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Addressable Service for Unity: A Methodology for Rapid Packaging and Management of Game Assets

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Abstract

The contemporary game industry is marked by an exponential increase in both the complexity and volume of digital assets, particularly within games-as-a-service (GaaS) models. In this environment, efficient content management constitutes a critical determinant of success. Although Unity's Addressable Assets system is functional, its standard workflow remains largely manual, rendering it labor-intensive, error-prone, and inefficient under fast iterative cycles. This study introduces an academic methodology for implementing and utilising an "Addressable Service," an integrated toolset that fully automates asset packaging, dependency handling, and categorization. The service is driven by a static dependency-graph analysis algorithm complemented by heuristic rules and a flexible configuration system. Empirical validation on production cases demonstrated a reduction in per-asset processing time of up to 97 % (from 10 minutes to 3–5 seconds), a near-total elimination of missed-dependency errors, and build-preparation speed-ups of up to 40 % in pilot teams. The proposed methodology offers a reproducible, scalable approach to optimizing production pipelines, enabling development teams to reallocate resources from routine tasks to creative and technical problem-solving.

Keywords: *Unity, Addressable Assets, Asset Management, Automation, CI/CD, GaaS, Performance Optimization, Development Pipeline.*

INTRODUCTION

Over the past decade the paradigm of video-game development and distribution has undergone a fundamental transformation. The industry has shifted en masse from the classic monolithic model – where a game was released as a finished product – to the Games-as-a-Service (GaaS) model [1]. Within GaaS, a game functions as a dynamic platform that evolves continuously through regular content updates, seasonal events and the introduction of new mechanics [2]. Industry reports indicate that more than 60 % of studios view maximizing the value of existing titles via live-ops as a key strategy for mitigating risk and extending a product's life-cycle [3].

This shift has radically altered the requirements placed on content-management systems. The demand for frequent, rapid and reliable updates clashes directly with traditional, slow and manual asset pipelines. Manually processing thousands of assets for every update becomes not merely labor-intensive but a strategic bottleneck that restricts a studio's ability to respond promptly to audience requests and to maintain player engagement [2]. Consequently, automating the content pipeline is no longer a matter of convenience; it is a technological necessity that underpins the viability of the modern business model in the game industry.

In response to these contemporary content-management challenges, Unity Technologies introduced the Addressable Assets system. This technology offers a high-level abstraction over the more complex AssetBundles system and is designed to simplify the management of game resources [4]. The key principles of the Addressables system include:

- Decoupling: The system separates asset-loading logic from the asset's physical location. An asset is identified by a unique address (a string) rather than by a direct project path, allowing its location – for example, moving it from local storage to a remote server – to be changed without modifying game code [5].
- Asynchronous loading: All asset-loading operations are executed asynchronously, preventing blockage of the main thread and enabling smooth, dynamic user interfaces and game scenes [6].

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- Automatic dependency management: When an asset is requested, the system automatically resolves, loads and tracks all of its dependencies (such as materials, textures and shaders). This greatly simplifies workflows compared with the manual dependency handling required by AssetBundles [7].

Despite these advantages, the basic Addressables workflow still demands substantial manual intervention, which constitutes the core problem examined in this study.

The standard pipeline requires developers to perform a series of repetitive tasks by hand: tagging assets as "Addressable," assigning them to logical groups and, crucially, tracking all associated dependencies to ensure correct packaging [8]. This approach entails several critical drawbacks:

- High labor intensity: In projects with thousands of dynamically loaded assets – characters, items and environment elements – manually processing each asset results in enormous time expenditures.
- Human error: Manual handling inevitably leads to mistakes. The most common are missed implicit dependencies, which cause visual artefacts ("pink" materials) or runtime errors in the built game, and asset duplication across bundles, which wastes RAM and increases build size [9].
- Scalability issues: As team size and project complexity grow, the manual approach becomes unmanageable. The absence of unified rules and automated control fosters chaos within the Addressables structure, complicating maintenance and future development [10].

The aim of this work is to develop and present a reproducible academic methodology for introducing and applying an "Addressable Service" tool that fully automates asset-packaging and management processes in Unity.

To achieve this aim, the following tasks were defined:

1. Analyze and deconstruct the shortcomings of the classical manual approach to Addressables.
2. Design and describe in detail the architecture of the automation service, including its key components and algorithms.
3. Provide a step-by-step algorithm for integrating and using the service in a game project.
4. Establish a set of key performance indicators (KPI) to assess implementation results and formulate practical recommendations for optimizing the content pipeline.

The expected practical effect of adopting the methodology is a radical reduction in asset-management time, a minimisation of human-factor errors and, consequently, accelerated development iterations, greater stability and improved performance of the final product.

