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APIs in the Metaverse—A Systematic Evaluation

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Abstract: One of the most critical challenges for the success of the Metaverse is interoperability amongst its virtual platforms and worlds. In this context, application programming interfaces (APIs) are essential. This study analyzes a sample of 15 Metaverse platforms. In the first step, the availability of publicly accessible APIs was examined. For those platforms offering an API, i.e., Decentraland, Second Life, Voxels, Roblox, Axie Infinity, Upland, and VRChat, the available API contents were collected, analyzed, and presented in the paper. The results show that only a few Metaverse platforms offer APIs at all. In addition, the available APIs are very diverse and heterogeneous. Information is somewhat fragmented, requiring access to several APIs to compile a comprehensive data set. Thus, standardized APIs will enable better interoperability and foster a more seamless and immersive user experience in the Metaverse.

Keywords: Metaverse; application programming interface (API); interoperability; standards

1. Introduction

The Metaverse represents an epicenter of innovation, where a confluence of events, corporate activities, virtual real estate, and user-generated experiences creates an increasingly vibrant digital ecosystem [1]. Many researchers define the Metaverse as an interconnected web of virtual worlds in which users represented by avatars connect and interact with each other [2]. The attraction of the Metaverse lies not just in its potential for human interaction but also in the economic opportunities it presents—a digital universe filled with potential yet to be fully discovered. The Metaverse can have a many applications in many domains, ranging from industry, where production plants can be virtually simulated before construction [3], to education, where remote participants can learn and practice even manual tasks [4].

As the Metaverse is envisioned to comprise a plurality of virtual worlds, interoperability between these virtual worlds is an essential success factor [5]. Interoperability in the Metaverse ensures that assets, identities, and information can move freely across various environments, which is essential for creating a unified virtual experience. This fluidity is critical for user engagement and the long-term viability and evolution of the Metaverse [6,7]. Interoperability can have various aspects, e.g., transferability of assets or digital currencies between virtual worlds, which is related to file formats amongst other topics [8]. For example, the service Ready Player Me, which allows the creation of cross-platform avatars that can easily be transferred between virtual worlds, addresses this aspect of interoperability [9]. The article focuses on data and information exchange between virtual worlds and other information systems. Making data from a virtual world accessible from the outside is an essential precondition for services providing an overview of the Metaverse and its offerings. Such services could be catalogs or search engines listing events, experiences, addresses of shops, and the like in virtual worlds.

In the Internet, specifically the World Wide Web, as we know it today, Application Programming Interfaces (APIs) play an important role, enabling data exchange between web services [10]. Similarly, APIs could connect virtual worlds to each other and any web

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service. For example, APIs could be the technical basis for building catalogs and search engines listing information across virtual worlds, such as events, land ownership, and experiences. Thus, APIs have the potential to serve as gateways, offering structured and user-friendly access to diverse and rich information within the Metaverse. Using APIs, the Metaverse's layers could be decoded and made available to a broader audience, facilitating a deeper engagement with this virtual space.

In light of these considerations, this paper articulates the following research questions:

R1. What APIs are currently available in the Metaverse?
R2. What information can be retrieved through the available APIs?

This investigation aims at making the following contributions to the Metaverse community:

- The study gives an overview of which virtual worlds from a sample offer APIs.
- The paper provides a guide to information accessible through APIs provided by virtual worlds.
- The study compares APIs regarding the available information and identifies generic weaknesses and future research directions.

The structure of this article is organized to provide a comprehensive understanding of the current state of APIs in the Metaverse. Section 1 presents related work to prove that this article addresses a relevant research gap and an introduction to API technology. Section 2 outlines the applied methodology, detailing the approach used to select and systematically examine various Metaverse platforms and the criteria for API evaluation. Section 3 presents the findings and provides a detailed overview of the available APIs in these environments. Section 4 finally discusses the diversity and complexity of Metaverse APIs, examining the challenges and potential opportunities for future research and development.

1.1. Related Work

A structured search was conducted to collect the relevant literature and existing research related to Metaverse APIs. This search aimed to identify existing comparisons, surveys, and studies focusing on APIs within the Metaverse.

