Virtually (re)constructed reality: the representation of physical space in commercial location-based games

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ABSTRACT

Location-based games (LBGs) are based on digital representations of our surroundings and the spaces we inhabit. These digital twins of the real world, real world metaverses, are subsequently augmented by imaginary game content. However, the virtual reconstruction of the world inevitably emphasises some aspects of reality and disregards others. In this work we explore and discuss the elements of reality that are included, and omitted, in popular commercial LBGs. We focus on eight popular contemporary LBGs from five different developers and investigate their connections to the real world. Subsequently, we compare the identified real world features of the LBGs to the landscape dimensions of the widely adopted Landscape Character Assessment framework. The findings show that settlement, hydrology, climate and land cover are the most commonly incorporated landscape dimensions, albeit in low fidelity. By contrast, dimensions, such as geology, soils and enclosure were not represented in the observed LBGs. In addition, we discovered several anthropogenic and cultural aspects, such as land ownership and time depth that are implicitly included in some commercial LBGs, notably in the Niantic Wayfarer system providing unique high-fidelity data of cultural and historical locations. Overall, we find only little variance within landscape dimensions between the observed commercial LBGs. Our findings open discussions on choices regarding the virtual representation of the real world in systems, such as LBGs, navigational software and a reality-based metaverse.

CCS CONCEPTS

• **Information systems** → *Massively multiplayer online games*; • **Human-centered computing** → **Ubiquitous and mobile computing systems and tools**.

KEYWORDS

Location-based games, augmented reality, point of interest, procedural content creation, user-generated content, metaverse, real world metaverse

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1 INTRODUCTION

Location-based games (LBGs) are understood as games in which the users' real-world location is an integral part of gameplay. This location is translated to a virtual representation within a more or less abstract game world. Most game elements only become available and interactable if the users' real-world coordinates are in close proximity to the location of respective virtual game elements. The real world is *(re)constructed* through a virtual representation of the most salient features (e.g., roads and land cover) and augmented by a fantastic game layer (e.g., virtual monsters and buildings) [52, 72]. Within the scope of this study, we understand reconstructed reality as the digital representation of real-world entities and dimensions. Recently, commercial LBGs have increased this connection between the game-world and reality by, for example, utilising real-world maps as the main playing interface and by including digital representations of real-world objects into the game. This effectively introduces two important realms which influence a user's movement and behaviour: (1) real-world features; as well as (2) the virtual representations of these and the added imaginary content. Real-world features, such as the terrain, the spatial configuration of buildings and the size and quality of sidewalks and roads influence the accessibility and, in extension, a player's movement. Additional more dynamic real-world features include other people, traffic and weather. When considering these real-world elements, the possibilities *of*, and motivation *for*, mobility arise from considerations, such as health, safety and lawfulness. The virtual and imaginary dimensions of LBGs can also attract players *to*, or deter them *from* certain locations [23], even when many of these virtual dimensions have no real-world manifestation. In these cases, players' mobility and spatial behaviour are mediated through the imaginary game

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content and influenced by the representation of the physical world within the game.

Waern et al. [97] argue that pervasive games, such as LBGs try to create a *"believable world"* and that players get the most out of the playing experience if they pretend as if the game was real. These thoughts are also echoed in commercial LBG design. In *Pokémon GO*, the players assume the role of a Pokémon trainer and are asked to imagine Pokémon in the real world. In *Harry Potter: Wizards Unite*, players assume the role of a witch or wizard and are asked to project a magical world onto their everyday environments. A similar design can be seen in *The Walking Dead: Our World*, *Jurassic World: Alive*, *The Witcher: Monster Slayer*, *Ingress Prime* and many other LBGs. It can thus be argued that a high fidelity connection between LBGs and the real world helps players immerse themselves into the commonly fantastic LBG lore, fusing virtual elements and real-world features [50].

Academic studies focusing on landscape generation and reconstruction of believable environs in a virtual environment are plentiful, especially in the domains of (participatory) urban planning [cf. 27, 76, 90, 96], education [cf. 18, 76, 81] and ecology [cf. 18, 19, 90]. The literature agrees that it is indeed possible to facilitate strong connections between real-world environments and respective virtual counterparts by reconstructing believable scenery [18, 27, 90] and incorporating soundscapes [18, 27]. However, these efforts use purposefully created realistic landscapes to answer specific research questions and do not primarily focus on gameful experiences as in the analysed LBGs. The term *geogame* denotes the utilisation of geographic data in games and includes all games that incorporate geographic data into the gameplay [5]. However, the geogames framework, suggested by Ahlqvist and Schlieder [5] does not specifically focus on virtually reconstructed environments and the individual dimensions thereof. This calls for new approaches of more fine grained characterisation and exploration of digital environments by, for example, using existing landscape characterisation frameworks [95].

Studies regarding the connection between LBGs and the physical world are scarce. Existing studies drawing from players' experiences have observed the roles of AR features and the players' location [50], but a holistic evaluation of other forms of connections is missing. Similarly, technical analyses on the topic have primarily focused on points of interest (PoIs) within LBGs [43, 51, 94]. However, there is a lack of studies on virtual representations of real-world features. We thus propose the following research questions (RQs) that guide this study.

- **RQ1:** *How and to what extent do popular contemporary commercial LBGs represent real-world features?*
- **RQ2:** *What salient real-world features are missing from contemporary commercial LBGs and how could these be added to existing games?*

By answering the RQs, we aim to provide an overview of the current state of contemporary commercial LBGs in terms of their connections to the real world and suggest improvements for future iterations. In so doing, we contribute to the research on the convergence between the physical and the augmented [50] world as well as the technical design and implementation of LBGs [43, 51, 93, 94]. Finally, since industry leaders on LBGs have argued for the creation of a real world metaverse [34], our study also contributes to the literature on metaverses by discussing the technical foundations of the real world metaverse.

2 BACKGROUND

2.1 The connections between LBGs and the physical world

How space is represented in games has been the topic of interest for over two decades, with [1] pointing out that "computer games are essentially concerned with spatial representation and negotiation, and therefore, a classification of computer games can be based on how they represent – or, perhaps, implement – space" [1, p.154]. This is of particular interest with the advent of ubiquitous access to broadband internet and emergent LBGs, exploiting or augmenting various dimensions of our environment. When exploring how spatial dimensions are represented and implemented in LBGs, it makes sense to distinguish between *space* and *place*. Space comprises the biophysical and anthropogenic arrangements of our surroundings, whereas place denotes an area laden with individual or shared meanings. In other words "space is the opportunity; place is the (understood) reality" [24, p. 299].

