Designing and implementing a global multilingual real-time location-based game as a novel highly gamified spatial crowdsourcing platform

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Abstract

Spatial crowdsourcing and other participatory methods of high-quality spatial data generation are increasingly popular in academic research. However, participatory approaches face issues of user motivation and retention. Gamification has been identified as a valuable approach towards increasing user motivation, engagement and retention by offering an entertaining experience. This paper presents a case study of the literature-based development and implementation of *Arcane Shift*, a novel globally available location-based game as a highly gamified spatial crowdsourcing platform. In particular, this paper focuses on the first three activities (problem identification, problem definition and application development) of the *Design Science Research Methodology* and how the implementation was guided by the established *Gamification Framework for Volunteered Geographic Information* and the *Mechanics, Dynamics and Aesthetics Framework*. Internal testing revealed the game to be enjoyable, albeit in need of further content. Four concrete implementation recommendations and considerations (develop for testing, incorporate caching, build for longevity and spatial is special) were gleaned from the development process and are presented as a methodological contribution to the design and development of location-based games and spatial crowdsourcing platforms. Finally, a list of future research agendas is provided including urban data generation, educational content delivery and motivating physical activity.

Keywords

Design science research; mechanics, dynamics, aesthetics framework, gamification framework for volunteered geographic information; spatial crowdsourcing; gamification; location-based game

1. Introduction

Participatory approaches to generating spatial data for academic research have enjoyed a surge in popularity over the past two decades [1, 2, 3, 4]. In particular, spatial crowdsourcing approaches have shown immense potential in generating rich high-quality spatial information about our environments for comparatively low financial investments [5, 6, 7, 2]. However, a limiting factor of crowdsourcing approaches, and participatory approaches in general, is user motivation and retention [8, 9, 10, 11]. A maturing approach to increasing user engagement, retention and satisfaction in crowdsourcing tasks is gamifying the participatory process. Gamification, summarised as *"hedonic or entertainment-oriented technologies being re-appropriated for productive use"* [12, p. 191], has been applied to a number of crowdsourcing initiatives (e.g. [13, 14, 15, 16]) and has shown to successfully motivate users to participate [9, 17]. However, many gamification efforts in academic crowdsourcing have implemented a limited number of gamified elements such as points, badges and leaderboards [18, 17] whilst highly gamified applications such as location-based games remain rare.

Meanwhile, commercial location-based games such as Ingress[1] and Pokémon GO[2] have motivated millions of users [19, 20, 21] to contribute data on unprecedented scales [22, 23]. Location-based games offer playful virtual interactions according to the real-world coordinates of a respective user [24, 21] and are predominantly played in urban areas [25, 24] (showing spatial biases towards wealthier neighbourhoods [26, 19]).

Skillfully balancing entertainment and spatial crowdsourcing tasks has seen success in a handful of academic studies [cf. 27, 13, 16], and seeing the great potential of using more ludic applications such as location-based games to motivate users to contribute data towards scien-

[1] https://www.ingress.com/ (accessed: 19.11.2023)

[2] https://pokemongolive.com/ (accessed: 19.11.2023)

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tific crowdsourcing efforts, this paper presents the design, development and implementation of a globally available, modular, multilingual real-time location-based game as an underlying crowdsourcing platform. Specifically, this paper aims to make a theoretical contribution to the design and implementation of entertaining spatial crowdsourcing platforms by presenting the case study of *Arcane Shift*, a location-based game as a spatial crowdsourcing platform. This paper is particularly interested in how we can design and implement a highly gamified spatial crowdsourcing platform in the form of a globally accessible location-based game by focusing on the following research questions:

- What are the key underlying game feature requirements to develop a highly gamified spatial crowdsourcing platform and how do these map onto established implementation frameworks?
- How can underlying crowdsourcing functionalities be complemented with entertaining game features offering global real-time gameplay?
- What are key considerations and recommendations for developing spatial crowdsourcing platforms and location-based games?

In the following, I introduce relevant previous work as well as the topical background before diving into the specifics of the underlying systems and how individual features were designed and implemented. The final sections of the paper culminate in discussing the implemented location-based game in light of the literature, presenting key lessons learnt during the design, development and implementation processes as a theoretical contribution to the design of gamified spatial crowdsourcing platforms. Finally, this paper presents further recommendations and propositions as well as future avenues of research.

2. Previous work

Multiple studies showcase the direct influence our surroundings have on our social, mental and physical well-being [28, 29, 30]. Examples range from street design increasing perceived safety [31, 32], over particular areas offering tranquillity [33, 34] boosting mental well-being [35, 36], to public transportation networks increasing physical activity [37] whilst reducing personal motorised vehicles. However, much of the data used to understand the status quo of our environment are produced by sensors, through computational algorithms or reported by specific demographic groups. Temperature and pollution readings are captured by fixed measuring stations [38] or through remote sensing [39], walkability analyses of urban and residential areas focus on tangible variables of the built environment disregarding individual perceptions [40], and city planning is only now gravitating from top-down approaches towards the inclusion of local citizens [41, 42].

2.1. Spatial crowdsourcing and participatory data collection

Contrasting more automated spatial data collection approaches are initiatives that include non-expert users in spatial crowdsourcing tasks. Many approaches exist concerning the collection of spatial information contributed by non-experts including *volunteered geographic information* [5] where individuals voluntarily make some form of spatial data available [1] and *public participation geographic information systems (PPGIS)* [43] where individuals contribute data through a participatory mapping effort. An umbrella term for many participatory (spatial) data collection approaches is crowdsourcing [1, 3, 4], *“a type of participative online activity in which an individual, an institution, a non-profit organization, or company proposes to a group of individuals of varying knowledge, heterogeneity, and number, via a flexible open call, the voluntary undertaking of a task“* [44, p. 197]. This participatory approach can broadly be split into two categories: (1) active crowdsourcing where data is actively contributed for a specific task or question as part of a data collection effort (e.g. *open street map (OSM)*[3]), and (2) passive crowdsourcing where data is contributed for another intention than what it is ultimately used for (e.g. social media data) [1].

Spatial crowdsourcing initiatives have been found to produce high-quality data at a fraction of the cost of more traditional expert-based approaches [1] and have been found to complement more technocratic and top-down approaches to data collection (e.g. through sensory networks and remote sensing) by providing novel insights into more subtle dimensions of human perception [cf. 45, 46, 33, 34].

[3]https://www.openstreetmap.org/ (accessed: 19.11.2023)

This can lead to a more holistic understanding of emergent spatial issues such as urbanisation, sustainability and well-being, making spatial crowdsourcing an invaluable data generation approach. Whilst successful large-scale spatial crowdsourcing efforts in academia remain scarce, non-academic entities have identified the value of location-based user-generated content and boast several successful applications. Examples include the location-based games *Ingress* and *Pokémon GO* crowdsourcing the collection of culturally significant objects through their *Wayfarer* system [23], *Google Maps* collecting vast amounts of user-generated spatial information such as points of interest [47] and *Waze* focussing on mobility-related data such as real-time traffic updates [17]. Despite having large repositories of spatial data, these are not easily accessible, nor are these systems customisable to specific scientific data needs, and thus new academic initiatives are called for.