The databases Google Scholar, Web of Science, and Scopus were each searched for the following terms: "Metaverse API comparison", "Metaverse API interoperability", "Metaverse API survey", "Virtual World API comparison", and "Virtual World API interoperability". The first ten results for each search term on each platform were analyzed, ensuring a balance between the comprehensiveness and manageability of the literature review. After removing duplicates, this approach led to an initial pool of 83 unique results.

Upon a closer examination of these results, we found that only three of these studies were relevant to our research focus, specifically addressing APIs in the context of the Metaverse. These studies were then selected for a more detailed review and comparison.

For their article "Blockchain-based Asset Storage in the Metaverse (MetaRepo)", Ersoy and Gürfidan developed a blockchain-based solution for secure digital asset storage and transactions in the Metaverse. The paper diverges from the API-centric approach of this article by focusing on blockchain infrastructure. However, it aligns with this paper through its use of APIs for enhancing Metaverse interoperability and security [10]. The article "Privacy Risks in Metaverse Applications (METAseen)" by Yu et al. concentrates on platforms like Decentraland and Sandbox. This research systematically analyzes privacy policies and network traffic, revealing critical data privacy concerns in the Metaverse. The findings highlight the need for privacy-conscious and secure API development [11]. Fang and Cai finally address the topic of interoperability in 3D virtual worlds. They propose using RESTful Web Services to facilitate communication across various platforms. The paper underscores the importance of interoperable and scalable APIs, resonating with this paper's objective of creating an overview of existing API solutions for virtual world platforms.

While ample research on various aspects of the Metaverse is available, including its conceptual framework, technological infrastructure, and social implications, the specific

exploration of APIs still needs to be addressed. No scientific survey could be identified comprehensively depicting APIs available in today's virtual worlds. Thus, the need for more specific studies focusing on existing APIs within the Metaverse is a gap in current academic research. This observation sets the stage for the importance and novelty of the study at hand, which aims to fill this gap by systematically evaluating APIs across various Metaverse platforms. This approach offers a new perspective on how APIs contribute to the functionality and expansion of virtual environments.

1.2. API Technology

Application Programming Interfaces (APIs) are the links between different software components [12]. They allow for the integration of diverse systems and are instrumental in achieving interoperability within the Metaverse [6,13]. APIs define the methods and data formats that applications use to communicate with each other and users, serving as the building blocks for complex digital ecosystems [12]. The following types of APIs can be distinguished:

- RESTful APIs: Representational State Transfer (REST) APIs are widely used for web services and are known for their scalability and simplicity. They use standard HTTP methods and are stateless, making them ideal for public services in the Metaverse [14,15].
- GraphQL APIs: GraphQL is a query language for APIs that provides a more efficient and powerful way to work with data [16]. It allows clients to request exactly what they need, making it useful for Metaverse applications where data requirements are complex and varied [16].
- SOAP APIs: Simple Object Access Protocol (SOAP) APIs are protocol-based and known for their standardized format and extensive feature set, including built-in error handling and security [17].

In addition, the following technical differences were considered when analyzing APIs:

- Communication Patterns: RESTful APIs operate on a request-response model, SOAP APIs use a service-oriented approach, and GraphQL allows for dynamic queries and mutations [18].
- Data Format and Structure: REST typically uses JSON or XML for data exchange [15]; SOAP uses XML for messaging [17]; GraphQL employs a flexible query structure [19].
- Performance: REST APIs are stateless, SOAP can maintain state with WS-* standards, and GraphQL optimizes performance by fetching only required data [15,20,21].
- Error Handling and Security: SOAP has robust error handling and built-in security standards like WS-Security [21]. RESTful APIs handle errors through HTTP status codes and GraphQL through query validation [22].

Each type of API brings its unique advantages. Understanding these differences is crucial for designing systems that are not only interoperable but also efficient and user-friendly.

2. Methodology

This study utilized a systematic methodology to examine the application programming interfaces (APIs) across selected Metaverse platforms, focusing on their interoperability, which is crucial for the Metaverse's functionality.