In LBGs, real-world data is leveraged to build abstract, yet reality-grounded virtual environments [92]. LBGs are, by definition, reliant on location-based information of real-world dimensions, primarily consisting of the coordinates and types of real-world entities (e.g., road segment, building footprint, river). The virtual worlds of LBGs are thus explicitly connected to the real-world through a shared coordinate system (among other potential factors). Even though a shared coordinate system does not hinder the creation of a completely fantastic and imagined virtual world, all analysed LBGs chose to represent and visualise real-world entities at their respective coordinates. Users must recognise their position in LBGs as a means of navigating the virtual world and it is paramount to the user's safety as well as game experience that basic navigational information is shown. This primarily includes roads, footpaths as well as traversable and non-traversable terrain (e.g., water bodies). As such, virtually reconstructed *space* builds the backbone of all analysed LBGs and *place* offers a malleable dimension that can be augmented through additional virtual objects or entities to infuse LBGs with individual and shared meanings (e.g., portals in *Ingress Prime*, Pokémon spawn points in *Pokémon GO*, and Inns in *Harry Potter: Wizards Unite*).

In addition, LBGs incorporate particularly salient landscape features, such as land cover and anthropogenic infrastructure (space) in combination with underlying meanings of specific locations, such as PoIs (place). These elements of space and place are combined to build virtual environments inducing a feeling of familiarity in the player [cf. 72]. Further, virtual landscapes are infused with additional (fantastic) elements and affordances (possibilities of action) which allow for engaging and playful experiences [cf. 7, 51, 72], such as finding virtual monsters as in *Pokémon GO*, hacking portals in *Ingress Prime* or fighting zombies in *The Walking Dead: Our World*. With the increasing availability of real-time data about the earth, the connections between LBGs and real-world events are becoming stronger. Examples include slow long-term changes, such as updated road networks, over more frequent changes, such as incorporating time-zone-dependent in-game day and night cycles to highly dynamic changes, such as representing real-world weather events within the virtual world [7].

However, different LBGs incorporate real-world dimensions to varying degrees. This calls for further investigation of how and why some environmental dimensions are represented more frequently than others. Approaches of landscape characterisation provide interesting frameworks with which various environments can be compared and analysed. Seeing the strong connection between virtual landscapes and real-world environments in LBGs, we believe using landscape characterisation frameworks to compare LBGs can lead to novel insights into the choices and rationale behind representing particular environmental features in LBGs.

2.2 Approaches for classifying landscapes

Landscapes are distinguishable areas of the world with unique properties, which is reflected in the widely adopted definition of landscapes as "area[s], as perceived by people, whose character is the result of the action and interaction of natural and/or human factors" [28, p. 2], set out by the European Landscape Convention. How we interact with and perceive landscapes influences our mental, social and physical well-being [2] and guides our behaviour [35]. They have thus become enshrined in national and international policy, in particular in conservation efforts and urban planning [47]. Various frameworks have emerged in an attempt to compare different landscapes and their qualities, most prominent of which are *Ecosystem Services (ES)* [22, 80], *Landscape Character Assessment (LCA)* [95] and exploring landscapes through their *affordances* [35, 79].

Ecosystem service approaches aim to reduce landscapes to monetary values to make them comparable [10, 36], whereas affordances are commonly interested in the dynamic and interactional aspects of landscapes [cf. 32, 35, 79]. The LCA approach includes experiential and perceptual dimensions of landscapes and emphasises that landscapes are different as opposed to better or worse [95]. This approach has seen widespread adoption, especially in a European context and has been found invaluable in guiding policy-making processes [29]. The LCA framework reduces environments to natural (e.g., air/climate and hydrology), cultural/social (e.g., land use and land ownership), and perceptual and aesthetic (e.g., sight and memories) dimensions (cf. Figure 1) to allow for landscapes to be compared. The various dimensions are collected through a combination of desk studies, commonly revolving around expert opinions, and field studies incorporating perceptual and experiential dimensions of the general public [95].

These three approaches to characterising landscapes offer different yet complementary approaches to breaking down the complexity of our environments and the spaces and places they encompass. However, little attention has been given to these approaches when exploring LBGs and the virtual environments generated within. The LCA approach offers a particularly interesting starting point to analysing LBG worlds, seeing the combination of biophysical and anthropogenic factors as well as experiential and perceptual dimensions. The ES and affordance approaches were deemed less fitting seeing their emphasis on either comparing landscapes through monetary values or focusing on interactional and functional dimensions of landscapes.

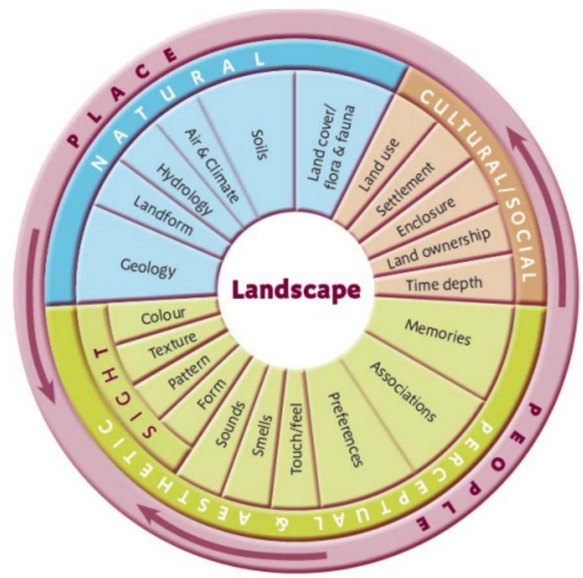


Figure 1: Landscape Character Assessment Framework Dimensions [95]; licensed under the Open Government Licence v3.0 (www.nationalarchives.gov.uk/doc/open-government-licence/version/3/)

3 MATERIALS AND METHODS

3.1 Data collection and selection of LBGs for analysis

In this study, we are particularly interested in highly popular commercial LBGs. We thus compiled a list of the ten highest grossing geolocation AR games in 2022[1] and excluded two entries which were only available in Japanese: *Dragon Quest Walk* and *Station Memories*. The remaining eight LBGs (cf. Table ??) were sorted into clusters based on the background map services they integrated. We also include the publication year of the games, their primary developer and a crude estimation of popularity using the number of downloads as a proxy. All games were available globally, with some notable exceptions to availability, such as China. The underlying base maps are all visualised as (tilted) two-dimensional planes and users can generally alter the viewing angle.