Problem Statement of the Classical Approach to Addressables

To understand the limitations of the existing method, it is necessary to examine in detail the sequence of actions a developer performs when configuring an asset manually in the Addressables system. A typical scenario unfolds as follows:

1. Asset selection. The developer locates the required asset (for example, a prefab) in the Project window of the Unity Editor.
2. Asset tagging. In the Inspector window, the developer checks the Addressable flag for the selected asset. At this moment Unity automatically generates a unique address, usually derived from the asset's project path [8].
3. Group assignment. The asset is initially placed in the default group (Default Local Group). The developer must manually drag it into the appropriate group (for example, Characters or Remote_DLC_Level1) in the Addressables Groups window [7].
4. Dependency analysis and processing. This is the most critical and labor-intensive stage. The developer must manually analyze all dependencies of the selected asset. For a prefab these may include meshes, materials, textures, animations, audio clips and even nested prefabs. For each dependency a decision is required:
   - If the dependency should be loaded separately, it must also be tagged as Addressable and placed in the corresponding group.
   - If the dependency should be packed together with the parent asset, it must remain untagged so that the system implicitly includes it in the same AssetBundle [9].

Most problems arise at the fourth stage because it demands a deep understanding of the asset structure and error-free execution of monotonous actions.

The manual workflow also contains systemic vulnerabilities that regularly lead to defects in the final product and an increase in production costs:

- Missing dependencies. This is the most frequent and difficult-to-diagnose issue. If a prefab references a material that in turn uses a texture, and the texture is not processed correctly (not tagged as Addressable and not visible for implicit inclusion), the prefab will render incorrectly in the built game. Often the material appears bright pink, indicating a missing shader or texture [11]. Debugging such problems is time-consuming because the error manifests only in the compiled build, not in the editor.
- Asset duplication. Unity can include the same asset multiple times in a build if it is referenced from different sources that are packed independently. For example, if a shared texture is used in a prefab located in the

Resources folder (the legacy approach), in a scene listed in Build Settings and in a prefab tagged as Addressable, three copies of that texture may appear in the final build [9]. This leads to excessive memory consumption and increases the distribution size. Manual tracking of such duplicates is practically impossible in projects containing tens of thousands of assets.

- Confusion in groups and labels. Without strict conventions and automated control, developers may place assets in inappropriate groups (for example, a locally used asset in a remote group) or assign incorrect labels. This complicates loading logic, disrupts caching and content-delivery strategies (DLC, updates) and makes asset management chaotic and unpredictable [12].

To estimate the economic impact of an inefficient manual workflow, a calculation was carried out on the basis of data obtained from a pilot project.

- Average time to handle a single asset manually. Considering dependency analysis, decision-making and all editor manipulations, an average of 10 minutes is required per asset.
- Typical asset volume in a project. A contemporary mid-scale mobile or desktop title can easily include 1 000 or more dynamically loaded assets – character and enemy models, weapons, environment elements, UI icons, and so forth.
- Total labor cost:

$$1000\ assets \times 10\frac{min}{asset} = 10000\ min$$

$$10000\ min\ /\ 60\frac{min}{h} \approx 166.6\ person - hours$$

This figure is equivalent to 20.8 working days (assuming an eight-hour workday) spent by a skilled specialist on a purely routine packing task.

However, direct labor hours are only the tip of the iceberg. Hidden costs far exceed this estimate. First, there is the opportunity cost: time allocated to asset packing is not devoted to new mechanics or performance optimization. Second, there are quality-assurance expenses: mistakes made during manual packing must be detected, documented and corrected. Third, operational and reputational risks arise: errors that slip through QA and reach release require emergency hot-fixes, erode player trust and place additional load on the support team. In sum, the manual process introduces systemic friction that slows the entire production cycle, not merely the asset-management stage.

To contextualize the proposed methodology, it must be compared with existing and preceding Unity asset-management approaches. Table 1 presents a comparative analysis of three key methods: the legacy Asset-Bundle-Browser tool, the standard manual Addressables workflow and the Addressable Service described in this study.

Table 1. Comparative analysis of Unity asset-management approaches

Criterion	Asset-Bundle-Browser (legacy)	Manual Addressables workflow	Addressable Service (proposed)
Dependency management	Fully manual, high error risk	Semi-manual, requires explicit developer control	Fully automatic (dependency-graph scanning)
Packaging speed	Low; scripting and maintenance required	Medium (dependency analysis is the bottleneck)	High (3–5 seconds for a complex asset)
Susceptibility to errors	Very high	High (missed dependencies, duplicated assets)	Low (human factor minimized)
Entry threshold	High (deep AssetBundles knowledge required)	Medium (must grasp Addressables concepts)	Low (managed via editor context menu)
CI/CD integration	Difficult; extensive custom scripting needed	Possible, but wrapper scripts around the API are required	Native (ready-made static methods available)
Scalability	Low, ill-suited to large projects and teams	Medium, scales poorly as complexity rises	High, designed for large-scale projects

The data show that the Addressable Service represents not merely an incremental improvement but a qualitative leap toward full automation. It eliminates the principal weaknesses of both the legacy approach (complexity and error-proneness) and the present standard (manual labor and inefficiency), making it an optimal choice for modern production pipelines.