A shift towards more bottom-up approaches to data collection in academic spatial research encourages a reformulation of traditional research agendas and has raised some underlying methodological questions about how we can effectively include citizens in science and how we can motivate long-term engagement. However, questions of user motivation and user retention arise [10, 11], especially when competing with an onslaught of entertainment and otherwise available playful activities.

2.2. Gamified crowdsourcing and location-based games

A recent development sees the emergence of crowdsourcing efforts capitalising on entertaining features through gamification [9]. Gamification can be summarised as *"a process of enhancing services with (motivational) affordances in order to invoke gameful experiences and further behavioral outcomes"* [18, p. 3026]. Gamification shows great potential in generating crowdsourced urban data and complementing geospatial crowdsourcing more generally [9, 2]. In the context of crowdsourcing, gamification has successfully been incorporated in a number of academic studies as a means of increasing user motivation (for an overview, see [9]), albeit commonly implementing simple competitive features such as points and leaderboards. More gamified geospatial crowdsourcing efforts include *Urbanopoly* [27], a gamified urban data crowdsourcing effort and *FotoQuest Austria* [13] as well as *StarBorn* [16], entertaining approaches to collecting landcover information.

Location-based games are entertaining applications, commonly played on devices with location tracking features such as a global positioning system, where a player's in-game position reflects their real-world coordinates [24]. Players navigate the virtual game world by changing their real-world position and in-game interactions are dependent on the real-world position of a user and their proximity to virtual objects. As such, location-based games offer a particularly interesting platform to collect geospatial data from a heterogeneous group of users. *Pokémon GO* and *Ingress* are highly popular commercial location-based games [21] shadowing other approaches in terms of user engagement, successfully motivating hundreds of millions of users to engage with the application and contribute rich spatial information [22, 23]. This begs the question: can a location-based game be implemented to crowdsource heterogeneous spatial information for research purposes?

2.3. Design science research and relevant frameworks

Application development and implementation processes concerning the construction of information systems as problem solutions to concrete issues can be grounded in *design science research* [48, 49, 50, 51] which *"seeks to enhance technology and science knowledge bases via the creation of innovative artifacts that solve problems and improve the environment in which they are instantiated"* [51, p. 1], or more generally *"the construction and evaluation of generic means–ends relations"* [50, p. 470]. One widely used and well-established framework is the *Design Science Research Methodology* presented by [49], dividing the overall goal of developing and evaluating an application aiming to address a specific problem statement into six distinct activities (for a detailed discussion, see [49]):

1. *Identifying* concrete research problems as well as *justifying* the importance of the proposed solutions
2. *Defining* specific objectives and requirements of the envisioned solutions
3. *Designing* and *implementing* the application or artefact

4. *Demonstrating* the implemented application's or artefact's ability to address the identified problems
5. *Evaluating* the application's or artefact's ability to address the identified problems
6. *Communicating* the initial problem statements, the implemented application or artefact and the design process as well as the evaluation to a heterogeneous audience

Whilst offering a stable foundation to conduct research relating to application design and offering clearly defined overarching activities, it makes sense to complement the *Design Science Research Methodology* with additional more specific frameworks when developing a specific application. To build a globally available, modular, multilingual crowdsourcing platform as a location-based game, further established frameworks exist to ground specific development decisions in theory and guide the implementation. Two established frameworks with increasing topic specificity include the *Mechanics, Dynamics, Aesthetics Framework* [52] concerning general gamified applications and the *Gamification Framework for Volunteered Geographic Information* [53] which focuses on volunteered geographic information, albeit applicable to geospatial crowdsourcing efforts in general.

A framework seeing widespread adoption in both designing [15] as well as analysing [54] games and gamified applications is the *Mechanics, Dynamics and Aesthetics framework* [52] which segregates an application into three underlying categories. Firstly, the aesthetics of an application is what the user directly experiences and what invokes a user's emotional response towards specific parts of the application (e.g. the design of the user interface). An application's aesthetics are of particular importance and can further be subdivided into eight categories: sensation, fantasy, narrative, challenge, fellowship, discovery, expression, and submission. Secondly, the dynamics represent the systems that influence or are influenced by a player's interaction with the application and which result in specific behavioural outcomes (e.g. a button that opens a specific screen affording new interactions within the application). Lastly, the underlying algorithms and data structures are summarised within the mechanics of an application and build the backbone of the gamified system (e.g. the database in which application data is stored). What makes the *Mechanics, Dynamics and Aesthetics framework* particularly interesting in terms of gamified application design is the emphasis on taking both the developers as well as the user's perspectives into consideration, allowing for a more holistic approach to application design.

Drilling down to specific frameworks regarding the gamification of geospatial information collection, the *Gamification Framework for Volunteered Geographic Information* aims at bridging the divide between geospatial crowdsourcing applications and their gamified equivalent by mapping the terminology between the two domains [53]. When translating from a native volunteered geographic information application to a gamified implementation, *users* become *players*, the *map* transforms into the *game board*, *geo-data* is used to generate *virtual goods* and *tasks* translate to *challenges*. Additional gamification elements aim at increasing collaboration and/or competition and include *leaderboards*, *social elements* such as *friends lists*, *votes* as well as *levels*, *points*, *badges* and *bonuses* as typical rewards.

This paper delves particularly into the first three activities of the *design science research* approach. After having identified the concrete research problem of increasing user motivation and retention in spatial crowdsourcing in the introduction and background sections (activity 1), in the following I focus on defining specific objectives and requirements of a solution (activity 2) and shed particular light on how the *Mechanics, Dynamics and Aesthetics framework* as well as the *Gamification Framework for Volunteered Geographic Information* were used to develop and implement the application *Arcane Shift* (activity 3).

3. Design and implementation

The location-based game named *Arcane Shift* aims to combine various game elements into an entertaining crowdsourcing experience. In a first step, and using the two aforementioned frameworks, a list of envisioned features was created to guide the development. Firstly, the overarching theme of the application was set as a synthwave-inspired sci-fi experience where users would captain a futuristic spacecraft. Setting the theme allowed for individual game features to be designed around said theme. To allow for persistent player data as well as to collect basic demographic information from the participants, crucial data in active crowdsourcing platforms, a *registration system* and *onboarding system* were needed. Seeing the location-based nature of the application, an underlying *spatial system* was needed to allow the generation and visualisation of location-based content, a common feature of location-based games [24, 21, 23]. Tying into the spatial system of the location-based game, the application required a number of spatial content systems (e.g. *resource system*, *building system*) to allow for the persistence and correct placement of in-game content such as items and structures. To introduce a form of progression and to reward the user for in-game activities, a *level system* was required which is commonly found in gamified applications [53, 12]. Seeing the application focuses on spatial crowdsourcing, a *questing system* was needed allowing the integration of a variety of crowdsourcing tasks. Primarily, the application should allow users to upload location-specific content such as location-based natural language reports and ratings, commonly collected variables in spatial crowdsourcing. To foster motivation and incentivise continued engagement with the platform, the application was in need of entertaining systems offering a variety of in-game activities. In line with the overarching theme of the application, a ship upgrade system, an attack system and a forge system were envisioned. Having unlockable and upgradable in-game items offers a form of progression and positively affects a user's motivation [53, 12]. Attackable in-game structures increase an application's competitive elements, which have been found to positively affect user engagement [17] and allowing users to forge new items offers a form of discovery and a collaborative element, increasing the likelihood that the application is recommended [17]. Lastly, an *alert system* was deemed necessary to inform users of important in-game activities.