The authors had extensive experience with some of the mentioned games and only limited curiosity-driven experiences of others. Therefore, to ensure a rigorous scientific approach, chosen authors installed and played each of the selected LBGs to familiarise themselves with the features and mechanics. The LBGs in Table ?? were installed primarily on two devices, OnePlus 6 and Samsung Galaxy A52. The games were played in three European

[1]The list was found on Statista here: https://www.statista.com/statistics/272332/top-grossing-ar-mobile-games/, accessed July 6, 2022

Category	Map Service	Release year	Developer	Downloads at PlayStore
1. Niantic Games				
Pokémon GO [69]	Wayfarer* & OSM**	2016	Niantic	100M+
Ingress Prime [66]	Wayfarer & OSM	2012	Niantic	10M+
Pikmin Bloom [67]	Wayfarer & OSM	2021	Niantic	1M+
Harry Potter: Wizards Unite [68]	Wayfarer & OSM	2019	Niantic	10M+***
2. Google Maps-based games				
Jurassic World: Alive [55]	Google Maps	2017	Ludia	10M+
The Walking Dead: Our World [65]	Google Maps****	2018	NextGames	5M+
The Witcher: Monster Slayer [87]	Google Maps	2021	Spokko	1M+
3. Other				
Orna [30]	OSM	2018	Northern Forge Studios	1M+

Table 1: LBGs that were played and evaluated in this study. *Niantic Wayfarer: wayfarer.nianticlabs.com (accessed: 08.10.2022); **OpenStreetMap (OSM) [71]; ***Game no longer available as it was shut down on January 31, 2022; ****The Walking Dead: Our World changed its map provider to MapBox, a map provider based on OSM data, in September 2022

countries. In addition to playing the games, the authors performed an in-depth online search for details about the games and their mechanics.

3.2 Analysis process

The primary aim of this study is to explore what aspects of the real world are represented in the digital counterparts of the most popular LBGs. For example, all the evaluated games contained an underlying basemap of the real world based on map data from Google Maps or OpenStreetMap (OSM) (cf. Figure 2), but the LBGs varied considerably in terms of what these maps contained. As an example we provide a screenshot in Figure 3 where the map interface from the same physical location is depicted for six games: *Pokémon GO*, *Ingress Prime*, *Pikmin Bloom*, *Jurassic World: Alive*, *The Witcher: Monster Slayer* and *Orna*. The authors played the games until they had explored all major interaction possibilities within the game. All games were played for at least 10 hours and no arbitrary maximum limit of time playing was set. During playing, the authors made notes of identified ways in which the LBGs were connected to the real world. For each individual LBG, the notes of all authors were compared and distilled into a final report for each individual LBG. As such, an initial list was obtained describing how each of the eight contemporary LBGs incorporates and represents real-world elements and dimensions.

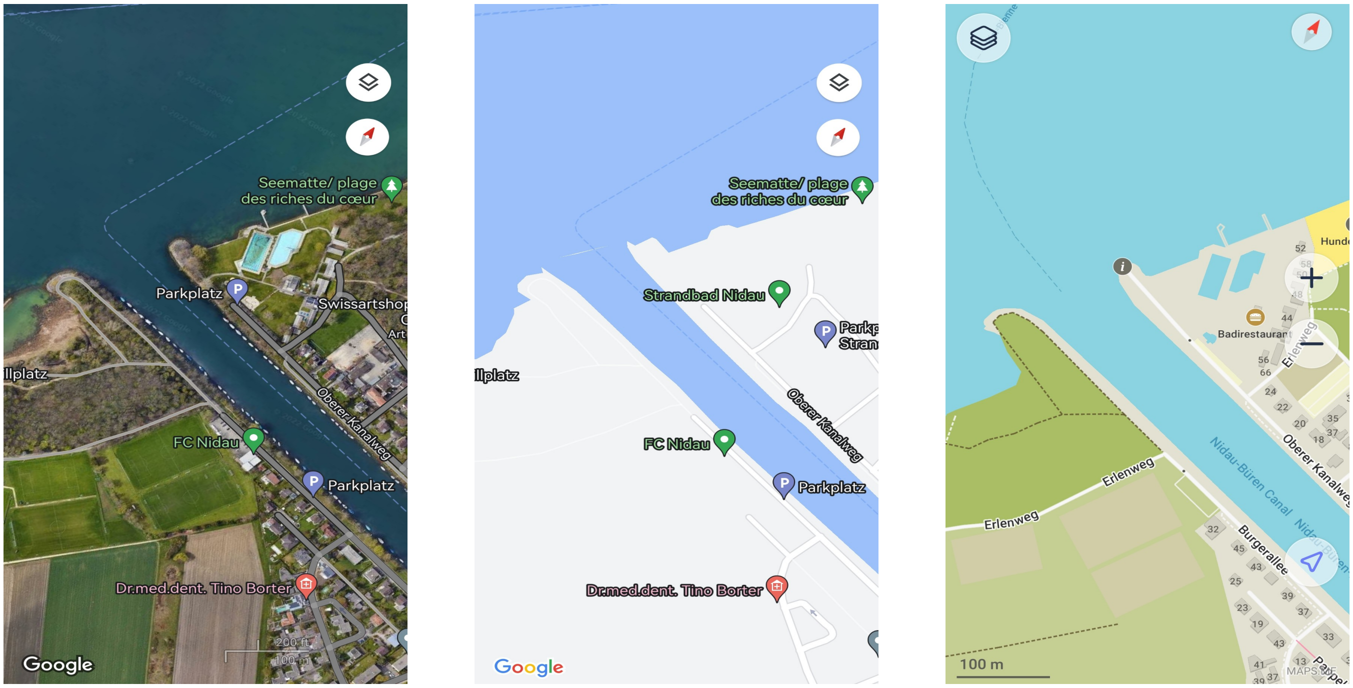
Following the familiarisation with the chosen LBGs, the authors explored the ways in which these games represent and use real-world data to build virtual game environments. To make the results comparable, the individual games and how they represent real-world entities and dimensions must be interpreted using some form of unified terminology. Using the compiled reports, the authors identified all aspects of the real world represented in the LBGs. Subsequently, the authors categorised the identified real-world dimensions into respective LCA dimensions, such as geology, landform, and hydrology. Since the authors identified various nuances in how the virtual environments of the evaluated LBGs related to their real-world counterparts, salient dimensions were explored and compared qualitatively. For example, all games are built upon a background map showing minimal landcover information with varying spatial and semantic precision. A qualitative approach allows for similarities and differences within individual LCA dimensions to be discussed, opening the door to more detailed discussions regarding shared landscape dimensions and potentially missing features.

4 FINDINGS

4.1 Connections between commercial LBGs and the physical world

The primary way of visualising real-world information in LBGs is a map interface. All eight evaluated popular games relied on either Google Maps (cf. Figure 2a - 2b) or OSM (cf. Figure 2c) as their respective spatial data providers and displayed a stylised map representing the ground upon which a player's virtual representation moves. The games commonly show mentioned virtual representations of the players in the bottom (vertical) centre (horizontal) of the device screen on which the game is being played from a tilted bird's-eye view as displayed (cf. Figure 3). To move within the game world, a player must move within the real world. This movement is captured through the device's location capabilities and translated to routes guiding the movement of the virtual representation of the player.