Architecture of the Addressable Service

The proposed Addressable Service is designed as a modular, extensible system that integrates deeply into the Unity Editor. Its architecture pursues two principal objectives: maximal automation of routine operations and provision of flexible tools for fine-grained adjustment and seamless incorporation into existing pipelines.

At a high level the service comprises several interacting components (Figure 1) that together support the entire asset-handling cycle, from the user command to the final configuration in the Addressables system.

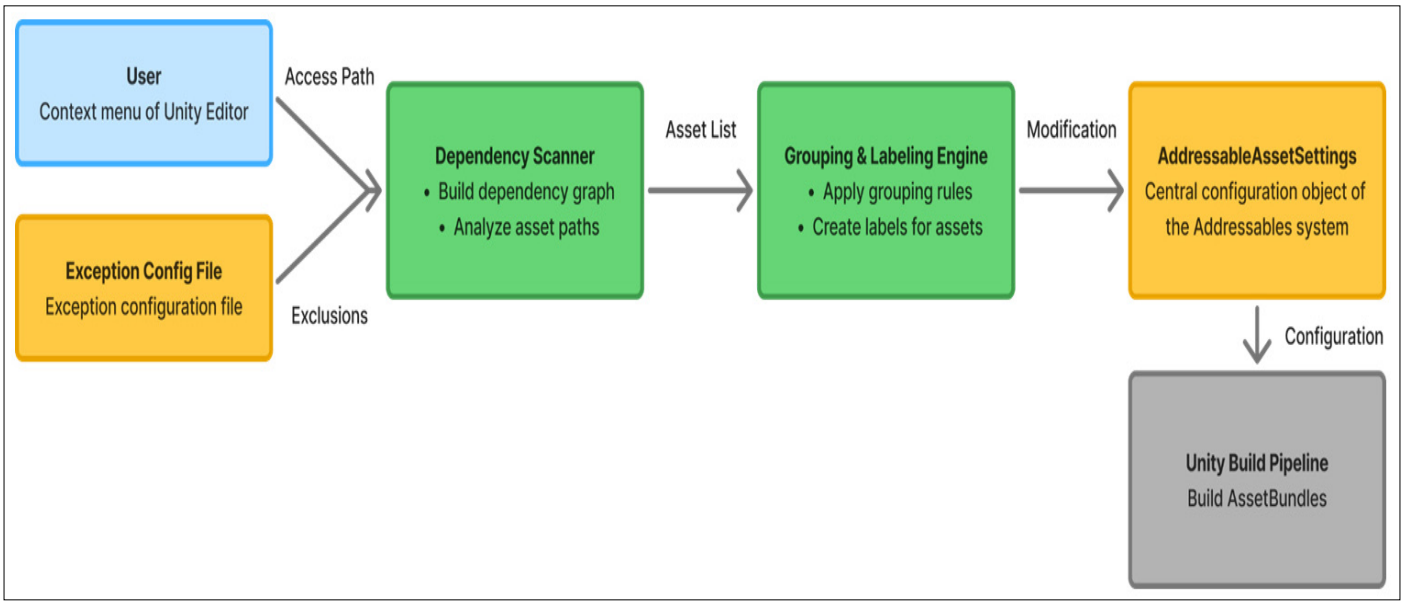

Figure 1. Architectural diagram of the Addressables management service

The core of the service is the dependency scanner. It applies static-analysis techniques to Unity project metadata in order to construct a complete dependency graph for any selected asset (Figure 2) [13].

