REAL-TIME NATURAL WORLDS

Latest research on procedural terrain, procedural flora, and water rendering for videogames

A research-to-engineering synthesis

Evidence cut-off: 2 September 2026

The practical frontier is a hybrid: deterministic spatial contracts, process-aware terrain, ecology-aware placement, GPU procedural geometry, and water representations chosen by phenomenon and scale.

Executive synthesis

The newest work does not point to one universal generator. It points to a composable world pipeline in which each representation owns the phenomena it can express and exposes stable data to gameplay.

Persistent IDs, gameplay queries and edit layers cross every stage; visuals are regenerated from bounded data.

Five conclusions

1. Learned terrain is becoming procedural. InfiniteDiffusion (SIGGRAPH 2026) targets determinism, infinite extent and random access rather than treating a diffusion model as a one-shot image tool.

2. Physical process remains the best structural prior. Stochastic geomorphological transport produces drainage-connected forms - meanders, braided rivers, deltas and fans - that are difficult to obtain from undirected noise.

3. Terrain fields should drive the rest of the world. The 2025 terrain-descriptor review makes slope, hydrology, visibility, landform, orometry and network metrics a reusable semantic layer for vegetation, settlements, traversal and materials.

4. Flora generation is moving onto the GPU. Work graphs and mesh shaders allow geometry, animation and continuous LOD to be produced per frame from compact programs; ecology and deterministic sampling still belong upstream.

5. Water needs multiple coupled representations. Spectral/height-field methods are efficient for broad surfaces; localized curves or deformation fields handle breaking waves; volumetric optical transport handles underwater appearance.

Recommendation

Build around a tiled, deterministic world-state contract. Generate macro terrain and drainage offline or asynchronously; add controllable detail at runtime; derive biome suitability and stable instance IDs from shared fields; render flora procedurally where hardware permits; and use a water-body graph coupled to localized surface solvers and a separate optical model.

1 / Procedural terrain

Terrain research is splitting into three complementary lanes: learned synthesis for fidelity, geomorphological simulation for structural plausibility, and controlled procedural amplification for cheap detail. A production engine can use all three at different scales.

InfiniteDiffusion / Terrain Diffusion (SIGGRAPH 2026)

PEER-REVIEWED

Finding. Reformulates diffusion sampling for spatially unbounded, seed-consistent generation with constant-time random access, then applies it to real-time terrain through a noise-like interface.

Game-engine use. Use as a chunk-addressable macro/meso proposal generator. Cache accepted tiles and extract gameplay fields rather than querying an opaque model everywhere.

Boundary. A conference result and technical demo, not proof of shipping-platform memory, latency, editability, multiplayer determinism or collision integration.

Stochastic geomorphological transport (SIGGRAPH 2026)

PEER-REVIEWED

Finding. A parallel stochastic point method couples long-distance transport and erosion across very different time scales; complex fluvial and mass-transport landforms emerge from momentum-aware transport.

Game-engine use. Use in authoring, world bake or low-frequency background jobs to generate coherent drainage basins, sediment corridors and depositional landforms.

Boundary. This is terrain synthesis/simulation, not a per-frame renderer. Preserve authored edits and gameplay constraints through masks or constrained re-simulation.

Terrain: measurement and controllability

Terrain descriptors for synthesis, analysis and simulation (CGF 2025)

SURVEY + CODE

Finding. Organizes geomorphological metrics into mathematical operators, visibility, landform, hydrology, orometry and river/ridge networks, with artist feedback and reference implementations.

Game-engine use. Treat descriptors as the semantic bus of the world: vegetation suitability, traversal cost, wetness, settlement probability, material choice and quest placement should consume the same named fields.

Boundary. Metrics quantify useful structure but do not by themselves guarantee visual realism, playability or fun; thresholds need biome- and scale-specific calibration.

Controlled procedural patterns for terrain detail (CGF 2024)

PEER-REVIEWED

Finding. Adapts phasor noise to flow and slope direction, nesting erosion-like ravines at multiple scales while retaining artist control through maps.

Game-engine use. Use after macro shape and drainage are locked: synthesize displacement/normal detail close to the camera without destroying the world-scale silhouette or river network.

Boundary. The reported browser/WebGL timings establish interactivity for the demonstrated cases, not a universal budget across consoles, materials and world sizes.

