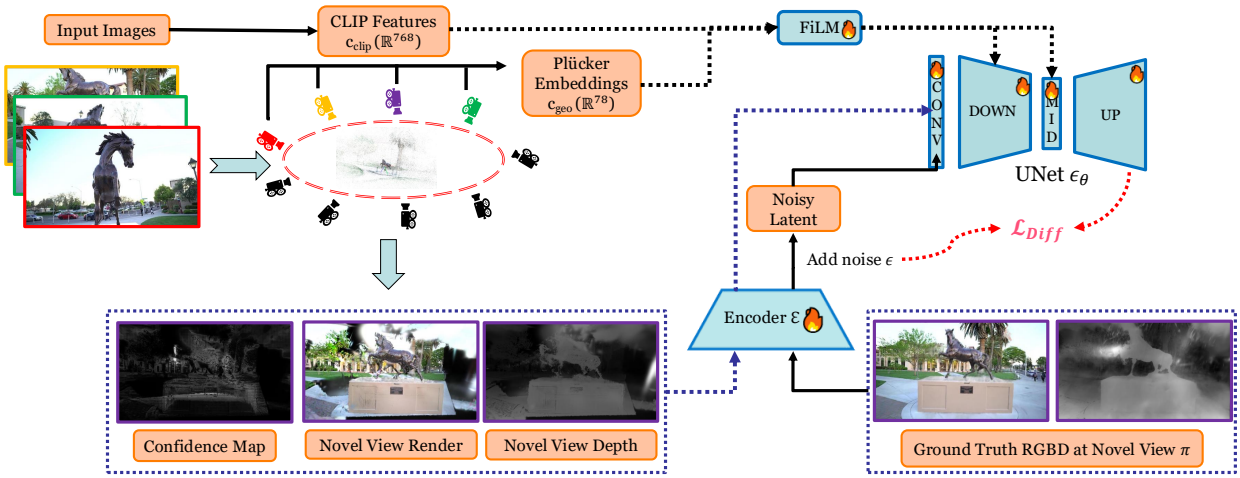

Figure 3: **Overview of *GScenes*.** We render 3D Gaussians fitted to our sparse set of M views from a novel viewpoint. The resulting render and depth map have missing regions and Gaussian artifacts, which are rectified by an RGBD image-to-image diffusion model. This then acts as pseudo ground truth to spawn and update 3D Gaussians and satisfy the new view constraints. This process is repeated for several novel views spanning the 360°scene until the representation becomes multi-view consistent.

This section begins with an overview of our method in Sec 2.1, detailing our approach for reconstructing a 3D scene from a sparse set of uncalibrated 2D images. In Sec 2.1, we describe how we initialize a Gaussian point cloud using MASt3R and 3DGS to provide a coarse 3D representation. Sec 2.2 introduces our RGBD image-to-image generative model, which refines rendered novel views by correcting artifacts and filling in missing details. In Sec 2.3, we propose a confidence measure based on cumulative transmittance and Gaussian density to guide the generative diffusion model in identifying unreliable regions in novel-view renders. Sec 2.4 outlines our synthetic dataset creation process, which enables training the generative model with high-quality RGBD supervision. Sec 2.5 details our depth-augmented autoencoder finetuning process to improve latent-space encoding for RGBD data. Sec 2.5.1 explains the fine-tuning of our UNet with synthesized training data

to generate photorealistic and geometrically consistent novel views. In Sec 2.5.2, we describe the inference process of our generative model, where novel views are synthesized using RGBD renders and confidence maps. Sec 2.6 presents our iterative 3D Gaussian optimization strategy that progressively integrates novel view constraints into the scene representation. Finally, Sec 2.7 describes a test-time pose alignment step that refines camera poses to align the rendered image with a given test view before evaluation.

2.1 Algorithm Overview

Problem Setup Given a set of M images $\mathcal{I} = \{I_1, I_2, \ldots, I_M\}$ of an underlying 3D scene with unknown intrinsics and extrinsics, our goal is to reconstruct the 3D scene, estimate the camera poses of a monocular camera at the M training views, and synthesize novel views at evaluation time given by N unseen test images $\{I_{M+1}, I_{M+2}, \ldots, I_{M+N}\}$.

Algorithm 1 Gaussian Scenes Training

Require: Sparse image set $\mathcal{I} = \{I_1, \ldots, I_M\}$, densification interval k, iterations N
Initialize 3D Gaussian primitives $\mathcal{G}$ from MASt3R 3D point cloud $\mathbf{P}$
Optimize $\mathcal{G}$ using 3DGS on input views $\mathcal{I}$ and estimated cameras $\pi_{train} = \{\pi_1, \ldots, \pi_M\}$ for $1k$ iterations
$\hat{\mathcal{I}} \leftarrow \mathcal{I}$ ▷ Initialize training images
for $t = 1, \ldots, N$ **do**
  if $t \mod k = 0$ **then**
    Sample novel pose π_{novel} from elliptical trajectory fitted to π_{train}
    $(\hat{I}, \hat{D}) \leftarrow R_{\pi_{novel}}(\mathcal{G})$ ▷ Render image and depth map
    Compute confidence map $\mathcal{C}$ (Eq. 2)
    Extract semantic context & geometry embeddings $\{c_{clip}, c_{geo}\}$ ▷ Sec 2.2.2
    $(I_{ref}, D_{ref}) \leftarrow \text{Refine}(\hat{I}, \hat{D}, \mathcal{C}, c_{clip}, c_{geo})$ ▷ Refine $\hat{I}$, $\hat{D}$ with generative priors (Sec 2.5.2)
    $\hat{\mathcal{I}} \leftarrow \hat{\mathcal{I}} \cup \{I_{ref}\}$ ▷ Synthesized novel view added as training sample
  end if
  Sample pose π_i from π_{train}
  Render $(I_\pi, D_\pi) \leftarrow R_{\pi_i}(\mathcal{G})$
  Optimize 3D Gaussians $\mathcal{G}$ ▷ Eq. 6 or 3DGS loss
end for

An overview of our method is given in Fig 3 and Alg 1. We initialize *GScenes* with an incomplete dense Gaussian point cloud reconstruction from sparse input images using MASt3R and *1k* iterations of 3DGS. Note that InstantSplat proposes the same framework for sparse-view reconstruction, but with a DUSt3R initialization. We choose MASt3R to initialize scene geometry instead due to its superior performance in the sparse-view setting. We use this incomplete scene representation as an implicit geometric prior and sample novel views along a smooth elliptical trajectory fitted to training views. An example trajectory is shown in Fig 4. We then use our RGBD generative prior to synthesize plausible novel views. In addition to CLIP features of source images for context and plücker embeddings of source and target cameras for geometric conditioning, we devise a novel 3DGS confidence measure to effectively guide our generative model towards empty regions and potential artifacts in a novel view render. We then run $10k$ iterations of 3DGS optimization, sampling a novel view before each densification step (Fu et al., 2023) to obtain our final scene representation.

