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Research on Cloud Platform Based Spatial Resource Organization and Ownership Identification Mechanism for Generative Digital Theatre

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Abstract. This study develops a cloud-platform-based mechanism for organizing spatial resources and identifying ownership in generative digital theatre production. The research object includes stage-space layouts, virtual scene modules, lighting structures, prop models, background layers, and composite scenographic assets generated or edited during digital theatre creation. A dataset of 240 digital theatre spatial resources is constructed from 12 generative theatre scenes using Blender 4.0 and Unity 2022.3 LTS. Each asset package contains an FBX geometry file, PNG texture file, JPG preview, and JSON metadata record. Alibaba Cloud OSS is used for file storage, MongoDB 7.0 for scene-composition metadata, PostgreSQL 16 for ownership and reuse records, and Python 3.11 FastAPI for metadata registration and permission validation. Ownership identification combines creator ID, SHA-256 asset hash, creation timestamp, version number, and authorization status. Results show that the proposed mechanism achieves 0.964 ± 0.018*** classification accuracy, 142.6 ± 21.4 ms metadata retrieval time, 0.987 ± 0.009*** ownership verification accuracy, and 0.952 ± 0.016*** authorized reuse execution rate, supporting asset-level management of generative digital theatre resources.

Keywords: Generative digital theatre, cloud platform, spatial resource organization, ownership identification, digital asset management

1. Introduction

Generative digital theatre produces numerous spatial and scenographic resources, including stage layouts, scenic modules, lighting rigs, props, backgrounds, projection layers, camera viewpoints, and composite assemblies. Unlike ordinary files, these resources are scene-dependent and gain meaning through spatial position, scale, depth, lighting, and dramaturgical relationships [1, 2].

In conventional production, resources are often scattered across local folders, Unity projects, Blender files, and temporary cloud links, resulting in duplicated creation, unclear version chains, weak ownership attribution, and poor retrieval. Generative workflows further increase this complexity because assets may be repeatedly generated, modified, recombined, and reused across scenes and rehearsal versions [3, 4]. Effective management therefore requires structured records of

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asset category, scenographic function, scene dependency, version, creator identity, and authorization [5].

Although previous studies have examined digital scenography, virtual theatre, metadata organization, and digital ownership [6], few integrate stage-space decomposition with ownership identification in one executable workflow. This study addresses the gap through a cloud-based framework that classifies assets into stage layout, virtual scene, lighting, prop, background, and composite scenography, while binding each asset to hierarchical storage, creator ID, hash, timestamp, version, and authorization status.

2. Literature review

2.1. Spatial resources in digital theatre production

Digital theatre production relies on spatial resources that construct both the visible stage world and the performative environment. These resources include stage zones, scenic walls, platforms, doors, furniture, projection surfaces, lighting layers, atmospheric backgrounds, and virtual extensions of physical stage space [2]. In digital scenography, the stage is not only a visual container but also a designed spatial system in which distance, depth, texture, object relation, and light composition shape audience perception. Virtual models and 3D scenes allow stage designers to test spatial proportion, sightline, transition rhythm, and scene atmosphere before performance execution [3].

2.2. Cloud-based resource management for creative content

Cloud-based content management supports centralized storage, collaborative access, version control, metadata indexing, and reuse tracking for digital creative assets [5]. For theatre-oriented spatial resources, cloud organization must operate beyond general file management. A stage layout asset must record the stage zone and spatial scale; a lighting asset must record fixture position, color temperature, direction, intensity, and cue relation; a prop asset must record scenic function, interaction status, and placement constraints. Scene-oriented metadata is therefore necessary for retrieval and reuse in rehearsal, redesign, and performance visualization [6].

2.3. Ownership identification in digital asset environments

Ownership identification assigns attribution, control, and circulation information to digital assets. In digital asset environments, ownership is represented through creator identity, timestamp, file fingerprint, version chain, permission status, and reuse record [7, 8]. For generative digital theatre, ownership is complicated by composite scenographic creation. A virtual scene may combine one stage layout, several prop models, multiple lighting layers, and AI-generated background textures. Therefore, ownership identification should operate at both single-asset and derived-asset levels. Hash-based registration, metadata binding, and version-chain recording provide a technical basis for tracking creation, modification, reuse, and authorization [9, 10].

3. Experimental methodology

3.1. Resource dataset construction and asset-type definition

The dataset contains 240 digital theatre resources from 12 generative theatre scenes, created in Blender 4.0 and Unity 2022.3 LTS. Each asset is exported as a structured package containing FBX

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geometry, PNG textures, JPG previews, and JSON metadata.

Resources are divided into six classes: stage layouts covering stage zones and spatial arrangements; virtual scenes including architectural and scenic elements; lighting assets containing rigs, presets, and cue-linked structures; props including furniture and interactive objects; backgrounds including projections and digital scenic layers; and composite scenography assets integrating stage, scene, lighting, props, and background into reusable performance-space packages.

