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**Research Paper**

# A Gamification Proposal to Support Crowdsourcing and Collaborative Mapping in Covid-19 Spatialization and Signaling

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**Abstract.** Active community involvement in health initiatives is crucial for combating Covid-19, particularly in vulnerable urban communities where detailed geographic data is often scarce. This study presents a gamified solution to support participatory mapping and crowdsourcing, aimed at gathering spatial data on Covid-19 transmission predictors. Using the Unified Theory of Acceptance and Use of Technology (UTAUT), we evaluated the factors influencing platform adoption. The proposed design, based on the GAFCC model, incorporates game elements to motivate engagement. A user study with 20 young participants from a vulnerable urban community in Salvador, Brazil, revealed that 'effort expectancy' and 'social influence' were significant determinants of the behavioral intention to use the platform. These results suggest that gamified participatory approaches can effectively mobilize community efforts in public health crises, offering valuable insights for similar contexts.

**Keywords:** Gamification, Crowdsourcing, Participatory Mapping, Covid-19, Vulnerable Communities

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## 1 Introduction

Notified for the first time in December 2019 in the city of Wuhan, Hubei Province (China), the SARS-CoV-2, a new Coronavirus causing the disease named Covid-19 by the World Health Organization (WHO), represented a significant risk to public health worldwide McKibbin and Fernando [2020]; Pervaiz *et al*. [2025]. Although efforts aimed at containing the virus were underway, the epidemic potential of SARS-CoV-2 allowed it to spread rapidly, reaching all continents in a short period Li *et al*. [2020]; Carvalho *et al*. [2025].

According to Zhong *et al*. [2020]; Soori and Attah [2025], to ensure success in tackling Covid-19, popular engagement and participation in health policies are fundamental. According to Heffernan *et al*. [2016]; Yang and Han [2025], the implementation of an interactive and gamified environment can contribute to popular engagement, awareness, and motivation in favor of the collective and participatory production of information and guidelines for combating diseases, for example, in a crowdsourcing initiative. Highlighting its applicability in the Web environment, as well as in applications for mobile devices.

Crowdsourcing involves the collaborative generation of ideas, content, and artifacts, typically employing methods to collect information or various resources from a crowd of individuals with the aim of meeting specific objectives or carrying out a particular project de Freitas and Ewerton [2019]; Dissanayake *et al*. [2025].The crowdsourcing approach can be employed for the organization and coordination of movements, political actions, and proposals, as well as to enable coordinated actions among individuals, organizations, and networks, becoming a common practice in the public sphere. It is essential to emphasize that the primary means responsible for facilitating crowdsourcing is the internet Brabham [2013]; Garrigos-Simon and Narangajavana-Kaosiri [2024].

The potential of mobile devices to amplify this problem-solving model is evident. It has been observed that through these devices, contributions can be made easier and more ubiquitous Chatzimilioudis *et al*. [2012]; Chen *et al*. [2025]. Thus, the sensing capabilities present in mobile devices favor both the crowdsourcing and participatory mapping approaches. Literature studies highlight that data collected through crowdsourcing are relevant for dealing with, responding to, and mitigating the damages caused by epidemics, more recently, the Covid-19 pandemic Leung and Leung [2020]; Huang *et al*. [2024]. The absence of spatial data to support spatial responses during this period of health emergency is evident, especially in vulnerable urban communities.

Participatory mapping is a branch focused on mapping with social application, utilizing techniques traditionally employed by geographers and individuals within the context of the studied area Araújo *et al*. [2017]; Saija and Pappalardo [2022]. Participatory mapping also emerges as an approach that contributes to various areas of knowledge, being employed in projects within the field of epidemiology in various countries, highlighting the dissemination of the term "participatory epidemiology".

Participatory epidemiology was initially developed by small-scale community health programs and later consolidated and reapplied by international disease control projects Jost *et al.* [2007]; Alders *et al.* [2020]. Studies have shown that game strategies and mechanics can be combined with crowdsourcing and participatory mapping for epidemic control Oliveira *et al.* [2016]; Hu *et al.* [2025].

Gamification corresponds to the use of game mechanics for solving practical problems or as a means of engaging a specific audience Ulbricht and Fadel [2014]; Zenkina *et al.* [2020]. It involves applying game elements to activities not directly related to the gaming domain Heffernan *et al.* [2016]; Dah *et al.* [2025]. Gamification can be explored in the field of health, providing significant benefits for promoting healthy behaviors and habits Heffernan *et al.* [2016]; Edwards *et al.* [2016]; Inagaki *et al.* [2025]. Additionally, there is potential for implementing gamified environments in conjunction with participatory approaches to combat epidemics Oliveira [2015]; Hu *et al.* [2025].

In this work, we present a solution that utilizes gamification to support participatory mapping and crowdsourcing approaches for obtaining spatially distributed indications regarding the presence of Covid-19 transmission predictors in a participatory manner. Additionally, it provides real-time notifications about users approaching areas previously identified as having the potential risk of Covid-19 transmission. This study was guided by the following research question: "Can the implementation of a gamification design model assist the use of participatory mapping and crowdsourcing approaches in practices aimed at combating Covid-19 in vulnerable communities?"

This article is an extended and revised version of the work originally presented in Arouca *et al.* [2024], in which we investigated the impact of using a gamification design model to support participatory mapping and crowdsourcing approaches to combat Covid-19 in vulnerable communities. In this version, we deepen the analysis by including new data and critical reviews that broaden our understanding of the impact of this practice.

The remainder of this article is organized as follows: Section 2 provides the research background and presents related works. Section 3 describes the methodology used in this work, including how data was collected and analyzed. The Mais Lugar (+Lugar) platform, along with the Covid-19 version proposed in this work, is presented in Section 4. Section 5 discusses the studies conducted with end users. Section 6 presents the results of the analyses performed. Section 7 offers a discussion. Finally, Section 8 concludes with the findings and suggests directions for future work.

# 2 Background and Related Work

This section provides a comprehensive and detailed overview of the fundamental concepts and previous studies relevant to this research, setting the context for the gamified approach and methodology applied.

## 2.1 Participatory mapping

The development of participatory mapping procedures began in the late 1980s with the Participatory Rural Appraisal (PRA) Rambaldi *et al.* [2006]. However, various initiatives proposing participatory mapping for map production processes started to gain popularity in the 1990s Acselrad and Coli [2008]; Brown *et al.* [2020]. Participatory mapping can be understood as a process of spatialization and recording knowledge of a group belonging to a community about the place where they are located Goldstein *et al.* [2013]; Laituri *et al.* [2023].

According to Corbett [2009]; Saija and Pappalardo [2022], participatory mapping is characterized by the production process, in this way, its process is outlined around an objective and strategy, and is generally carried out with the contribution of the community in an open and inclusive manner. Therefore, the greater the participation of community members, the more beneficial the result will be, since it tends to reflect the collective experience. dos Santos Linhares and Umbelino [2017] approaches participatory mapping as a collective effort, characterizing it as a way of perceiving the environment, therefore, the population participating in this process can incorporate a feeling of belonging in relation to the construction based on their systematized knowledge.

With the consolidation of the participatory mapping approach in the 1980s, the configuration of the mapping process was expanded, and people who did not have direct links with research institutes began to contribute to mapping and other spatial representations of the environment and context in which they are inserted Chambers [2006]; Guldi [2017]; Brown *et al.* [2020]. Consequently, the practice of participatory mapping began to be promoted by several public and private institutions, such as NGOs, government agencies, private companies, universities, and other multilateral and international cooperation organizations Acselrad and Coli [2008].

According to Goldstein *et al.* [2013]; Saija and Pappalardo [2022], the participatory mapping contributes to greater commitment and participation of the local population in the territorialization processes, providing greater responsibility in the construction of artifacts for the composition of decision-making processes. In this way, participatory mapping not only contributes to the construction of maps, but also to a variety of artifacts in different formats and related to different purposes.

## 2.2 Crowdsourcing

In the current context, the Internet has established itself as a remarkably favorable place for the dissemination of participatory culture. This turning point occurred in the early 2000s, with a significant wave of interest from organizations in promoting collective intelligence, in order to improve the process of public participation in governance, product development, and problem-solving. "This deliberate blend of bottom-up, open, creative process with top-down organizational goals is called crowdsourcing" Brabham [2013].

