A COMPARISON OF VIRTUAL WORLDS BASED ON THE METAVERSE MATURITY MODEL

Markus Weinberger[1], Daniel Gross[1]
[1]Aalen University of Applied Science, Beethovenstrasse 1, 73430 Aalen, Germany

NOTE: Corresponding author: Markus Weinberger, markus.weinberger@hs-aalen.de

Abstract *– The realization and adoption of the metaverse vision is still in its infancy. In order to answer the question of how close today's virtual worlds get to this metaverse vision, the metaverse maturity model has been applied to evaluate a sample of eight selected virtual worlds: Guild Wars 2, Fortnite, Second Life, Roblox, VRChat, Decentraland, Horizon Worlds, and The Sandbox. The model comprises eight core attributes with five maturity levels each. The results indicate that, on the one hand, technical preconditions for the metaverse, e.g., sufficient computing power, network technology, and interoperability standards, are not yet met. On the other hand, core attributes which mainly depend on strategy, e.g., persistence and economic systems can yield high maturity levels, if the strategy is aligned accordingly. As the study shows the usefulness of the metaverse maturity model, future research should repeatedly evaluate metaverse maturity to track progress and identify the need for further development.*

Keywords – Decentraland, Horizon Worlds, maturity model, metaverse, The Sandbox

1. INTRODUCTION

Neal Stephenson introduced the term metaverse in his novel Snow Crash in 1992 [1]. Since then, the topic has gained increasing attention from academia and industry, specifically after Facebook rebranded to Meta in late 2021 [2]. During this time, several Virtual Worlds (VWs) have been implemented, which aim to realize the vision of the metaverse; examples are Second Life [3] and Decentraland [4]. The vision emerged that the metaverse could be the next iteration of the Internet, following fixed-line Internet and social media [5]. While it is not considered to replace those mentioned above, the metaverse is envisioned to add a ubiquitous, persistent, and immersive digital layer to the physical world [2].

Various researchers agree that the realization and adoption of the metaverse vision is still in its infancy [6] and that the vision will probably evolve over time [5]. This raises the following research questions (RQ):

RQ1 – How close to the metaverse vision are the virtual worlds that are available today?

RQ2 – What differences can be found between virtual worlds related to their metaverse maturity?

RQ3 – Which aspects of the metaverse vision are bottlenecks in the sense that they are specifically challenging to fulfill today?

Thus, the article aims to transparently compare the state of virtual worlds available today to the metaverse as envisioned for the future. This could then serve as a baseline to measure progress towards realizing a full-featured metaverse.

The paper is structured as follows: Section 2 introduces related work, while Section 3 explains the methods applied to answer the research questions presented in Section 1. Section 4 explains the selected sample of virtual worlds and the reasoning behind this selection. The actual evaluation for each virtual world is presented in Section 5. It provides the dataset, which is further analyzed for insightful results. These are presented in Section 6. Section 7 finally draws conclusions from the results.

2. RELATED WORK

In past years, many researchers have explained their vision of the metaverse and characterized the essential aspects from their point of view [2]. A prominent example comes from Davis et al., who wrote in their 2009 article "Avatars, People, and Virtual Worlds: Foundations for Research in Metaverses": "Metaverses are immersive three-dimensional virtual worlds in which people interact as avatars with each other and with software agents, using the metaphor of the real world but without its physical limitations." [7]. Dionisio et al. published

Table 1 – Metaverse maturity model [11]

	Maturity Levels				
Core Attribute	**1**	**2**	**3**	**4**	**5**
Persistence	Turn-based; no persistence; resets are normal	Persistent online-platform; not turn-based; continu-ously online and accessible; planned resets, respawns and updates occur sometimes	Persistent virtual world, continu-ously online; entering or leaving has no impact on the world; no resets; partly not persistent	Large parts of the virtual world are fully persistent; some exceptions exist	Fully persistent virtual world - no exceptions
Synchronicity	Not an online world; no real-time interaction	Live interaction with a limited number of users in a limited space (e.g., lobby)	Live interaction with all users in the virtual world, but limited to regions of the physical world	Live interaction with all users in the virtual world, worldwide; some-times exceptions with increasing latency or pausing	Whole virtual world is accessible in real time; live communication and interaction; worldwide
Scalability	Up to 10 users simultaneously	Up to 250 users simultaneously	Up to 1000 users simultaneously	Up to 10 000 users simultaneously	No limit
Physical and digital coexistence	No connection to the physical world, except for screen and controller-based means to control an avatar	One interface, e.g., VR or virtual currency tradable for fiat money	Additional interfaces, several interfaces	Generic changes in the physical world influence the virtual world and vice versa	Physical and virtual worlds are continuously interfacing
Interoperability	No interoperability; prohibitive	One component, e.g., avatar or asset transferable	Several components transferable	Interoperability with several other virtual worlds	Interoperability with all other virtual worlds
User-Generated Content (UGC)	No UGC is possible. UGC is not in the vendor's focus	Users have very limited possibilities to change the virtual world. UGC is not in the vendor's focus.	UGC plays an important role. Users can create worlds or spaces, assets, etc.	UGC is possible in a large variety and complexity; UGC can be monetized	The virtual world depends heavily on UGC. The world must be created by users building on a given base environment. Everything can be monetized
Economy	No economy; in-app purchases available	Virtual economy with virtual currency; fiat money can be exchanged for virtual currency	Virtual economy; free self-regulating market (supply and demand); fiat money purchases	Virtual economy; free self-regulating market (supply and demand); virtual jobs and services can generate physical world income	Fully developed economy; self-regulating markets; virtual economy blending with physical world economy
Immersive realism	Hardly any feeling of immersion; text chats; avatars without facial expressions	Little immersive experience; avatars provide a feeling of individual presence; users can act freely; voice chat	Individual avatars with facial expressions and gestures; voice chat; VR; 3D audio; motion tracking; individual social presence for all users	Including haptic feedback; high-end VR	High level of realism perfectly serving all human senses; creates an immediate immersive experience; hardly distinguishable from the physical world