GSWT: Gaussian Splatting Wang Tiles (SIGGRAPH Asia 2025)

EMERGING

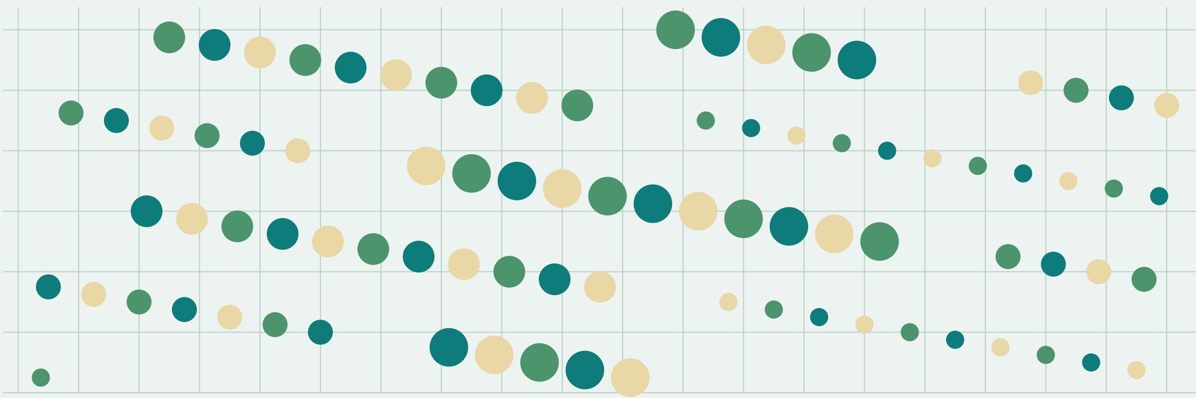
Finding. Stores boundary-constrained Gaussian fields in Wang tiles so a captured exemplar can be assembled into diverse, continuous, large-scale terrain and rendered in real time.

Game-engine use. Promising for high-fidelity scenic layers, distant terrain and reconstruction-derived worlds where relightability and collision can be supplied separately.

Boundary. Gaussian terrain is not automatically an authoritative gameplay surface. Physics, deformation, material semantics and ray-tracing interoperability remain separate contracts.

Engineering rule: generate topology and hydrology first; amplify appearance second. Never allow a near-field detail layer to silently become the source of collision, navigation or network authority.

2 / Procedural foliage and flora



Flora has three distinct problems: where organisms may exist, what individual organisms look like, and how billions of primitives are streamed and rendered. Recent GPU work mainly advances the third; ecological fields and art direction still govern the first two.

Real-Time GPU Tree Generation (HPG 2025)

PEER-REVIEWED

Finding. Uses D3D12 work graphs with mesh nodes to generate and render gigabytes of tree geometry from kilobytes of code each frame, with instant authoring, continuous frame-specific LOD, animation and seasonal details.

Game-engine use. Keep compact species/genotype parameters and stable tree IDs; expand only visible branches/leaves on the GPU. This converts storage bandwidth into bounded compute and makes growth/season changes parametric.

Boundary. Requires modern work-graph/mesh-node support. The public sample targets capable D3D12 hardware; portability, ray-tracing acceleration structures and console certification need separate work.

Real-time procedural resurfacing with mesh shaders (CGF 2025)

PEER-REVIEWED

Finding. Generates structured parametric geometry on arbitrary surfaces at render time with task/mesh shaders, control maps and screen-space LOD, reducing VRAM traffic versus static geometry.

Game-engine use. Useful for moss, ground cover, bark protrusions, coral-like structures and small plants that should conform to changing surfaces.

Boundary. Demonstrations ran on an RTX 3080-class GPU. This augments surfaces; it is not an ecosystem simulator or a full placement solution.

Flora: placement, ecology and persistence

GPU foliage instancing with quasi-Monte Carlo sampling (2025 preprint)

PREPRINT

Finding. Places leaf instances deterministically on arbitrary surfaces in a single compute dispatch using low-discrepancy sampling, avoiding Poisson-disk neighborhood validation and CPU involvement.

Game-engine use. Use for reproducible dense surface coverage when evenness matters. Hash surface/patch IDs into the sequence so streaming and re-entry reproduce identical instances.