2.1. Sample Selection

Popular virtual worlds were chosen for this study that implement critical features of the Metaverse. The following key features were identified from widely accepted Metaverse definitions [2].

- Persistence: The platform's ability to offer continuous, uninterrupted virtual experiences is essential. Persistence ensures that the digital environment and user-generated content remain accessible over time.

- Immersiveness: An essential attribute of the Metaverse, immersiveness refers to how convincingly the platform can engage users in a virtual environment. It includes sensory engagement and the depth of interaction within the virtual world.
- Social Interaction: The extent to which the platform supports and facilitates user interaction and social connectivity. This criterion evaluates how the platforms enable community building, collaboration, and social experiences.
- Accessibility: Accessibility is critical for broad adoption and usability. It encompasses the ease of access to the platform, user-friendliness, and the inclusivity of different user groups.
- Decentralization: Given the evolving nature of the Metaverse, decentralization is a forward-looking criterion. It reflects the platform's approach to governance, data control, and power distribution among users and developers.

As the Metaverse is still in its infancy, no virtual worlds exist that implement all the essential features listed above to a full extent [23]. On the other hand, these criteria help distinguish Metaverse platforms from 3D games like Fortnite or Minecraft, which reset the game world after each round [24] or only allow for minimal social interaction [25]. While not every platform in the sample embodies all the critical aspects of persistence, immersiveness, social interaction, accessibility, and decentralization to the same degree, each platform selected for the study demonstrates most of these criteria. These platforms serve as the primary subjects of our systematic evaluation, providing a comprehensive overview of the current landscape of APIs in the Metaverse. They are listed in Table 1.

Table 1. Sample of Metaverse platforms and API availability.

Metaverse Platform	Accessible Public API Available
Axie Infinity	Yes
Captic	No
Decentraland	Yes
EngageVR	No
Horizon Worlds	No
MONA	No
Roblox	Yes
Sansar	No
Second Life	Yes
Somnium Space	No
Spatial	No
The Sandbox	No
Upland	Yes
Voxels	Yes
VRChat	Yes

In the next step in the research process, the availability of APIs for the sample platforms was examined. This investigation focused on whether the platforms offered interfaces for programming and integrating external applications. This analysis revealed a narrowed list of seven platforms for which relevant APIs were available.

2.2. API Research Methodology

A multi-level approach was used to collect data regarding the available APIs of the chosen Metaverse platforms:

- Website Analysis: The official websites and developer documentation of the Metaverse platforms were examined. This analysis focused on identifying publicly available APIs, their features, and the scope of access they provided.
- Community Engagement: Active engagement with the developer community was conducted mainly through Discord channels. These discussions offered insights into the practical uses of the APIs and additional information not available in official documentation.
- Direct Correspondence: Where necessary, direct communication with the development teams of the Metaverse platforms was established via email. This method was employed to clarify details, gain further information, and request access to APIs where public information was insufficient.

The APIs and interfaces were cataloged based on their public accessibility and tailored functionalities for content creators within the Metaverse. The resulting data were tabulated to provide a clear overview of the Public APIs available for each Metaverse platform and their accessibilities as of the research time.

3. Results

The research process for this study involved several steps, as explained in Section 2. The following Sections present the results of the respective steps.

3.1. Identification and Evaluation Process

In the first step of our study, Metaverse platforms were collected, including a check on whether the candidate platforms meet the Metaverse criteria, explained in Section 2.1. This first step resulted in a sample of 15 Metaverse platforms, depicted in Table 1. The second step involved a meticulous examination to determine whether each platform had an API, focusing on public APIs' availability and accessibility. This process was critical to understanding how these platforms could be integrated into broader systems or accessed for data extraction and interaction.

The evaluation process involved the following stages:

- API Existence Check: Determining if the Metaverse platform offers any API.
- Public API Assessment: Identifying whether the APIs are public, ensuring external users and developers can access them.
- Accessibility Verification: Confirm these APIs' ease of access and usage, including the availability of documentation and developer support.