the article "3D Virtual Worlds and the Metaverse: Current Status and Future Possibilities" in 2013, in which they wrote: "Virtual worlds are persistent online computer-generated environments where multiple users in remote physical locations can interact in real-time for the purposes of work or play." [8]. In a later section of the same paper, they emphasize interoperability as an essential feature of virtual worlds in the metaverse. The aspect of an economic system being important to motivate users to contribute content has been mentioned, for example, by Wang et al. in their 2022 article "A Survey on Metaverse: Fundamentals, Security, and Privacy" [9].

An extensive literature survey published in 2022 proposes the following unified definition of the metaverse: "The Metaverse is an interconnected web of ubiquitous virtual worlds partly overlapping with and enhancing the physical world. These virtual worlds enable users represented by avatars to connect and interact with each other to experience and consume user-generated content in an immersive, scalable, synchronous, and persistent environment. An economic system provides incentives for contributing to the Metaverse." [2]

From the existing definitions, Gross in his 2022 thesis extracted eight core attributes of the envisioned metaverse of the future [10]. These eight core attributes are the foundation of the metaverse maturity model. For each of the core attributes, five Maturity Levels (MLs) have been defined, where ML 1 is the starting level. At the same time, ML 5 corresponds to a fully developed metaverse, as in today's understanding.

3. METHODOLOGY

The Metaverse Maturity Model (MMM) introduced in Section 2 is applied to compare the selected virtual worlds transparently and in a standardized way. The maturity model is based on existing metaverse definitions, from which the following eight core attributes were derived: *persistence, synchronicity, scalability, physical and digital coexistence, interoperability, User-Generated Content (UGC), economy*, and *immersive realism*. For each core attribute, five maturity levels with respective criteria were defined [11]. Thus, for a given virtual world or platform, e.g., Decentraland, all core attributes can be analyzed according to the above-mentioned criteria so that the platform's maturity level for the respective core attribute can be determined one by one in a transparent and reproducible manner. The average ML over all eight core attributes can be seen as an indicator of the platform's overall conformity with the metaverse vision. In contrast, the maturity level profile amongst the core attributes reveals strengths and weaknesses. The criteria for the maturity levels of all core attributes are presented in Table 1.

Section 6 applies descriptive statistics for data analysis and result presentation.

4. SAMPLE SELECTION

The metaverse is envisioned to comprise many virtual worlds [12], such as one worldwide web comprising many webpages or social media platforms. Already today, many virtual worlds exist. Often, games like Fortnite are called predecessors of metaverse virtual worlds [5]. Today's virtual worlds or platforms differ in various ways. There are platforms with a central and others with a decentral approach, which are blockchain-based systems and involve users extensively. Some virtual worlds are continuous open worlds in which users represented by their avatars move freely. Other platforms comprise thousands of separate spaces or experiences between which users can choose and switch. Finally, there are older virtual worlds that were launched more than 15 years ago, while younger platforms are still in beta.

Examples for different categories of virtual platforms were selected as follows, in order to obtain a broad picture of the state of development of the metaverse:

Guild Wars 2 is a Massive Multiplayer Online Role-Playing Game (MMORPG), one of the oldest forms of virtual worlds. It follows the open-world approach.

Fortnite is a video game that steps away from the classic game objectives and gives users more opportunities for creative freedom. Fortnite does not have an open world. Users join limited game experiences or create their own spaces.

Second Life is not a video game but rather a social virtual world in which users interact with each other through avatars and help shape the world. It is one of the first approaches to actually build the metaverse [3], leveraging an open-world approach.

Roblox is an online platform that allows users to play 3D games created by other users as separate experiences. It is one of the most popular platforms of its kind [13].

VRChat is a platform that has been optimized for the use of virtual reality, which is an important aspect of the metaverse idea. Its primary focus is on the communication and interaction of users through avatars and the co-creation of the virtual world. It comprises a multitude of distinct virtual spaces.

Decentraland is a browser-based, 3D virtual, open world based on blockchain technology, thus representing decentralized virtual worlds.

Horizon Worlds is an example of a virtual world developed by a large tech company. It has been released by Meta Platforms in 2021 [14] and comprises many separate spaces.

The Sandbox is a blockchain-based platform for creating and monetizing virtual experiences, which can be deployed on parcels of land on an open map [15].

5. VIRTUAL WORLD DATA

This section presents the core attribute maturity levels for the selected virtual worlds [10]. The reasoning for each evaluation is briefly explained and has to be seen in context with the metaverse maturity model, as depicted in Table 1.

5.1 Guild Wars 2

Guild Wars 2 (GW2) is an MMORPG published in 2012 by developer ArenaNet [16]. As of 2022, Guild Wars 2 has approximately 17 million players, of which an estimated 678 000 are active daily [17]. The maturity levels for Guild Wars 2 are explained in Table 2.