The crowdsourcing approach arises from three formative elements, namely: "crowd", "outsourcing", and the "social Web" Vaz [2018]. At that time, Howe [2006] defined crowdsourcing as the process of an organization "outsourcing" some task to a network of people in an open manner. However, it is observed in the literature that there is no consensus about the definition of this term. In Table 1, it is possible to see the definition of "crowdsourcing" from the perspective of different authors.

**Table 1.** Definitions of the term "Crowdsourcing"

| Crowdsourcing Definitions | |
|---|---|
| **Author** | **Definition** |
| Howe [2006] | The process of an organization "outsourcing" some task to an open network of people. |
| Vukovic [2009] | A model of distributed online production and problem-solving, where people network and collaborate to complete a task. |
| Pénin and Burger-Helmchen [2011] | A modality of open innovation, as it allows companies to leverage knowledge and assets developed by other companies and individuals. |
| Brabham [2008] | A model capable of aggregating talents, leveraging ingenuity, while reducing the costs and time required to solve problems. |

According to Oliveira [2015], a common aspect in other existing understandings about crowdsourcing is the dependence on some contribution from the crowd. That said, Gomes [2016] also highlights that there are other related, but not identical, approaches that resemble the crowdsourcing approach, for example: open innovation, co-creation, collective intelligence, user innovation, and open source.

The crowdsourcing model improves collaboration and fosters collective actions, allowing people with diverse skills, knowledge, and experiences to work together on projects in a flexible and accessible way. An interesting aspect of the crowdsourcing approach is that it often relies on online platforms, making it easy for people to participate in projects regardless of their geographic location or technical expertise Amorim *et al*. [2024].

## 2.3 Gamification

The growing success that permeates the gaming industry and its ecosystem has significantly attracted the attention of other areas of study that have gradually adopted game mechanics to enhance activities that originally do not belong to this scope e Souza *et al*. [2018]. Gamification consists of the use of mechanics and strategies present in games in environments unrelated to them, so that it is projected as an alternative for problem-solving, increasing motivation, and acquiring engagement Busarello [2016].

According to Vianna *et al*. [2013] and Menezes and De-Bortoli [2018], gamification involves the use of game mechanics to solve practical problems or to engage a specific audience. Therefore, they highlight its applicability to various branches, as well as its focus on adopting new behaviors, getting accustomed to new technologies, and transforming tedious activities into enjoyable ones.

According to Sailer *et al*. [2017], gamification focuses on capturing the "building blocks" of games and applying them to real-world situations to motivate specific individual behaviors. It is therefore stated that the choice of "building blocks" that form part of the characteristic elements of game design is generally made in a particular and subjective manner. Furthermore, for the software gamification process, having precise knowledge of the problem and user needs is crucial to achieving the effective applicability of gamification dos Anjos *et al*. [2024].

To guide and assist in the development process of gamification solutions, various models and frameworks have been proposed. These structured resources provide comprehensive guidance, from defining goals and the target audience to selecting and implementing the most appropriate gamification mechanics Mora *et al*. [2017]. With the use of these resources, it's possible to achieve a higher chance of success in the development projects of gamified solutions Mora *et al*. [2015].

## 2.4 GAFCC Model

Gamification and the theories developed to explain the need for people's motivation are directly related. Many authors base their work on motivation theories to develop gamification models and frameworks in various contexts Marins [2013]; Prasetya *et al*. [2025]. Some motivation theories are frequently used in gamification projects, such as the Goal-setting Theory and the Self-determination Theory Landers *et al*. [2015]; Pg Arshad *et al*. [2023]; Gao [2024].

Originally developed for the scope of education, the GAFCC model employs the synthesis of crucial aspects of the five main motivation theories (Flow Theory, Goal Setting Theory, Social Comparison Theory, Self-Determination Theory, Behavioral Reinforcement Theory) to design a theory-driven gamification design model. Therefore, the model proposes the use of five elements that contribute to a motivating experience: goal, access, feedback, challenge, and collaboration (GAFCC) Huang and Hew [2018]. The GAFCC model aims to transform motivating elements into components such as points, items, badges, and leaderboards. As can be seen in Figure 1, Huang and Hew attribute to the elements goal, access, feedback, challenge, and collaboration, their respective transfigured components. Additionally, Table 2 presents up to three of the main characteristics of each theory in light of elements of the GAFCC model.

To ensure alignment of motivation theories, gamification strategies, and instructional objectives, it is recommended that a five-steps gamification design procedure be followed. These five steps of the procedure are: i) examine, ii) decide, iii) match, iv) launch, and v) evaluate. In Figure 2, all the steps of the gamification design procedure of the model proposed by Huang and Hew [2018] are illustrated.

## 2.5 State of the art

Even with limited resources and a deficient healthcare system, India launched the country's first participatory disease surveillance initiative through the Aarogya Setu app Garg *et al*. [2020b]. The Aarogya Setu app aims to track individuals infected with Covid-19. Using device location data and Bluetooth to detect the proximity of infected individuals, the app also features a chatbot providing health ministry updates on the disease. The app's usage by the population is optional.

In Israel, a system named Hashomer was developed as an enhancement to the official app published by the country's Ministry of Health, HaMagen Pinkas and Ronen [2021]. To trace contact with infected individuals, it utilizes the same principles described earlier: through the use of GPS and Bluetooth. However, Hashomer focuses on user privacy and data security. In Singapore, the government provided a system for tracking and monitoring contact with confirmed Covid-

**Table 2.** Main Theories of Motivation (Adapted from Huang and Hew [2018].)

| Theories of Motivation | | | |
|---|---|---|---|
| **Flow Theory** | Clearly defined goals (Goal) | Immediate feedback on performance and progress (Feedback) | Appropriate level of challenges (Challenge) |
| **Goal Setting Theory** | Set long-term and short-term goals (Goal) | Provide feedback on performance (Feedback) | |
| **Social Comparison Theory** | Self-evaluation (Feedback) | Provide opportunities for individuals to compete with peers (Access, Challenge) | |
| **Self-Determination Theory** | Allow choice between various options (Access) | Provide opportunities for individuals to compete with themselves or peers (Access, Feedback) | Provide opportunities for individuals to work together to reach a shared goal or interact with others (Collaboration) |
| **Behavioral Reinforcement Theory** | Reinforcement (Feedback, Goal) | | |

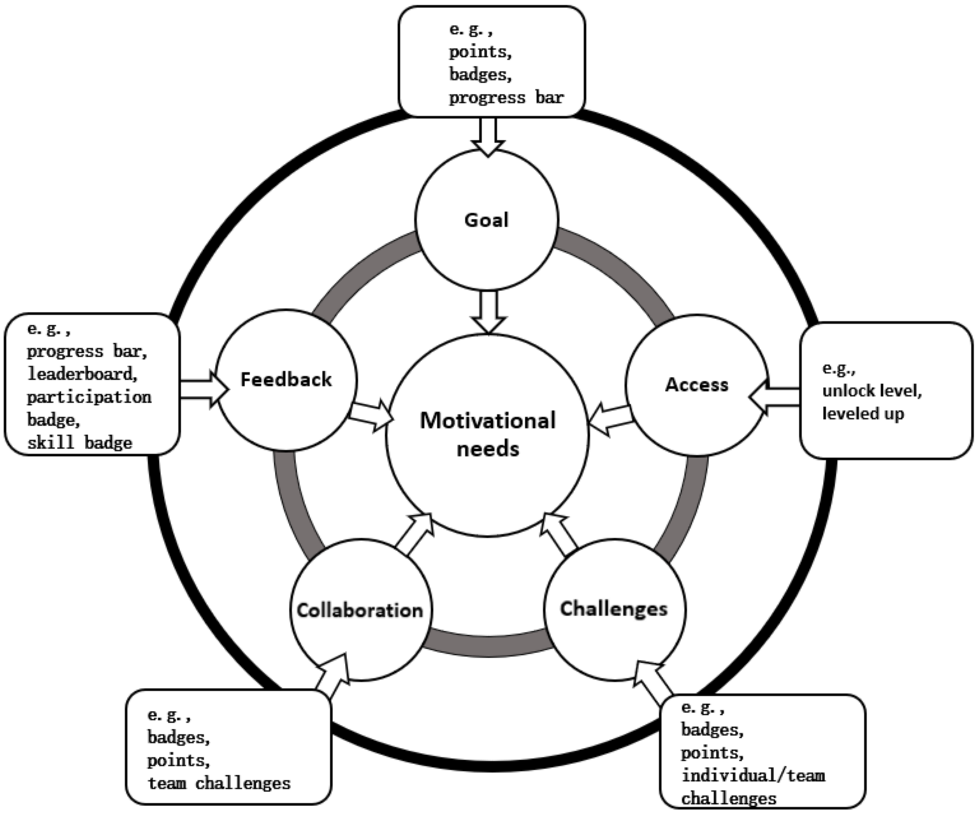


**Figure 1.** Need for motivation, motivating and facilitating elements (game design elements) [Huang and Hew, 2018].

19 cases, the digital contact tracing system called "TraceTogether" Huang *et al*. [2021]. The studied system consists of a mobile app and a low-energy Bluetooth token, both capable of tracking the user's location and contacts using GPS and Bluetooth.