These envisioned features of the application were mapped to the broader categories of the two aforementioned frameworks helping to structure the development and guide the implementation. Table 1 shows the implemented features of the location-based game and the corresponding categories of the frameworks.

3.1. The core game loop

Within the location-based game, users captain a futuristic spacecraft (Figure 1 *H*) and initially collected basic ores that were procedurally generated depending on the underlying real-world land cover of an area (Figure 1 *G*). Users could either combine specific combinations of ores into new materials increasing their value or sell ores for gold rewards. Gold could then be used to construct buildings for their team (Figure 1 *D*) or to buy other ores. If a user's ship had enough energy (Figure 1 *I*), enemy buildings (Figure 1 *E*) could be attacked (Figure 1 *F*) and destroyed freeing up an area for friendly buildings. Further, users could accept and complete a variety of quests (individual crowdsourcing tasks) from survey drones (Figure 1 *B*) or their quest log (Figure 1 *J*). Many in-game activities such as completing quests, collecting resources, forging items and building friendly or destroying enemy buildings rewarded experience points (Figure 1 *I*). Leaderboards showed the top-performing users and an activity log (Figure 1 *L*) displayed a user's past actions as well as the enemy users who attacked their buildings. By limiting a player's view to a fixed distance (approximately a radius of 1km) the game aimed to engage the users' inquisitive nature and hoped to motivate users to explore their surroundings.

First user feedback revealed the core game loop to be interesting, albeit lacking content to motivate long-term engagement. As such level-dependent unlockable content was introduced. Thereafter, users could additionally spend gold on unlocking various spacecraft component upgrades such as energy generators (e.g. increasing energy regeneration rate), tractor beams (e.g. increasing number of simultaneous ore collections) and weapons (e.g. increasing damage). Gold could also be spent on unlocking and constructing improved buildings for the user's team such as forges with reduced forge times or markets with increasingly discounted prices. An overview of the current core game loop is presented in Figure 2.

In the following, I first present the infrastructure with which the application was built before introducing core features as well as discussing the implemented systems.

3.2. Infrastructure and core systems

The location-based game was built from scratch in the Unity[4] game engine (version: 2022.2).

[4]https://unity.com/ (accessed: 10.01.2024)

Table 1
Features of the implemented location-based game and how they map to the *Gamification Framework for Volunteered Geographic Information* and the *Mechanics, Dynamics, Aesthetics Framework*

Game Feature	Gamification Framework for Volunteered Geographic Information	Mechanics, Dynamics, Aesthetics Framework
registration and onboarding	user / player	*aesthetics*: narrative, fantasy; *dynamics*: registration form, email confirmation, demographic information report, character selection, team selection; *mechanics* unity game code, firebase authentication, firestore database
spatial system	map / gameboard	*aesthetics*: discovery; *dynamics*: providing and translating coordinates, downloading, caching and displaying map tiles; *mechanics*: unity game code, MapBox tile server
level system	challenges, levels	*aesthetics*: challenge *dynamics*: increasing levels unlocks various in-game items *mechanics*: unity game code, firestore database
ship system	virtual goods, challenges, levels	*aesthetics*: fantasy, narrative, challenge, discovery; *dynamics*: ship components can be unlocked and equipped changing the behaviour of a user's ship; *mechanics*: unity game code, firestore database
quest system	tasks / challenges, geodata	*aesthetics*: challenge, discovery, expression; *dynamics*: quests can be accepted and submitted, submitting quests rewards the user; *mechanics*: unity game code, firestore database
resource system	virtual goods, challenges	*aesthetics*: fantasy, narrative, challenge, discovery; *dynamics*: spawning resources depend on the real-world landcover in the spawn location, resources can be collected and forged into new resources, collecting resources rewards experience points, resources can be bought and sold; *mechanics*: unity game code, firestore database
forge system	virtual goods, challenges	*aesthetics*: sensation, challenge, discovery; *dynamics*: forging allows new items to be discovered increasing their value, forging rewards experience points; *mechanics*: unity game code, firestore database
building system	gameboard, social element	*aesthetics*: fantasy, challenge, fellowship, expression; *dynamics*: buildings can be built and interacted with by users on the same team. Enemy buildings can be attacked and destroyed; *mechanics*: unity game code, firestore database
attack system	gameboard, points, levels, challenges	*aesthetics*: sensation, fantasy, challenge, fellowship, discovery; *dynamics*: in-game buildings of the enemy team can be attacked and the attack damage depends on a user's ship's weapon, destroying a building rewards experience points; *mechanics*: unity game code, firestore database
activity alerts	social element	*aesthetics*: discovery, fellowship, challenge; *dynamics*: alerts of important in-game activities; *mechanics*: unity game code, firestore database

Google Firebase[5] and Firestore[6], massively scalable NoSQL database solutions, were introduced to provide authentication and storage for the application. Leveraging Firestore's event functionality I introduced real-time gameplay

[5]https://firebase.google.com/ (accessed: 10.01.2024)

[6]https://firebase.google.com/docs/firestore (accessed: 10.01.2024)