Table 2 – Maturity levels for Guild Wars 2

Core Attribute	ML	Explanation
Persistence	3	In general, GW2 is persistent. Users can leave and re-enter without affecting the VW. Some exceptions exist, e.g., so-called dungeons [18].
Synchronicity	2	Events like fights or quests take place in real time. Users can meet a selection of other users. However, this is limited to regions of the physical world [19].
Scalability	2	Official data on the maximum number of users per area is not available. This maximum is assumed to be below 200 users [18].
Physical and digital coexistence	1	A connection to the physical world beyond screen and controller-based means to control an avatar does not exist [18].
Interoperability	1	Means to transfer any components like assets or avatars to other VWs do not exist [18].
User-Generated Content (UGC)	2	Users can create assets depending on their avatar´s profession. The palette of assets is minimal. Skins cannot be created by users [18].
Economy	3	A virtual currency can be used to trade assets like arms or materials at a market. Prices reflect supply and demand [18].
Immersive realism	1	In particular, interaction with other users is limited to text chat with hardly any other means to express emotions, etc. [18].

5.2 Fortnite

Fortnite appeared on the market in July 2017 as a cooperative survival shooter and was developed by Epic Games. However, Fortnite achieved great popularity with the Battle Royale mode, released in September 2017 [20]. As of 2021, Fortnite had an estimated 400 million registered [21] and 25 million daily active users [22]. Various game modes are available: Battle Royale, Save the World, and Fortnite Creative [23]. The maturity levels for Fortnite are explained in Table 3.

Table 3 – Maturity levels for Fortnite

Core Attribute	ML	Explanation
Persistence	2	Persistence depends on the game mode, while the Battle Royale mode is not persistent at all, the other modes are to some extent persistent [23].
Synchronicity	2	Live interaction is only possible with limited users from the same geographic region [24].
Scalability	2	The maximum number of users in the Battle Royale mode is 100. In Creative mode, the limit is 16 users [23].
Physical and digital coexistence	1	A connection to the physical world beyond screen and controller-based means to control an avatar does not exist [23].
Interoperability	2	Fortnite is available on many platforms, e. g. PC, Playstation, and mobile phones. Epic is the developer of Unreal Engine, a game engine that many game developers use. This fosters interoperability [25].

Table 3 – Maturity levels for Fortnite

Core Attribute	ML	Explanation
User-Generated Content (UGC)	3	Only in Fortnite Creative can users create worlds, experiences, and, for example, buildings that are persistent [23].
Economy	1	There is no economic system in Fortnite [23].
Immersive realism	1	There is voice chat in Fortnite, but only with players of the own team or in Creative mode. Otherwise, there are only limited means to act freely and express emotions, which would increase a feeling of immersion [23].

5.3 Second Life

The 3D virtual world of Second Life (SL) was released in 2003 by the developer and publisher Linden Lab. Second Life had its highest activity in 2009 and 2010, with up to 80 000 daily users [26]. Since then, user numbers have steadily declined and currently stand at around 40 000 daily users [27]. Second Life is a social virtual world. The maturity levels for Second Life are explained in Table 4.

Table 4 – Maturity levels for Second Life

Core Attribute	ML	Explanation
Persistence	4	SL is, in general, persistent. The world exists and evolves independently of user presence. Assets etc. are persistent [28].
Synchronicity	4	SL is a real-time world. In general, live interaction with other users at the same location is possible independently of their physical location [28].
Scalability	2	The number of users being present simultaneously in a location of the VW is limited. The maximum number is 100 users [29].
Physical and digital coexistence	2	There are no VR or other advanced interfaces available. However, the in-world currency can be exchanged freely with fiat currencies [30].
Interoperability	1	Means to transfer any components like assets or avatars to other VWs do not exist [28].
User-Generated Content (UGC)	4	Users can create buildings, assets, and avatar accessories. This plays an important role [28]. Experiences are not the main focus.
Economy	4	Users can trade assets, etc., on a self-regulating market [31]. They can offer services and do paid jobs [32].

Table 4 – Maturity levels for Second Life

Core Attribute	ML	Explanation
Immersive realism	2	There is some feeling of immersion as spatial voice chats and some means to express emotions are available [28].

5.4 Roblox

Roblox debuted in 2006 as an Internet gaming platform. It allows users to create their own virtual experiences, games, or worlds. Other users can play these games and interact with peers represented by avatars. In recent years, during the COVID-19 pandemic, the popularity of Roblox increased considerably to 65.5 million daily active users and more than 202 million monthly active users as of mid-2023 [13]. Table 5 presents the maturity levels for Roblox.

Table 5 – Maturity levels for Roblox

Core Attribute	ML	Explanation
Persistence	2	Persistence of the worlds or games in Roblox can be implemented but is not given in general [33].
Synchronicity	3	Live interaction with other users of the same experience or game is generally only possible with other users on the same server [34].
Scalability	2	The maximum number of users per server is 200 [35].
Physical and digital coexistence	1	A connection to the physical world beyond screen and controller-based means to control an avatar does not exist [36].
Interoperability	3	It is possible to import assets and avatars via standard file formats [37].
User-Generated Content (UGC)	4	UGC is very important in Roblox. Users are creating experiences and assets, e.g., avatar accessories. UGC can be monetized [38].
Economy	3	There are many aspects of an economy in place. An in-world currency exists; users can create assets and experiences and charge money for them. Those items can be traded between users [38].
Immersive realism	3	Limited possibilities to interact with other players. Voice chat is available in a beta version only. Limited means to express emotions and to act freely [39]. Some games support VR headsets [40].

5.5 VRChat

VRChat is a free platform comprising more than 25 000 worlds or chat rooms and has some 63 000 daily active users [41]. It was published in 2017 by VRChat Inc. VRChat was optimized for use with VR headsets [42]. The maturity levels for VRChat are explained in Table 6.