Upon analyzing the mentioned works, it becomes that contact tracing initiatives are beneficial in addressing infectious diseases like Covid-19. However, due to the privacy policies adopted by Western countries, this methodology is not widely adopted in these countries Garg *et al*. [2020a], unlike in Eastern countries, where the use of such technologies is, in some cases, mandatory.

Frequently used as a means of controlling social behavior during the Covid-19 pandemic, the participatory surveillance approach is explored in various ways across different countries. Therefore, this research did not adopt any practices related to this approach, especially social control. This study is limited solely to the use of gamification to support crowdsourcing and participatory mapping approaches, with all procedures carried out by participants being optional.

While the solutions analyzed prioritize contact tracing through automated technologies such as GPS and Bluetooth, our approach stands out in both its methodology and objectives. Unlike systems like Aarogya Setu and TraceTogether, which passively collect data on movements and personal contacts, our proposal promotes active participation through collaborative reporting of predictors of SARS-CoV-2 transmission. Furthermore, it prioritizes spatial predictors of transmis-

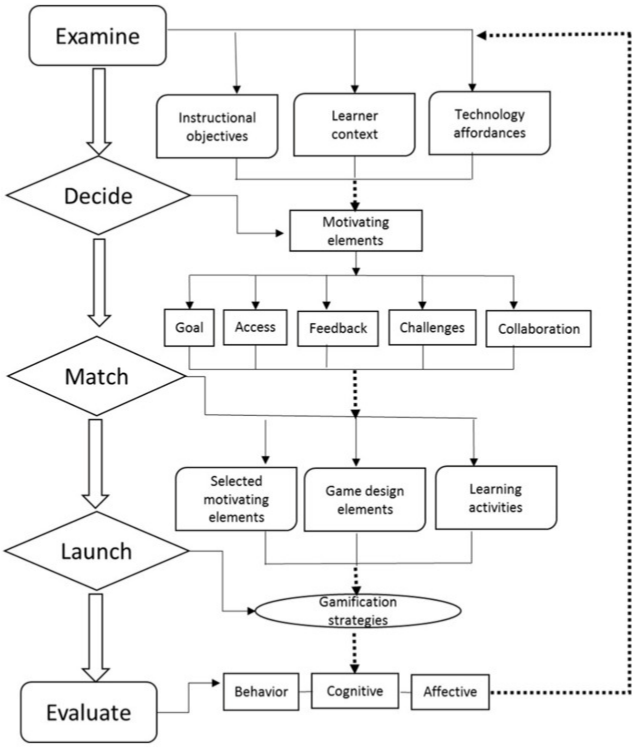


**Figure 2.** Five-step gamification design procedure [Huang and Hew, 2018].

sion, such as crowded areas and a lack of personal protective equipment, rather than individual exposure events. To encourage voluntary engagement, we incorporate gamification elements, avoiding reliance on mandatory adoption, and offer real-time community alerts about risk locations while preserving individual privacy.

The proposed participatory mapping approach fills a critical gap in pandemic response tools by enabling the identification of high-risk areas that would be difficult to capture through individual contact tracing. By engaging communities as active partners in epidemiological surveillance, this strategy provides spatial data that enables targeted interventions without raising concerns about individual privacy. Our solution lies in combining gamified crowdsourcing and participatory spatial mapping focused on predictors of SARS-CoV-2 transmission, offering an alternative to traditional contact tracing strategies, particularly effective in urban settings with limited resources.

## 3 Research Method

The research question elucidated in this work is verified through qualitative-quantitative research of an applied nature. In this way, the research question is addressed through action research methodology. In Figure 3, it is possible to observe the diagram of the action research methodology applied to this study.

Aimed at solving collective problems, as well as learning for research participants and researchers involved Picheth *et al*. [2016], the action research methodology was chosen for its cyclical characteristic, where a change is planned, implemented, described, and evaluated to improve your practice Tripp [2005]; Zandee and Coghlan [2025]. In view of the problem addressed in this study, action research in a practical mode is a method that allows us to investigate gamification and

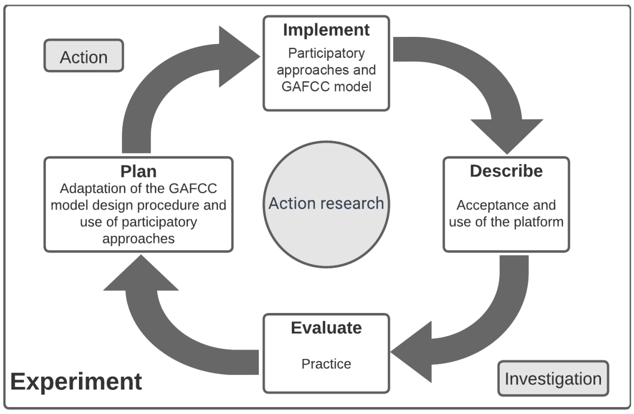


**Figure 3.** Relationship between methods and the research question.

participatory approaches of Crowdsourcing and Participatory Mapping in a real scenario, in which the hypothesis raised could be verified, and the context addressed really exists.

Carrying out this research in partnership with the project Building Healthy Communities in Brazilian Urban Slums enabled the association of knowledge, attitudes, and practices regarding the new Coronavirus pandemic for participants in this research. Thus, although some project activities were carried out remotely, through the participatory approaches proposed in this work, the participating young people and adolescents had the opportunity to practice and exercise their knowledge through activities provided on the +Lugar platform. The methodology of this research was structured in four main stages, detailed as follows:

1. The first stage of the main investigation was an integrative literature review to investigate gamification frameworks and models used in health contexts, as published in Arouca *et al*. [2021]. This review and discussion of related works allowed for the definition of the gamification model to be used in the context of this work;
2. In the second stage, we chose the GAFCC model, and its design procedure was adapted for use in the health context. This adaptation involved modifying elements and mechanics to ensure that the model was relevant to support participatory approaches of Crowdsourcing and Participatory Mapping in the health context addressed;
3. The third stage consisted of implementing the GAFCC model on the +Lugar platform, which was achieved through the integration of gamification elements such as points, challenges, rankings, and more, as described in the model;
4. Finally, the fourth and final stage of this investigation consisted of a User Study to evaluate the proposed solution using the Unified Theory of Acceptance and Use of Technology (UTAUT) model. The study included the participation of 20 young people and adolescents from vulnerable communities in Salvador, Bahia, Brazil.

### 3.1 Unified Theory of Acceptance and Use of Technology (UTAUT)

To evaluate the acceptance and use of the proposed methodology, UTAUT was used. This is a model of acceptance and use of technologies that uses constructs with four moderating conditions (gender, age, experience, and voluntariness) and four determining conditions (performance expectation, effort expectation, social influence, and facilitating conditions). Thus, it is possible to observe the implication of moderating factors in relation to determining factors, as well as determining factors in relation to behavioral intention and usage behavior Venkatesh *et al*. [2003].