The information included on the map interface primarily consists of (1) roads and paths, (2) building outlines and (3) land cover. The evaluated LBGs developed by Niantic also include selected real-world objects, all of which are anthropogenic and most of which were uploaded by volunteer players (cf. Figure 4). The anthropogenic nature of these user-contributed PoIs - referred to as waypoints - can be traced back to the criteria for viable contributions set out by Niantic. These objects include buildings, monuments, memorials or other entities of religious, historical or cultural relevance as well as urban artwork (cf. Figure 4c). In addition to



(a) Google Maps - Satellite (b) Google Maps - Abstract (c) OSM in MAPS.ME

Figure 2: Screenshots (taken by the authors) of the underlying map providers in commercial LBGs

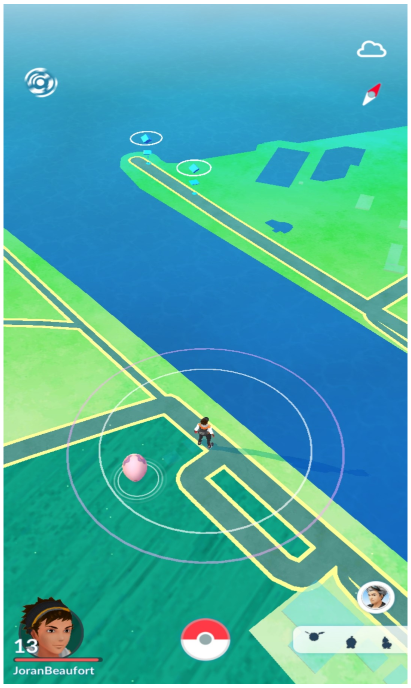
being located on the map in respective games, the waypoints include pictures and information about the object (cf. Figure 4b - 4c). This suggests a deeper connection between the virtual game world and real-world places of significance. Worth mentioning is *The Walking Dead: Our World* and *Orna* include additional virtual buildings placed by the player (cf. Figure 3f). However, these are purely virtual game elements with no real-world counterparts. Also, *The Witcher: Monster Slayer* textures larger roads as cobble-stone and visualises river banks (cf. Figure 3e). These are also purely virtual aesthetic features with no real-world counterparts.

Temporal aspects can be found to various degrees in LBGs. Whilst all games have some form of progression system (e.g., levels, experience points, and resources), which can be seen as a proxy of time played, some of the evaluated LBGs include more specific temporal features. In the earliest version of *Pokémon GO* (2016 only), players were able to see the exact time and location where they had caught Pokémon, effectively adding time-depth and a history of individual spatial mobility to the game. In *Ingress Prime* a Comm channel broadcasts all players' actions and the time of these actions is stored. Further game elements directly connected to real-world time include portal decay in *Ingress Prime* (gradual weakening of in-game defences over time) and gym combat power loss in *Pokémon GO* (gradual decrease in virtual strength over time).

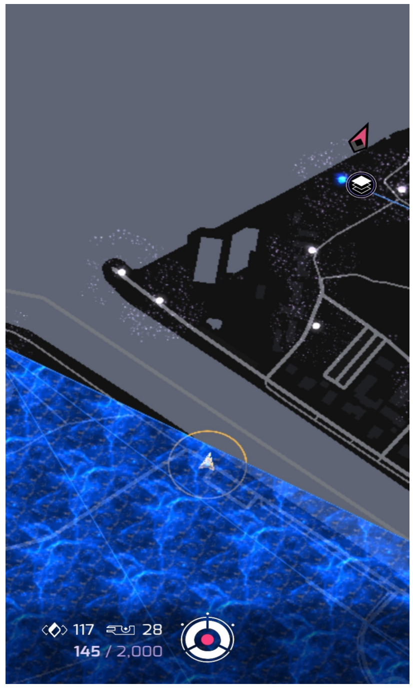
Tied to temporal features are weather-related phenomena and day-night cycles. *Pokémon GO*, *Pikmin Bloom* and *The Witcher: Monster Slayer* integrate weather data and update the in-game weather periodically to match the real-world experienced weather of players (with the weather options being clear, partially clear, cloudy, rain, fog and snow). Further, various in-game textures and respective skyboxes (the representation of the sky within virtual environments) are adjusted to match the outside brightness. This was primarily found in *Pokémon GO*, *Jurassic World: Alive* and *The Witcher: Monster Slayer*, which included some form of day-night cycles.

Lastly, many of the evaluated LBGs considered geographic regions or specific biomes to some degree. *Pokémon GO*, *Wizards Unite* and *Jurassic World: Alive* were found to incorporate regional specific in-game events. In addition, *Pokémon GO* includes Pokémon that are exclusive to select countries (e.g., Sigilyph only appearing in Egypt, Klefki only appearing in France), continents (e.g., Heracross in South America and Kangaskhan in Australia) or hemispheres (e.g., Corsola near the equator and Pachirichu near the northern pole). A number of games also took biomes into account. Once again, taking the example of *Pokémon GO*, specific Pokémon spawns correlated to the real-world biomes of the players (e.g., city, forest, mountainous, and water bodies). This was particularly prominent in earlier versions of the game. *Pokémon GO* also created "nests" of certain rarer Pokémon species in park areas and provided special raid invitations (ex-raids) for gyms located in parks, highlighting the role of parks as real-world arenas affording the play of LBGs. In Orna, environmental data was used to place monster spawns so that certain monsters appeared more often in certain biomes.

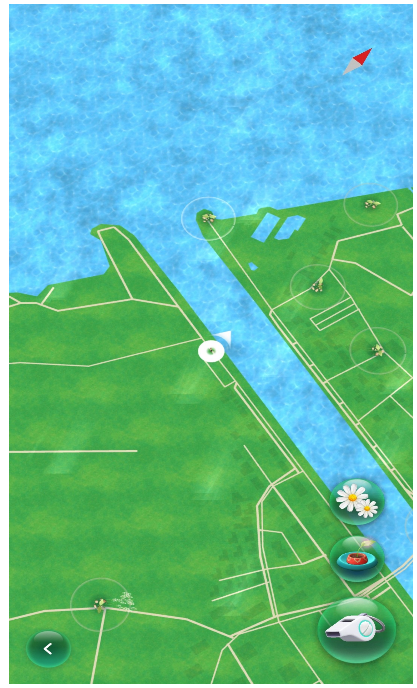
Besides the direct connection between the real and virtual worlds, location elements not directly tied to geodata can direct player movement. With the introduction of *daily incenses*, an item that