Table 6 – Maturity levels for VRChat

Core Attribute	ML	Explanation
Persistence	3	The worlds in VRChat are, in general, persistent. The content of instances itself cannot be altered by the users. Empty instances are closed [43].
Synchronicity	3	Live interaction is possible with people in the same world and instance [43].
Scalability	2	The number of users per instance is limited to 80 [44].
Physical and digital coexistence	2	Several VR headsets can be used with VRChat [42].
Interoperability	2	Avatars created on platforms like Ready Player Me can be used in VRChat and other VWs [45]. There are no assets to be transferred. Unity is used for content creation [42].
User-Generated Content (UGC)	4	Users can create worlds and avatars. In particular, user-generated worlds are a core component of VRChat [42]. In addition, events can be held.
Economy	1	There is no economic system in VRChat [42].
Immersive realism	3	Individual and detailed avatars, high graphical details, gestures, lip-sync features, and 3D audio increase the immersive feeling [42].

5.6 Decentraland

Decentraland is a virtual world using the Ethereum blockchain as a decentral backbone [46]. Furthermore, it is governed by a Decentralized Autonomous Organization (DAO), involving users and contributors in essential decisions related to the virtual world [47]. The project started in 2015 [4] and today attracts some 20 000 monthly active users [48]. The maturity levels for Decentraland are explained in Table 7.

Table 7 – Maturity levels for Decentraland

Core Attribute	ML	Explanation
Persistence	4	Decentraland is, in general, persistent. Users can leave and enter without influencing the world or other users. Assets and buildings are persistent [49].
Synchronicity	4	In general, Decentraland is a real-time virtual world. The ability for users to interact with each other depends on so-called realms and islands. Users can interact independently of their physical location [50].
Scalability	2	The number of users per island is limited to 100 [51].
Physical and digital coexistence	2	Decentraland can only be accessed via a web and desktop client [52]. VR headsets are not supported natively, nor are other user interfaces. The in-world currency can be exchanged into fiat currencies [53].
Interoperability	1	Means to transfer any components like assets or avatars to other VWs do not exist.
User-Generated Content (UGC)	4	User-generated content plays a vital role in Decentraland. Users can create scenes or experiences on land they own. They can create assets and accessories and organize events like parties or concerts [53].
Economy	4	UGC can be monetized. Assets are being traded on Decentraland's and other marketplaces like OpenSea [53, 54]. Users and their avatars can get hired for jobs and earn money [55].
Immersive realism	2	The feeling of immersion is limited. The visualization of Decentraland is in a comic style rather than realistic. Interactions with other users and gestures and emotes of the avatars are very limited [49]. Users can talk to each other via voice chat [50].

5.7 Horizon Worlds

Horizon Worlds (HW) is a social VR platform from Meta Platforms, released on December 9, 2021 [14]. It comprises many separate worlds, of which several copies can exist depending on the number of users [56]. By October 2022, Horizon World had about 200 000 monthly users [57]. Currently, Horizon Worlds can only be used via Meta VR headsets. Access to the virtual world is free of charge [56]. The maturity levels for Horizon Worlds are explained in Table 8.

Table 8 – Maturity levels for Horizon Worlds

Core Attribute	ML	Explanation
Persistence	3	The worlds in HW are, in general, persistent. Users can enter and leave the world without influencing other users. Assets and items are persistent, too. Some game worlds are round-based and not persistent [56].
Synchronicity	3	Live interaction is possible with people in the same world and copy [56].
Scalability	2	The max. number of users per world copy is limited to 20 [58].
Physical and digital coexistence	2	HW is designed for use with a VR headset [56].
Interoperability	1	Means to transfer any components like assets or avatars to other VWs do not exist. HW is only available on one hardware platform [56].
User-Generated Content (UGC)	4	Users can create worlds and avatars. In particular, user-generated worlds are a core component of Horizon Worlds [56]. In addition, events can be held.
Economy	3	Consumables and some in-world items can be sold and purchased. Entrance to worlds and events can be monetized [59]. There is no in-world currency. Instead, fiat currency is used [60].
Immersive realism	3	Individual avatars, gestures, lip-sync features, and 3D audio increase the immersive feeling [56].

5.8 The Sandbox

The Sandbox is a virtual 3D world where users can create experiences. The platform is blockchain-based and emphasizes monetization of the user's creations and an in-world economy [61]. The Sandbox was launched in 2021 as an alpha version [62]. Currently, the platform is available in a beta version, which does not yet allow users to publish experiences on the open world map of the Sandbox [63]. The platform attracts some 30 000 monthly active users [64]. Maturity levels for The Sandbox are presented in Table 9.

Table 9 – Maturity levels for The Sandbox

Core Attribute	ML	Explanation
Persistence	4	Many aspects of The Sandbox are persistent; for example, assets are represented by NFTs, which persist on a blockchain [61].
Synchronicity	2	Live interaction is only possible with a limited number of users on the same piece of land at the same time [65].
Scalability	2	Strong recommendations exist to keep the number of users per experience at some tenths of users [65].
Physical and digital coexistence	2	In-game currency can be traded for fiat money. No other interfaces to the physical world [61].
Interoperability	4	Assets and currency are blockchain-based and can, therefore, be transferred [15].
User-Generated Content (UGC)	4	The platform comprises tools to create assets and experiences. UGC can be monetized and traded on marketplaces within or outside the virtual world [15].
Economy	3	Economy plays a vital role with an in-world currency and an integrated marketplace. Currency and assets are blockchain-based and can be traded on blockchain marketplaces [61].
Immersive realism	1	Very limited possibilities to interact with other players. Limited means to express emotions and to act freely [67].