Platforms that lacked accessible public APIs were systematically excluded from the sample. This filtering ensured that our final selection represented Metaverse platforms with available and practically usable APIs for external purposes. The result of step 2 is included in Table 1, too.

The Metaverse platforms selected for further examination encompass a range of virtual environments, each with distinctive characteristics and user base. The refined sample for our API research comprises platforms that met our criteria for having accessible public APIs:

- Axie Infinity: A digital pet universe where players breed, raise, battle, and trade fantasy creatures called Axies [26].
- Decentraland: An open-world virtual reality platform that leverages the Ethereum blockchain to provide a decentralized user-owned environment [27].
- Roblox: A platform that revolutionized user-generated content, providing a suite of tools for users to create their own experiences [28].
- Second Life: One of the earliest and most mature virtual worlds, offering rich user interactions and a complex economy [29].
- Upland: A virtual property trading platform mapped to the real world, allowing users to buy, sell, and trade virtual properties [30].
- Voxels: Focused on simplicity and ease of use. This platform allows users to create and trade virtual assets on the blockchain [31].

- VRChat: A social virtual reality platform that enables users to interact with others in various immersive, user-created worlds [32].

3.2. Available APIs

This Section presents various aspects of the available APIs. Section 3.2.1 presents a comprehensive overview of all available APIs for the six virtual worlds presented in Section 3.2. Section 3.2.2 provides more detail on selected API endpoints to further illustrate the heterogeneity of Metaverse APIs. Finally, Section 3.2.3 compares the information made available through the provided APIs.

3.2.1. Comprehensive Overview of Available APIs

This Section presents detailed information about the available APIs. This illustrates the range of functionalities and critical features these APIs offer, providing insights into the diverse capabilities and limitations inherent in each platform's approach to virtual world interaction and data accessibility. The table serves as a reference point in understanding the current state of API offerings within the Metaverse landscape.

Table 2 presents a comprehensive overview of the APIs identified for the Metaverse platform Decentraland.

Table 2. Overview of Decentraland APIs.

APIs Identified	Description and Key Features
Tiles API [33]	The endpoint returns all tiles in the Decentraland map. This API is key for accessing detailed data about the virtual land parcels in Decentraland. In Decentraland, a tile represents the smallest unit of land, similar to a single square on a chessboard. These tiles are collectively known as parcels, the basic building blocks of the Decentraland world.
Parcel API [33]	The endpoint returns metadata about a specific parcel by its coordinates using the OpenSea Metadata Standard [34]. A parcel in Decentraland is a single tile or a unit of land that players can own and develop. Parcels are 3D spaces where users can create experiences, games, or other interactive content.
Estates API [33]	The endpoint provides metadata about an estate that comprises several contiguous parcels (or tiles) by its ID. An estate is a larger piece of land made by grouping adjacent parcels. Estates allow for the creation of more extensive developments.
Districts API [33]	The endpoints return information about all districts or specified districts in Genesis City. Districts in Decentraland are large areas comprising multiple parcels, usually centered around a specific theme or community. They are akin to neighborhoods or sectors within a city, providing a communal space for users with similar interests.
Map API [33]	The endpoint returns a PNG of the genesis map, customizable via various query parameters such as width, height, and center coordinates. It provides a bird's-eye view of Decentraland, showcasing the layout of parcels, estates, and districts.
Event API [35]	The endpoint provides information about upcoming events. It includes details like event names, descriptions, dates, and coordinates, facilitating the discovery and participation in various virtual events.

Table 3 presents APIs available in Second Life.

Table 3. Overview of Second Life APIs.

APIs Identified	Description and Key Features
Registration API [36]	This API allows for registering Second Life residents directly from a web page. It streamlines adding new users to the Second Life community by integrating the registration process into external websites.
Map API [36]	This API allows for embedding Second Life maps onto web pages. This is particularly useful for integrating Second Life features into external platforms or creating custom user interfaces.
Live Data API [36]	Linden Lab provides live data feeds that offer real-time information relevant to the Second Life environment, such as current events or user activities.
Inventory API [36]	This API provides information on agent inventory within Second Life. It is crucial for managing and accessing the inventory data of users.
Search API (unofficial) [37]	This API enables searching within Second Life for events, groups, people, and places and also facilitates searching the Second Life Wiki.