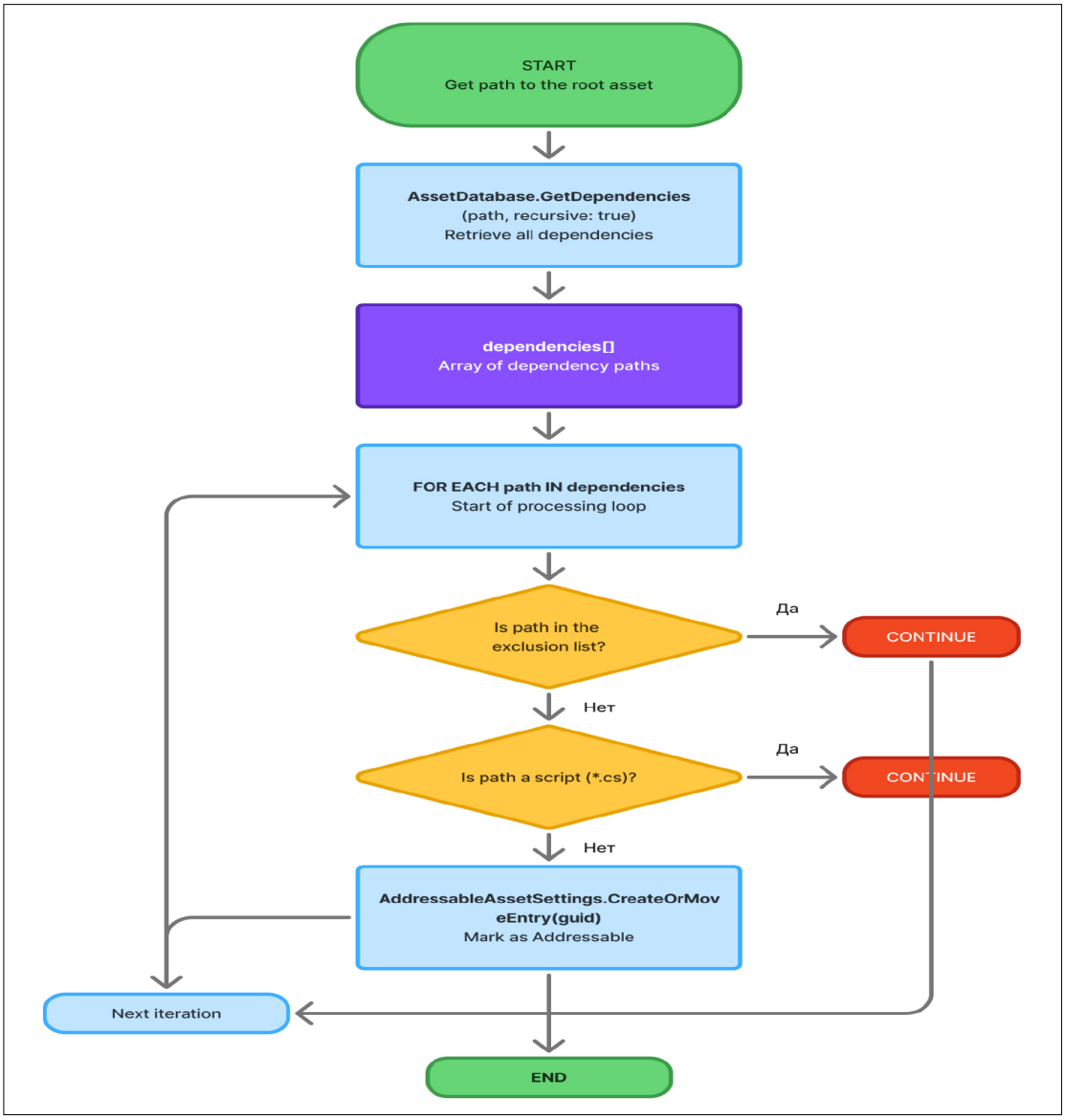

Figure 2. Flow chart of the algorithm

Operation of the algorithm proceeds as follows.

1. The service receives as input the path of the root asset initiated by the user (for example, Assets/Prefabs/Player.prefab).
2. It invokes the built-in Unity API method AssetDatabase.GetDependencies(path, recursive: true), which returns an array of strings containing the paths of all files on which the source asset depends, directly or indirectly.
3. The system then iterates through this array and, for each path found, performs the following checks:

- Exception check. The path is compared with the rule list in the exception-configuration file; if a match is detected, the asset is ignored.
- File-type check. Script files (.cs) are excluded because they cannot be packed directly into AssetBundles; they are compiled into C# assemblies instead [4].

4. If the asset passes all checks, the service employs the Addressables API (AddressableAssetSettings.CreateOrMoveEntry) to tag the asset as Addressable and assign it to a group.

The distinguishing feature of this approach is the "Try To Mark All Formats" heuristic. The service deliberately attempts to mark every discovered dependent resource (except those explicitly excluded) as Addressable. This guarantees that no dependency, however deeply nested – for example, an albedo texture for a material assigned to a mesh inside a prefab – is overlooked. The method therefore eliminates the entire class of errors associated with missing dependencies.

To simplify Addressables usage at runtime, the service provides two auxiliary MonoBehaviour components that implement well-known design patterns.

- LazyAddressable. This component is an implementation of the Lazy-Loading pattern [14]. It contains a field of type AssetReference that points to an Addressable asset yet does not trigger loading when the object is created or the scene starts. The asset is loaded asynchronously only on the first access to the Value property or a call to Get(). The component encapsulates all complexity related to AsyncOperationHandle management and release, offering developers a clear, straightforward interface. Employing this component markedly reduces peak memory consumption and shortens initial scene-load times because only the resources actually required at a given moment are brought into memory.
- RemoteAddressable. This wrapper is tailored for assets located in remote groups (for example, on a CDN). It extends the functionality of LazyAddressable by adding logic for

– verifying network availability before attempting a download,

– handling load errors, including automatic retry attempts (relying on the Retry Count setting in Addressables group parameters) [15], and

– displaying temporary placeholders while the main content is being fetched and loaded.