6. RESULTS

Data from the example virtual worlds presented in Section 5 have been aggregated and will be presented and discussed below.

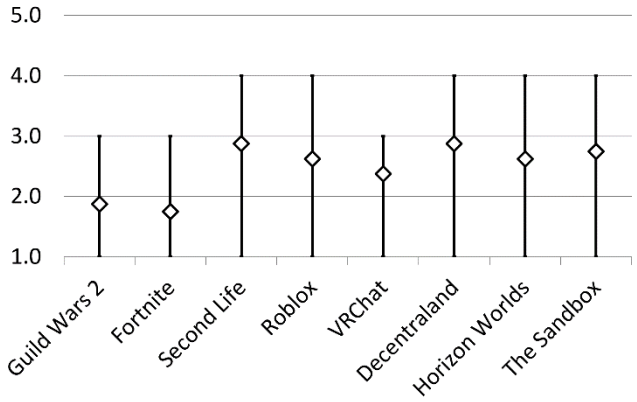

Fig. 1 – Average maturity levels per virtual world. Bars indicate minimum and maximum values. (own chart)

Fig. 1 provides data related to research question 1, "How close to the metaverse vision are the virtual worlds that are available today?". As for all core attributes in the metaverse maturity model, level 5 would correspond to a full-featured metaverse as it can be envisioned today, and the average maturity level indicates whether a sample virtual world gets close to this vision. The diamonds in Fig. 1 correspond to the average maturity level for each virtual world across all eight core attributes. These average values range from 1.8 (Fortnite) to 2.9 (Second Life and Decentraland). On the maturity scale from level 1 to 5, a score of 2.9 is still just below a medium level of 3. The bars depicted in Fig. 1 indicate the lowest and highest maturity levels for individual core attributes. As the chart shows, none of the examined sample virtual worlds reached the maximum level of 5 for any core attribute. At the same time, at least one core attribute had to be evaluated for all virtual worlds to remain on the lowest level 1. With the average maturity level amongst the sample of this study being below the medium level, there is still significant development and adoption of the metaverse vision required, to get even close to the same.

Research question 2, "What differences can be found between virtual worlds related to their metaverse maturity?" requires further analysis of the data presented in Fig. 1. The highest average maturity levels with a score of 2.9 are reached by Second Life and Decentraland, followed by The Sandbox with 2.8. All these virtual worlds have an open-world approach in common, in which users represented by their avatars can move freely. Roblox, VRChat, and Horizon Worlds follow closely behind, ranging between 2.4 and 2.6. They all comprise of many closed spaces or experiences the users need to choose between. Due to this concept, the core attributes persistence and synchronicity are evaluated lower compared to the open-world concepts. The lowest average maturity levels earn Fortnite (1.8) and Guild Wars 2 (1.9), which have both been launched as games rather than metaverse implementations. These two lack immersive realism, synchronicity, and an economic system, in the case of Fortnite. Although Tim Sweeny, CEO of Epic Games, the company developing Fortnite, focused on the metaverse for years [65], Fortnite itself is still mainly a game. In contrast, the inventor of Second Life, Philip Rosendale, intended to build a metaverse-like virtual world from the beginning [3]. This is reflected in the higher average ML. As an answer to research question 2, the following can be stated: Virtual world games fall behind virtual worlds that aim at building the metaverse. The latter reach similar average maturity levels, with a slight advantage of using the open-world approach.

Fig. 2 presents a different perspective on the data. It focuses on the results related to the eight core attributes of the metaverse maturity model. This contributes to answering research question 3, "Which aspects of the metaverse vision are bottlenecks in the sense that they are specifically challenging to fulfill today?". The diamonds in Fig. 2 show the average maturity levels per core attribute, while the bars indicate the dataset's corresponding minimum and maximum values. The four core attributes with the lower average maturity models are scalability (2.0), physical and digital coexistence (1.6), interoperability (1.9), and immersive realism (2.0). These four can hardly be influenced by one entity developing a virtual world alone. Scalability mainly depends on computing power, network bandwidth, and latency, which a single virtual world developing entity can hardly push forward. The core attribute physical and digital coexistence depends on the definition of the maturity model, on advances in interface technology between physical and digital world. This is related to immersive realism, as it depends highly on means to have avatars reflect the emotions, gestures, and facial expressions of humans realistically, which again requires technological advancements to be realized. Interoperability, by definition, depends on the joint development and implementation of standards and protocols that foster the transfer of avatars, assets, and more, between virtual worlds. These cannot be defined by one entity alone.

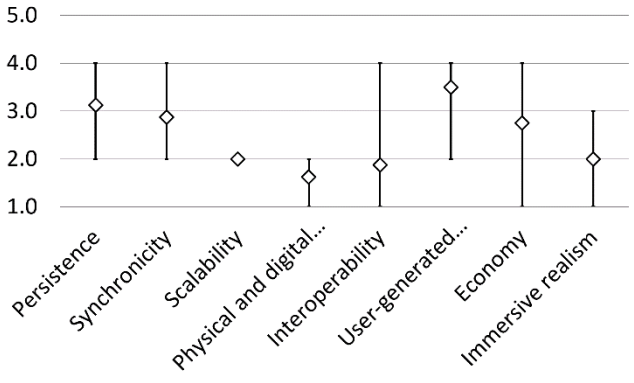

Fig. 2 – Average maturity levels (diamonds). Bars indicate minimum and maximum values. (own chart)

7. CONCLUSION

The results presented in Section 6 show low maturity levels mainly for core attributes depending on technology. Further advancements in computing power, network bandwidth, and latency, as well as performance and ubiquity of AR and VR devices, to name just a few examples, will lead to higher maturity levels for these core attributes. This is equivalent to getting closer to realizing the metaverse vision. Interoperability might require specific attention as development towards this core attribute requires the alignment of many distinct entities and companies in the metaverse ecosystem.