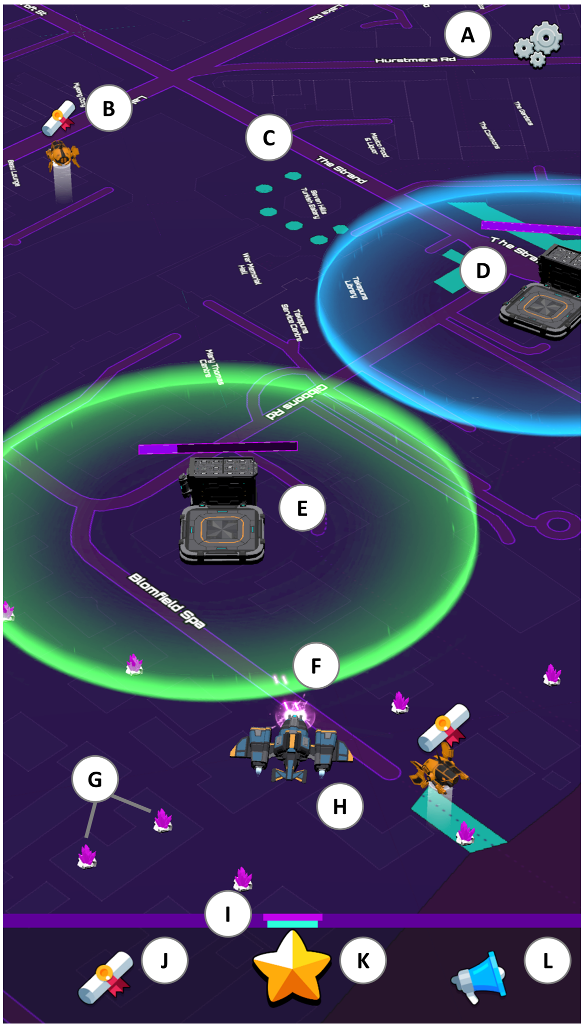

Figure 1: The main game screen. (A) settings; (B) location-based quest / spatial crowdsourcing task; (C) stylised base map; (D) friendly building; (E) enemy building; (F) weapon charging and weapon projectile; (G) procedurally generated ores; (H) user's spacecraft; (I) ship energy generator and user experience point indicator bars; (J) quest log; (K) ship menu; (L) in-game alerts

through subscribing to database document events and acting accordingly. In other words, updating a document in the database triggers an update event, which in turn triggers all listening devices to call a respective method. This event-based approach allows for chosen in-game actions to be propagated to all connected user devices, allowing for real-time gameplay.

For example: When a user attacks an enemy building the persisting building data in Firestore is updated, triggering all listening devices to call the method to update the respective building's health.

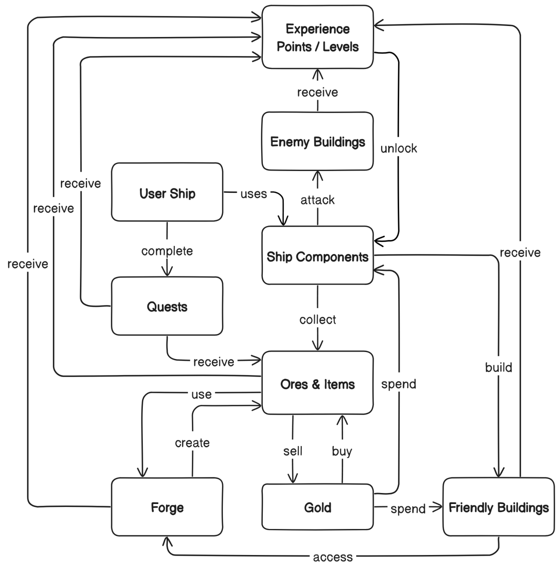

Figure 2: Schematic representation of the current core game loop of the location-based game

3.2.1. Data downloading and caching

In a first iteration, all game data was stored on the user's device, however, to allow for rapid development and balancing during testing, game content must remain updatable allowing for small tweaks according to user feedback (e.g. weapon damage). Seeing the uneven coverage of mobile broadband internet, especially in rural areas [55], and to limit needed mobile data, specific game content is cached on a user's device. A caching pipeline was implemented where content is initially stored on a server and is only (re)downloaded from the server if the content is not found in the user's persistent data cache or if the content has been updated on the server. The downloaded content is then stored in a persistent cache on the user's device as well as in memory, allowing future access to up-to-date data without needing to (re)download the content (cf. Figure 3).

3.2.2. Application environments

At the start of the development process, a single environment was used for development and testing. However, with growing complexity and to allow for easy updates and continuous integration [56, 57], the application was segregated into three separate environments: a development environment for rapid prototyping, a staging environment for beta-testing with test users and a production environment used for the live application. Each environment is accompanied by a decoupled database instance, allowing for

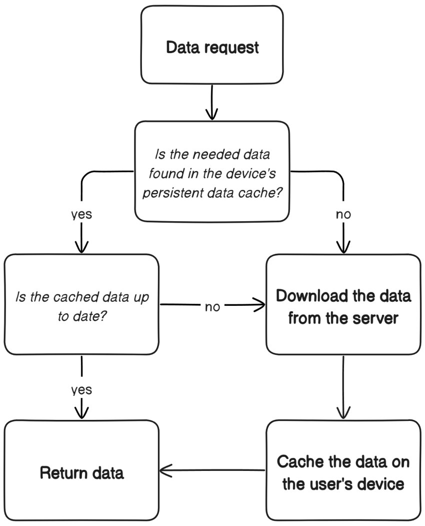

Figure 3: Schematic representation of the data caching pipeline

large changes to be implemented and tested without affecting other environments. This approach follows general software development guidelines and allows for rapid prototyping, continuous integration and stable production environments.

3.2.3. Internationalisation

Having multilingual content allows for a more diverse audience and has been found to be an important consideration in modern applications [58, 59]. Internationalisation of game content was thus implemented as an integral part of the application and allows the game to be played in multiple languages (at the time of writing, this includes te reo Māori, English, French and German). Chosen game content (e.g. textual content) was translated into the mentioned languages and respective translations were initially stored using Unity's *Localization* package. However, similar to the reasoning of moving game content data to an external database to allow for rapid prototyping and quick adjustments (Section 3.2), translation tables were moved to the Firestore database. In the current iteration, translated texts are referenced as translation keys and translation data is handled similarly to general game data in terms of caching where data is only downloaded if it is not found in the translation table cache on a user's device, or if any updates to the translation table are detected. In other words, translation tables for textual content are stored online and downloaded on demand and only if the database document has been updated. This allows the textual content to be seamlessly translated and updated in the application, a key ingredient in contemporary application design [60].

3.3. Registration and onboarding

To ensure an individualised experience, users must register and go through an onboarding process (Figure 4). After registering with email and password, users are required to confirm their email address to minimise misuse. When logging in for the first time, an onboarding process is started, where users are first presented with the free and prior informed consent of the application's intended use and how a user's data will be used and processed. This allows users to make an informed decision on whether they would like to proceed, in line with contemporary data protection regulations when collecting user-generated data [61]. Users are then introduced to the underlying narrative of the location-based game and are asked to make a character, provide basic demographic information and choose their preferred username and team. The onboarding process ties into the game narrative, which has been found to increase user engagement and motivation [62]. Once a user has provided the required information, they enter the location-based game world.

3.4. Spatial features

A defining feature of location-based games is the translation of a user's real-world coordinates into a (virtual) game world [24]. This generally requires two broader systems: (1) querying a user's real-world coordinates as well as (2) translating these to respective game-world coordinates and constructing the game world accordingly. At first, the location-based game was developed implementing the MapBox Software Development Kit (SDK)[7] for Unity. However, the SDK was accompanied by three main limitations: (1) computational overhead due to the number of features, (2) complexity of extending the SDK and (3) discontinued development of the SDK leading to deprecated third-party code. As such, two custom spatial systems were built to allow customisation and integration in the game.