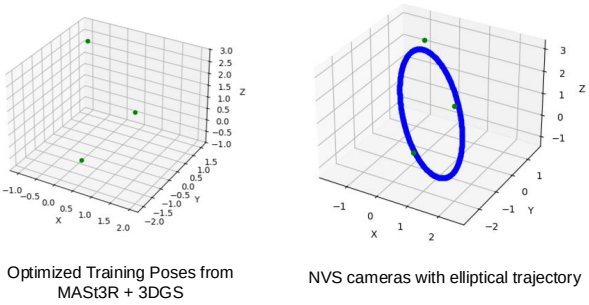

Figure 4: Camera Trajectory Visualization for Novel View Synthesis in pose-free sparse-view setting.

Gaussian Point Cloud Initialization The MASt3r initialization gives us a pixel-aligned dense-stereo point cloud $\mathbf{P} \in \mathbb{R}^{S \times 3}$, camera intrinsics $\{\mathbf{K_i} \in \mathbb{R}^{3\times3}\}_{i=1}^{M}$ and extrinsics $\{\mathbf{E_i} = [\mathbf{R_i}|\mathbf{T_i}]\}_{i=1}^{M}$ for our M input

images. Nevertheless, both $\mathbf{P}$ and the estimated poses demonstrate sub-optimal alignment compared to those generated by COLMAP from the dense observation dataset. We cannot also use COLMAP for camera or geometry estimation as the method fails when there is minimal overlap between training images, as in our setting. Consequently, similar to the approach in InstantSplat, we initialize 3D Gaussians at each location in the globally aligned point cloud $\mathbf{P}$. We then jointly optimize both the Gaussian attributes and camera parameters over the $1k$ iterations. The MASt3R point cloud is already quite dense (1.5-3M points), which alleviates the need for any form of Adaptive Density Control (Kerbl et al., 2023).

2.2 RGBD Generative Priors for Novel View Synthesis (NVS)

Reconstructing complete 3D scenes from sparse observations requires inferring content in unobserved regions—a fundamental challenge that geometric regularization and 3D priors alone cannot adequately address. We introduce a diffusion-based generative approach that leverages 2D image priors to synthesize plausible content.

2.2.1 Generative Model Architecture

Despite our initial geometric reconstruction, sparse input views inevitably result in regions with no Gaussian primitives ("0-Gaussians"), causing empty areas and artifacts in novel views. Unlike regularization-based methods that merely constrain optimization without generating content, our approach directly synthesizes missing scene details.

Our model comprises of (1) A variational autoencoder (encoder $\mathcal{E}$, decoder $\mathcal{D}$) operating in a compressed latent space. (2) A UNet denoiser ϵ_θ predicting noise in diffused latent z_t (3) A multi-modal conditioning incorporating RGBD renders, confidence maps, semantic context, and geometric information.

The UNet ϵ_θ receives four inputs: an artifact-laden RGBD image $\hat{I}$, a confidence map $\mathcal{C}$ identifying unreliable regions, CLIP features c_{clip} of $\mathcal{I}$ providing semantic context, and camera encodings c_{geo} establishing geometric relationships between views.

2.2.2 Multi-modal Conditioning

We initialize ϵ_θ with pretrained Stable-Diffusion-2 model weights and expand the first convolutional layer to accept additional inputs by concatenating the noisy latent z_t, the encoded RGBD image $\mathcal{E}(\hat{I})$, the confidence-weighted encoded image $\mathcal{E}(\hat{I} \cdot \mathcal{C})$ and the downsampled confidence map $\hat{\mathcal{C}}$. To ensure view coherence and geometric consistency, we incorporate following conditioning signals:

Semantic Context: CLIP features $c_{\text{clip}} \in \mathbb{R}^{M \times d}$ from source images serve as semantic anchors, ensuring generated content remains consistent with observed scene elements.

Geometric Information: For each camera with center $\mathbf{o}$ and forward axis $\mathbf{d}$, we compute its plücker coordinates $\mathbf{r} = (\mathbf{d}, \mathbf{o} \times \mathbf{d}) \in \mathbb{R}^6$ and apply frequency encoding for obtaining higher-dimensional features:

$$\mathbf{r} \mapsto [\mathbf{r}, \sin(f_1 \pi \mathbf{r}), \cos(f_1 \pi \mathbf{r}), \cdots, \sin(f_K \pi \mathbf{r}), \cos(f_K \pi \mathbf{r})] \tag{1}$$

where $K = 6$ is the number of Fourier bands, and f_k are equally spaced frequencies. This yields a 78-dimensional embedding for each camera ($c_{\text{geo}} \in \mathbb{R}^{(M+1) \times 78}$), capturing geometric relationships between viewpoints. Plücker coordinates were originally introduced by LFNs (Sitzmann et al., 2021) for per-pixel parameterization of a ray. We instead obtain a single representation per camera using extrinsic parameters $\mathbf{E_i}$ for obtaining $\mathbf{o}$ and $\mathbf{d}$.