Other core attributes, e.g., user-generated content and economy, relate to the design decisions of the entities developing virtual worlds. User-generated content can be fostered by providing users with tools and editors to create content, while elements like marketplaces and exchangeable in-world currencies contribute to the economic system of a virtual world.

In general, the evaluated virtual worlds are not yet close to the metaverse vision, as reflected in the definitions presented in Section 2.

The study evaluates a limited number of selected virtual worlds, which are not necessarily representative of the totality of today's virtual worlds. Furthermore, this study evaluates the maturity concerning the metaverse definition presented above. This definition has been derived through a process taking the views of scholars and other influential voices into account [2]. Still, virtual worlds that do not intend to fulfill the corresponding requirements will consequently fall behind. This might be due to a different approach and strategy for a metaverse virtual world, e.g., not implementing an in-world economic system.

The applied metaverse maturity model proved to be a helpful tool to analyze virtual worlds in the metaverse context transparently and objectively. The study revealed valuable insights related to different virtual world designs and strategies and to the character of the core attributes included in the maturity model.

Future research can repeatedly leverage the metaverse maturity model to transparently and reproducibly evaluate the progress of virtual worlds towards realizing the metaverse vision and to clarify further need for development. As the understanding and idea of the metaverse evolves, future revisions of the metaverse maturity model might be necessary.

8. REFERENCES

[1] N. Stephenson, *Snow crash*. New York: Bantam Books, 1992.

[2] M. Weinberger, “What Is Metaverse?—A Definition Based on Qualitative Meta-Synthesis,” *Future Internet*, vol. 14, no. 11, p. 310, 2022, doi: 10.3390/fi14110310.

[3] S. J. Dubner, *Philip Rosedale Answers Your Second Life Questions.* [Online]. Available: https://freakonomics.com/2007/12/philip-rosedale-answers-your-second-life-questions/?hp (accessed: Feb. 9 2023).

[4] C. Goanta, “Selling LAND in Decentraland: The Regime of Non-fungible Tokens on the Ethereum Blockchain Under the Digital Content Directive,” in *Disruptive technology, legal innovation, and the future of real estate*, A. Lehavi and R. Levine-Schnur, Eds., Cham: Springer, 2020, pp. 139–154.

[5] M. Ball, *The metaverse: And how it will revolutionize everything*. New York, NY: Liveright Publishing Corporation, a division of W.W. Norton & Company, 2022.

[6] A. Tlili, R. Huang, and Kinshuk, “Metaverse for climbing the ladder toward ‘Industry 5.0’ and ‘Society 5.0’?,” *The Service Industries Journal*, vol. 43, 3-4, pp. 260–287, 2023, doi: 10.1080/02642069.2023.2178644.

[7] A. Davis, J. Murphy, D. Owens, D. Khazanchi, and I. Zigurs, “Avatars, People, and Virtual Worlds: Foundations for Research in Metaverses,” *JAIS*, vol. 10, no. 2, pp. 90–117, 2009, doi: 10.17705/1jais.00183.

[8] J. D. N. Dionisio, W. G. Burns, III, and R. Gilbert, “3D Virtual worlds and the metaverse,” *ACM Comput. Surv.*, vol. 45, no. 3, pp. 1–38, 2013, doi: 10.1145/2480741.2480751.

[9] Y. Wang *et al.,* “A Survey on Metaverse: Fundamentals, Security, and Privacy,” 2022.

[10] D. Gross, “Untersuchung und Vergleich des Entwicklungsstands existierender virtueller Plattformen in Bezug auf essenzielle Kernattribute des Metaverse,” Bachelor's thesis, Aalen University of Applied Science, Aalen, 2022.

[11] M. Weinberger and D. Gross, “A Metaverse Maturity Model,” *GJCST*, vol. 22, H2, pp. 39–45, 2023, doi: 10.34257/GJCSTHVOL22IS2PG39.

[12] L-H. Lee *et al., All One Needs to Know about Metaverse: A Complete Survey on Technological Singularity, Virtual Ecosystem, and Research Agenda*: arXiv, 2021.

[13] D. Ruby, *Roblox Statistics 2023: (Users, Revenue & Trends).* [Online]. Available: https://www.demandsage.com/how-many-people-play-roblox/ (accessed: Sep. 19 2023).

[14] Meta Platforms, *Opening Horizon Worlds to Everyone 18+ in the US and Canada.* [Online]. Available: https://about.fb.com/news/2021/12/horizon-worlds-open-in-us-and-canada/ (accessed: Feb. 8 2023).

[15] Cointelegraph, *Sandbox (SAND): A beginner's guide to the trending metaverse platform.* [Online]. Available: https://cointelegraph.com/learn/sandbox-sand-metaverse-platform (accessed: Sep. 12 2023).

[16] GameSpot, *Best PC Game of 2012 Winner*, 2012. Accessed: Feb. 7 2023. [Online]. Available: https://www.youtube.com/watch?v=MfJWlwI6ANI

[17] MMO Populations, *Guild Wars 2, Game popularity, player count, server population, subscribers and game activity for Guild Wars 2.* [Online]. Available: https://mmo-population.com/r/guildwars2/ (accessed: Feb. 7 2023).

[18] ArenaNet, *Guild Wars 2*: NCSoft, 2012.