[7] https://www.mapbox.com/unity (accessed: 05.09.2023)

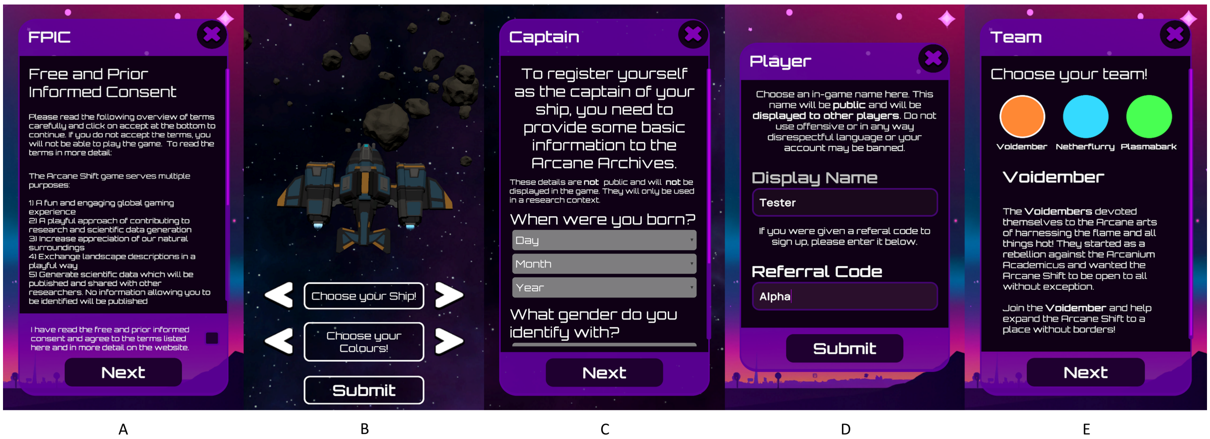

Figure 4: Screenshots showing the onboarding in the application. (A) free and prior informed consent; (B) spacecraft selection and customisation; (C) personal information; (D) display name and referral code; (E) team selection

In the implemented application, a location provider was implemented which uses a respective device's location features to periodically query the user's current coordinates. A mapping engine was built to leverage the location provider and convert between the retrieved real-world latitude and longitude coordinates and the game world coordinates. The mapping engine calculates the current map extent of the player and identifies the needed map tiles. The device's cache is queried and existing map tiles within the user's vicinity are retrieved and drawn to the screen as an underlying base map in the game world. Missing map tiles are downloaded from MapBox[8] and cached on the user's device to reduce the bandwidth needed when a user revisits locations. When the user changes their location in the real world their position within the game is updated to reflect the player's new real-world position. This in return triggers the querying, downloading and displaying of new relevant tiles as well as disabling no longer needed tiles. Another key implemented spatial feature of the mapping engine is the support for the global hexagonal indexing system H3[9]. This allows chosen content (e.g. quests, buildings, resources) to be placed in hexagonal tiles on a global grid.

3.5. Level system

An important dimension in gamified applications is progression and inducing a sense of long-term in-game goals [53, 12]. The implemented platform features experience points and a levelling system, belonging to the most common gamification elements [18]. Users initially start the game at level 1 and are rewarded with experience points for several in-game activities such as the completion of quests, destroying enemy buildings, building friendly buildings and collecting or forging ores (cf. Figure 2). Once a level-specific threshold of experience points is reached, the player's level is incremented. Initially, the application featured a linear progression system, where every level required the same amount of accumulated experience points to advance. However, in a later iteration, this was changed to exponential experience point thresholds to ensure long-term challenges. With increasing player levels new game content is unlocked, providing an additional incentive to accumulate experience points.

3.6. Ship system

Gaining increasing levels within the application unlocks further in-game content. In an initial version of the application, additional game content was restricted to additional buildable structures. However, user feedback highlighted the lack of incentives and thus a ship component system was introduced, where users could upgrade individual components of their spacecraft. Implemented ship components consisted of energy generators, tractor beams and weapon systems. The energy generator component provides a limited amount of energy that recharges over time and which limits the

[8] https://www.mapbox.com/ (accessed: 04.01.2024)

[9] https://h3geo.org/ (accessed: 03.01.2024)

allowed use of other components. Upgrades to the energy generator include a higher energy capacity and a faster recharge over time. The tractor beam component uses energy to collect resources. Upgrades include faster resource collection times and an increasing number of simultaneous collections. Finally, the weapon system uses energy to fire projectiles at enemy structures. Key upgrades include increasing the number of simultaneous projectiles and increasing each projectile's damage. Users can view key statistics as well as access their ship's cargo bay, ship components, a general market and the building tool through the ship menu (Figure 5).

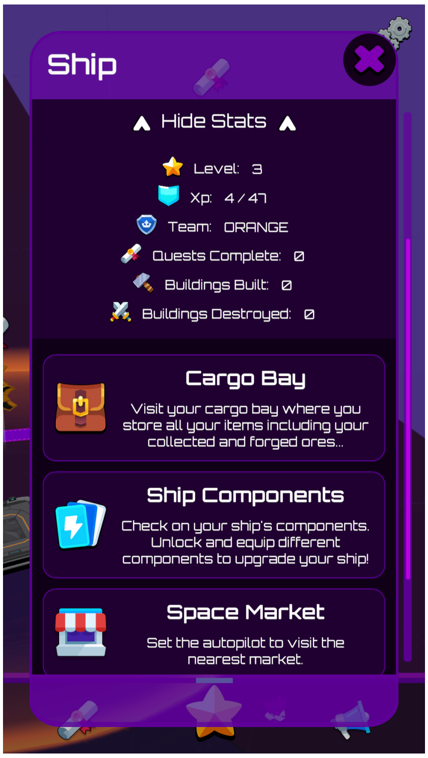

Figure 5: A screenshot of the ship menu and the user's key statistics as well as the available options

3.7. Quest system

According to the *Gamification Framework for Volunteered Geographic Information*, spatial data contribution tasks in crowdsourcing are mapped to challenges in gamified systems [53]. These are commonly implemented as quests, short in-game tasks that afford progression in the game, and commonly reward a player with virtual in-game items or points. The quests implemented in *Arcane Shift* fall into the broad categories of designed or generated. The former refers to quests that are purposefully designed and placed at specific locations to collect specific location-dependent information. In contrast, the latter refers to crowdsourcing tasks that are randomly generated throughout the game world, independent of location. In a preliminary version of the application, each user could complete each quest once. However, many spatial crowdsourcing tasks are suited to be repeated in different locations (e.g. perceived scenicness of an area) or at varying times (e.g. perceived safety during the day vs. during the night). Seeing the global nature of, and the focus on, geospatial crowdsourcing, quests were thus extended to be either local or global and repeatable or non-repeatable. Table 2 shows an overview of the quest categories and examples of questions or tasks that could be incorporated.