2.2.3 Parameter-Efficient FiLM Conditioning

We employ Feature-wise Linear Modulation (FiLM) instead of cross-attention for incorporating context and geometry information, achieving both computational efficiency and strong performance. We process context and geometry embeddings through self-attention to capture inter-view relationships as: $c^i_{\text{attn}} = \text{SelfAttention}(c_i); \quad i \in \{\text{clip}, \text{geo.}\}$ We then generate scaling and shifting parameters via layer-specific networks as: $\gamma^{(l)}, \beta^{(l)} = \text{FC}^{(l)}(c^i_{\text{attn}})$. Finally, we modulate the UNet feature maps through element-wise operations as: $\mathbf{F}^{(l)}_{\text{mod}} = \gamma^{(l)} \cdot \mathbf{F}^{(l)} + \beta^{(l)}$.

Critically, we apply FiLM modulation only to down and mid blocks of the UNet—not up blocks—based on empirical evidence showing this selective application yields optimal results (Fig. 5).

Our FiLM-based approach requires only 8.14M parameters (7.38M for CLIP features, 758K for pose embeddings) compared to 29.8M for an equivalent cross-attention implementation—a 3× reduction while maintaining comparable quality, enabling more efficient training and faster inference during iterative reconstruction.

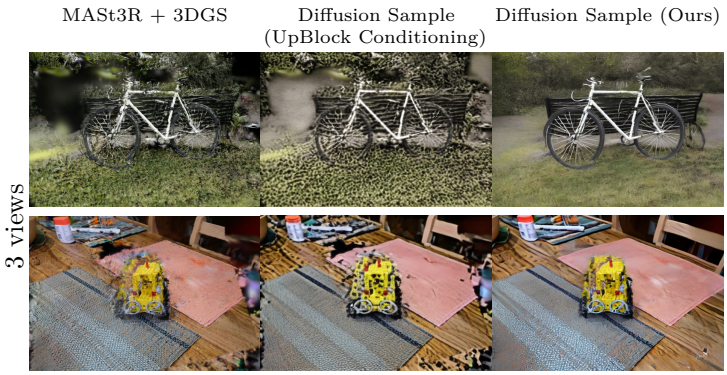

Figure 5: Incorporating context and geometry conditioning in the up blocks of the UNet negatively impacts latent and subsequent image reconstruction.

2.3 Pixel-Aligned Confidence Map

To guide our generative diffusion model in identifying problematic and artifact-ridden regions in novel views, we introduce a pixel-aligned confidence measure combining transmittance with Gaussian density:

$$\mathcal{C}_i = -\log(T_i + \epsilon) \times n_{\text{contrib}} \tag{2}$$

where $T_i = \prod_i (1 - \alpha_i)$ represents light transmission without Gaussian interaction, n_{contrib} counts contributing 3D Gaussians, and $\epsilon > 0$ prevents logarithmic singularities. This formulation captures two complementary reliability signals: (1) low transmittance indicates significant Gaussian interactions, suggesting higher rendering confidence, and (2) consensus among multiple Gaussians validates pixel reliability through primitive agreement.

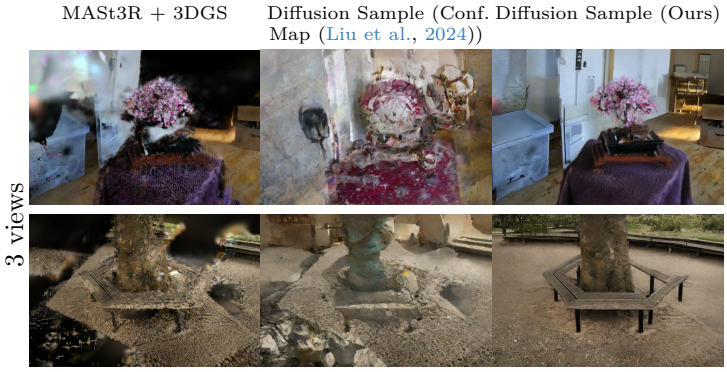

Figure 6: As an ablation for our confidence measure, we train a variant of our diffusion model using the confidence measure proposed in 3DGS Enhancer (Liu et al., 2024). Conditioning the UNet with this inaccurate confidence measure leads to implausible NVS.

Unlike 3DGS-Enhancer (Liu et al., 2024), (one of the few methods that propose confidence measures for sparse-view scene reconstruction), which assumes that well-reconstructed areas contain small-scale Gaussians, our measure remains effective for monotonous textures, where fine-grained Gaussian representation is unnecessary. Such regions are usually represented by a few high-opacity large-scale Gaussians (low $n_{contrib}$, but also low T_i) and hence not flagged as low-confidence regions by our confidence measure. Fig. 7 demonstrates how our approach accurately identifies both empty regions and reconstruction artifacts while avoiding false positives. The significance of this improved confidence measure is evident in Fig. 6, where models trained with previous confidence formulations produce implausible novel views due to misleading confidence signals.

2.4 RGBD Dataset Creation

For training the additional weights in $\boldsymbol{\epsilon_\theta}$ for RGBD image-to-image diffusion, we rely on a set $\mathcal{X} = \{(I^i, \hat{I}^i, \mathcal{C}^i, c^i_{clip}, c^i_{geo})_{i=1}^N\}$, each containing a clean RGBD image I^i, an RGBD image with artifacts $\hat{I}^i$ and the corresponding confidence map $\mathcal{C}^i$, CLIP features of source images $c^i_{clip} \in \mathcal{R}^{M\times 768}$, and plücker embeddings of source and target cameras $c^i_{geo} \in \mathcal{R}^{(M+1)\times 78}$, to "teach" the diffusion model how to inpaint missing details