[19] C. Johanson and S. Loretan, *Introducing the Megaserver System.* [Online]. Available: https://www.guildwars2.com/en/news/introducing-the-megaserver-system/ (accessed: Feb. 7 2023).

[20] E. Makuch, *Fortnite: Battle Royale Has Hit 10 Million Players In Two Weeks.* [Online]. Available: https://www.gamespot.com/articles/fortnite-battle-royale-has-hit-10-million-players-/1100-6454008/ (accessed: Feb. 7 2023).

[21] M. Iqbal, *Fortnite Usage and Revenue Statistics (2023).* [Online]. Available: https://www.businessofapps.com/data/fortnite-statistics/ (accessed: Feb. 7 2023).

[22] R. Shewale, *Fortnite Statistics In 2023 (Active Players, Revenue & More).* [Online]. Available: https://www.demandsage.com/fortnite-statistics/ (accessed: Sep. 21 2023).

[23] Epic Games and People Can Fly, *Fortnite*: Epic Games; Gearbox Publishing, 2017.

[24] Epic Games, *Where are Fortnite's servers located?* [Online]. Available: https://www.epicgames.com/help/en-US/fortnite-c5719335176219/battle-royale-c5719350646299/where-are-fortnite-s-servers-located-a5720318187163 (accessed: Feb. 7 2023).

[25] Epic Games, *The world's most open and advanced real-time 3D creation tool.* [Online]. Available: https://www.unrealengine.com/ (accessed: Feb. 7 2023).

[26] D. Voyager, *Second Life History.* [Online]. Available: https://danielvoyager.wordpress.com/sl-history/ (accessed: Feb. 8 2023).

[27] D. Voyager, *Second Life Stats.* [Online]. Available: https://danielvoyager.wordpress.com/sl-stats/ (accessed: Feb. 8 2023).

[28] Linden Lab, *Second Life*: Linden Lab, 2003. [Online]. Available: https://secondlife.com/

[29] Second Life, *Community - Buying Private Regions.* [Online]. Available: https://community.secondlife.com/knowledgebase/english/buying-private-regions-r15/#Section__1 (accessed: Jul. 5 2022).

[30] Second Life, *Community - Buying and selling Linden dollars.* [Online]. Available: https://community.secondlife.com/knowledgebase/english/buying-and-selling-linden-dollars-r46/ (accessed: Feb. 8 2023).

[31] Second Life, *Marketplace.* [Online]. Available: https://marketplace.secondlife.com/ (accessed: Feb. 8 2023).

[32] Second Life, *Wiki - Guide to Jobs in Second Life.* [Online]. Available: https://wiki.secondlife.com/wiki/Guide_to_Jobs_in_Second_Life (accessed: Feb. 8 2023).

[33] Roblox, *Saving Data.* [Online]. Available: https://create.roblox.com/docs/tutorials/scripting/intermediate-scripting/saving-data (accessed: Sep. 12 2023).

[34] Roblox, *Questions about server allocation when a game is run.* [Online]. Available: https://devforum.roblox.com/t/questions-about-server-allocation-when-a-game-is-run/663267 (accessed: Sep. 12 2023).

[35] Roblox, *Experience Join Improvements: Server Size, Join Queues and Social Slots Reservations.* [Online]. Available: https://devforum.roblox.com/t/experience-join-improvements-server-size-join-queues-and-social-slots-reservations/2294621 (accessed: Sep. 12 2023).

[36] Roblox, *Computer Hardware & Operating System Requirements.* [Online]. Available: https://en.help.roblox.com/hc/en-us/articles/203312800-Computer-Hardware-Operating-System-Requirements (accessed: Sep. 12 2023).

[37] J. George, *How To Import Custom Avatar In Roblox Studio: 2022 Guide.* [Online]. Available: https://brightchamps.com/blog/import-custom-avatar-roblox-studio/ (accessed: Sep. 12 2023).

[38] E. D'Angelo, *Our Vision for the Roblox Economy.* [Online]. Available: https://blog.roblox.com/2023/07/vision-roblox-economy/ (accessed: Sep. 12 2023).

[39] Roblox, *Chat with Voice.* [Online]. Available: https://en.help.roblox.com/hc/en-us/articles/4405807645972-Chat-with-Voice (accessed: Sep. 12 2023).

[40] R. O'Neill, *21 Best Roblox Games That Support VR.* [Online]. Available: https://www.thegamer.com/best-vr-roblox-games/#clashers-vr (accessed: Sep. 12 2023).

[41] MMO Stats, *VRChat.* [Online]. Available: https://mmostats.com/game/vrchat (accessed: Sep. 21 2023).

[42] VRChat, *Hello.* [Online]. Available: https://hello.vrchat.com/blog (accessed: Feb. 8 2023).

[43] VRChat, *Community FAQ.* [Online]. Available: https://hello.vrchat.com/community-faq (accessed: Feb. 8 2023).

[44] VRChat, *Instance Hosts and Player Limits?* [Online]. Available: https://ask.vrchat.com/t/instance-hosts-and-player-limits/8315 (accessed: Feb. 8 2023).

[45] VRChat, *Avatar Creator Systems.* [Online]. Available: https://hello.vrchat.com/avatar-systems (accessed: Feb. 8 2023).

[46] Decentraland, *Decentraland Documentation: Introduction.* [Online]. Available: https://docs.decentraland.org/player/general/introduction/ (accessed: Nov. 17 2022).

[47] Decentraland, *Decentraland DAO.* [Online]. Available: https://dao.decentraland.org/en/#lean-more (accessed: Nov. 17 2022).

[48] Decentraland, *Decentraland Status - Historical Metrics.* [Online]. Available: https://status.decentraland.org/metrics (accessed: Sep. 19 2023).