3.2. Cloud storage structure and metadata organization schema

The cloud platform uses Alibaba Cloud OSS, MongoDB 7.0, PostgreSQL 16, and Python 3.11 FastAPI. OSS stores FBX, PNG, JPG, and JSON files; MongoDB manages flexible scene-composition metadata; and PostgreSQL records ownership, authorization, reuse, and version relations. Assets follow a fixed project / scene / asset class / asset ID / version hierarchy.

Each asset contains identifiers, file paths, version and authorization data, spatial metadata, dependency relations, lighting cues, prop functions, and scenographic roles. The registration API validates files and metadata, stores resources and records across the three systems, and logs each operation with its timestamp, account, API route, and action type.

3.3. Ownership identification and reuse-control mechanism

Ownership identification uses five fields: creator ID, SHA-256 asset hash, timestamp, version number, and authorization status. The hash is generated from the FBX geometry and JSON metadata during upload, while ownership records are stored in PostgreSQL and linked to cloud metadata. Authorization includes private, project-shared, and cross-project reusable levels, respectively allowing creator-only access, reuse within the same project, or reuse across projects after permission validation.

The ownership and reuse-control function is specified as shown in Equation (1):

$$\Gamma_a = H\left(FBX_a \mid JSON_a \mid creator_a \mid t_a \mid V_n\right), \tag{1}$$

$$R(a,u,s) = I\left[Perm(u,A_a) = 1 \wedge \Gamma_a = \Gamma_a^{reg} \wedge V_n \geq V_{min} \wedge s \in Scope\left(A_a\right)\right]$$

where Γ_a denotes the SHA-256 ownership fingerprint of asset a, FBX_a and $JSON_a$ are the geometry and metadata bundles, $creator_a$ is creator ID, t_a is creation timestamp, V_n is version number, $R(a,u,s)$ is the reuse decision for user u in scene s, $Perm(u,A_a)$ is user permission under authorization level A_a, Γ_a^{reg} is the registered hash, and $Scope\left(A_a\right)$ is the allowed reuse scope.

Any modification of an existing asset generates version_no + 1 and a derived-asset relation linked to the original ownership chain. For composite scenography assets, ownership records include both parent asset IDs and component asset IDs. Reuse actions write call records, update reuse count, and return permission status through the platform API.

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4. Experimental procedure

4.1. Platform deployment, resource upload, and registration workflow

The experiment deploys OSS storage, MongoDB, PostgreSQL, and FastAPI on a cloud server cluster. A batch-ingestion script uploads 240 resource packages to Alibaba Cloud OSS, validates file formats and required FBX, PNG, JPG, and JSON files, extracts metadata, generates SHA-256 hashes, and stores metadata and ownership records. Each asset follows a fixed project-scene-class-ID-version hierarchy. The platform then generates preview indexes and ownership logs, while failed records are returned with specific error types.

4.2. Classification, retrieval, and reuse test procedure

After registration, metadata indexing is performed on asset class, scene relation, creator ID, spatial keyword, stage zone, visual layer, dependency relation, and authorization level. Retrieval testing includes three fixed query tasks: scene-based retrieval, asset-class retrieval, and cross-project reusable asset retrieval. In scene-based retrieval, assets are searched by scene ID and dependency relation. In asset-class retrieval, all resources of one class are returned with version information. In cross-project reusable retrieval, only assets marked as cross-project reusable are returned.

4.3. Versioning, ownership verification, and performance evaluation

Version testing edits and re-uploads 48 assets, including eight from each of the six asset classes. The system increments the version number, preserves the ownership chain, and records derived-asset relations in PostgreSQL.

Ownership verification covers 240 original assets and 48 derived versions using creator ID, asset hash, and version trace. Performance is evaluated by upload success, query response time, ownership accuracy, reuse execution, version continuity, and dependency traceability. Response time is tested through 500 API queries, while reuse validation covers all 60 operations across three authorization levels.

5. Experimental results

5.1. Classification accuracy and cloud storage organization results of digital theatre spatial assets

The platform successfully registered 236 of 240 original assets, producing an upload success rate of 0.983 ± 0.012. Four failed uploads were caused by incomplete texture or invalid metadata fields. Classification accuracy reached 0.964 ± 0.018*** across six asset classes (see Table 1). Lighting assets and composite scenography assets produced slightly lower classification stability because lighting cues and composite dependencies contained more cross-scene metadata fields. The cloud hierarchy correctly generated project / scene / asset class / asset ID / version paths for all successfully uploaded packages.