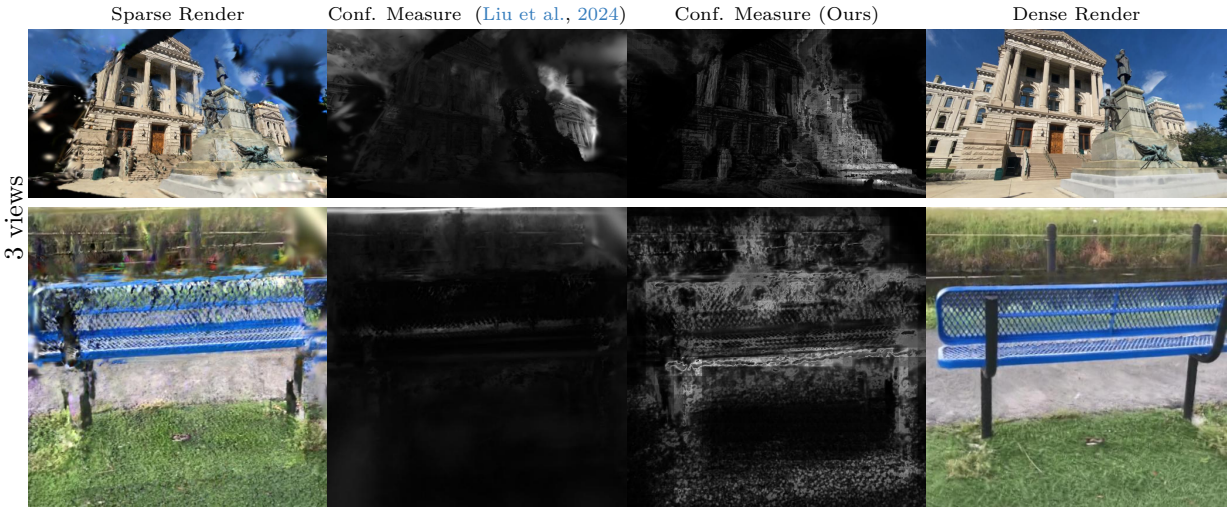

Figure 7: Confidence Measure comparison with 3DGS-Enhancer (Liu et al., 2024). Our confidence map accurately identifies artifacts and 0-Gaussian regions in the sparse-view (darker pixels) while Liu et al. (2024) incorrectly attributes high confidence to regions with overlap of small-scale Gaussians. NVS render from a densely fitted 3DGS representation is provided for reference.

and detect Gaussian artifacts guided by the confidence map, context and geometry features and generate a clean version of the conditioning image. For this, we build a dataset generation pipeline comprising a high-quality 3DGS model fitted to dense views, a low-quality 3DGS model fitted to few views, and camera interpolation and perturbation modules to use supervision of the high-quality model at viewpoints beyond ground truth camera poses. For a given scene, we fit sparse models for $M \in \{3, 6, 9, 18\}$ number of views. We render I^i using the high-quality model and $\hat{I}^i$, $\mathcal{C}^i$ using the low-quality model. We save the CLIP features c_{clip} and plücker embeddings of the M sparse views and 1 target view per sample for conditioning $\boldsymbol{\epsilon_\theta}$. Our fine-tuning setup is illustrated in Fig 12 (Sec C).

2.5 Depth-Augmented Autoencoder Finetuning

For encoding and decoding RGBD images, we customize a Variational AutoEncoder by introducing additional channels in the first and last convolutional layers of the Stable Diffusion VAE. A similar approach was followed by Stan et al. (2023), where their KL-autencoder was finetuned with triplets containing RGB images, depth maps, and captions to train the weights in the new channels. However, the depth maps used for fine-tuning this VAE were estimated using MiDaS (Ranftl et al., 2020), which are usually blurry monocular depth estimates. As such, reconstructing RGBD images using this VAE produces depth maps with extreme blur - not ideal for a scene reconstruction problem. Hence, we further finetune this VAE with our synthetic dataset, which contains depth maps rendered by the differentiable 3DGS rasterizer, giving accurate pixel depth with high-frequency details. Specifically, we use the following objective:

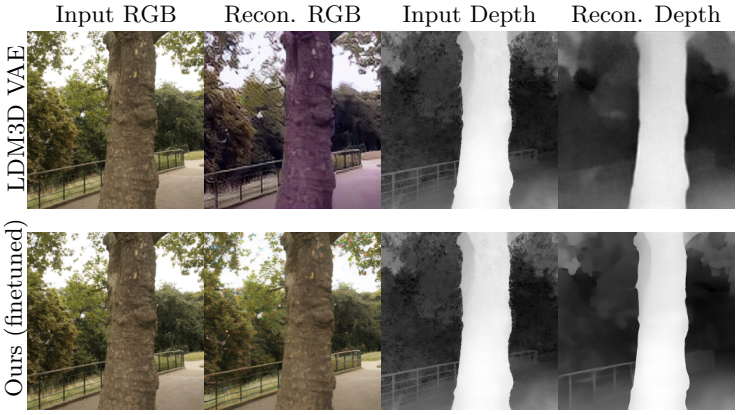

Figure 8: RGBD reconstruction comparison of our finetuned VAE with the LDM3D VAE (Stan et al., 2023). Unlike LDM3D, our VAE finetuned on a synthetic dataset preserves sharp details and edges of the input depth map while also preventing color artifacts in RGB.

$$\mathcal{L}_{\text{autoencoder}} = \min_{\mathcal{E},D} \max_{D_\psi} \big(\mathcal{L}_{\text{rec}}(x, D(\mathcal{E}(x))) - \mathcal{L}_{\text{adv}}(D(\mathcal{E}(x))) + \log(D_\psi(x)) + \mathcal{L}_{\text{reg}}(x; \mathcal{E}, D) \big) \tag{3}$$

where $\mathcal{L}_{rec}$ is a combination of L1, perceptual losses for the RGB channels, and Pearson Correlation Coefficient (PCC), TV regularization losses for the depth channels. $\mathcal{L}_{\text{adv}}$ is the adversarial loss, D_ψ is a patch-based discriminator loss, and $\mathcal{L}_{\text{reg}}$ is the KL-regularisation loss. The incorporation of PCC and TV terms for the depth channels leads to better retention of high-frequency details in the reconstructed depth map, as observed in Fig 8. We finetune this VAE on a subset of our dataset for 5000 training steps with batch size 16 and learning rate 1e-05.