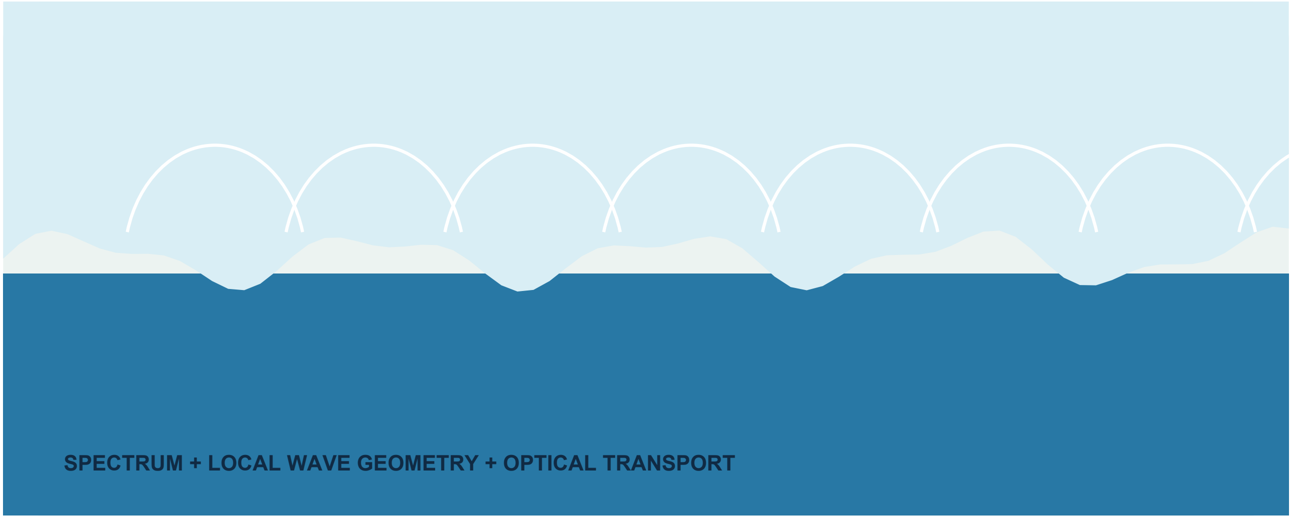
Boundary. The method is a 2025 SSRN preprint, not the same evidence tier as a peer-reviewed HPG/CGF paper; uniform coverage is not ecological plausibility.

A robust placement stack

Layer	Inputs	Output / invariant
Suitability	moisture, irradiance, elevation, slope, soil, disturbance	per-species probability or carrying capacity
Community	succession, competition, clustering, exclusions	coherent patches and age structure
Sampling	tile ID, species ID, seed, density	stable instance IDs; no camera dependence
Geometry	genotype, age, season, wind state	procedural mesh/strands with continuous LOD
Gameplay	damage, harvest, fire, growth, regrowth	sparse persistent deltas over regenerated baseline

The critical product distinction is baseline versus delta. The baseline forest can be regenerated from seeds and fields; only player-visible changes - felled trees, burned patches, harvested plants, construction exclusions - need durable storage.

3 / Water rendering



Water is not one shader. A complete game system couples body topology and flow, surface displacement, breaking phenomena, foam/spray, reflection/refraction, underwater transport and gameplay queries. Each should have an explicit owner and scale range.

Topology-changing rolling waves for massive open-ocean games (SIGGRAPH 2024 Talk)

PRODUCTION R&D;

Finding. Captures simulated wave behavior with approximation curves capable of representing overhangs and changing topology under strict open-world budgets, overcoming the height-only limit of displacement maps.

Game-engine use. Use a broad spectral ocean as the base, then place curve-driven localized rolling/breaking wave patches near coasts and hazards.

Boundary. A conference talk provides production-oriented method evidence, but less reproducible detail than an archival full paper; platform timings and tooling constraints must be validated locally.

Rendering Water in Horizon Forbidden West (SIGGRAPH 2022)

SHIPPED SYSTEM

Finding. Processes Houdini simulations into localized deformation textures, assembles them into artist-controlled wavefronts and generates fine surface geometry in compute shaders.

Game-engine use. Still one of the clearest production blueprints for hybrid water: offline high-quality simulation compressed into reusable, placeable runtime primitives.

Boundary. Older than the research cut-off window but retained as a production baseline. It demonstrates a shipped solution, not a universal architecture for rivers, interiors or multiplayer physics.

Water: appearance below and above the surface

Real-Time Underwater Spectral Rendering (CGF 2024)

PEER-REVIEWED

Finding. Models single and multiple scattering across wavelength bands and different water types. The reported eight-wavelength configuration rendered the demonstrated scene in 16.44 ms total, including 3.57 ms single scattering and 1.8 ms multiple scattering.

Game-engine use. Use spectral coefficients as authorable water-body data, then reduce or preintegrate for lower tiers. This supports physically meaningful variation between clear ocean, coastal and turbid water.

Boundary. The timing is scene- and hardware-specific and includes a particular rendering pipeline. It is evidence of feasibility, not a guaranteed 60 Hz budget in a full game.

RefracGS: refraction-aware Gaussian rendering (2026 preprint)

ADJACENT

Finding. Separates a neural water height field from an underwater Gaussian scene and traces refracted rays with Snell's law, reporting real-time novel-view rendering at 200 FPS after training.