In the diagram shown in Figure 4, it is possible to observe the association of implications of each moderating condition in relation to the determining factors of UTAUT, as well as the association of implications of determining factors in relation to the intention to use and the behavior of use.

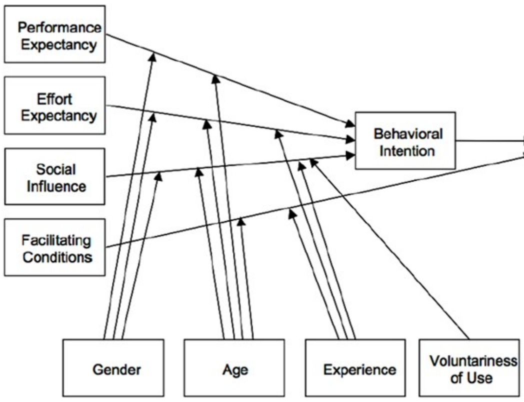


**Figure 4.** UTAUT Structure from Venkatesh *et al*. [2003].)

The determining constructs of UTAUT, as well as its impacts on the Behavioral Intention (BI) of young people and adolescents to use the platform, were adjusted in the research model. The relationship between these four constructs and their respective elucidated hypotheses is presented in Table 3.

**Table 3.** Constructs and Hypotheses.

| Determining constructs | Hypotheses |
|---|---|
| Performance Expectation (PE) | H1: PE has a positive impact on the BI of platform usage. |
| Effort Expectancy (EE) | H2: EE has a positive impact on the BI of platform usage. |
| Social Influence (SI) | H3: SI has a positive impact on the BI of platform usage. |
| Facilitating Conditions (FC) | H4: FC has a positive impact on the BI of platform usage. |
| ***Behavioral Intention (BI)** | |

The hypotheses presented in Table 3 were formulated based on both the theoretical foundations of UTAUT and empirical observations from prior gamification studies in health contexts. Specifically, each hypothesis reflects one of the determinant constructs of the UTAUT model: Performance Expectancy, Effort Expectancy, Social Influence, and Facilitating Conditions. These constructs are examined in light of the unique challenges and affordances associated with gamified participatory health systems in vulnerable communities, particularly during the Covid-19 pandemic. The hypotheses are detailed below:

- **H1:** Hypothesis H1, which postulates a positive impact of Performance Expectancy (PE) on Behavioral Intention (BI) to use the platform, is based on the central premise of UTAUT that users are motivated to adopt technologies they perceive as useful for performing their tasks Venkatesh *et al*. [2003], supported by evidence that health apps with clear utility see higher adoption Zhou *et al*. [2020]. In the context of this research, it is expected that participants who perceive that the +Lugar platform and its gamified features truly help in identifying and flagging predictors of Covid-19, improving their ability to contribute to public health, will have a greater intention to use;
- **H2:** Hypothesis H2 proposes that Effort Expectancy (EE) positively influences Behavioral Intention (BI). This hypothesis is derived from the UTAUT principle that a technology's ease of use is a critical factor in its acceptance. In crowdsourcing and participatory mapping systems, especially in vulnerable communities where access to technology may vary and familiarity with complex digital interfaces may be limited, the perception that the +Lugar platform is easy to learn and operate should be essential. If users find the system simple and intuitive, without requiring significant cognitive or technical effort, their intention to use it will be greater. This is corroborated by research on usability and user experience Davis [1989]; Nielsen [1994]; Holden and Karsh [2010];
- **H3:** Hypothesis H3 proposes that Social Influence (SI) positively affects Behavioral Intention (BI). In the UTAUT model, Social Influence captures the impact of the perceptions of significant others (friends, family, or community leaders) on an individual's decision to use a technology. Given the collaborative and community-based nature of the participatory mapping and crowdsourcing initiative to combat Covid-19, recommendations or examples of platform use by peers and other individuals in the community are expected to exert a positive and encouraging influence on participation. Community endorsement is known to significantly impact technology adoption in collectivist cultures Zhang *et al*. [2018] and gamified health interventions Johnson *et al*. [2016];
- **H4:** Finally, hypothesis H4 proposes that Facilitating Conditions (FC) positively impact Behavioral Intention (BI). This UTAUT construct refers to an individual's perception that adequate resources and support are available for using a technology. For the +Lugar platform, this implies the availability of mobile devices, internet access, technical or instructional support, and clarity about how and when the platform can be used. In vulnerable communities, where infrastructure can be challenging, the perception of the existence and accessibility of these resources is crucial Alsswey *et al*. [2020].

## 3.2 Ethics statement

This study was approved by the Research Ethics Committee of the Collective Health Institute/Federal University of Bahia (CEP/ISC/UFBA), with CAAE number 68887417.9.0000.5030, and by the National Research Ethics Committee (CONEP) linked to the Brazilian Ministry of Health under approval numbers 2.245.914–2.245.914.17–3.315.568.

To ensure the utmost respect for participants' privacy and data confidentiality, strict data protection measures were implemented throughout the study. All data collected from participants were anonymized immediately after collection. This process involved the removal of any directly identifiable information, such as names, contact details, or precise geographic coordinates that could reveal an individual's exact location. It is important to emphasize that the spatial data collected referred exclusively to public places and areas of collective interest for identifying predictors of Covid-19 transmission (e.g., public squares, bus stops, commercial areas), ensuring that no private residences or highly sensitive personal locations were identified or linked to any participant. Furthermore, data access was restricted to the research team members directly involved in the analysis. When data were shared for analysis or presented in any form, they were always in an aggregated and encoded format, making it impossible to trace any information back to an individual participant.

All participants, or their legal guardians in the case of minors, signed an Informed Consent Form (ICF), in which they were informed about the exclusive use of the data for research purposes, the right to withdraw consent at any time without any penalty, and the previously described anonymization protocols. These measures are fully aligned with the principles established by the Brazilian General Data Protection Law (LGPD, Law No. 13,709/2018), ensuring the ethical and legal compliance of the research.

# 4 +Lugar Platform: Covid-19 Version

Developed by a multidisciplinary team of researchers with support from the Bill and Melinda Gates Foundation and the UK Medical Research Council (MRC), the initial version of the +Lugar platform consisted of a multiplatform application. The platform's primary objective is to promote user engagement and commitment to improving their surrounding environment, with a particular focus on collective health and the control of zoonoses Arouca *et al.* [2019, 2020].

The +Lugar platform[1] [2] enables participatory mapping of zoonoses and their predictors through gamification resources. It also includes a section dedicated to external projects from different segments that aim to use participatory mapping for social contribution. Although the platform was originally designed to incorporate gamification, no framework or model was initially adopted to guide this process.

The Covid-19 version of the +Lugar platform integrates all the contributions developed throughout this work, incorporating insights gained during the first five stages of the action research. Due to the chronological flexibility allowed by action research, updates were implemented even after the conclusion of the first cycle. Figure 5 presents screenshots of the Covid-19 version, which includes the new features resulting from this study. This version was structured into two main components: a backend with an API and database, and two client-facing applications, namely a hybrid mobile app and a web application.

In addition to the spatialization and signaling mechanism for Covid-19 transmission predictors, this work also presents contributions to several components of the platform. These include the development and implementation of avatars through a co-design approach, improvements to the participatory mapping process, the use of crowdsourcing to address social and public health demands, and, most notably, the adaptation of the GAFCC gamification design model Huang and Hew [2018] to support the participatory approaches explored in this study.

[1] https://play.google.com/store/apps/details?id=com.maislugar.app. Accessed in March 2026.

[2] https://www.maislugar.org/. Accessed in March 2026.

## 4.1 GAFCC Model

When analyzing the feasibility of implementing the GAFCC model in this work, some gaps were found in relation to the fulfillment of some steps of the gamification design procedure recommended in Huang and Hew [2018]. Thus, as can be seen in Figure 6, the steps i) examine, iii) match and v) evaluate were the determining objects for the process of adapting this procedure, since the examination of the implementation context, as well as the objects to be evaluated, directly portrayed scenarios within the scope of education and did not directly contemplate support for participatory approaches.