2.5.1 UNet Finetuning

With our finetuned autoencoder, we next train the UNet with the frozen VAE on $\mathcal{X}$ with this objective:

$$\mathcal{L}_{diff} = \mathbb{E}_{i \sim \mathcal{U}(N), \epsilon \sim \mathcal{N}(\mathbf{0}, \mathbf{I}), t} \Big[\| \epsilon_t - \boldsymbol{\epsilon}_{\boldsymbol{\theta}}(\mathbf{z}_t^i; t, \mathcal{E}(\hat{I}), \hat{\mathcal{C}}, \mathcal{E}(\hat{I} \cdot \mathcal{C}), c_{attn}^{clip}, c_{attn}^{geo}) \|_2^2 \Big] \tag{4}$$

2.5.2 RGBD Novel View Synthesis

At inference time, given a render and depth map with artifacts, and confidence map, CLIP features and camera embeddings for conditioning, the finetuned UNet $\boldsymbol{\epsilon}_{\boldsymbol{\theta}}$ learns to predict the noise in latent $\mathbf{z}_t$ according to $t \sim \mathcal{U}[t_{min}, t_{max}]$ as:

$$\begin{aligned} \hat{\epsilon}_t = & \boldsymbol{\epsilon}_{\boldsymbol{\theta}}(\mathbf{z}_t; t, \varnothing, \varnothing, \varnothing, c_{attn}^{clip}, c_{attn}^{geo}) \\ & + s_I(\boldsymbol{\epsilon}_{\boldsymbol{\theta}}(\mathbf{z}_t; t, \mathcal{E}(\hat{I}), \hat{\mathcal{C}}, \mathcal{E}(\hat{I} \cdot \mathcal{C}), c_{attn}^{clip}, c_{attn}^{geo}) - \boldsymbol{\epsilon}_{\boldsymbol{\theta}}(\mathbf{z}_t; t, \varnothing, \hat{\mathcal{C}}, \varnothing, c_{attn}^{clip}, c_{attn}^{geo})) \\ & + s_C(\boldsymbol{\epsilon}_{\boldsymbol{\theta}}(\mathbf{z}_t; t, \varnothing, \hat{\mathcal{C}}, \varnothing, c_{attn}^{clip}, c_{attn}^{geo}) - \boldsymbol{\epsilon}_{\boldsymbol{\theta}}(\mathbf{z}_t; t, \varnothing, \varnothing, \varnothing, c_{attn}^{clip}, c_{attn}^{geo})) \end{aligned} \tag{5}$$

where s_I and s_C are the RGBD image and confidence map guidance scales, dictating how strongly the final multistep reconstruction agrees with the RGBD render $\hat{I}$ and the confidence map $\mathcal{C}$, respectively. After $k = 20$ DDIM (Song et al., 2021) sampling steps, we obtain our final RGBD render by decoding the denoised latent as $x_\pi = [I_\pi, D_\pi] = \mathcal{D}(z_0)$.

2.6 Scene Reconstruction with Generative Priors

Our generative diffusion model provides a generative prior to infer plausible detail in unobserved regions. Despite view conditioning using pose embeddings, the generated images at novel poses lack complete 3D consistency. For this, we devise an iterative strategy where we first sample novel views along an elliptical trajectory fitted to the training views. We initialize the Gaussian optimization with the set of Gaussians $\mathcal{G}$ fitted to the training views (Sec 2.1). Each novel view is added to the training stack at the beginning of every densification step to encourage the optimization to adjust to the distilled scene priors. At every iteration, we sample either an observed or unobserved viewpoint from the current training stack. We bring back Adaptive Density Control to encourage densification of Gaussians in 0-Gaussian regions. We employ the 3DGS objective for the training views. For novel views, we employ the SparseFusion (Zhou and Tulsiani, 2023) objective in the RGB space and a PCC loss for the rendered and denoised depths.

$$\mathcal{L}_{sample}(\psi) = \mathbb{E}_{\pi,t} \Big[w(t)(\| I_\pi - \hat{I}_\pi \|_1 + \mathcal{L}_p(I_\pi, \hat{I}_\pi)) \Big] + w_d \cdot PCC(D_\pi, \hat{D}_\pi) \tag{6}$$

where $\mathcal{L}_p$ is the perceptual loss (Zhang et al., 2018), $w(t)$ a noise-dependent weighting function, I_π, D_π are the rendered image and depth at novel viewpoint π, and $\hat{I}_\pi, \hat{D}_\pi$ are their rectified versions obtained with our diffusion prior. The PCC loss is defined as $PCC(D_\pi, \hat{D}_\pi) = 1 - \frac{\text{Cov}(D_\pi, \hat{D}_\pi)}{\sigma_{D_\pi} \sigma_{\hat{D}_\pi}}$.

2.7 Test-time Pose Alignment

GScenes reconstructs a plausible 3D scene from pose-free source images. However, reconstruction with few views is inherently ambiguous as several solutions can satisfy the train view constraints. Hence, the reconstructed scene would probably be quite different from the actual scene from which M views were sampled. Hence, for a given set of test views, following prior work (Fan et al., 2024; Jiang et al., 2024), we freeze the Gaussian attributes and optimize the camera pose for each target view by minimizing a photometric loss between the rendered image and test view. Following this alignment step performed for 500 iterations per test image, we evaluate the NVS quality.