(a) Pokémon GO



(b) Ingress Prime



(c) Pikmin Bloom

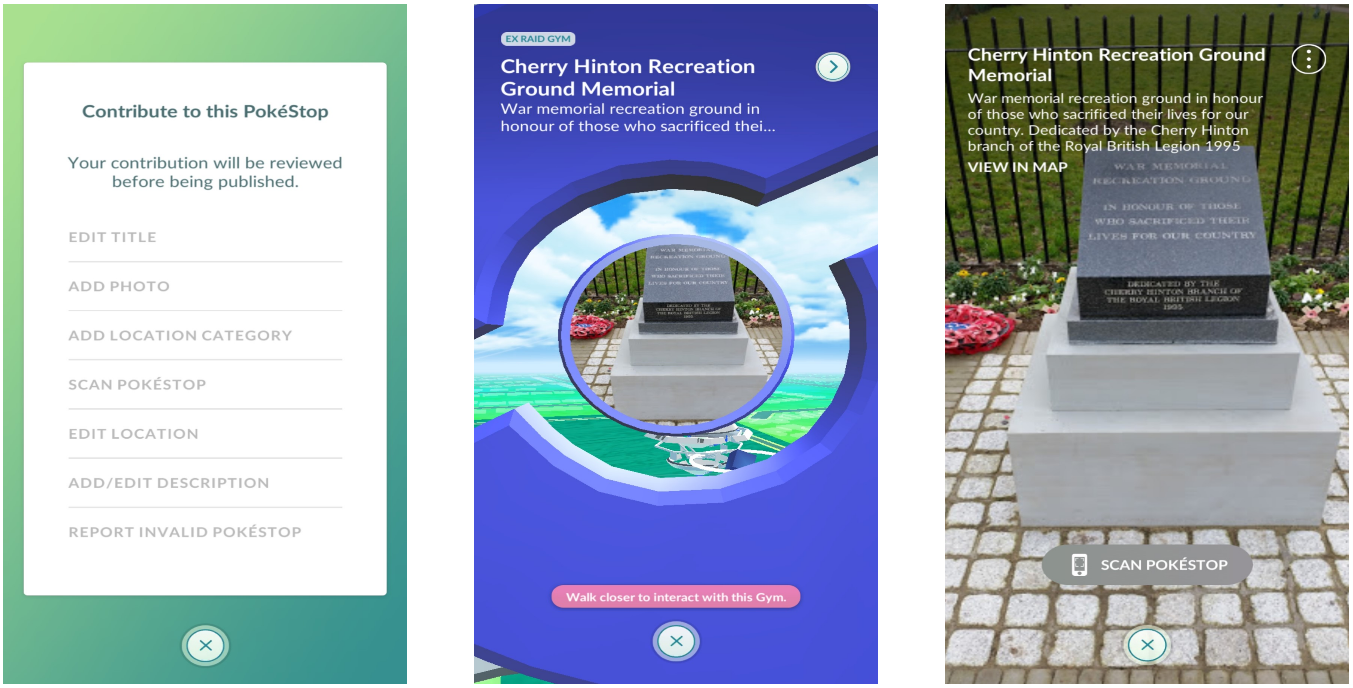
(d) Jurassic World: Alive

(e) The Witcher: Monster Slayer

(f) Orna

Figure 3: Screenshots (taken by the authors) of the same map location in six of the analysed games

virtually attracts Pokémon for its duration when players are moving, the game aims to motivate players to move on a daily basis. Here, a player's location and geodata are irrelevant as long as directional outdoor movement is measured. Its duration of 15 minutes matches the WHO's guideline of daily physical activity for health [100]. In



(a) Pokémon GO - Crowdsourcing feature **(b) Pokémon GO - PoI** **(c) Pokémon GO - PoI details**

Figure 4: Screenshots (taken by the authors) of the user contribution feature and points of interest in Pokémon GO

this example the connection between the game and the real world is indirect and less obvious.

In the following, we shift our focus to the landscape dimensions of the LCA and how these are represented and incorporated into the analysed highly popular LBGs.

4.2 Natural dimensions in location-based game landscapes

The LCA framework divides natural factors into six clusters: (1) geology, (2) landform, (3) hydrology, (4) air and climate, (5) soils, and (6) land cover [95]. Natural factors belong to the most prominently represented landscape character dimensions in all the evaluated popular LBGs and are primarily visualised through the map interface. **Geology** (solid and drift) describes the composition of the ground itself. While geology maps exist, real-world geology data is not integrated into the analysed LBGs. **Landform** (topography and geomorphology) primarily refers to geomorphological features of a given terrain (e.g., valleys, mountains, rolling hills and plains). In the evaluated LBGs, landform elements are not explicitly depicted. However, the terrain is presented as a two-dimensional continuous abstract map and is the foundation for salient features, such as roads, forests, water bodies, and building footprints. Interestingly, altitude was not found to be included in any of the analysed games, even though global data would be readily available. **Hydrology** (rivers and drainage, water quality and water flows), in particular major water bodies and rivers, is represented to varying degrees in all evaluated LBGs, albeit water quality and water flow directions are omitted. All evaluated LBGs depict water bodies as simple blue areas except for *The Witcher: Monster Slayer* which also visualises procedurally generated river banks and *Ingress Prime* choosing to display water bodies as grey non-traversable terrain. **Air and climate** (Climate, Microclimate, Patterns of weather) is included through real-time weather data in the analysed LBGs *Pokémon GO*, *Pikmin Bloom* and *The Witcher: Monster Slayer*. Further, all evaluated LBGs visualise the atmosphere according to the game lore, for example, *Harry Potter: Wizards Unite* showing bright scattered white clouds and *The Walking Dead: Our World* showing dull and ominous fog. **Soils** (Soils and Agricultural Land Classification) are not differentiated within the contemporary commercial LBGs. **Land cover/flora and fauna** (Habitats/biodiversity, land cover, vegetation cover, tree cover - forest/woodland etc.) is represented in all LBGs with notable differences in granularity. For example *Ingress Prime* merely differentiates between water bodies and land mass, whereas *Orna* and *Pokémon GO* include additional information such as recreational areas and parks. Common to all analysed games is that they only depict a small selection of salient land cover features (e.g., water bodies, parks and forests, buildings). The visualisation of land cover in the analysed LBGs is a function of the underlying map provider and respective land cover classification schemes. For example, we observe differences in the underlying map providers (cf. Figure 2b vs. Figure 2c), especially in terms of visualised land cover classes. It is thus unsurprising that we find considerable differences in, for example, what the analysed LBGs depict as forest or parks. These inconsistencies in land cover classifications are in line with the literature finding major discrepancies between different notions of land cover classes, especially in regards to forests

[14, 83]. No information about specific real-world plants or animals nor details about biodiversity are provided. However, many of the games include fantastic in-game fauna and flora, such as Pokémon, Monsters and Pikmin (cf. Figure 3). These are purely virtual and part of the game experience.