To implement the GAFCC model carried out in this work, small adaptations were made to the gamification design procedure, where the motivating elements were transfigured into game design elements. Figure 6 provides an overview of the adaptation of the design procedure proposed in the GAFCC model, the adaptations are highlighted in gray. Although the model has not been altered, the modifications proposed in the original procedure are fundamental for the implementation of the model in the context of the study. It is important to highlight that the "Decide" and "Launch" steps have not been modified.

As set out in the original structure, it is possible to verify that the variables tangent to the "examine" step are driven by a context belonging to the educational scope, however, although the +Lugar platform also aims at scientific dissemination, other variables need to be examined to support the implementation of the model. The 'Examine' step involved an in-depth analysis to define the project's instructional objectives, which aimed to educate young people about Covid-19 and participatory mapping. We investigated the geographic layout of communities, considering population density, infrastructure, and the distribution of points of interest relevant to signaling disease predictors. Furthermore, we analyzed other user contextual elements, such as digital literacy level, availability of mobile devices, internet access, and local social dynamics. This step highlighted the need for a design that, when applied to the +Lugar platform, not only focused on data collection but also on educating and empowering young people, making their contributions a rewarding and socially relevant activity.

Based on the analysis performed in the "Examine" step, the "Decide" step focused on strategically defining the motivational elements that would be incorporated into the +Lugar platform, aligning them with the proposed education and engagement objectives. Components of the GAFCC framework were selected and adapted, including clear and achievable goals such as "conduct 3 collaborations in mapping Covid-19 transmission predictors" or "Complete 3 QuizCovid," with progress displayed in the interface to encourage continued contributions. Accessibility was another guiding principle, with an intuitive interface that allowed users to freely choose the types of information to map, increasing their autonomy. The immediate feedback system rewarded actions such as mapping transmission predictors and completing quizzes with visible experience points, coins, and performance bars, while the impact of contributions on the map served as direct reinforcement. Furthermore, challenges with varying levels of difficulty were incorporated to maintain progressive engagement.

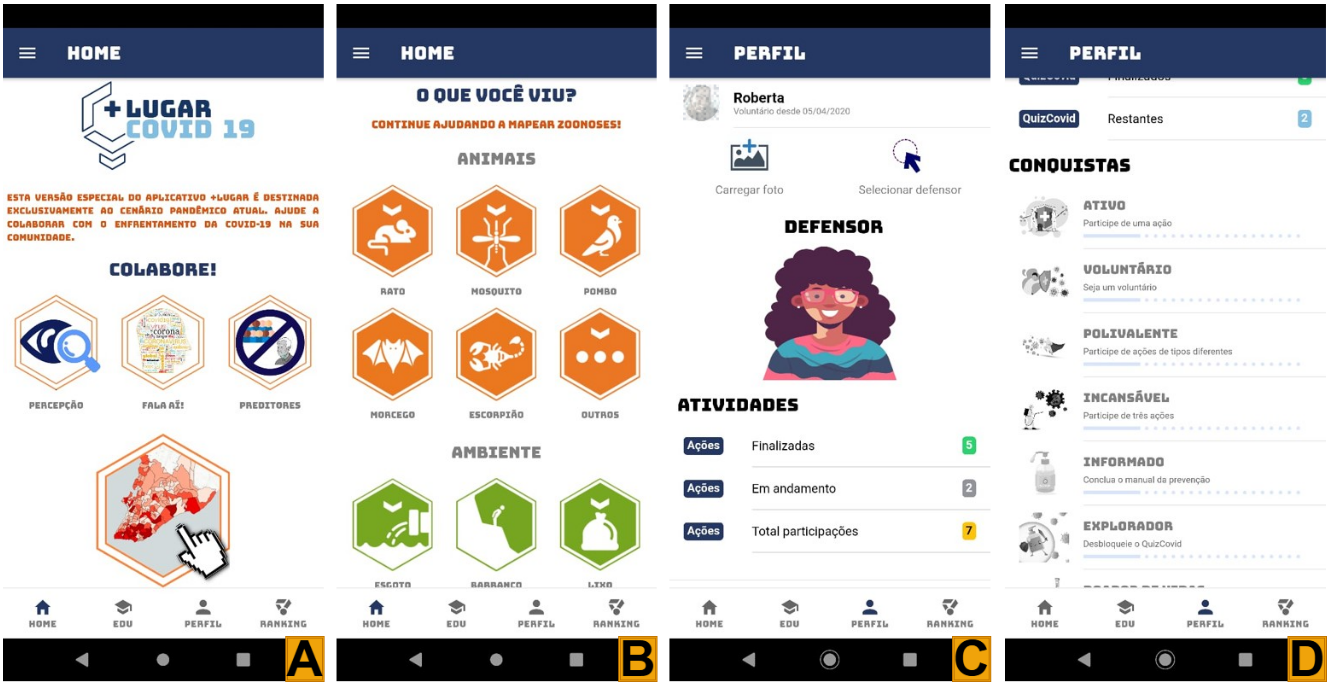


**Figure 5.** Mobile application of the +Lugar platform (Covid-19 version): a) section for collecting and visualizing data about Covid-19, b) section for collecting data on zoonoses, c) section for interface customization, d) components of gamification and engagement.

As can be seen in the original structure of the "match" step, the combination of the selected motivation elements, as well as the game design elements, are the pillars of the GAFCC model design process. Thus, in order to adapt this step to the proposed context, participatory approaches were added to this process together with the learning activities listed in Huang and Hew [2018]. In the 'match' step, we translated the selected motivating elements of the GAFCC into concrete, functional game design elements within the +Lugar platform architecture. This included awarding experience points (XP) for relevant actions, granting virtual badges for specific achievements, and displaying progress levels to encourage platform use. Participatory crowdsourcing and mapping approaches were directly integrated into these game mechanics, with each user contribution generating experience points and progress. Additionally, gamified learning activities were developed, such as interactive quizzes (QuizCovid) about Covid-19, which also awarded points and badges, aligning gamification with instructional objectives.

In the "Launch" step, after designing and developing these gamification strategies on the platform, the +Lugar Covid-19 platform was launched in a controlled environment for the young participants in the user study. Initial support and follow-up were provided to ensure users could interact with the platform and its gamified elements.

The last step of the original design procedure of the GAFCC model is aimed at an evaluation compatible with the educational context. However, the "behavior" factor is configured as a fundamental aspect for this step in the proposed implementation of the model, mainly because it is consolidated as the main object of verification for a gamification implementation in general, and indispensable in health contexts. Therefore, to the detriment of the proposed context, engagement and social interaction were inserted as an object of evaluation of the procedure.

The "Evaluate" step was conducted through a user study, using the UTAUT model, as detailed in Section 5. The research results (presented in Section 6) allowed us to measure the Behavioral Intention to use the platform, evaluating the effectiveness of the gamified elements incorporated in the platform in influencing users' perceptions of usefulness (PE), ease of use (EE), peer influence (SI), and available support (FC). This evaluation considered the behavior (through intention to use), engagement (implied by the expectation of performance and effort in interacting with the gamified mechanics), and social interaction (measured by perceived social influence) of the participants.

Observing the modifications made to the design procedure, the motivating elements were transformed into game design elements. Thus, new game design elements were implemented in the Covid-19 version of the platform, for example: achievements, ranking, avatars, and progress bars. In Figure 7, it is possible to verify the association made between the game design elements and the motivating elements. In this way, adapting the context of the motivating elements to the definition of the game design elements is essential.

## 4.2 Co-design and Avatars

To acquire artifacts that would support the application of the co-design approach in the development of avatars, an avatar production workshop was held in November 2019, before the advent of the Covid-19 pandemic. This workshop took place at the 1st Health, Culture, Citizenship, and Technology Fair [3], organized by the Institute of Public Health of UFBA, at the municipal school of Marechal Rondon. On this occasion, around forty young people from the community contributed

[3] 1st Health, Culture, Citizenship, and Technology Fair. Accessed in March 2026.