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Table 1. Classification and cloud organization performance by asset class

Asset Class	Number of Assets	Classification Accuracy	Upload Success Rate	Metadata Completeness	Path Generation Accuracy
Stage Layout Asset	40	0.982 ± 0.011***	0.975 ± 0.018	0.968 ± 0.020	0.992 ± 0.006***
Virtual Scene Asset	44	0.971 ± 0.014***	0.977 ± 0.016	0.956 ± 0.024	0.987 ± 0.008***
Lighting Asset	38	0.947 ± 0.022**	0.974 ± 0.019	0.941 ± 0.027	0.982 ± 0.011**
Prop Asset	46	0.976 ± 0.013***	0.989 ± 0.010	0.964 ± 0.018	0.991 ± 0.007***
Background Asset	36	0.958 ± 0.020**	0.972 ± 0.021	0.949 ± 0.025	0.986 ± 0.009***
Composite Scenography Asset	36	0.948 ± 0.023**	0.972 ± 0.020	0.936 ± 0.030	0.979 ± 0.012**
Overall	240	0.964 ± 0.018***	0.983 ± 0.012	0.952 ± 0.024	0.986 ± 0.009***

5.2. Retrieval efficiency, version management, and reuse-execution results on the cloud platform

Metadata retrieval showed stable response times under repeated API queries. The average scene-based retrieval time was 142.6 ± 21.4 ms, asset-class retrieval time was 118.3 ± 18.7 ms, and cross-project reusable retrieval time was 156.8 ± 24.9 ms. Version testing on 48 edited assets produced 0.979 ± 0.014** version-chain continuity. Among 60 reuse tests, authorized reuse execution reached 0.952 ± 0.016***. The retrieval mechanism performed better for prop and stage layout assets than for composite scenography assets because composite assets required dependency verification across multiple component records.

5.3. Ownership identification accuracy, authorization verification, and asset traceability results

Ownership verification accuracy reached 0.987 ± 0.009*** across 240 original assets and 48 derived versions. Hash matching achieved 0.993 ± 0.006***, creator-ID matching 0.981 ± 0.011***, authorization validation 0.972 ± 0.014**, and composite dependency traceability 0.958 ± 0.019**. Results indicate that creator ID and hash provide the strongest verification for individual assets, while composite scenography requires dependency-chain validation. The mechanism enables stage-space resources to become traceable, reusable, and permission-controlled cloud assets (see Figure 1).

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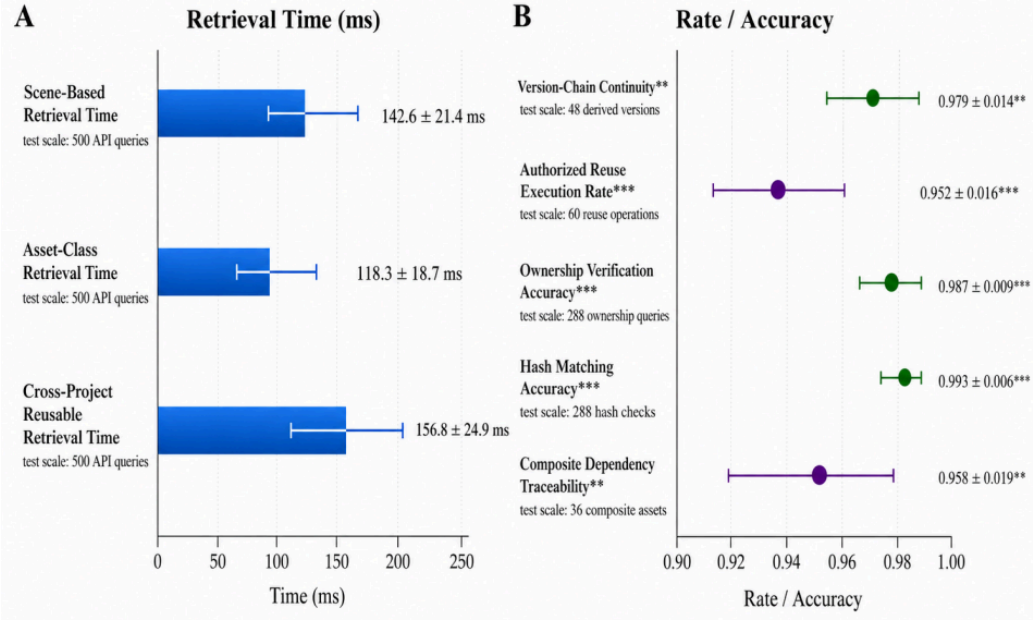


Figure 1. Retrieval, reuse, ownership verification, and traceability results

6. Conclusion

This study establishes a cloud-based mechanism for spatial resource organization and ownership identification in generative digital theatre. Theatre materials are classified into six asset types: stage layout, virtual scene, lighting, prop, background, and composite scenography, with each asset indexed through scene-oriented metadata. Results show that the platform enables accurate classification, structured cloud storage, efficient retrieval, version control, ownership verification, and asset reuse. By integrating stage design, scenographic composition, ownership tagging, and reuse authorization, the mechanism provides a traceable and reusable workflow for managing generative digital theatre assets.

Author contribution

Lehan Zhang and Zixuan Zuo contributed equally to this paper.

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