Voxels offers the APIs depicted in Table 4.

Table 4. Overview of Voxels APIs.

APIs Identified	Description and Key Features
Parcels API [38]	Returns details about every parcel in Voxels, including the owner, collaborators, description, and geometry.
Single Parcel API [38]	Provides basic information for a specific parcel in Voxels when given the parcel's ID as a parameter. This API focuses on individual parcel data.
AllFeaturesParcel API [38]	Returns all features inside a specific parcel based on the provided parcel ID and goes deeper into the details of a specific parcel, revealing all its features (e.g., items or structures) when provided with the parcel's ID.
Suburbs API [38]	The endpoint offers information about all suburbs in Voxels, including their characteristics and locations.
Islands API [38]	Provides a list of all islands in Voxels and their geometric data, giving a comprehensive overview of these distinct areas within the virtual environment.
Womps API [38]	Returns the last 100 womps (user-generated messages or actions) and their associated information in Voxels.
Avatars API [38]	The endpoint gives information about avatars, including details of their corresponding parcels. This API links virtual characters to specific locations in Voxels.
Collectibles API [38]	The endpoint provides information on all collectibles within Voxels, including details about each collectible item.

The Roblox APIs are presented in Table 5.

Table 5. Overview of Roblox APIs.

APIs Identified	Description and Key Features
Users API [39]	This API handles direct Roblox user information. It provides access to user-related data, such as profiles, statistics, and other critical user-specific details.
Avatar API [39]	This API focuses on the customization of player avatars. It includes endpoints for modifying and retrieving information about player avatars.
Catalog API [39]	Enables browsing and searching for catalog items. It also recommends content and user-based catalog items.
Games API [39]	This API provides valuable data for game discovery. It includes endpoints for retrieving detailed information about games available on Roblox.
Groups API [39]	Manages groups within Roblox, including creating, managing, and moderating user groups. This API is essential for community building and management on the platform.
Presence API [39]	It contains all endpoints for managing user presence. It helps track and display the online status and activity of users.
Inventory API [39]	It focuses on viewing (but not granting) ownership of items. Users must manage and view their in-game inventory, including items owned, collected, or earned through gameplay.
Premium Features API [39]	This API plays a crucial role in managing premium subscriptions and features available to users who opt for the premium service on Roblox.

Table 6 presents APIs available in Axie Infinity.

Table 6. Overview of Axie Infinity APIs.

APIs Identified	Description and Key Features
Item API [40]	This API includes endpoints for listing all runes, charms, and other items and retrieving specific items by ID. It is used for managing the different items available in the game.
User Item API [40]	With the query parameter of the UserID, all Items of the given user are displayed in the format of the Item API.
User Map API [40]	With the query parameter of the UserID, all the cleared Chapters of the given user are displayed.
User Fighter API [40]	With the query parameter of the UserID, all the fighters of the given user are displayed.
Leaderboard API [40]	This API Lists the current leaderboard of players and the current season leaderboard. The maximum number of players in the response object can be limited with query parameters.
Season API [40]	This API shows basic information about the current Season.

An overview of APIs for Upland is depicted in Table 7.

Table 7. Overview of Upland APIs.

APIs Identified	Description and Key Features
Tracks API [41]	This API response provides an overview of a track in Upland, offering details like location, physical attributes, and conditions that can be used for game mechanics or player decision-making.
Tracks Buildings API [41]	This API response describes a building in Upland, including its physical characteristics and location.
Cities API [41]	This API response provides information about cities in Upland, listing each city with a unique identifier and its name.
Properties API [41]	This API lists information about properties in Upland, detailing their location, status, and related financial information.

Table 8 presents information on VRChat APIs.

Table 8. Overview of VRChat APIs.