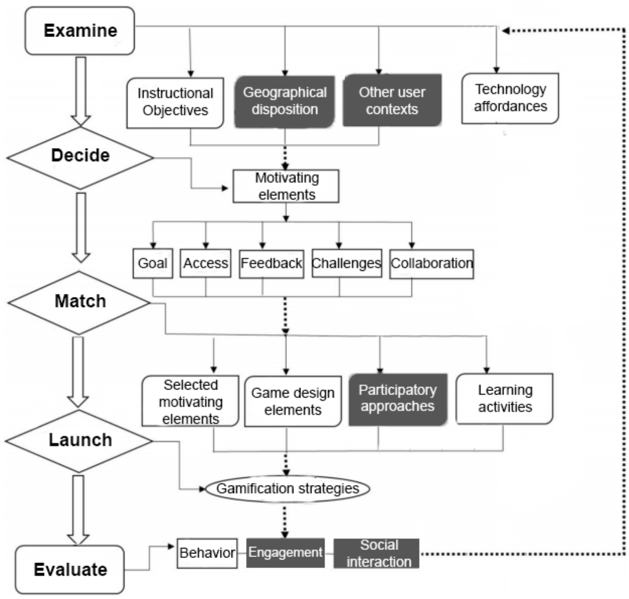


**Figure 6.** Overview of adaptation of design process steps (Adapted from Huang and Hew [2018].)

to the development of avatars for the +Lugar platform.

Thus, the young people who participated in the workshop received papers with two printed bases and material to draw and color. In this way, the young people were offered the opportunity to express their preferences in a playful way, in addition to actively participating in the modeling of the avatars that would be made for the platform. The idea behind this dynamic is to awaken a sense of belonging in young people, seeking to understand how they would like to be represented on the platform, doing so in a participatory way.

In total, 53 avatar sketches were developed, which later served as guiding artifacts for the development of the avatars implemented in the Covid-19 version of the platform. The sketches highlighted several characteristics inherent to the context of young people, such as chronic health conditions such as vitiligo, a dermatosis that does not threaten the physical integrity of the individual. In 2009, it was believed that this disease affected approximately 1% of the world's population Nogueira *et al*. [2009].

As can be seen in Figure 8, a young woman from the community suggested an avatar with vitiligo. In addition to this chronic condition, the representation of other health conditions also stands out, such as the use of respiratory devices, indicated by another young woman from the community in one of the sketches, as can be verified in Figure 9.

### 4.3 Spatialization and signaling of Covid-19 transmission predictors

Due to the need for collective effort to mitigate damage and confront the Covid-19 pandemic Wolf *et al*. [2020], a specific mechanism was implemented in the +Lugar platform (Covid-19 version) to promote the mapping of disease transmission predictors. For instance, this includes points of congregation, absence of the use of Personal Protective Equipment (PPE), and Collective Protection Equipment (CPE) in public places. It also facilitates signaling the proximity between these reported areas and the platform users.

The spatial identification of locations where public health guidelines are not adhered to can be important for alerting the population about critical points regarding virus transmission, especially given the high mortality and transmission rates present in the pandemic scenario. Thus, this work used gamification to support crowdsourcing and participatory mapping approaches regarding data based on the population's risk perception. Although this study is limited to the use of georeferenced data related to risk perception, the platform contains other non-georeferenced questionnaires related to risk perception. In Figure 10, it is possible to observe the data collection interface about Covid-19 transmission predictors in the platform's mobile environment.

Increasingly present in the context of epidemiology, studies utilizing individuals' risk perception are frequently conducted, as they can signal subjective indicators that are often not available in other research approaches. This is because risk perception studies uniquely consider cultural and social factors that can interfere with individuals' perceptions Giulio *et al*. [2015].

The proximity alert mechanism operates through communication between the application and the server. Based on georeferenced data stored on the server, the application notifies and spatially signals the user in real-time if they enter a 30-meter radius of an area indicated by the presence of a transmission predictor. In Figure 11, you can observe the interface of this mechanism on the +Lugar platform. It is essential to highlight that this mechanism is addressed by the gamification strategies present in the platform. Thus, the mechanism is related to the narrative created about the context resulting from the Covid-19 pandemic, using avatars. Avatars in this context are referred to as "Defenders."

## 5 User Study

The study conducted in this work took place within the context of the "Building Healthy Communities in Brazilian Urban Slums" project. The project aims to integrate a community-based participatory approach into an adaptable management framework for designing, implementing, and evaluating interventions. This combines knowledge and action for social change to improve community health and eliminate health disparities.

With the participation of 20 young people and adolescents from a suburban community in Salvador, Brazil, in partnership with the collaborative mapping and extension team of the project, virtual meetings were conducted regularly in September and October 2021 through Google Meet. The objective was to present, test, and validate the contributions from this research for the Covid-19 version of the platform.

Participants were recruited directly from the existing cohort of the "Building Healthy Communities in Brazilian Urban Slums" project. This purposive sampling approach allowed for the involvement of individuals who were already familiar with the project's community-based goals and possessed a level of trust with the research team. The interaction followed a structured protocol: first, participants attended a live demonstration where the gamified features and mapping tools were presented. Subsequently, they engaged in a hands-on session, exploring the platform on their own devices to simulate the reporting of COVID-19 transmission predictors