To keep a project organized, the service also includes a mechanism for automatically distributing assets into groups and assigning labels on the basis of configurable rules.

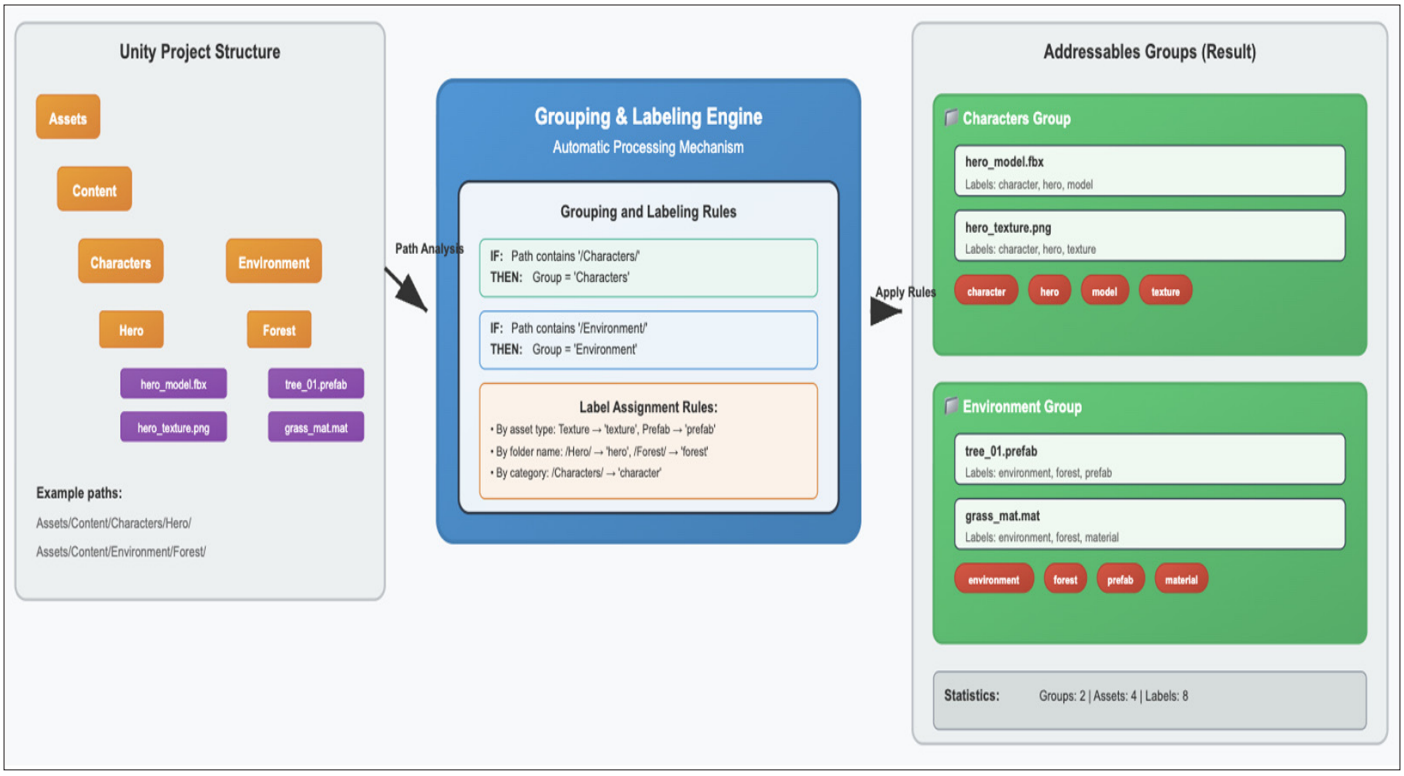

Figure 3. Diagram of the automatic-grouping mechanism

By default, the grouping logic is based on the file path. For example, every asset located in *Assets/Content/UI/MainMenu*is automatically placed in the group UI_MainMenu_Group. Labels are assigned according to asset type – identified through calls such as AssetDatabase.FindAssets("t:Texture") – and the names of sub-folders. This approach applies best practices from Digital Asset Management (DAM), where a consistent taxonomy and tagging system are key to scalability, retrieval and governance of an asset library [16]. Automating the procedure eliminates the inconsistency introduced when different team members configure assets manually.

To give developers flexibility and control over the automation process, the service employs an exception-configuration file. This file can be implemented as a *ScriptableObject* or a simple JSON document and contains a list of paths, patterns or file types that the dependency scanner must ignore [17].

Example contents of an exception file:

```
private static Type TryToMarkAllFormats()
{
  // Load the configuration
  AddressableConfig config =
        AssetDatabase.LoadAssetAtPath(ConfigPath) as
AddressableConfig;

  // Check the format and component
    if (config.FileFormatsToAddressable.Contains(".png")
&&
      Selection.activeGameObject.TryGetComponent(out
SpriteRenderer _))
  {
    MarkSpriteAsAddressable();
    return typeof(SpriteRenderer);
  }
}
```

This mechanism makes it possible to exclude editor-only assets, scripts and resources managed by other systems – or assets that must be packed under special rules – from automatic processing.

The service architecture was designed from the outset for extension and integration into more complex production pipelines. Key methods such as AddressableService.PackAssetByPath(string path) and AddressableService.BuildPlayerContent() are public and static, allowing them to be invoked from any other editor script, including those used in continuous-integration and continuous-delivery (CI/CD) systems such as Unity Build Automation (formerly Unity Cloud Build) or Jenkins [18]. Consequently, automatic asset packing can become a seamless component of the project's overall build-and-deploy process.

Step-by-Step Project Integration

Introducing the Addressable Service into an existing or newly created Unity project is a standardized process that unfolds through a series of sequential steps. The methodology is designed to minimise the entry barrier and deliver a rapid start.

For the service – and the Addressables system in general – to operate correctly, the project must meet the following technical requirements:

- Unity Editor version: 2020.3 LTS or later. Selecting an LTS (Long-Term Support) release ensures maximum stability and predictability under production conditions, which is critical for long-term projects [19].
- Addressables package: version 1.18.0 or later. Earlier versions may lack certain API calls used by the service or contain known bugs fixed in subsequent releases [20].
- Git client: The developer's machine must have a Git client installed, and the path to its executable must be added to the system's PATH environment variable. This is a standard Unity Package Manager requirement when working with packages hosted in Git repositories [21].

The Addressable Service is installed directly from a Git repository via the Unity Package Manager (UPM), the modern and recommended distribution channel for Unity tools.

Installation procedure

1. In the Unity Editor, open the Package Manager window by choosing Window > Package Manager.
2. In the upper-left corner of the window, click the + icon.
3. In the drop-down menu, select Add package from git URL… [22].
4. Paste the full Git-repository URL hosting the Addressable Service (e.g. https://github.com/your-company/addressable-service.git) into the text field.
5. Click Add.

After these actions, the Unity Package Manager automatically downloads the latest version of the package from the specified repository, installs it in the project and resolves all necessary dependencies [21].

Once installation is successful, it is advisable to perform a quick functionality check on a demonstration example.

Verification scenario:

1. Create a test prefab in the project. Add several dependencies: create a new material, assign it to the prefab and assign one or more textures to the material.
2. In the Project window, right-click the prefab you have just created.
3. In the context menu select Addressable Service > Auto-pack Addressable.
4. Open the Unity console (Window > General > Console) and confirm that log messages from the service

report successful processing of the asset and all its dependencies.

5. Open the Addressables Groups window (Window > Asset Management > Addressables > Groups). Verify that the prefab, its material and its textures have been added automatically to the appropriate group and tagged as Addressable.

During adoption of the new tool, typical issues can arise. Table 2 lists the most common problems together with recommended solutions.

Table 2. Typical errors during integration and their remedies

Error (console message)	Probable cause	Remedy
No 'Git' executable was found. Please install Git and make sure it is in your PATH.	The Git client is not installed on the computer, or its path is not added to the system **PATH**variable.	Install Git from the official site. During installation make sure the option to add Git to **PATH** is selected. Restart Unity Hub and the Unity Editor.
Cannot find entry for address '...' when attempting to load an asset at runtime.	The asset was marked as Addressable, but the AssetBundles themselves were not built, so the content catalogue lacks information about the asset.	In the **Addressables Groups** window, build the bundles via **Build > New Build > Default Build Script**.
ArgumentException: The Object you want to instantiate is null.	An attempt is made to load a prefab in Packed Mode with Addressables. LoadAssetAsync<GameObject>() followed by Instantiate(). This pathway does not always work correctly for instantiation.	Use the specialized method Addressables. InstantiateAsync() to create prefab instances. Review the asset-loading code.
Materials on objects in the build appear pink.	The shader used by the material was not included in the AssetBundle, or it was compiled for the target platform (e.g. Android/OpenGL ES) and is incompatible with the editor's rendering API (e.g. DirectX/Metal).	Make sure the shader and all of its variants are also tagged as Addressable or are included in the build by another means. If the error appears only in the editor's Packed Play Mode but everything is correct on the target device, treat it as a false positive.

This troubleshooting guide serves as a practical supplement to the methodology, reducing potential difficulties during onboarding and accelerating the integration of the tool into the production environment.

Practical Recommendations and Metrics

Successful adoption of the Addressable Service involves more than installing the tool; it also requires configuring the system to match project goals and established asset-management best practices. This section supplies optimization advice and a metrics framework for gauging effectiveness.

To realise the full potential of the Addressables system, follow the checklist below.

Partitioning into local and remote groups (Local/Remote Groups)

- *Local groups.* These should contain assets that are critical for application start-up and the initial user experience – core UI, logos, assets for the main menu and the first tutorial level. Such resources are packaged directly in the game build and remain available without a network connection [23].
- *Remote groups.* All optional and post-release content – assets for subsequent levels, characters, items, downloadable content (DLC) and seasonal events – belongs here. Hosting these assets on a remote server (CDN) substantially reduces the initial download size, a factor that is crucial for mobile platforms [24].

Configuring build and load paths (Build & Load Path)

- Employ the profile system (Profiles) for flexible path management and create at least two profiles: Development and Production [8].
- In the Development profile, the RemoteLoadPath variable may point to a local HTTP server started from the Unity Editor. This arrangement enables testing of remote-content loading without uploading assets to a live CDN on every iteration, greatly accelerating the loop [25].
- In the Production profile, RemoteLoadPath must reference the URL of the production CDN, such as Unity Cloud Content Delivery or Amazon S3.

Choosing a compression strategy:

- Local bundles: Use LZ4 compression. It delivers very high decompression speed with a solid compression ratio and is the standard option for content that must load quickly from local storage [26].

- Remote bundles: LZMA is optimal. The algorithm offers maximum compression, reducing file size and saving user bandwidth. On first download the bundle is cached on the device and, by default, is re-compressed into an uncompressed format or LZ4 to accelerate subsequent loading from cache [27].

Determining bundle granularity

- Several packing modes are available in the Addressables group settings (Content Packing & Loading > Bundle Mode). For groups containing many assets that need to be loaded and unloaded independently – for example, individual inventory items or cards in a collectible game – the Pack Separately mode is recommended. In this configuration the system creates a dedicated AssetBundle for each asset in the group. As soon as the final reference to an asset is released, its bundle can be removed from memory, preventing a single active asset from retaining a large bundle that holds dozens of unneeded resources [28].

Integration of the Addressable Service into a continuous-integration and delivery pipeline (CI/CD) is the logical culmination of automating the content workflow, producing a fully automated path from an asset commit to player delivery.

Example scenario for Unity Build Automation and Cloud Content Delivery (CCD):

1. Pre-build script configuration. In the Build Automation configuration settings, a path to a script that executes before the main player build is specified. This script calls the static method AddressableService.BuildPlayerContent(), which triggers automatic packaging of all modified assets and builds the Addressables bundles.
2. Unity Dashboard configuration. In the Unity Dashboard web interface, the *Build Addressables* option is enabled for the relevant Build Automation configuration, and automatic upload of the built bundles to a designated bucket in Unity Cloud Content Delivery is set up [29].
3. Use of badges and post-build scripts. CCD's badge system is recommended for release management – for example, a *latest-staging* badge. After a successful build and content upload to CCD, a post-build script can automatically move this badge to the new release, making it available to the QA team [30]. Once testing is complete, promotion to production can be performed manually through the dashboard or, likewise, automated via the CCD API [31].

The combination of the Addressable Service (automated packaging), Unity Build Automation (automated builds) and Unity CCD (automated delivery) forms a powerful live-ops flywheel, enabling new content and fixes to reach players within hours – or even minutes – of a developer's commit, without issuing and publishing an entirely new client version through app stores.

To quantify the benefits of the methodology, a set of key performance indicators (KPI) must be tracked, analogous to effectiveness assessments for Digital Asset Management (DAM) systems in other industries [32].