APIs Identified	Description and Key Features
Avatars API [42]	This endpoint manages avatar data within VRChat. It provides details such as the avatar's unique ID, author information, creation and update timestamps, and description. The API also includes the avatar's image URLs, release status, tags, and unity package details, which are crucial for avatar customization and management.
Groups API [42]	This endpoint handles group-related data in VRChat. It includes the group's ID, name, short code, and other descriptive information. The API also manages group icons, banners, owner details, member count, and tags, offering insights into group characteristics and dynamics. Additionally, it covers galleries within groups, encompassing details like ID, name, description, and roles for viewing and submitting content.
Users API [42]	This endpoint provides comprehensive user profile information in VRChat. It includes bio, current avatar images, display name, user ID, friendship status, and platform information. The API also covers status descriptions, tags, user icons, and location, which are essential for user profile management and social interaction within VRChat.
Worlds API [42]	Provides detailed information about the virtual worlds or experiences within VRChat. Key data includes the world's unique identifier, author information, capacity, recommended capacity, creation and update timestamps, and encompasses retrieving world metadata and exploring world categories.
Economy API [42]	This Endpoint is essential for managing VRChat's virtual economy and user subscriptions and manages transactions and subscriptions within VRChat. It details transaction ID, status, subscription information (including ID, steam item ID, amount, description, period, and tier), sandbox status, creation/update timestamps, and steam-related information.

3.2.2. Details on Selected API Endpoints

As can be seen from Tables 2–8, each Metaverse platform offers individual APIs that differ in name, content, and specification from other platforms' APIs. The following selected examples are explained in more detail to illustrate the variety of functionalities of these APIs:

- Decentraland's Tiles API: The Tiles API in Decentraland has been updated to a more efficient v2 endpoint. It returns detailed information about all tiles in the map in a new, more readable format. This API is crucial for accessing comprehensive data about virtual land parcels in Decentraland, offering insights into the layout and distribution of land.
- Decentraland's Estates API: The Estates API in Decentraland allows users to retrieve metadata about an estate based on its ID. An estate represents a building or facility often stretching across multiple tiles. This functionality is essential for accessing detailed information about estate properties, including their ownership and characteristics.
- Voxels Parcel API: The response provides detailed information about a parcel in the virtual world. An example response includes data such as the parcel's ID, dimensions, location coordinates, contributors, and ownership details. However, a blockchain explorer like Etherscan [30] is essential for comprehensive insights, especially on transaction history and ownership changes. It complements the API by providing deeper transactional data, which is crucial for understanding the full economic context of each parcel.
- Roblox's Avatar API: In Roblox, each user is represented by a customizable avatar. The Avatar API provides functionalities for character model customization, allowing users to interact with experiences and personalize their avatars with a wide range of clothing and accessories available in the Roblox Marketplace. This API is a cornerstone for user identity and personalization within the Roblox platform.
- Second Life's Map API: The Map API of Second Life enables the integration of dynamic Second Life maps into websites or applications. It provides a way to embed real-time maps showing the virtual world's layout, including regions and significant landmarks. Developers can use this API to create interactive map features for users, enhancing navigation and spatial awareness in the Second Life Metaverse.

3.2.3. Comparison of Available APIs

The virtual worlds providing APIs cover a variety of information made accessible through respective endpoints. Table 9 presents an overview of the available information per virtual world. As can be seen, none of them covers the full range of information. Roblox comprises many closed experiences instead of an open, explorable landscape [28]. This renders information on a virtual property, district, or map meaningless. In light of this consideration, the Roblox API provides the most comprehensive information in the sample. On the other hand, Upland focuses primarily on trading virtual property [41], making corresponding APIs reasonable. In this case, an additional map API, which is not available today, could also be beneficial. Information on events and experiences could be specifically helpful to gain users' attention and drive traffic to a virtual world. Nevertheless, only Decentraland, Roblox, and VRChat offer corresponding APIs. Live data could enable users to determine whether and where friends are active in a virtual world. The majority offers respective APIs, but not all of the worlds in the sample.

Table 9. Overview of available information.