4.3 Cultural, social, and anthropogenic dimensions in location-based game landscapes

The cultural and social factors in the LCA report are divided into (1) land use and management, (2) settlement, (3) enclosure, (4) land ownership, and (5) time depth. **Land use and management** is generally not explicitly represented within the analysed LBGs. However, some LBGs such as *Pokémon GO*, *Pikmin Bloom* and *The Witcher: Monster Slayer* display recreational land use, such as parks and football fields. **Settlement** (Settlement patterns, building types and styles, materials) is primarily included as building and structure footprints in the map interface of the analysed LBGs. Building footprints are observed in various strengths from faded areas (e.g., *Pikmin Bloom & The Witcher: Monster Slayer*) to extruded three dimensional footprints (e.g., *The Walking Dead: Our World*). In addition, in the Niantic games, particular culturally or historically significant objects and structures are incorporated into the game as interactable game elements (cf. Figure 4b). Further, roads and paths, as well as bridges (depending on zoom level in *Orna*) and other anthropogenic mobility infrastructure, are depicted in all games to varying degrees of accuracy. **Enclosure** (Pattern and type of field enclosure (rural), Urban morphology) refers to walls, fences, railings and other barriers and ways to divide and enclose geographic areas. These are not visualised or otherwise present in the commercial LBGs. **Land ownership** (land ownership and tenure) is implicitly present in all the analysed LBGs. Building footprints, for example, indicate that the land is owned by a person or entity. Further, there are no Pokémon spawns on school grounds or in areas owned by the military. However, the games lack a distinction between publicly and privately owned areas leading to issues of trespassing [48]. **Time depth** (Archaeology and the historic dimension) is currently not explicitly present in commercial LBGs. In the Niantic solutions time depth is implicitly incorporated through the user generated PoIs capturing certain historical dimensions. In addition, when the physical world counterpart of a digital PoI is removed, Niantic encourages players to report that PoI for removal.

4.4 Perceptual and aesthetic dimensions in location-based game landscapes

The perceptual and aesthetic factors in the LCA report are divided into (1) memories, (2) associations, (3) preferences, (4) touch/feel, (5) smells, (6) sounds and (7) sight. These dimensions are highly subjective and are harder to capture in real-world landscapes as they require field surveys and participatory data [cf. 95], let alone in procedurally generated virtual landscapes of LBGs. Therefore, we only briefly touch upon these dimensions. **Memories** revolve around the memories of individuals in specific landscapes, whereas **associations** refer to specific thoughts a place can trigger, for example, legends and folklore. Both of these dimensions can be found in LBGs using crowdsourced PoIs where players upload important landmarks. These landmarks carry some significance for the uploading player and can thus be seen as entities triggering memories and associations. **Preferences** are also linked to these PoIs as a higher density of these PoIs (e.g., Pokéstops, Ingress portals, Wizard Inns) can indicate a higher shared preference of a given area due to the presence of more significant landmarks. However, this must be considered with caution, as it can also merely be a function of population density. The perceptual dimensions of **sight**, **sound**, **smell** and **touch/feel** are more difficult to judge seeing the LBGs were not experienced with all senses. All evaluated LBGs allowed for some form of manipulation of sight (e.g., rotating and tilting the view). The analysed LBGs with user generated PoIs additionally include an image of the real-world entity the PoI describes (cf. Figure 4c). Further, the games incorporated game-specific soundtracks and auditory interaction queues in favour of trying to replicate real-world soundscapes of respective real-world locations. The dimensions of smell and touch/feel can not be judged, seeing these are not perceivable in a virtual environment.

5 DISCUSSION

LBGs are a special category of games as they are inherently linked to the real world. They augment our surroundings with a virtual layer which is directly tied to real-world locations [41, 53]. This results in a two-way connection as the real world becomes an integral part of gameplay, whereas the virtual layer augments the world with imaginary features. The game influences players' movement in the real world whereas players' actions do not remain enclosed inside a digital realm, but their actions and movement also influence the real world [53]. Through the qualitative analyses in this study we were able to identify to what extent real-world features and dimensions are reflected in the virtual game worlds of the eight studied LBGs. In the following, we discuss our findings, particularly regarding these connections between the virtual landscapes of LBGs and their real-world counterparts, in the light of relevant literature.

5.1 Representation of real-world features in contemporary location-based games

As a response to our first **RQ** (*How and to what extent do popular contemporary commercial LBGs represent real-world features?*) we discovered various features as well as ways to represent these features in the observed LBGs.

What makes LBGs interesting is the fact that every location on earth has a virtual counterpart. In other words, all coordinates of our earth are mapped onto a digital representation of our earth upon which LBGs are built [64]. A player's device acts as a gateway of sorts between these worlds, translating the player's real-world coordinates to the virtual game landscapes to move the virtual representation of the player [52]. This inherent connection between the virtual and the real world is further strengthened by real-world entities and dimensions being represented in a more or less abstract way in the virtual environments of LBGs. The results of our qualitative inspection of the chosen LBGs show specific features to be salient in many of the LBGs, including settlement infrastructure, such as roads and building footprints, hydrological features, such as rivers and lakes and prominent land covers such as parks and

Location-based game	**Geology**	**Landform**	**Hydrology**	**Air & climate**	**Soils**	**Land cover/flora & fauna**	**Land use**	**Settlement**	**Enclosure**	**Land ownership**	**Time depth**	**Memories**	**Associations**	**Preferences**	**Touch/feel**	**Smells**	**Sound**	**Sight**
Pokémon GO	✗	✗	✓	✓	✗	✓	~	✓	✗	~	~	~	~	~	✗	✗	✗	✓
Ingress Prime	✗	✗	✓	✗	✗	~	✗	✓	✗	~	~	~	~	~	✗	✗	✗	✓
Pikmin Bloom	✗	✗	✓	✓	✗	✓	~	✓	✗	~	~	~	~	~	✗	✗	✗	✓
Harry Potter: Wizards Unite	✗	✗	✓	✗	✗	✓	~	✓	✗	~	~	~	~	~	✗	✗	✗	✓
Jurassic World: Alive	✗	✗	✓	~	✗	✓	~	✓	✗	~	✗	✗	✗	✗	✗	✗	✗	~
The Walking Dead: Our World	✗	✗	✓	✗	✗	✓	~	✓	✗	~	✗	✗	✗	✗	✗	✗	✗	~
The Witcher: Monster Slayer	✗	✗	✓	✓	✗	✓	~	✓	✗	~	✗	✗	✗	✗	✗	✗	✗	~
Orna	✗	✗	✓	✗	✗	✓	~	✓	✗	~	✗	✗	✗	✗	✗	✗	✗	~

Table 2: Table showing the analysed popular commercial location-based games and the real-world landscape character assessment dimensions they incorporate at the time of writing. ✓: dimension incorporated; ~: dimension loosely incorporated; ✗: dimension not incorporated

recreational areas. In addition, the games developed by Niantic incorporated PoIs referring to real-world entities of significance. We also identified dimensions that were only present in specific LBGs, such as visualising the weather in *Pokémon GO*, *Pikmin Bloom* as well as *The Witcher: Monster Slayer* and purely virtual buildings with no real-world counterparts or significance as in *The Walking Dead: Our World* and *Orna*.

When building a game world using global datasets, questions of data accuracy and quality become important [6], especially seeing that a considerable amount of underlying data is crowdsourced (e.g., OSM) [59]). This effectively boils down to the virtual worlds in LBGs being a function of data availability and quality. The two underlying data sources were found to be Google Maps and OSM, which have been found to map entities, such as roads with varying accuracy and frequency [20]. Further, global land cover information has been found to show a high amount of disagreement between individual datasets [31], resulting in potentially different representations in the chosen LBGs (e.g., an area depicted as a forest in one LBG could be urban green-area in another, resulting in differing visualisations in the games). Seeing that many of the LBGs have some form of location or biome-specific virtual assets (e.g., Pokémon spawning according to the landcover), in combination with the primarily user-generated underlying spatial data in OSM, reports of cartographic vandalism for in-game gain have been identified, where users deliberately attempt to modify the underlying spatial data to enhance their gameplay [42].

With an increasing number of connections between the real and the virtual world of LBGs, the borders between the two are increasingly blurred with questions of perceived realism, immersion and presence becoming important [cf. 98]. The LBGs that were evaluated as part of this article were found only to incorporate enough realism to allow for players to locate and orient themselves. As such, underlying base maps visualising the immediate surroundings of a player show minimal additional information to reduce cognitive load, a known issue in map visualisations [46]. Somewhat counter-intuitively, the evaluated LBGs do not strive for a high degree of verisimilitude in the environments they recreate. On the contrary, their attempts at realism remain marginal in favour of encouraging players to use their imagination and project the game world onto their real-world surroundings. This goes against the long-standing trend of achieving ever-increasing levels of realism in virtual environments, ranging from digital excursions [99] to contemporary games [6, 25, 91].

While our research was conducted in the setting of LBGs, our findings have implications more broadly to the way in which physical space is presented and represented in digital products. Besides map interfaces we find selective representations of the real world in applications, such as social media, news and more objective reports, such as weather forecasts. Selective representations inevitably bias the consumer of media towards certain actions (e.g., changing ones route due to omitted footpath visualisations in LBGs) and perceptions of the environment (e.g., visualising certain structures over others in a LBG). Our work underlines the importance of considering the trade-offs between incorporating and implementing certain information whilst disregarding other aspects of reality.

5.2 Missing real-world features and how they could be added to LBGs

As a response to the second **RQ** (*What salient real-world features are missing from contemporary commercial LBGs and how could these be added to existing games?*) we discovered various missing features.

LBGs seem a perfect fit to incorporate as much real-world data as possible to make the game feel local and relatable for the individual players. However, the evaluated LBGs seem only to contain a minimal number of features. This calls for further discussions of additional real-world features that show potential, and that could be added to existing or new LBGs.

One of the most obvious additional spatial dimensions that could be added to LBGs is altitude. This would effectively transcend contemporary LBGs, visualising the basemap as a two-dimensional plane, to a more realistic three-dimensional environment. Adding altitude information would add a further level of familiarity to the games, especially in regions of high elevation change, such as mountainous areas and could make in-game tasks (e.g., hatching eggs in Pokémon) seem more realistic and balanced since altitude can be incorporated into distance travelled. However, it is important to note that the data source's accuracy must be appropriate for the intended tasks. For example, suppose the performance of a player is calculated using elevation. In that case, a respective underlying data source must be of high enough resolution to accurately represent a landscape's topography in three dimensions, in line with spatial calculations in general [75]. Examples for (mostly) globally available, up-to-date data sources are *ASTER Global Digital Elevation Model* (1x1 arcsecond [2]) [62], *Elevation1* (1x1 meter - also available in resolutions 4x4m, 8x8m and 30x30m) [84], and *WorldDEM4-Ortho* (24x24 meter - artifact-cleaned *WorldDEM* model) [85].

Climate models and impacts can also be integrated into LBGs using curated geospatial data sources. Information on monthly temperatures and precipitation could elevate LBGs and open the door to new locally specific gameplay. Examples of (mostly) globally available, up-to-date data sources are *CHELSA* (30x30 arcseconds) [44], *CRU TS3.21* (0.5°x0.5°) [15], and *GPCC* (0.25°x0.25° - 2.5°x2.5°) [58]. In addition to temperature and precipitation forecasts, further datasets could include information on biodiversity, pollution and natural disasters. These show potential not only in additional game features which can be built upon but also as educational opportunities (e.g., learning about air pollution and mitigation strategies through the gameplay).

One central aspect identified in all the evaluated LBGs' map views is the uniform visualisation of impassible terrain in the form of building footprints. However, the vast differences between landuse were rarely visualised on the underlying basemaps. By including higher detail landuse data, LBGs could incorporate gameplay mechanics specifically tailored toward different landuses. This would allow landuse-specific interactions in the games, resulting in more opportunities for individualised and local gameplay. Examples of globally available data are provided by the *Sentinel-2* (10x10m) [3] and *Landsat 9* (15x15m) [63] missions. They are applicable for different landuses and real-world vegetation information [74] and are easily accessible, e.g., with *WorldCover* [4].

Another identified category of missing features revolves around moving objects, either anthropogenic (e.g., cars, trains, busses, and planes) or natural (e.g., animals). Various proxies exist to gauge anthropogenic moving objects, including live traffic reports, boat and plane tracking systems and train timetables. However, these data are not included in any of the analysed LBGs. Further, animal migration models and home-range movement predictions offer datasets with the potential of adding real-world animals and their behaviours into contemporary LBGs. With the launch of the ICARUS initiative [56], real-time animal tracking could advance to unprecedented spatial and temporal resolutions, offering a further additional dataset for LBGs. However, questions of data privacy and misuse become important, calling for caution in tracking natural and anthropogenic moving objects. In addition, the game lore may not support the addition of specific features (e.g., elephants do not exist as such in the world of Pokémon), which merits further consideration.

Finally, there would be many additional open data sources compiled by volunteers through crowd-sourcing or citizen science initiatives, including bird observations [11, 89], environmental monitoring in general [40, 77], car sensor data [13] as well as noise mapping initiatives [26]. Freely accessible geo-referenced maps are also constantly being developed, for example, Open Sense Map [3] and National Transportation Noise Map [4]. However, these forms of data have yet to be incorporated into LBGs. Interestingly, gamification [12] and games are also used in citizen science projects to increase the motivation of potential citizen scientists [17, 54, 60], for example location-based games geared towards generating and curating landcover and landuse datasets [8, 9].