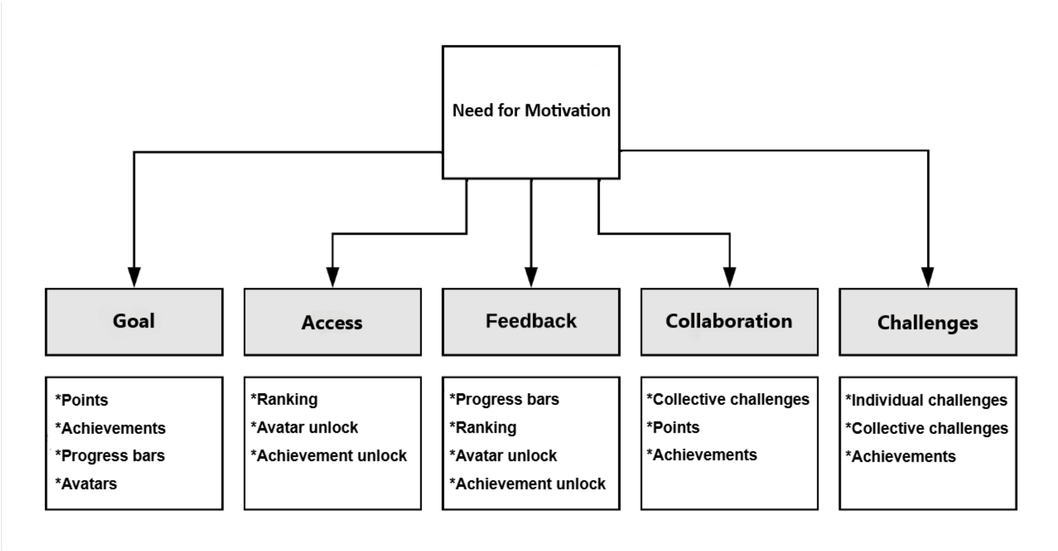


**Figure 7.** Proposed motivating and facilitating elements (game design elements).

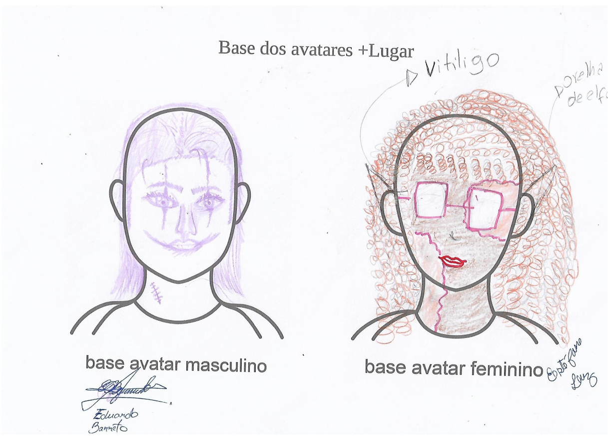


**Figure 8.** Sketch of avatar with chronic health condition.

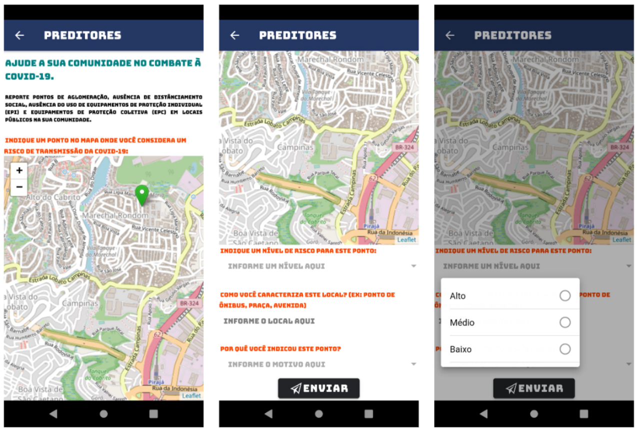


**Figure 10.** Georeferenced data capture in the mobile application.

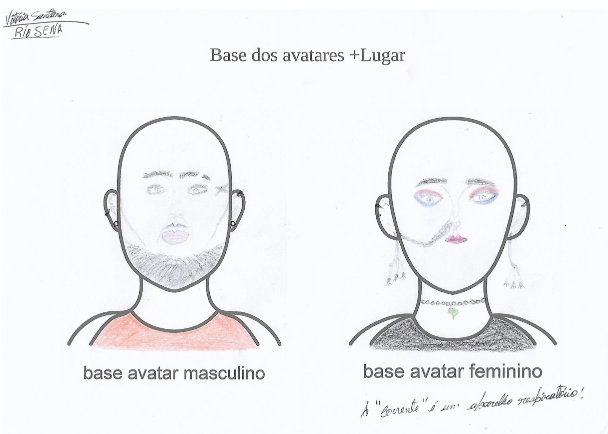


**Figure 9.** Sketch of avatar with chronic health condition.

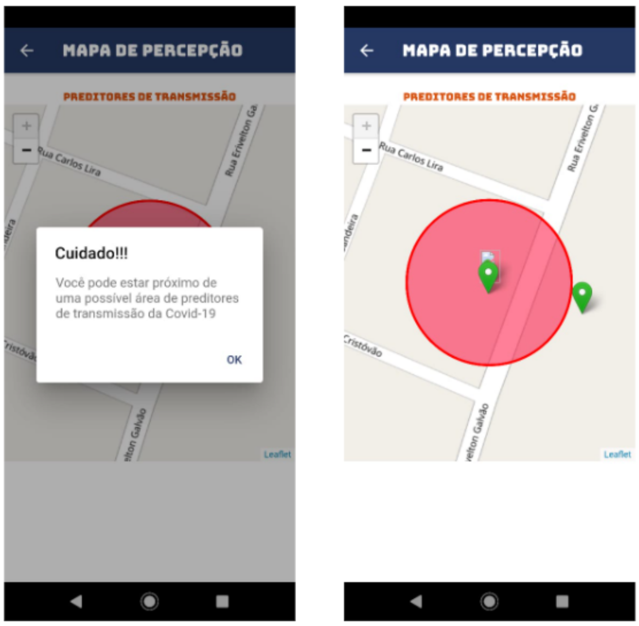


**Figure 11.** Perception map where all transmission predictors signaled by users are spatialized.

and navigate the rewards system. This practical experience ensured that their subsequent evaluation was based on actual usage of the tool.

The instrument used to collect data was an electronic form [4] made available to the research participants. The questionnaire based on the UTAUT was created using Google

[4]User study form (PDF). Accessed in March 2026.

Forms and included questions about the theory constructs presented in Venkatesh *et al*. [2003]. The form consisted of 22 questions, among which there were questions about moderating conditions, determining conditions, and behavioral intention. A Likert scale ranging from "1 = Completely Disagree" to "7 = Completely Agree" was used for the questions related to the determining conditions of the UTAUT. As shown in Table 4, three questions were listed in the questionnaire for each determining condition.

**Table 4.** Questions about determining conditions

| Construct | ID | Question |
|---|---|---|
| Performance expectation | Q1 | I believe the platform is/will be useful for the Covid-19 confrontation. |
| | Q2 | Using the platform allowed/will allow me to contribute to the fight against Covid-19. |
| | Q3 | Using the platform provides more ways to contribute to facing Covid-19. |
| Effort expectation | Q1 | My interaction with the platform is/will be clear and easy to understand. |
| | Q2 | It is/will be easy for me to become a skilled user of the platform. |
| | Q3 | Learning to use the platform was/will be easy for me. |
| Social influence | Q1 | People who influence my behavior think I should use the platform. |
| | Q2 | People who matter to me think I should use the platform. |
| | Q3 | Collectives and community associations in my neighborhood encourage the use of the platform. |
| Facilitating conditions | Q1 | I have/will have the necessary resources (device and internet) to use the platform. |
| | Q2 | I have/will have the necessary knowledge to use the platform. |
| | Q3 | Someone will be available to help if I have difficulties using the platform. |

To ensure participants fully understood the questionnaire content and felt comfortable responding, two researchers conducted a brief briefing before data collection began. During this session, they presented concrete examples unrelated to the research topic to illustrate how the Likert scale works, such as rating favorite foods, and provided guidance on completing the electronic form. Technical terms such as "hardware" and "platform" were simplified with local analogies, making them easier for the young participants to understand. Throughout the questionnaire, the researchers remained available to clarify questions in real time and reformulate questions when necessary.

## 5.1 Moderating conditions

Concerning the distribution of participants by sex, 30% of the participants in this study are female, and 70% are male. In terms of the distribution of participants with respect to experience in using collaborative platforms (such as Waze, ViconSAGA, Wikipedia, Fogo Cruzado, among others), it is noteworthy that only 15% of the participants indicated having little or no experience with the use of these platforms, while 50% reported having a significant or satisfactory level of experience.

Regarding the distribution of age groups, it is observed that 75% of the respondents were between 15 and 23 years old at the time of filling out the questionnaire. In terms of measures of central tendency, the mode corresponds to the age range of 18-20 years. Figure 12 provides a more detailed view of the age distribution across sexes. Concerning the distribution of participants in terms of voluntariness in using the platform, 95% of the participants indicated that they use the platform voluntarily. Table 5 provides a summary of the data that comprise the moderating conditions of the UTAUT.

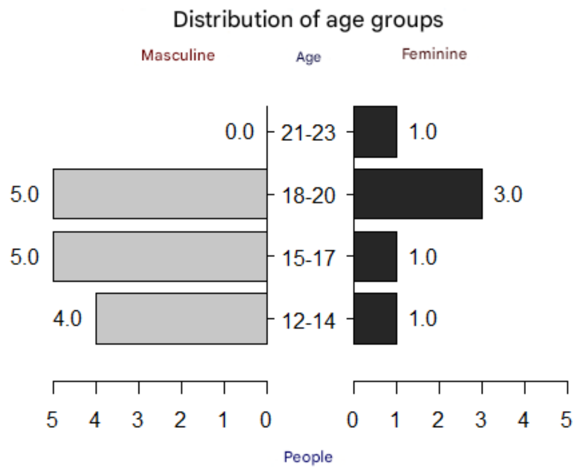


**Figure 12. Distribution of age groups of respondents.**

**Table 5.** Participants' Moderating Conditions. The 'Frequency' column presents the absolute values corresponding to the sample (n=20).

| Variable | Frequency | F (%) |
|---|---|---|
| **Age Group (years)** | | |
| 12 - 14 | 5 | 25.0 |
| 15 - 17 | 6 | 30.0 |
| 18 - 20 | 8 | 40.0 |
| 21 - 23 | 1 | 5.0 |
| **Sex** | | |
| Male | 14 | 70.0 |
| Female | 6 | 30.0 |
| **Experience** | | |
| None | 3 | 15.0 |
| Little | 0 | 0.0 |
| Reasonable | 7 | 35.0 |
| Satisfactory | 6 | 30.0 |
| A lot | 4 | 20.0 |
| **Voluntariness in using the platform** | | |
| Yes | 19 | 95.0 |
| No | 1 | 5.0 |
| Total | 20 | 100.0 |

## 5.2 Determining conditions

Participants tend to believe that the presented solution is useful for combating Covid-19, thereby endorsing the value of the provided resources. It is also evident that 95% of the participants agree that the platform contributes to the fight against the disease, while 85% believe that using the platform provides them with more opportunities for contribution.