Available Information	Decentraland	Second Life	Voxels	Roblox	Axie Infinity	Upland	VRChat
Virtual Property Information (e.g., ownership or characteristics of land, parcels, estates)	X		X			X	
District, Island, or Neighborhood Information (e.g., community topics)	X		X			X	
Map	X	X			X		
Event and Experience Information (e.g., topics, types, dates, location)	X			X			X
Admin Functions (e.g., register users, user groups, season data)		X		X	X		X
Live Data (e.g., user activity, leader board, presence, messaging, economy)		X	X	X	X		X
User and Avatar Data (e.g., public account data, inventory)		X	X	X	X		X
Asset and Collectible Information (e.g., properties, IDs)			X	X	X		

4. Discussion

Table 1 shows that only 7 platforms of a sample with 15 platforms offer publicly accessible APIs. Thus, most sample platforms do not provide this widespread and widely accepted means of interaction and interoperability.

A distinct diversity and complexity become apparent when examining the available APIs of various Metaverse platforms. While allowing for unique and tailored experiences in each virtual world, this variety also creates a barrier to the interoperability of different Metaverse environments. In particular, significant marketplaces such as OpenSea [43] could be pivotal in driving standardization across various APIs, particularly in domains like real estate and other digital assets. Their widespread usage and influence in the digital asset market could set a precedent for uniform API structures and data formats, thereby supporting a more cohesive and efficient approach to data management in the Metaverse.

An additional critical issue is the fragmentation of information accessible through these APIs. For many virtual worlds, generating a comprehensive picture requires accessing several APIs, including sources outside the respective virtual platform. This underscores the need for a more unified approach to data management and retrieval within the Metaverse. The varying levels of complexity and data availability across platforms necessitate customized strategies, leading to inefficiencies in both development and user experience. While internal APIs like the Voxels Parcel API provide foundational data, they often need more detailed historical and transactional context. The reliance on external sources reflects a broader need within the Metaverse for APIs to provide a more comprehensive data spectrum. Blockchain explorers are essential tools that provide historical and economic data on virtual assets, which are crucial for the analysis and traceability of Metaverse's digital assets. This underscores the potential for evolving API offerings to deliver more integrated data solutions within these virtual environments.

For users, the current limitations of APIs may restrict the scope of interaction and immersion in virtual worlds. For developers, it represents a challenge in navigating a diverse and sometimes limited API landscape. Addressing these issues could significantly enhance the user experience and the ease of development within the Metaverse. This scenario presents an opportunity to develop more standardized and comprehensive APIs within the

Metaverse. Such advancements could improve interoperability between different virtual environments and provide a more seamless experience for both users and developers.

The study examined a sample of 15 virtual world platforms. As the number of available Metaverse platforms is at least in the hundreds [44], this poses a significant limitation. In addition, the Metaverse is developing rapidly. Thus, the API landscape might change, too. Future research could examine larger and updated samples and re-evaluate the results of this study.

Furthermore, following a user-centered approach, future research could evaluate which API topics are specifically interesting from a user point of view. In this respect, users could be Metaverse users, visitors of virtual worlds, content creators, and developers alike. A proposal for standardized APIs addressing user needs should be developed in the second step.

5. Conclusions

The Metaverse is envisioned as a network of interconnected virtual worlds [2,8], emphasizing the need for interoperability. While this includes, but is not limited to, aspects such as standardized data formats for 3D objects, avatars, and in-world experiences, the paper at hand focuses on interfaces for the data exchange between virtual worlds or with other web services. This study revealed that only a fraction of the examined virtual world platforms offer APIs at all. The available APIs have been analyzed regarding their functionality and the accessible information. Thus, this study contributes a guide to today's Metaverse APIs.

Furthermore, this study revealed that in most cases, the accessible information is limited, and gathering meaningful information, in many cases, requires complex queries, and the APIs are very different for specific virtual worlds. This is an essential barrier for interoperability in the Metaverse and, thus, for the Metaverse itself. Future research, industry, and developers should focus on standardizing API and data structures to foster Metaverse adoption and success. An excellent example of the power of standardization is the ERC20 standard [45] in the Ethereum ecosystem. ERC20 defines a standard interface for smart contracts on the Ethereum blockchain defining tokens. ERC20 was introduced in 2015 [46]. Today, it accounts for 80% of initial coin offerings [47].

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