Quests are comprised of one or multiple quest steps, which in return are made up of one or multiple quest tasks (Figure 6). In addition, quest steps can be locked and only made available to the user if other specific quest steps are completed first. This allows a sequence of quest steps to be combined into a journey, guiding the user through multiple locations in the real world. This in return opens the door to collecting specific spatially nuanced information or guiding users through educational journeys in a given landscape.

Example: *A quest could ask a user to go to the main train station and report on their experience. This quest would be divided into two quest steps (1) navigate to the specific area of the train station and (2) report on their experience, where (2) only becomes available after completing (1).*

3.8. Resource system

Collectable entities are common in location-based games and provide an incentive to navigate the game world as well as a means of generating in-game value. Within *Arcane Shift* users can collect a variety of basic ore crystals which are procedurally generated depending on the respective real-world land cover of a given area (Figure 1 G). Collected basic ore crystals are stored in the users inventory and can be sold for in-game gold, a basic in-game currency. This currency can be used to buy specific in-game ores as well as to unlock a variety of in-game content (e.g. ship component upgrades), supposing all level requirements are

Table 2
Quest Categories and Types

Category	Type	Description	Examples of Underlying Tasks
Designed	Local non-repeatable	Quests that are purposefully placed and that can be completed exactly once in each available location.	Complete the educational coast walk and do the quiz.
Designed	Local repeatable	Quests that are purposefully placed and that can be repeated multiple times in each available location, requiring a set amount of time to pass between submissions.	Is any of the infrastructure in this park in need of repair?
Designed	Global non-repeatable	Quests that are purposefully placed and that can be completed exactly once globally.	Describe your favourite place in the world.
Designed	Global repeatable	Quests that are purposefully placed and that can be repeated multiple times globally, requiring a set amount of time to pass between submissions.	Tell us about your favourite new place you have discovered this month.
Generated	Local non-repeatable	Quests that are randomly generated and that can be completed exactly once in each available location.	What is your first impression of this area?
Generated	Local repeatable	Quests that are randomly generated and that can be repeated multiple times in each available location, requiring a set amount of time to pass between submissions.	How safe do you feel in this area?
Generated	Global non-repeatable	Quests that are randomly generated and that can be completed exactly once globally. These quests are useful to generate generic not necessarily spatial data.	Do you prefer urban or rural landscapes?
Generated	Global repeatable	Quests that are randomly generated and that can be repeated multiple times globally, requiring a set amount of time to pass between submissions.	Upload an image of your favourite place this month.

met.

3.9. Forge system

Exploration as a dimension of gamification ties into the *Mechanics, Dynamics, Aesthetics Framework* aesthetic of discovery and has been found to increase user motivation [63, 64]. Besides exploring the game world, another implemented form of exploration revolves around the forging feature, where players can submit four ore crystals and have the chance to discover new items (Figure 7). However, only specific combinations of ores will result in a successful forge rewarding a new item, meaning players must explore the various combinations and potentially share their findings with other players.

3.10. Building system

Another key dimension is collaboration, which has been found to boost motivation in and engagement with an application as well as the likelihood of word-of-mouth recommendations [65, 17]. Within *Arcane Shift*, the users must choose between one of three teams during the onboarding process. The teams each boast an intriguing backstory and players within a team can interact with buildings built by other players within the same team. Buildings of the same team allow for more in-game interactions (e.g. access to the forging mechanic as shown in Figure 7) and as such, there is a strong incentive for players to be in proximity to friendly buildings. In a first iteration, users could build buildings if they had sufficient gold in their inventory and if there was an unoccupied hexagonal H3 tile in the vicinity of the user. The application would display preview buildings and once a user chose the preferred building location by clicking on a preview, a loading screen would show whilst the building was created and subsequently saved on the server. However, constant loading screens were perceived as disruptive to the game experience.

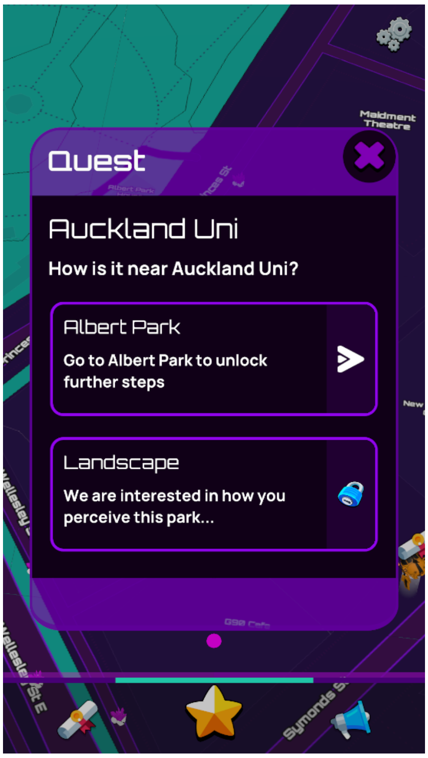

Figure 6: A screenshot of an example location-based quest or spatial crowdsourcing task with two dependent quest steps

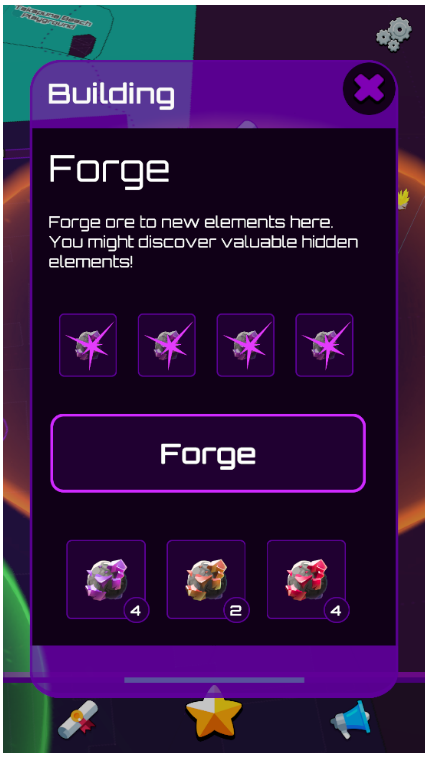

Figure 7: A screenshot of the forging mechanic, only accessible through friendly buildings

As such, loading screens were masked with a new building warp mechanic, where the application would show a warping animation instead of a loading screen (Figure 8). In addition, further unlockable building tiers were added as additional game content.

3.11. Attack system

Competition, if provided in adequate amounts, has been found to increase user motivation and engagement in games and gamified applications [9, 17]. As such, providing the right amount of competitive elements is a valuable tool within gamification efforts. Within the location-based game, besides incorporating a variety of leaderboards, competition is fostered by the limited building space in the virtual world and enemy buildings being destroyable to make room for buildings for one's own team. If a user's ship's generator has enough energy, a user can click on an enemy structure to fire the ship's weapons at the enemy structure, inflicting weapon-specific damage to the structure. Once a structure's health depletes, it is destroyed to make room for buildings for one's own team, leading into the dimension of competition. Building updates must be propagated to all other players with view of a specific building. This was achieved by: (1) starting a weapon charging animation to mask client-server communication lag, (2) updating the persistent building data in the database, (3) firing a document update event informing all connected devices of a change and (4) updating a respective building's health on all connected devices.