5.3 LBGs in the light of the metaverse

Recently, the term metaverse has been used more frequently to refer to a virtual-reality universe as a kind of perpetual and persistent multi-user environment in which reality is unified with digital virtuality [61, 73, 101]. In the introduction, we emphasise that the data used in LBGs can be understood as a digital twin of specific dimensions of the real world [33]. As the fidelity of this reconstructed digital twin increases, the digital world becomes increasingly complex and intertwined with players' daily lives and their perception of reality [50, 53]. This is in line with observations of the virtual environment Second Life more than ten years ago [16] and is now resurfacing in light of the accelerated digitalisation sparked by the COVID-19 pandemic, in particular for virtual reality and augmented reality games [45]. The importance of user-generated content for the design of metaverses is no new idea [70] and crowdsourcing the digitalisation of real-world entities for digital asset creation has gained traction [49]. This has led to new perspectives at the intersection of real and virtual environments and scholars have argued that eventually AR objects may start replacing real world objects as the real world and the digital counterpart converge [78]. However, a detailed framing of LBGs as part of the metaverse discourse remains an outstanding research task.

To illustrate the need for further scientific inquiries into the connections between LBGs and the metaverse, Niantic Labs, the company behind many of the most popular commercial global LBGs envisions LBGs helping to transform the real world into a real-world metaverse [34]. According to Hanke, a purely digital metaverse disconnected from geography and people's daily activities is a "dystopian nightmare", and he proposes a real world augmented reality metaverse as an alternative [34]. To bring about such a vision, the connection between the digital and the virtual needs to be enhanced. To improve this connection, a number of approaches are viable. In particular, we see potential in the categories of hardware, software, and data. With regards to hardware, in addition to the smartphones commonly used for LBGs, AR Head Mounted

[2] An arcsecond refers to $\frac{1}{3600}$ of a degree (°)

[3] https://opensensemap.org/

[4] https://maps.dot.gov/BTS/NationalTransportationNoiseMap/

Displays (HMDs) are worth considering, as past research has highlighted their potential for scaffolding immersive experiences [39]. However, AR HMDs currently face technical shortcomings that limit their range of use [86], especially in daylight environments. Future advances in related technologies may mitigate these limitations. Software is also an imperative part of enhancing immersion through the application and processing of AR, presenting an entertaining story and other elements which support imagination and immersion [50, 57]. Finally, the potential of data for enhancing connectivity is presented in this paper including a discussion of landscape elements found within LBGs (cf. 5.1) as well as available data that has, to date, not been incorporated (cf. 5.2). Seeing data are repeatedly cited as the basis for the metaverse [37, 82], our work aims to spark important discussions regarding what should be emphasised and highlighted in digital representations of our complex world and potential implications of doing so.

5.4 Limitations and future work

This study has certain key methodological and conceptual limitations that we wish to discuss. First, we limited the qualitative evaluation of LBGs to eight globally playable commercial games. At the time of writing, the chosen games were the most popular LBGs in terms of active players and income. However, they are tied to the current technology, state of game design and availability of solutions. The games are also constantly subject to change, as evidence by the updated map textures of Pokémon GO in October 2022 (see Figure 5). We predict the field of LBGs to evolve in the upcoming years in multiple different ways, especially in the type and amount of real-world data used to build these virtual environments. Second, the chosen LBGs were analysed from the researchers' perspective, and thus, the results reflect an academic approach towards exploring LBGs and their connections to the real world. Future inquiries should include user experience studies of how players experience the gameplay and perceive the (re)constructed reality of LBGs. One option would be to utilize the Mechanics, Dynamics and Aesthetics (MDA) framework [38], focusing on the designers' as well as the users' perspective, to analyse LBGs in more detail.

A third limitation relates to the chosen approach of landscape characterisation [95]. Several alternative approaches and frameworks exist to compare and characterise landscapes and environments. The chosen characterisation framework, the LCA, was found particularly helpful in reducing landscapes into individual comparable dimensions. However, ambiguities and overlaps (e.g., farmland as land cover or land use?), as well as varying levels of granularity (e.g., all anthropogenic features, such as roads, buildings and electricity lines classified as settlement?), call for adapting landscape characterisation approaches to virtual environments. Careful consideration must be given to the varying particularities when comparing connections between virtual landscapes and real-world environments, especially when encountering virtual entities (e.g., fauna/flora, structures, natural features) that are purely game elements and have no real-world counterpart. Further, a key requirement is that the data must be available for the locations where the LBG is to be deployed, in this case, globally. Numerous standards are available for location-based data (i.e. geospatial data) [88], including the EU's INSPIRE directive [21], which requires member

Figure 5: A comparison between the old map textures in Pokémon GO and the new Halloween textures of October 2022. Screenshot taken by the authors.

states of the EU to make location data available. Data categories collected under this initiative include many of those mentioned above, such as hydrology, transport networks, elevation, and atmospheric conditions, as well as previously unmentioned data categories, such as species distribution or population distribution [21]. However, finding such globally available normalised datasets is more challenging.

A fourth limitation of this study is that the analysed LBGs all facilitate outdoor play and as such, questions of indoor environments were not considered. Future work could expand our analysis to also include indoor areas and their representation within virtual environments. Recent advances in indoor mapping, such as Google Indoor Maps or LiDAR scanned home environments already offer tools for developers to develop high fidelity locative experiences for indoor environments, and future research could thus focus on assessing the potential uses of these technologies in recreating real-world indoor areas in virtual location-based game environments.

Finally, many of the underlying data sources used to build the virtual LBG worlds are crowdsourced, either within the games themselves, such as in *Ingress Prime* and *Pokémon GO* [49] or in the underlying spatial data, such as in OSM [59]. We predict that in the near future we may start seeing LBGs that feature other characteristics of the real world than those in the currently existing games, and in this case future work should investigate these new technologies and the innovations they present. Especially important in light of a real world increasingly intertwined with a digital replica will be questions of reconstructing reality in the digital realm, to serve as the basis of the so-called real world metaverse.

6 CONCLUSION

LBGs are a wildly popular and constantly growing mobile game genre. So far there has been little research on how real-world spatial entities and dimensions are represented in these games and the connections between our surroundings and their virtual representations. To explore this research space, we reviewed the eight most popular contemporary LBGs in terms of the data they use to build their virtual environs. Ensuring a systematic approach, we evaluated each LBG qualitatively using the LCA dimensions, widely used to describe real-world landscapes. The LCA was used to both categorise the types of data used and represented in LBGs and to highlight missing data which could potentially be added to future LBGs. The results show many of the evaluated LBGs being built upon the same sources of spatial data, namely OpenStreetMap (OSM) and Google Maps, and thus representing similar real-world entities. Further, the results underline that contemporary LBGs commonly incorporate the natural dimensions *hydrology*, *landcover/flora and fauna* as well as the cultural/social dimension of *settlement*. Other dimensions (e.g., *geology*, *land use*) are scarce or are missing altogether. To guide future development, this article points to several additional data sources showing potential to be incorporated in future iterations. However, further inquiries into their suitability, including availability, accessibility and meaningfulness for game contexts, are needed. Furthermore, we suggest that LBGs and the data visualised using LBGs might be conceived as parts of the metaverse requiring further research.

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