Game-engine use. Relevant to captured environments, underwater reconstruction and reference-quality validation of refraction, but not yet a replacement for general dynamic game water.

Boundary. This is a March 2026 arXiv preprint focused on novel-view synthesis; training, dynamic objects, gameplay interaction and conventional engine integration are outside its core claim.

Representation ladder

Phenomenon	Representation	Best use
Far ocean / lakes	FFT or Gerstner spectrum + clipmap	wide area, periodic waves, cheap queries
Rivers / currents	spline or graph + shallow-water/flow maps	directed motion, banks, traversal
Breaking shore waves	localized deformation fields or curve patches	overhangs, art direction, foam sources
Spray / foam	particles + advected masks + temporal decay	topology and high-frequency breakup
Underwater light	absorption/scattering transport	depth color, beams, turbidity

4 / Recommended engine architecture

Persistent IDs, gameplay queries and edit layers cross every stage; visuals are regenerated from bounded data.

A practical 2026 architecture

1. World contract. Define a projected coordinate system, hierarchical tile IDs, deterministic seeds, material/species registries, edit layers and versioned generation recipes. All procedural outputs must be reproducible from these inputs.

2. Macro terrain. Produce height/topology, drainage and broad materials from authored constraints plus erosion or learned proposals. Validate seams, accessibility and gameplay metrics before accepting a tile.

3. Descriptor atlas. Cache slope, curvature, wetness, flow accumulation, landform class, exposure and distance fields at explicit scales. Make them available to rendering, AI, audio and gameplay.

4. Flora baseline. Evaluate species suitability and community rules, then sample stable instance IDs. Store compact organism parameters; expand visible geometry with GPU procedural pipelines where supported.

5. Water-body graph. Represent sources, sinks, banks, levels, flow directions and connectivity as authoritative data. Renderers consume this graph but do not own it.

6. Surface and optics. Select spectral, shallow-water, localized breaking-wave and underwater-scattering representations by body type and camera state. Share foam/velocity/depth fields across passes.

7. Sparse persistence. Save only authored overrides and gameplay deltas over the regenerated baseline. Version migrations must be deterministic and inspectable.

A 90-day prototype sequence

Weeks	Milestone	Exit evidence
1-3	Tile contract + descriptor atlas	same seed reproduces hashes; seam and query tests
4-6	Terrain + drainage + controlled detail	playable 4x4 tile world; stable collision/nav/material fields
7-9	Biome placement + persistent deltas	camera-independent IDs; harvest/fire/regrowth save-load tests
10-12	Water graph + two surface tiers	ocean/lake/river coverage; shoreline and underwater captures
13	Integrated budget and failure review	frame, memory, streaming, determinism and visual QA report

5 / Evaluation and risk

Evidence matrix

Claim to test	Terrain	Flora	Water
Determinism	tile hash across machines	stable IDs across culling	body state independent of camera
Continuity	height/normal/drainage seams	density and age seams	level/flow/wave seams
Scalability	random tile access; bounded cache	instance/triangle/AS budgets	near/far solver transitions
Gameplay	collision/nav/edit fidelity	harvest/fire/growth persistence	buoyancy, depth, wetness, hazards
Visual QA	silhouette, repetition, erosion logic	clumping, LOD pop, wind coherence	reflection, foam, shore, underwater

Top risks

Representation drift. A beautiful render field becomes an accidental source of truth. Mitigation: explicit authoritative data and one-way render adapters.

Camera-dependent generation. Culling changes persistent identities. Mitigation: generate IDs from world tiles/species/seeds; camera only selects LOD and expansion.

Unbounded regeneration cost. Learned or physical synthesis stalls traversal. Mitigation: asynchronous acceptance pipeline, cache, fallbacks and generation budgets.

Feature silos. Terrain, vegetation and water disagree on elevation, wetness or edits. Mitigation: a shared descriptor atlas and versioned dependency graph.

Research-to-product overclaim. A paper demo is treated as shipping proof. Mitigation: label evidence tier, hardware, scene, timings and missing integration tests exactly as this report does.

Adoption gate

Adopt a technique only when it improves a named world invariant or budget, not merely because it produces an impressive isolated image.

References and method

Source method

Search was conducted through 2 September 2026 with priority given to peer-reviewed ACM/Eurographics/Computer Graphics Forum work, official SIGGRAPH course materials and author project pages. Preprints and adjacent research are labeled. Claims were limited to what the cited source establishes; game-engine recommendations are synthesis and engineering inference.

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Prepared as a local research artifact and public technical note. All diagrams in this report are original explanatory schematics.