4. Internal user testing

A testing pipeline was set up on the Google Playstore to perform internal user testing. This allowed invited test participants to download the application through the Google Playstore and update the application as soon as new versions of the application became available, a crucial feature to allow for iterative development. First internal pilot tests were conducted with a small group of three users to test the stability of the main game systems and to identify points of improvement. All users were between the ages of 32 - 45 years old and covered all levels of expertise with location-based games including one user with no experience, one casual user and one expert user. The users were given access to the application and received an overview of the location-based game, the

Figure 8: A screenshot of the building warp mechanic which masks loading screens with a warping animation whilst data is being persisted to the server

various features of the application as well as detailed instructions of the testing process. The internal test users were asked to pay particular attention to the core systems (e.g. questing, collecting, building, attacking) and were asked to report if they encountered any errors or unexpected behaviour. In addition, the users were asked for their opinion of the first test version and potential improvements that would make the game more enjoyable. Feedback was collected through an online form, as voluntarily submitted additional written feedback and as one-on-one discussions.

The users generally enjoyed the location-based game and reported it being engaging and mostly stable (n = 3). The users reported liking (n = 1) or loving (n = 2) the overall aesthetics of the game and it being a little (n = 1), very (n = 1) or extremely (n = 1) motivating in its current state. Chosen features of the game such as upgrading ship components, gaining experience points and levelling up were reported to be enjoyed by the test users (n = 3). However, many features such as collecting resources, constructing buildings and buying items from the in-game market were reported to be only moderately enjoyed due to the limited amount of in-game content. Further key feedback revolved around user convenience and interaction features such as auto-login or revising the touch detection and tap interactions within the application. The location-based game will be trialled with a larger test user group before being opened up for public beta testing.

5. Discussion and outlook

The developed and implemented location-based game is a novel highly gamified crowdsourcing and citizen science platform, upon which various interesting systems can be built. This paper presents the implementation and the literature-based reasoning behind various design decisions as well as gives an overview of the current state of the application and future potential. In the following, I first discuss gamifying spatial crowdsourcing in general before presenting key recommendations for building highly gamified spatial crowdsourcing platforms and location-based games, gleaned from lessons learnt during the development of *Arcane Shift*. Finally, I lay out specific future agendas for the platform and summarise the findings in the conclusions.

5.1. Gamifying crowdsourcing through a location-based game

Common approaches implementing the *design science research method* identify a specific topical research question or organisational problem, which is subsequently distilled into application features to be implemented [48, 49, 50, 51]. The approach presented here attempts to address the more general problem of how users can be motivated to participate in spatial crowdsourcing tasks through a gamified application, in return allowing a plethora of domain-specific research questions to be asked. Specifically, *Arcane Shift* was built to allow for a variety of user contributions, allowing for most crowdsourcing tasks to be translated into location-based game quests, offering a novel approach to crowdsourcing and citizen science.

The implemented location-based game further transcends traditional crowdsourcing platforms in regards to the special focus on entertaining and motivational elements, allowing for high-quality data generation whilst offering entertaining virtual experiences. This contrasts with many more traditional crowdsourcing approaches, where participants are motivated through monetary rewards, scientific or other forms of acknowledgements or are encouraged to participate as part of a curriculum [1, 9, 10, 2]. Scientific inquiries leveraging crowdsourced spatial data are plentiful with examples ranging from characterising specific landscapes [66], over detecting popular viewports [67] and analysing urban mobility [68], to mapping a city's smellscape [45]. These generally use the rich spatial information contained within geolocated social media data as well as other forms of (online) user-generated content and are a welcomed source of easily accessible data from a heterogeneous crowd. However, such datasets are generally noisy with many irrelevant data points. The implemented location-based game aims at minimising irrelevant contributions through an active approach to collecting data. Being able to strategically place crowdsourcing tasks (quests) at specific locations and the ability to create tailored tasks to collect any information needed makes the implemented application a novel highly gamified crowdsourcing platform, transcending more passive approaches to generating crowdsourced data.

Combining the ease of adding new crowdsourcing tasks either globally or in specific locations with the general goal of developing extendable core systems makes this platform especially interesting for longitudinal studies. As such, this surpasses general academic crowdsourcing efforts which are typically developed for a specific project after which they tend to disappear [69], potentially due to the difficulty of updating the underlying systems to accommodate new research endeavours. The location-based game presented in this paper takes a different approach: the core systems are built to function independently of overarching projects and research questions.

5.2. Recommendations and lessons learnt

During the implementation of *Arcane Shift* the application has gone through several versions and substantial amounts of code were refactored with each new iteration. This dynamic and evolving nature of the application is in line with modern agile software engineering approaches [70, 71] and allows for flexibility in design and development. In the following, I touch upon four key areas of location-based game design that have proven to be key improvements or important considerations in the design and implementation process.

5.2.1. Develop for testing, test for development

Rapid prototyping and user testing are the backbones of creating new information systems and have proven to be invaluable in the development of *Arcane Shift*. Developing applications can be seen as an iterative circular process starting with implementing features, subsequently testing features and collecting feedback and finally refactoring or implementing new features according to the collected feedback, effectively starting a new iteration loop. This approach however requires two key implementation considerations from the start of a project.

Firstly, a given application should be divided into at least three distinct environments: (1) a development environment in which development takes place, (2) a staging environment with which internal or open user testing is conducted and (3) a production environment encompassing the live application. These environments can further be extended according to the needs of the project (e.g. additional internal, closed and open beta testing environments). Using modern versioning software such as GIT[10], the code base for each environment can be tracked and changes can be merged as required. Finally, each environment should incorporate a decoupled database instance so changes to one environment's backend database does not influence the other environments. Seperating environments and using version control is common practice in software development [71, 72] and despite the additional overhead of setting up versioning and distinct environments with decoupled database instances, this has proven invaluable to allow for simultaneous testing of multiple versions as well as continued development.

A second important consideration is making content easily updatable and propagating updates to test users. This is especially important for data where minor changes might become necessary, for example for balancing (e.g. weapon damage, energy use, recharge rates). Storing such content online and having the application download updated values when the application starts allows developers to change values as needed without needing to distribute a new application build to the test

[10] www.git-scm.com (accessed: 03.01.2024)

users. However, downloading content on the fly has the caveat of needing an internet connection, a particularly important consideration when designing mobile applications.

5.2.2. Incorporate caching and on-demand content retrieval

Moving content to online storage and downloading needed data when starting an application allows for rapid value updates, however, loading content from external sources can result in notable amounts of mobile data usage. During the development of *Arcane Shift* it became evident that the majority of content remained unchanged between application usages. This highlighted the importance of caching content on the device to minimise mobile data usage. Caching was introduced where content was only downloaded from an external source if the online content was updated. This allowed the seamless updating of existing content as well as the addition of new content, whilst minimising needed bandwidth and mobile data usage. This is in line with modern online application design best practices, advocating for fast content loading and easy navigation [73, 74]. Carefully considering which content is immutable and which content requires dynamic updating is thus a key consideration when building location-based games or spatial crowdsourcing applications.