[49] Decentraland, *Let's build the metaverse together.* [Online]. Available: https://docs.decentraland.org/creator/ (accessed: Nov. 17 2022).

[50] Decentraland, *Player data.* [Online]. Available: https://docs.decentraland.org/creator/development-guide/user-data/ (accessed: Nov. 17 2022).

[51] Decentraland, *Communication Protocol Improvements.* [Online]. Available: https://decentraland.org/blog/project-updates/communication-protocol-improvements/ (accessed: Nov. 17 2022).

[52] Decentraland, *Hardware requirements.* [Online]. Available: https://docs.decentraland.org/player/general/hardware-requirements/ (accessed: Nov. 17 2022).

[53] Decentraland, *Marketplace.* [Online]. Available: https://docs.decentraland.org/player/market/marketplace/ (accessed: Nov. 17 2022).

[54] OpenSea, *Decentraland.* [Online]. Available: https://opensea.io/collection/decentraland (accessed: Nov. 17 2022).

[55] D. Nelson, *This Casino in Decentraland Is Hiring (for Real): Decentraland's Tominoya Casino is paying real people to staff the virtual pit in a job that game developers usually reserve for bots.* [Online]. Available: https://www.coindesk.com/tech/2021/03/18/this-casino-in-decentraland-is-hiring-for-real/ (accessed: Nov. 17 2022).

[56] Meta Platforms, *Horizon Worlds*: Meta Platforms. Accessed: Feb. 8 2023. [Online]. Available: https://www.meta.com/de/horizon-worlds/

[57] J. Horwitz, Rodriguez Salvador, and M. Bobrowsky, "Company Documents Show Meta's Flagship Metaverse Falling Short: Most visitors to Horizon Worlds generally don't return after first month; 'an empty world is a sad world'," *The Wall Street Journal*, 15 Oct., 2022. https://www.wsj.com/articles/meta-metaverse-horizon-worlds-zuckerberg-facebook-internal-documents-11665778961 (accessed: Feb. 8 2023).

[58] Meta Quest, *CAPACITY SETTINGS.* [Online]. Available: https://www.oculus.com/horizon-worlds/learn/tutorial/capacity-settings/ (accessed: Feb. 8 2023).

[59] Meta Quest, *Events in Meta Horizon Worlds.* [Online]. Available: https://www.oculus.com/experiences/quest-2/2532035600194083/events/ (accessed: Feb. 8 2023).

[60] Meta Platforms, *V64 Release Notes.* [Online]. Available: https://communityforums.atmeta.com/t5/Horizon-Worlds-Announcements/V64-Release-Notes/td-p/970632 (accessed: Feb. 8 2023).

[61] A. Madrid, S. Borget, M. Santurio, P. Iglesias, and L. Shrewsbury, "The Sandbox: Play. Create. Own. Govern. Earn," 2020. Accessed: Sep. 12 2023. [Online]. Available: https://installers.sandbox.game/The_Sandbox_Whitepaper_2020.pdf

[62] The Sandbox, *Introducing The Sandbox Alpha: Step into the Metaverse! Your chance to join the launch of a new era of gameplay is fast approaching.* (accessed: Sep. 19 2023).

[63] The Sandbox, *Experience Publishing.* [Online]. Available: https://sandboxgame.gitbook.io/the-game-maker-academy/experience-publishing/experience-publishing (accessed: Sep. 19 2023).

[64] MMO Stats, *MMO Stats - The Sandbox.* [Online]. Available: https://mmostats.com/game/the-sandbox (accessed: Sep. 19 2023).

[65] The Sandbox, *Games and experiences on LAND.* [Online]. Available: https://sandboxgame.gitbook.io/the-sandbox/land/general-faq-land/games-and-experiences-on-land (accessed: Sep. 12 2023).

[66] P. Tassi, *'Fortnite' Is Building The Metaverse Whether You Realize It Or Not.* [Online]. Available: https://www.forbes.com/sites/paultassi/2019/12/27/fortnite-is-building-the-metaverse-whether-you-realize-it-or-not/?sh=33c116bb56f6 (accessed: Feb. 9 2023).

[67] The Sandbox, *Multiplayer Performance.* [Online]. Available: https://sandboxgame.gitbook.io/the-game-maker-academy/getting-started/understanding-multiplayer/multiplayer-performance (accessed: Sep. 12 2023).

AUTHORS

Markus Weinberger was born in Munich, Germany in 1972. He received a diploma in mechanical engineering in 1998 and a Ph.D. degree in 2001, both from TU Munich. From 1998 to 2001, he was a research assistant with Robert Bosch GmbH in the field of advanced driver assistance systems. From 2001 to 2008 he held various positions at Robert Bosch GmbH. In 2008 he became Director of Quality Management and Processes with Bosch Engineering GmbH and in 2012 he was appointed founding Director of the Bosch IoT Lab at the University of St. Gallen and ETH Zurich. In this position, he was affiliated with Bosch Software Innovations GmbH. In 2016, he joined Aalen University as a professor of the Internet of Things. Prof. Dr. Markus Weinberger was called an IoT thought leader by Industry of Things World in 2015. His research interests include the Internet of Things, digital business models, blockchain technology, and the metaverse.

Daniel Gross was born in 1994 in Schwäbisch Gmünd, Germany. In 2017, he successfully completed an apprenticeship as a mechatronics engineer. He then studied the Internet of Things at Aalen University, where he obtained his Bachelor of Engineering in 2022. Since 2022, he has been working as a software developer at Robert Bosch Automotive Steering GmbH.