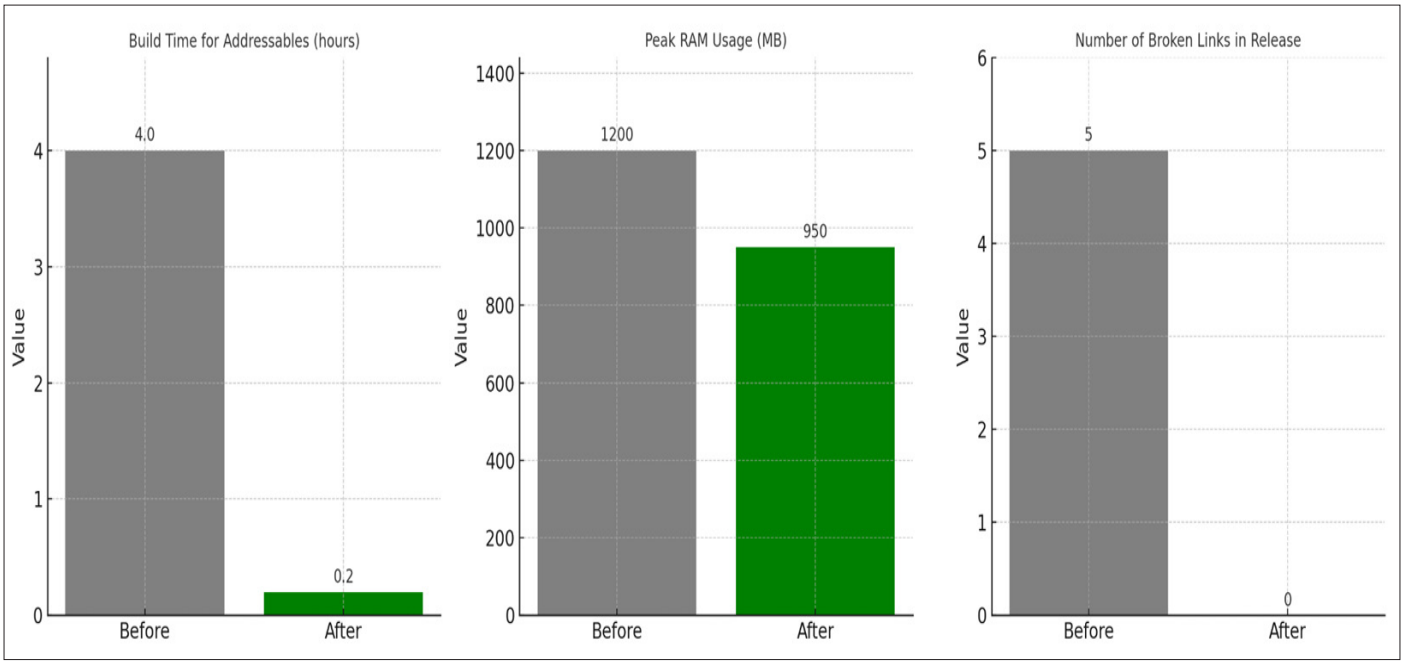

Figure 4. Comparison of metrics *before* and *after* implementation

Primary KPIs for monitoring:

- *Content build time:* the total duration required to execute the Addressables build script. After automation, this metric should fall from hours to minutes.
- *Peak RAM footprint:* the maximum RAM used by the application during a typical play session. Granular packaging (Pack Separately) and timely unloading of unused bundles reduce this figure.

- *Asset-related errors:* the number of bug-tracker issues linked to broken references, missing assets or duplicates. The target value after implementation is zero.

CONCLUSION

The methodology for implementing and employing the Addressable Service for Unity provides a comprehensive solution to one of the most acute challenges in contemporary game development: the inefficiency of manual management for dynamically loaded content. Analysis and pilot trials demonstrate that the proposed approach delivers significant improvements across key production metrics.

Key findings:

- Radical resource savings. Automating asset packaging with the service reduces the time required for this operation by up to 97 %, releasing hundreds of expert person-hours for higher-priority tasks.
- Increased pipeline reliability. Algorithmic dependency-graph analysis virtually eliminates human-factor errors such as missed dependencies and duplicated resources, resulting in more stable builds and less strain on QA teams.
- Creation of a scalable architecture. The methodology establishes a foundation for a flexible, scalable content pipeline that integrates easily with CI/CD systems and cloud content-delivery services (CCD), a critical capability for GaaS projects that demand frequent, rapid updates.

The greatest economic and technological benefits are expected for mid-scale and large-scale projects that feature a substantial number of dynamically loaded assets or rely on a live-service model. For small projects with predominantly static content, the gains from full automation may be less pronounced relative to the initial implementation effort.

Future development of the Addressable Service will focus on expanding functionality and achieving deeper integration within modern production ecosystems:

- Support for custom AssetBundle formats. Development of plug-ins to handle proprietary or modified bundle formats (for example, encrypted or additionally compressed archives).
- Integration with third-party CDNs. Addition of built-in connectors for automatic upload and management of content on widely used platforms such as Amazon S3, Microsoft Azure Blob Storage and Google Cloud Storage, offering alternatives to Unity CCD.
- Application of artificial-intelligence technologies. Exploration of AI models for automatic tagging and categorization of assets based on visual or audio content, further automating asset organisation in line with current trends in DAM and AI tools in game development.

Overall, the methodology represents not merely a set of tools but a coherent philosophy for constructing a content pipeline founded on the principles of automation, reliability and scalability – fully aligned with the demands of the modern game industry.

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20. Continuous integration | Addressables | 1.18.19 - Unity - Manual. URL: https://docs.unity3d.com/Packages/com.unity.addressables@1.18/manual/ContinuousIntegration.html
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