5.2.3. Build for longevity

The location-based game was built keeping future development in mind and thus, particular focus was set on building expandable core systems and interchangeable modular components with accessible interfaces. An important consideration when building an application is following established software development principles. Modern well-known software design principles advocate single responsibility classes (such as advocated by the SOLID principle [75]) and urge not to repeat code. Developing an application in line with these principles ensures a modular system with accessible interfaces making code reusable and testable. An added benefit is the ease of updating individual components of the application. For example, seeing the location provider implemented in *Arcane Shift* exposes the current coordinates of the player through a public interface that other classes can consume, the location provider can be updated or completely changed at any point as long as it exposes the same public interface that provides coordinates. This becomes particularly important when incorporating an increasing amount of third-party software with unclear development and maintenance roadmaps. Adhering to established principles where sensible ensures code is reusable and remains maintainable. Using interfaces and favouring composition over inheritance also allows for the easy addition of new items such as different ores and a variety of new buildings or new ship component upgrades. This effectively allows for large updates of the location-based game with new content, keeping players engaged and motivated (with infrequent large updates reported as preferable over frequent small updates [76]), and as such arguably increasing the likelihood of players contributing to the various crowdsourcing tasks.

5.2.4. Spatial is special

A final key area worth considering is the special nature of developing a globally available spatial application. Firstly, visualising a digital representation of a user's surroundings as the game world requires careful consideration of the level of abstraction of the spatial features. Adding too many details such as points of interest or cluttered map labels can result in cognitive overload [77] whilst reducing the available screen real estate for virtual game objects. Reducing map complexity could also be in part responsible for the lack of altitude information in many location-based games [21]. However, not adding enough spatial information can confuse the user as to their in-game location and the translation between real-world and game-world coordinates. As such, striking a balance between incorporating a minimalist base map with enough spatial information to ground the user in the game world is needed. Secondly, seeing the potentially global scale of location-based games, I recommend pursuing a threefold content creation strategy: (1) designed content, (2) user-generated content and (3) procedurally generated content. Developing the application to accommodate these three distinct content generation strategies will allow for specific areas of the game to be purposefully designed especially in highly frequented areas inviting the creation of custom content. In addition, having user-generated content allows for a dynamic and changing game world and procedurally generated content offers globally available content. Finally, of particular importance when designing applications geared towards crowdsourcing spatial information is considering the spatial and temporal availability and repeatability of crowdsourcing tasks. During the development of *Arcane Shift*, four overarching categories of tasks emerged: spatially and temporally repeatable, spatially but not temporally repeatable, temporally but not spatially repeatable and neither spatially nor temporally repeatable. This allows for the collection of detailed information about specific areas over time as well as increasing spatial coverage.

5.3. Future agendas

Within this paper, I have presented the design decisions and the reasoning behind the individual implementation steps in creating *Arcane Shift*, a global gamified crowdsourcing platform. In the following, I divulge three key lines of research building on top of the implemented platform. These aim to showcase the potential of the application for sparking future research in a wide variety of domains.

Crowdsourcing and participatory approaches have been identified as valuable complementary approaches in policy and decision-making contexts [78, 79, 80]. A first scientific avenue to explore is thus the potential of using the implemented location-based game to collect policy and decision-making relevant spatial datasets. Seeing the particular need for urban data to pave the way for future urban living [81, 82] in combination with the high spatial coverage of mobile broadband internet in urban areas, the implemented location-based game offers a particularly interesting platform to collect a variety of urban information from the local citizens themselves.

Secondly, location-based games have shown great potential in delivering certain educational content [83, 84]. The possibility of implementing chained quest steps as journeys opens the door to investigating the platform's ability to deliver location-based educational content, which may be of particular interest to educational professionals seeking new ways to engage with their students in a time of increased blended and gamified learning [85]. The platform offers the ability to create tailored educational journeys, guiding learners through specific real-world locations. Thus, testing educational variables such as knowledge acquisition and learner motivation could become an interesting future investigation.

Lastly, exergames (applications that motivate physical activity), and location-based games in general, have been found to increase physical activity and in return affect users' overall health and well-being [86, 87]. This offers a third and important line of research for the implemented application: questioning the ability of the location-based game to motivate increased physical activity. Motivating users for physical activity in urban environments has become an important dimension of urbanisation research and entertaining motivational incentives such as location-based games show great potential.

6. Limitations

The implemented location-based game is accompanied by various limitations, key of which are listed here.

Firstly, a large active player base and broad spatial coverage of game content are needed to make a virtual world feel alive and motivate user engagement [88]. This limitation can be somewhat mitigated by procedurally generated content and non-player characters or large-scale in-game events, conjuring the illusion of an active and dynamic game world.

A second key limitation is the requirement of an adequate internet connection. This excludes many rural areas which have generally been underrepresented in location-based games [19], potentially reinforcing the digital divide [5]. However, an active internet connection is required to allow for real-time updates as needed for the game experience. As such, an inevitable tradeoff between real-time multiplayer features and asynchronous offline gaming must be carefully considered. One possible approach to address this limitation is to implement specific offline features accessible anywhere (e.g. accepting a quest) which are not dependent on real-time updates from other players or the game world.

One final major limitation of the implemented location-based game is the dependence on commercial products. The implemented platform was built from scratch using state-of-the-art technology and commercial products (e.g. Unity, MapBox, FireStore) were used or integrated as a means of minimising overall platform maintenance. Access to these products may change in the future, raising an important issue of longevity. I try to address this issue by implementing many of the core systems to be modular and adapted if need be. For example, the developed mapping system displaying the base map can easily be modified to display map tiles of other providers such as Open Street Map.

7. Conclusions

Within this paper, I have presented the development and implementation of a novel spatial crowdsourcing platform in the form of a globally available real-time location-based game. The implemented application was not developed to address a specific research question in favour of serving as an underlying gamified platform to host a variety of spatial crowdsourcing initiatives globally. The design and implementation of the application were grounded in the *Design Science Research Methodology* and the application was built using two well-established frameworks. The location-based game itself revolves around collecting and forging resources, upgrading one's spacecraft, building structures, attacking enemy buildings and completing location-based quests which are crowdsourcing tasks. I further presented a list of key design an implementation recommendations, distilled from the lessons learnt during the implementation of the application, to contribute to the theoretical discussions on implementing gamified spatial crowdsourcing platforms or location-based games more generally. Finally, by presenting three distinct future research agendas, I hope to have highlighted the intended impact and present real-world scientific domains that would benefit from the implemented platform. *Arcane Shift* hopes to pave the way towards an era of entertaining engagement in science and societally relevant data collection.

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