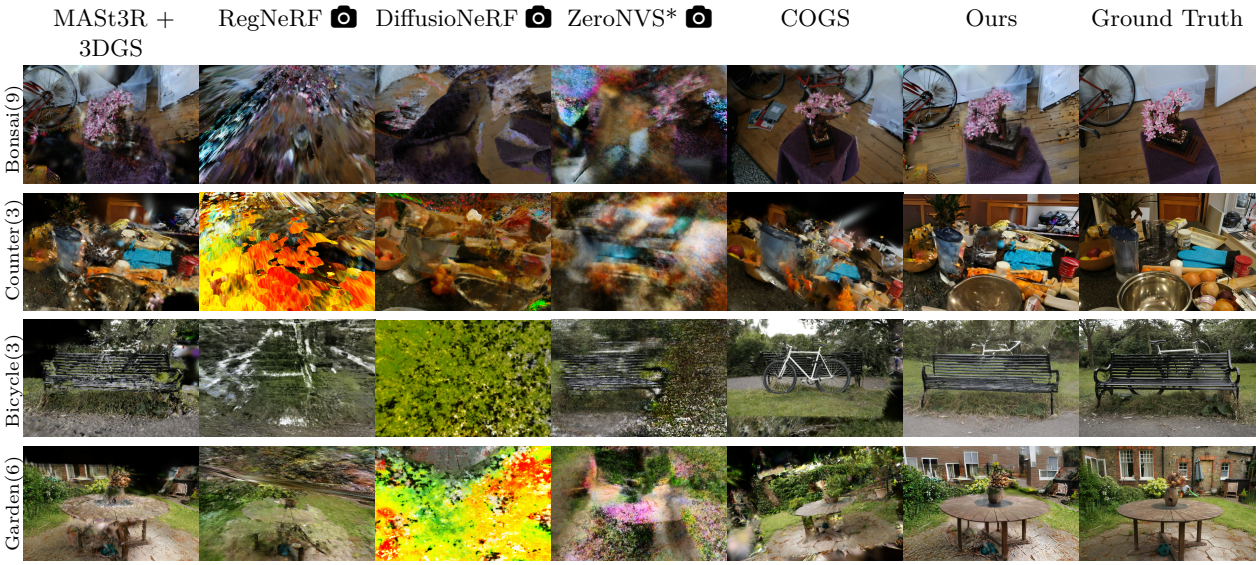

Figure 9: **Qualitative comparison** of GScenes with few-view methods on the **MipNeRF360** dataset. Our approach consistently fairs better in recovering image structure from foggy geometry, where baselines typically struggle with "floaters" and color artifacts.

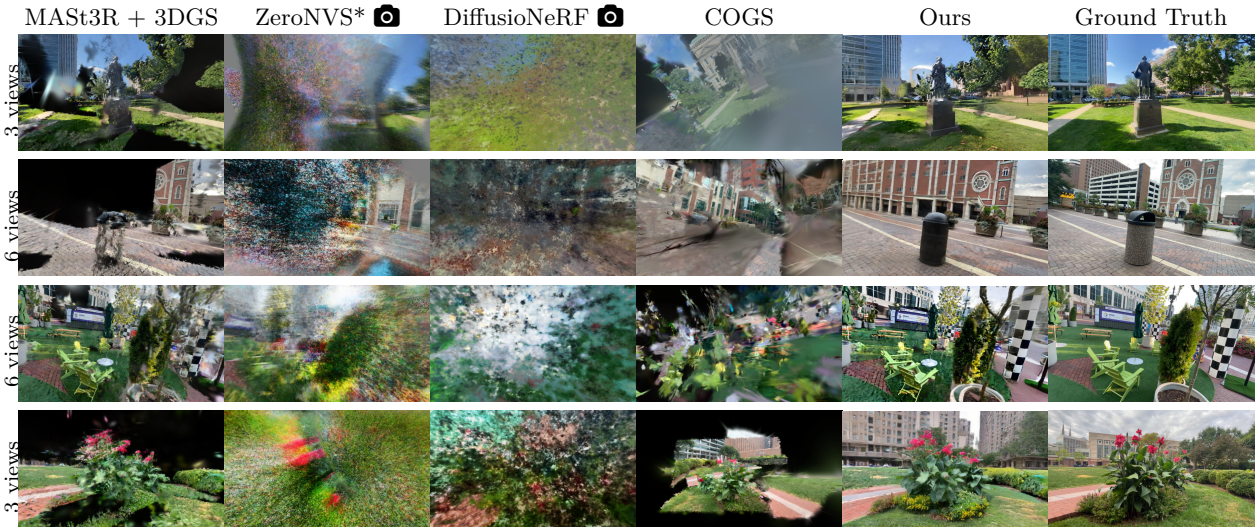

Figure 10: **Qualitative comparison** of *GScenes* with few-view methods on the **DL3DV benchmark**. Our method achieves plausible reconstruction in unobserved areas of complex scenes where even posed reconstruction techniques struggle.

3 Experiments

We compare *GScenes* with state-of-the-art pose-free and posed sparse-view reconstruction methods in Fig 9, 10 and Table 1, 2. We also ablate the different components and design choices of our diffusion model.

3.1 Experimental Setup

Evaluation Dataset We evaluate GScenes on the 9 scenes of the MipNeRF360 dataset (Barron et al., 2022), and 15 scenes (out of 140) of the DL3DV-10K benchmark dataset. For MipNeRF360, We pick the M-view splits as proposed by ReconFusion and CAT3D and evaluate all baselines on the official test views where every 8th image is held out for testing. For DL3DV-10K scenes, we create M-view splits using a greedy view-selection heuristic for maximizing scene coverage given a set of dense training views, similar to the heuristic proposed in Wu et al. (2024). For test views, we hold out every 8th image as in MipNeRF360. Additionally, we pick the *plant* scene of CO3D for qualitative comparison with ReconFusion and CAT3D.

Fine-tuning Dataset We fine-tune our diffusion model on a mix of 1043 scenes encompassing Tanks and Temples (Knapitsch et al., 2017), CO3D (Reizenstein et al., 2021), Deep Blending (Hedman et al., 2018), and the $1k$ subset of DL3DV-10K (Ling et al., 2024) to obtain a total of $171,461$ data samples. We first train 3DGS on sparse and dense subsets of each scene for $M \in \{3, 6, 9, 18\}$. For $M > 18$, novel view renders and depth maps mostly show Gaussian blur as artifacts. Finetuning this model takes about 4-days on a single A6000 GPU.

Metrics Our quantitative metrics are used to evaluate two tasks - quality of novel views post reconstruction and camera pose estimation. For the former, we compute 3 groups of metrics - FID (Heusel et al., 2017) and KID (Bińkowski et al., 2018) due to the generative nature of our approach, perceptual metrics LPIPS (Zhang et al., 2018) and DISTS (Ding et al., 2020) to measure similarity in image structure and texture in the feature space, and pixel-aligned metrics PSNR and SSIM. However, PSNR and SSIM are not suitable evaluators of generative techniques (Chan et al., 2023; Sargent et al., 2024) as they favor pixel-aligned blurry estimates over high-frequency details.