Regarding the "Expectation of Effort", participants believe that the presented solution is easy to understand, requires a significantly small learning curve, and they understand that becoming a proficient user of this platform is easy. Consequently, 80% of the participants agree that they are or will become proficient users without significant difficulties, and 75% agree that their interaction with the platform's resources occurs easily and clearly.

Concerning "Social Influence", it is evident that participants can be influenced by others to use the platform. It can be seen that 75% of the participants agree that important people in their social circle believe they should use the platform. Furthermore, 65% of the participants agree that social movements and community collectives have encouraged them to use the platform. Regarding "Facilitating Conditions", participants believe they have the necessary conditions to use the platform. Thus, 80% of the participants agree that they have the required resources to use the platform, and 90% agree that specific support will be available to assist with any potential difficulties related to the platform.

# 6 Results

Critical aspects of the study findings were investigated, starting with reliability and correlation analysis. We analyze the robustness and consistency of our data and the extent to which variables correlate with each other. Subsequently, the hypotheses formulated in our research are rigorously tested and validated. Through these analyses, we aim to provide a comprehensive understanding of the empirical support for the central claims of our study and the implications of our findings.

## 6.1 Reliability and Correlation Analysis

To assess the reliability of the questionnaire used in the research, the Cronbach's alpha coefficient was employed, a significant coefficient when it comes to checking the internal consistency of a scale for a set of construct indicators through correlation Bland and Altman [1997]. The reliability analysis result obtained through the Cronbach's alpha coefficient was 0.86, and the standardized alpha coefficient was also 0.86. Thus, this analysis demonstrates a satisfactory internal consistency.

In Table 6, it is possible to check the mean and standard deviation of each question listed in the form. The Cronbach's alpha coefficient generally ranges from 0 to 1, and any value above 0.70 is considered acceptable for the coefficient Gliem and Gliem [2003]. Thus, internal consistency is considered low for values below this threshold, and its reliability becomes questionable. Therefore, the coefficient obtained through the analyses indicates that the scale presented in the questionnaire used in this study demonstrates reliable internal consistency.

In a reliability analysis based on Chrobach's alpha coefficient, it is found that some questions have a tendency to increase the consistency of the questionnaire, while others have a tendency to decrease it. Table 7 shows the consistency of the Cronbach's alpha coefficient and Standardized Alpha Coefficient (SAC) if questions were removed from the form.

In order to determine which correlation test to apply to assess a potential correlation between the determinants factors and behavioral intention, the Shapiro-Wilk normality test was used to evaluate the data distribution for each construct, checking for data parametrization.

In Table 8, it is possible to observe that the constructs PE, FC, and BI do not exhibit a normal distribution. Since this involves a correlation analysis between pairs of ordinal qualitative variables, the Spearman correlation coefficient was utilized, a coefficient commonly used to perform correlation analysis between pairs of ordinal qualitative variables, and which can be used with significantly small sample sizes, is the Spearman correlation coefficient Gauthier [2001].

**Table 6.** Descriptive data from reliability analysis.

| Code | N | Mean | Standard deviation |
|---|---|---|---|
| PE1 | 20 | 6.0 | 1.15 |
| PE2 | 20 | 6.2 | 0.97 |
| PE3 | 20 | 6.2 | 0.99 |
| EE1 | 20 | 5.6 | 1.18 |
| EE2 | 20 | 5.7 | 1.26 |
| EE3 | 20 | 5.5 | 1.05 |
| SI1 | 20 | 5.5 | 1.28 |
| SI2 | 20 | 5.4 | 1.32 |
| SI3 | 20 | 5.0 | 1.96 |
| FC1 | 20 | 5.6 | 1.50 |
| FC2 | 20 | 5.8 | 1.32 |
| FC3 | 20 | 6.4 | 1.00 |
| BI1 | 20 | 5.6 | 1.35 |
| BI2 | 20 | 6.6 | 0.82 |
| BI3 | 20 | 5.6 | 1.27 |

**Table 7.** Reliability if a question is discarded.

| Code | Cronbach's alpha coefficient | SAC |
|---|---|---|
| PE1 | 0.87 | 0.87 |
| PE2 | 0.85 | 0.86 |
| PE3 | 0.85 | 0.86 |
| EE1 | 0.84 | 0.85 |
| EE2 | 0.86 | 0.86 |
| EE3 | 0.86 | 0.86 |
| SI1 | 0.84 | 0.85 |
| SI2 | 0.85 | 0.85 |
| SI3 | 0.85 | 0.85 |
| FC1 | 0.84 | 0.85 |
| FC2 | 0.85 | 0.86 |
| FC3 | 0.84 | 0.85 |
| BI1 | 0.84 | 0.85 |
| BI2 | 0.85 | 0.85 |
| BI3 | 0.84 | 0.85 |

**Table 8.** Normality test (Shapiro-Wilk).

| Construct | W-Statistic | P | Result |
|---|---|---|---|
| PE | 0.865 | 0.009 | Failed |
| EE | 0.919 | 0.093 | Passed |
| SI | 0.940 | 0.244 | Passed |
| FC | 0.858 | 0.007 | Failed |
| BI | 0.893 | 0.030 | Failed |

The results of the Spearman correlation test presented in Table 9 demonstrate that the constructs "Effort Expectation" and "Social Influence" exhibit a positive and significant correlation (p-value <0.05) with the Behavioral Intention to use the platform. It is evident that "Performance Expectation" and "Facilitating Conditions" do not show a significant correlation (p-value >0.05) with the Behavioral Intention to use of the platform.

**Table 9.** Spearman correlation matrix between the determining constructs and Behavioral Intention.

| | | **BI** | **PE** | **EE** | **SI** | **FC** |
|---|---|---|---|---|---|---|
| BI | Spearman correlation | 1 | 0.085 | 0.468* | 0.617* | 0.358 |
| | N | 20 | 20 | 20 | 20 | 20 |
| PE | Spearman correlation | 0.085 | 1 | -0.091 | 0.125 | 0.224 |
| | N | 20 | 20 | 20 | 20 | 20 |
| EE | Spearman correlation | 0.468* | -0.091 | 1 | 0.499* | 0.452* |
| | N | 20 | 20 | 20 | 20 | 20 |
| SI | Spearman correlation | 0.617* | 0.125 | 0.499* | 1 | 0.246 |
| | N | 20 | 20 | 20 | 20 | 20 |
| FC | Spearman correlation | 0.358 | 0.224 | 0.452* | 0.246 | 1 |
| | N | 20 | 20 | 20 | 20 | 20 |

* Significant correlation (p-value <0.05)

## 6.2 Confirmation of Hypotheses

- **Hypothesis 1: “Performance Expectation" has a positive impact on the Behavioral Intention to use the platform.**
  The results indicate that “Performance Expectation" does not have a significant impact on the intention of platform use by the young and adolescent respondents (p-value >0.05). Therefore, Hypothesis 1 is rejected.
- **Hypothesis 2: “Effort Expectation" has a positive impact on the Behavioral Intention to use the platform.**
  The results indicate that “Effort Expectation" has a positive effect on the Behavioral Intention to use the platform (p-value <0.05). They suggest that young respondents believe it is easy to become a skilled user of the platform, and they judge that the interaction with the platform is clear and easy to understand. Therefore, Hypothesis 2 is confirmed.
- **Hypothesis 3: “Social Influence" has a positive impact on the Behavioral Intention to use the platform.**
  The results indicate that “Social Influence" also has a positive impact on the Behavioral Intention to use the platform (p-value <0.05). They suggest that the respondents’ social circle, including people who are important to them, and even community collectives and associations, influence them to use the platform. Thus, Hypothesis 3 is confirmed.
- **Hypothesis 4: “Facilitating Conditions" has a positive impact on the Behavioral Intention to use the platform.**
  The results indicate that “Facilitating Conditions" does not have a significant impact on the Behavioral Intention to use the platform by young and adolescent respondents (p-value >0.05). Therefore, Hypothesis 4 is rejected.

Table 10 shows a summary of the confirmation of hypotheses.

**Table 10.** Confirmation of hypotheses.

| Hypothesis | Correlation result | Confirmation |
|---|---|---|
| Hypothesis 1 | Not significant (p-value >0,05) | No |
| