Radiance Cascades Compared to Unity's Standard Global Illumination Methods

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ABSTRACT

This paper presents an empirical evaluation of real-time global illumination (GI) methods in the Unity Universal Render Pipeline (URP). Developers working with dynamic scenes must often choose between fundamentally different GI approaches while balancing performance, visual stability, and implementation complexity. To investigate these trade-offs, this study compares three methods available in URP environments: Screen Space Global Illumination (SSGI), built-in Realtime Lightmaps (RTLM), and the recently proposed Radiance Cascades (RC) technique. The evaluation was conducted across three representative game scenarios—a realistic FPS environment, an isometric scene, and a stylized interior—using controlled camera paths and dynamic lighting events. Performance metrics (FPS and frame time) were collected alongside qualitative analysis of visual artifacts. The results highlight practical strengths and limitations of each approach and provide developer-oriented recommendations for selecting GI techniques in URP-based projects.

Keywords

Radiance Cascades, Dynamic GI, Unity Engine, performance benchmarking, visual quality assessment, cross-genre evaluation, empirical analysis

INTRODUCTION

Real-time Global Illumination (GI) in modern game engines represents a set of approximate methods designed to balance visual fidelity, temporal stability, and computational performance (Kung 2025). When working with dynamic scenes in the Unity Universal Render Pipeline (URP) ecosystem, developers often face a choice between fundamentally different approaches to indirect lighting (Abou 2025).

The practical selection of a GI method is rarely dictated by visual quality alone; it depends on the game genre, level structure, and target hardware constraints. This paper investigates Screen Space Global Illumination (SSGI), Realtime Lightmaps (RTLM), and the recently introduced Radiance Cascades (RC) technique in order to identify their strengths and limitations in dynamic environments.

Several studies have previously explored the comparative performance of real-time global illumination methods. Lambru et al. (2021) presented a broad analysis of multiple GI techniques, including Reflective Shadow Maps, Light Propagation Volumes, Screen-Space methods, and voxel-based approaches. However, many of these techniques are either unavailable or not directly applicable within the URP ecosystem, and the study reflects the technological landscape of 2021, which may not fully represent the current state of real-time rendering pipelines. More recent work has investigated Radiance Cascades in

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comparison with Voxel Cone Tracing (Kung 2025), yet practical implementations of voxel-based GI solutions are currently not freely available for URP environments, limiting their applicability for many developers and researchers.

Consequently, there remains a lack of practical comparative studies evaluating currently accessible real-time GI solutions within the URP pipeline. This work addresses this gap by conducting an experimental comparison of SSGI, RTLM, and Radiance Cascades across several representative game scenarios, focusing on performance characteristics, visual stability, and practical usability in dynamic environments.

METHODOLOGY

Hardware and Software Configuration

All experiments were conducted on a laptop running Windows 11, equipped with an Intel Core i7-13620H CPU, 16 GB of RAM, and an NVIDIA GeForce RTX 4060 Laptop GPU. The tests were performed using Unity 6000.2.12f1 with the Universal Render Pipeline (URP).

Frame time and performance metrics were captured using Unity Recorder in combination with a custom CSV logging script that recorded per-frame timing data.

The goal of this setup was not to achieve absolute reproducibility across different hardware configurations, but to maintain consistent conditions within the same hardware and software environment, allowing for relative performance comparison between different global illumination methods.

Experimental Scenarios

Three distinct scenarios were used to evaluate the performance and visual behavior of the global illumination methods:

- A realistic first-person environment representing a typical FPS-like urban exterior scene with dynamic lighting interactions and partial occlusion.
- An isometric environment with a fixed camera angle. Due to the lack of support for orthographic cameras in Radiance Cascades, all methods were tested using a perspective camera with a very narrow field of view to approximate isometric projection.
- A stylized low-poly interior scene designed under mobile-tier constraints, emphasizing simplified geometry and materials while preserving dynamic lighting interactions.

All camera movements were defined using predefined spline paths to ensure identical motion across all test runs. Dynamic lighting events (e.g. muzzle flashes, door opening sequences, and moving point lights) were synchronized across all global illumination methods to preserve temporal consistency between runs.

Each test run had a fixed duration of approximately one minute and consisted of two full passes of the camera path through the scene. For each global illumination method and scenario combination, one representative run was recorded and used for analysis.

Data Collection and Processing

Performance data was recorded and exported to CSV format using a custom log script. The collected metrics included frame time, milliseconds per frame, and frames per second.

- average performance trends,
- stability of frame time over time,
- relative performance differences between global illumination methods under identical scene conditions.

Visual Evaluation Protocol

In addition to performance measurements, a qualitative visual inspection was conducted. Representative frames and screenshots were captured for each scenario and method.

Observed visual artifacts were manually annotated and categorized. The analysis focused on:

- temporal instability and ghosting,
- limitations in handling dynamic emissive surfaces,
- inconsistencies in indirect lighting,
- characteristic artifacts specific to each global illumination method.

Reproducibility and Scope

The experimental scenes used in this study were constructed using publicly available Unity Asset Store packages. Specifically, the isometric scenario was based on the Tanks Complete Project tutorial scene, the stylized indoor FPS scenario used the Unity Learn FPS Microgame (URP), and the realistic FPS environment was built using the Industrial Set V2.0 asset package. In each case, a representative scene from the asset pack was adapted by introducing controlled lighting setups and test conditions required for the evaluation.

The resulting experimental artifacts, including performance logs, generated graphs, and recorded video demonstrations—are publicly available in the project repository:

https://github.com/Zertass-2-0/Radiance-Cascades-Compared-to-Unity-s-Standard-Global-Illumination-Methods

RESULTS AND ANALYSIS

Performance Evaluation

Across all evaluated scenarios, a stable relative performance correlation was observed. In general, Screen-Space Global Illumination demonstrated the lowest performance, while Radiance Cascades and Realtime Lightmaps showed significantly higher frame rates.

Isometric Scene

In the isometric scenario, the median frame rate for both RC and RTLM remained close to 220 FPS throughout most of the test run. RC consistently outperformed RTLM by approximately 5--10 FPS on average.

SSGI exhibited the most stable frame time behavior; however, it was also the most expensive method in this scenario. Its frame rate remained near 105 FPS for the majority of the test duration, resulting in roughly a twofold performance drop compared to RC and RTLM.

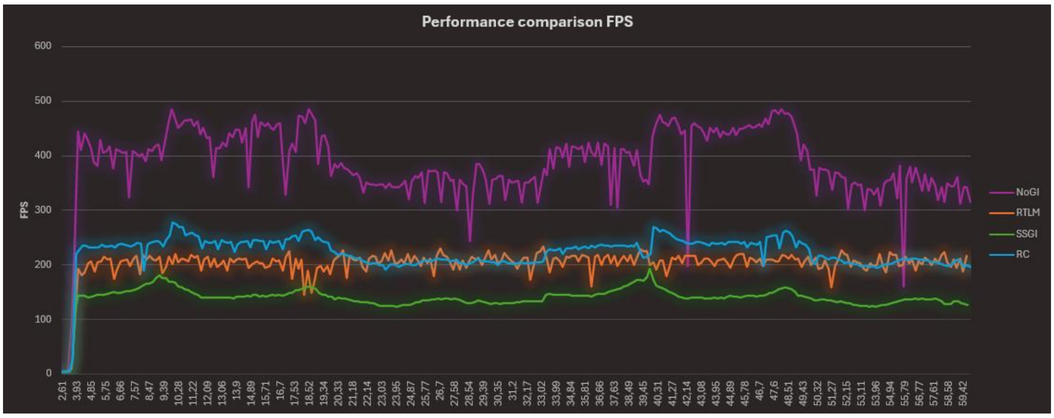

Figure 1: Frame rate dynamics in the isometric scenario.

Realistic Environment Scene

In the realistic exterior environment, RC demonstrated the highest overall performance for most of the camera path. However, during the segment featuring a dynamically moving point light between dense columns, RC performance temporarily converged with RTLM, indicating increased sensitivity to high-frequency local lighting changes.

SSGI achieved moderate frame rates (approximately 150 FPS on average). This apparent improvement in performance is largely explained by the camera-dependent nature of SSGI: a significant portion of the scene's reflective and indirectly lit surfaces remained outside the view frustum for most of the test, effectively reducing the amount of indirect lighting being computed (Abou 2025). As a result, large parts of the scene remained underlit, artificially reducing the computational workload.

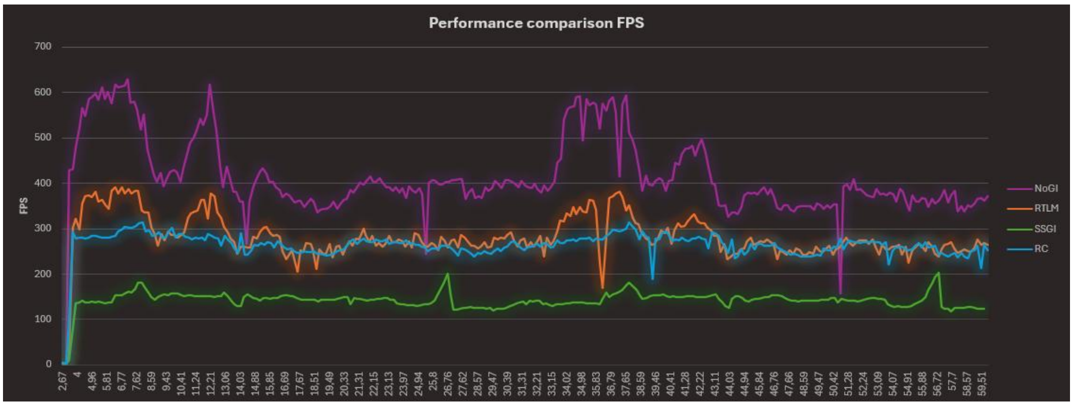

Figure 2: Frame rate dynamics in the realistic scenario.

Stylized Interior Scene

In the stylized low-poly interior environment, all methods preserved the same relative performance correlation observed in other scenarios: RC ≈ RTLM > SSGI.

Compared to the isometric case, the average frame rate increased by approximately 20% across all methods, likely due to reduced geometric and shading complexity. However, frame time stability decreased slightly for all methods, particularly for RTLM. Despite this instability, RC and RTLM remained significantly more performant than SSGI.

Figure 3: Frame rate dynamics in the stylized scenario.

Qualitative Visual Analysis

The qualitative visual evaluation revealed several characteristic limitations and artifacts for each global illumination method, which varied depending on scene structure and lighting dynamics.

Isometric Scene

In the isometric scenario, dynamic emissive surfaces became the primary source of visual artifacts.

Radiance Cascades produced visually convincing indirect illumination from emissive materials and dynamic light sources. In contrast, RTLM failed to incorporate dynamic emissive contributions into the global illumination solution, as emissive lighting could only be baked for static geometry.

SSGI exhibited two dominant artifacts: a noticeable overall darkening of the scene and light traces behind moving emissive objects. The trailing effect was caused by reliance on previous frames (Abou 2025), producing an effect similar to long-exposure photography.

Figure 4: Visual comparison of GI methods in the isometric scene. Left to right: RTLM, RC, SSGI

Realistic Environment Scene

In the realistic environment, RC produced a pronounced bloom-like effect on illuminated surfaces even under neutral daylight conditions. This behavior significantly reduced visual plausibility, suggesting that RC, in its current form, is not well-suited for physically plausible daylight illumination scenarios. In particular, the method appears to over-amplify indirect radiance in high-intensity lighting conditions, leading to excessive light bleeding and loss of material definition.

RTLM produced the most visually natural and stable indirect lighting in this scenario. However, dynamic objects such as opening doors could not be baked into the lightmaps (Lambru 2021), requiring the introduction of extra artificial light simulation on such surfaces.

SSGI, as was observed previously, failed to provide meaningful indirect illumination for large portions of the scene, as most contributing geometry remained outside the camera frustum. Consequently, large areas of the environment appeared unnaturally dark.

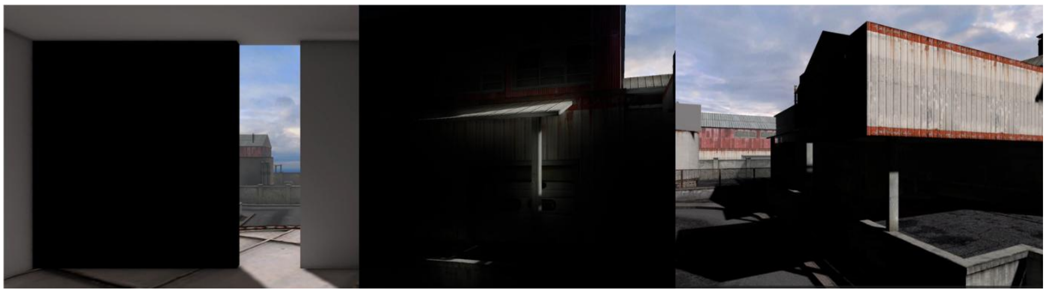

Figure 5: Visual comparison of GI methods in the Realistic scene. Left to right: RTLM, RC, SSGI

Stylized Interior Scene

In the stylized interior environment, RTLM continued to ignore dynamic emissive contributions, limiting its applicability for interactive lighting effects.

RC produced excessive visual noise and blur, particularly noticeable at close viewing distances (Abou 2025; Kung 2025).

SSGI provided the most visually pleasing results in this scenario, producing coherent indirect lighting and natural-looking light interactions in a confined space where most contributing geometry remained visible on screen. The only notable artifact was the presence of multi-colored noise during the first few frames after initialization.

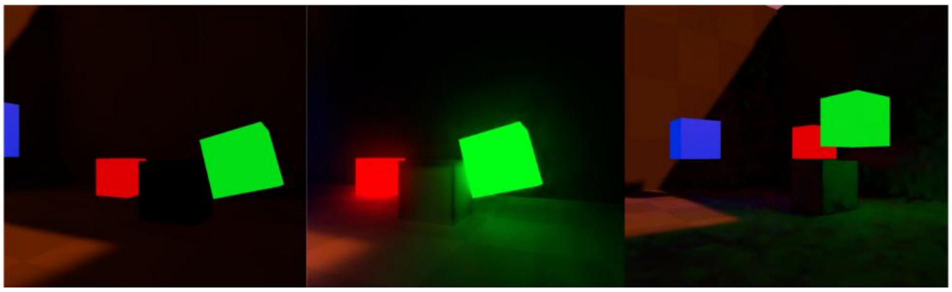

Figure 6: Visual comparison of GI methods in the Stylized scene. Left to right: RTLM, RC, SSGI

DISCUSSION AND RECOMMENDATIONS

Based on the empirical results, the following practical recommendations are proposed:

Criterion	RC	SSGI	RTLM
Performance	High	Low	High
Dynamic Objects Support	Full	Full	Limited
Temporal Stability	Medium	Low	High

Table 1: Comparative Overview of GI Methods.

- **Radiance Cascades** is optimal for scenes with numerous dynamic light sources observed from a distance.
- **SSGI** is recommended for contained interiors where the primary reflecting surfaces remain within the screen space.
- **Realtime Lightmaps** should be utilized as a supplement to traditional baking to ensure stable lighting for static geometry from dynamic light sources.

Beyond technical performance, the choice of a global illumination method has direct implications for player experience and genre-specific aesthetic goals. In fast-paced FPS environments, temporal instability and flickering artifacts (as observed with SSGI) can reduce visual clarity and negatively affect target perception and player responsiveness. In contrast, stable lighting solutions such as RTLM contribute to consistent spatial readability, which is critical for competitive gameplay. For stylized or controlled interior scenes, SSGI can enhance perceived depth and material richness, supporting atmosphere-driven design despite its temporal limitations. Radiance Cascades, while less stable in high-intensity daylight conditions, can provide visually rich indirect lighting in scenes with multiple dynamic light sources, which may benefit genres emphasizing spectacle or dynamic lighting effects. Therefore, the selection of a GI method should not be treated purely as a rendering decision, but as a design choice that influences immersion, readability, and the overall aesthetic coherence of the game experience.

CONCLUSION

This study presented a practical, cross-genre comparison of currently available real-time global illumination solutions in Unity URP, focusing on performance, visual stability, and perceptual quality across representative scene types.

The study is limited to free and openly available methods within URP, a single hardware configuration, and qualitative perceptual evaluation without formal user studies. Additionally, each experimental condition was evaluated using a single controlled measurement run, which may limit the statistical robustness of the reported results. Future work includes extending the comparison to HDRP and custom GI implementations, evaluating additional hardware tiers, incorporating controlled user studies, and exploring hybrid GI pipelines that combine multiple techniques for improved robustness across diverse production scenarios.

REFERENCES

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