Baselines We compare our approach against 8 baselines, but our main comparison is with 2 pose-free methods - COGS and our 3D reconstruction engine - MASt3R + 3DGS. The other 6 methods are posed and included for a stronger comparison. Out of these, FreeNeRF, RegNeRF, and DiffusioNeRF are sparse-view regularization methods based on NeRFs. ZeroNVS reconstructs a complete 3D scene from a single image using a novel camera normalization scheme and anchored SDS loss. We use the ZeroNVS* baseline introduced in ReconFusion, designed to adapt ZeroNVS to multi-view inputs. Further, we also provide the reported quantitative results from ReconFusion and CAT3D, which are closed source and unverifiable, to show that our method gets close to their performance despite using a fraction of their compute. We also pick the relevant scenes and test views from the 2 papers for qualitative comparison.

3.2 Implementation Details

GScenes is implemented in PyTorch 2.3.1 on single A5000/A6000 GPUs. Images and depth maps are rendered at 400-600 pixels to align with Stable Diffusion's resolution. The diffusion model is finetuned for $100k$ iterations (batch size 16, learning rate 1e-4) with conditioning element dropout probability of 0.05 for CFG.

Following InstantSplat, we fit 3D Gaussians to sparse inputs and MASt3r point clouds for $1k$ iterations to obtain $\mathcal{G}$. We use classifier-free guidance scales $s_I = s_C = 3.0$ and sample with $k = 20$ DDIM steps. We linearly decay w_d from 1 to 0.01 and $\mathcal{L}_{sample}$ weight from 1 to 0.1 over $10k$ iterations. *GScenes* completes full 3D reconstruction in approximately 5 minutes on a single A6000 GPU.

3.3 Comparative Results

We report qualitative and quantitative comparisons of *GScenes* against all related baselines in Fig 9, 10 and Tables 1 and 2. Additional qualitative results are provided in Fig 14 and 15 (Sec E). Out of the 8 baselines, only *MASt3R + 3DGS* and *COGS* are pose-free techniques, but *COGS* relies on ground truth camera intrinsics while *GScenes* and *MASt3R + 3DGS* do not. In classical metrics (Tab 1), our baseline *MASt3R +*

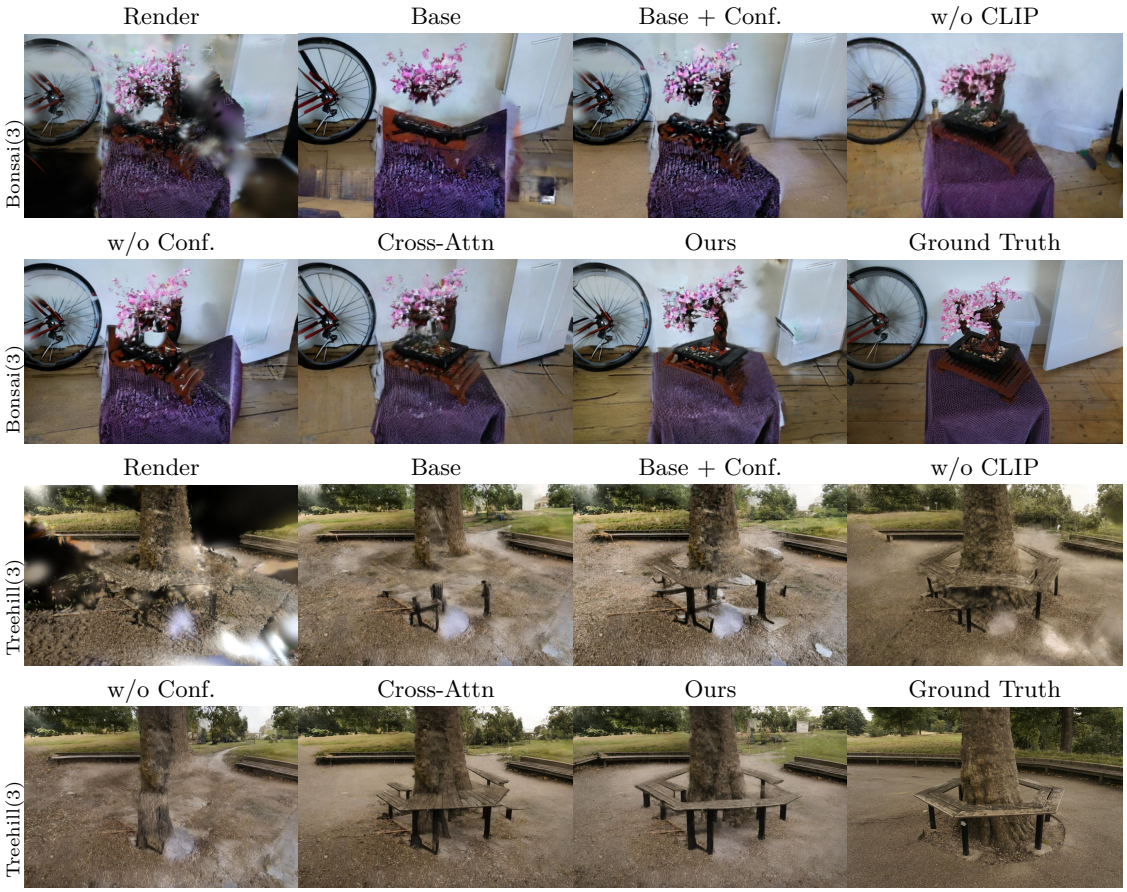

Figure 11: Ablation Study with the 3-view splits of *Bonsai* and *Treehill* scenes from MipNeRF360. Images show samples from different variants of our diffusion model based on conditioning.

Table 1: **Quantitative comparison** with state-of-the-art sparse-view reconstruction techniques on classical metrics. Red, orange, and yellow indicate best, second-best, and third-best performing methods, respectively. † indicates numbers as reported in the original paper, which could not be confirmed due to closed-source models and data. 📷 indicates posed methods.

	Method	PSNR ↑			SSIM ↑			LPIPS ↓		
		3-view	6-view	9-view	3-view	6-view	9-view	3-view	6-view	9-view
MipNeRF360	FreeNeRF 📷	11.886	12.874	13.673	0.180	0.218	0.236	0.675	0.654	0.638
	RegNeRF 📷	12.294	13.204	13.796	0.182	0.207	0.217	0.668	0.656	0.625
	DiffusioNeRF 📷	9.996	12.025	12.567	0.159	0.211	0.213	0.715	0.648	0.659
	ZeroNVS* 📷	11.991	11.817	11.729	0.142	0.129	0.128	0.710	0.705	0.694
	ReconFusion† 📷	15.50	16.93	18.19	0.358	0.401	0.432	0.585	0.544	0.511
	CAT3D† 📷	16.62	17.72	18.67	0.377	0.425	0.460	0.515	0.482	0.460
	MASt3R + 3DGS	12.585	14.285	15.042	0.231	0.279	0.310	0.593	0.550	0.531
	COGS	11.814	12.095	12.555	0.183	0.210	0.228	0.619	0.630	0.605
	GScenes	13.809	14.507	14.831	0.265	0.275	0.282	0.547	0.530	0.521
DL3DV	DiffusioNeRF 📷	11.715	13.245	14.504	0.245	0.317	0.376	0.606	0.544	0.500
	ZeroNVS* 📷	12.145	12.560	12.774	0.202	0.206	0.209	0.679	0.658	0.648
	MASt3R + 3DGS	13.217	16.417	17.840	0.371	0.476	0.531	0.443	0.359	0.326
	COGS	11.057	12.350	13.300	0.241	0.282	0.318	0.598	0.564	0.539
	GScenes	14.751	15.761	16.199	0.340	0.372	0.394	0.410	0.373	0.360

Table 2: **Quantitative comparison** with few-view reconstruction techniques on metrics suited for generative reconstruction. Red, orange, and yellow indicate best, second-best, and third-best performing methods.

	Method	FID ↓			KID ↓			DISTS ↓		
		3-view	6-view	9-view	3-view	6-view	9-view	3-view	6-view	9-view
MipNeRF360	FreeNeRF 📷	354.244	353.480	346.874	0.261	0.271	0.282	0.388	0.369	0.365
	RegNeRF 📷	358.855	360.380	338.183	0.281	0.301	0.264	0.407	0.405	0.377
	DiffusioNeRF 📷	370.346	347.522	342.373	0.293	0.267	0.257	0.441	0.386	0.402
	ZeroNVS* 📷	356.395	350.920	343.930	0.283	0.296	0.300	0.433	0.426	0.413
	MASt3R + 3DGS	294.819	252.830	231.169	0.210	0.164	0.133	0.303	0.273	0.264
	COGS	251.694	284.829	270.118	0.158	0.183	0.159	0.297	0.313	0.303
	GScenes	163.747	156.368	160.919	0.053	0.052	0.055	0.234	0.227	0.230
DL3DV	DiffusioNeRF 📷	251.341	210.596	199.629	0.179	0.154	0.147	0.352	0.314	0.300
	ZeroNVS* 📷	267.407	243.095	233.998	0.214	0.200	0.199	0.372	0.346	0.330
	MASt3R + 3DGS	174.665	136.013	118.675	0.117	0.077	0.062	0.247	0.204	0.187
	COGS	249.530	224.605	207.782	0.198	0.159	0.128	0.308	0.295	0.283
	GScenes	107.750	107.329	105.871	0.036	0.046	0.046	0.193	0.190	0.189

3DGS shows better values than *GScenes*, as these metrics are usually inadequate for evaluating generative NVS techniques. Nevertheless, we include them for completeness and observe that either our method or the baseline is the best pose-free, open-source method. CAT3D and Reconfusion appear to do better in a posed setting, but we cannot confirm these values nor do a fair comparison in a pose-free setting as they are closed-source. For metrics tailored for generative reconstruction (Tab 2), our method comprehensively outperforms the baseline as well as all related methods for both MipNeRF360 and DL3DV-Benchmark datasets. Due to the unavailability of open-source code, evaluating *ReconFusion* and *CAT3D* on these measures is unfortunately not possible. However, we do provide a qualitative comparison with both methods in Sec D. Qualitative comparisons with other open-source posed and pose-free methods clearly show that *GScenes* is far more adept at generating plausible scene content from partial observations.

3.4 Ablation Studies

In Fig 11 and Tab 3 (Sec F), we thoroughly ablate different components of our diffusion model. We pick the *bonsai* and *treehill* scenes and their 3-view splits for this experiment. The 1st out of 8 columns shows the initial novel-view render obtained from the 3D reconstruction pipeline (MASt3r + 3DGS). The *Base* variant only performs image-to-image diffusion with no other conditioning, and this already provides a strong baseline for inpainting and artifact elimination in novel-view renders. Without CLIP context guidance, the model fails to adhere to the semantics of the input images when inpainting missing details. Without our confidence measure, the model typically fails to differentiate between image structures and artifacts, often producing implausible images despite context and geometry conditioning. Additionally, we train a *Cross-Attn* variant where context and geometry conditionings are incorporated using cross-attention instead of FiLM modulation layers in the down and middle blocks of the UNet. Our method achieves similar quality and FID/KID/DISTS scores with more than **3x** fewer additional trainable parameters. Similar to Tab 1, *GScenes* performs a little worse on PSNR, SSIM, and LPIPS compared to the baseline, as these metrics penalize the generation of plausible scene details, slightly dissimilar from the original scene. Nevertheless, the qualitative results clearly show the benefits of our proposed context, geometry, and confidence map conditioning.

4 Conclusion

In this work, we present *GScenes* where we integrate an image-to-image RGBD diffusion model with a pose-free reconstruction pipeline in MASt3R to reconstruct a 360°3D scene from a few uncalibrated 2D images. We introduce context and geometry conditioning through FiLM layers achieving similar performance as a cross-attention variant. We also introduce a pixel-aligned confidence measure to further guide the diffusion model in uncertain regions with missing details and artifacts. Our experiments show that *GScenes* outperforms existing pose-free reconstruction techniques in scene reconstruction and performs competitively with state-of-the-art posed sparse-view reconstruction methods.

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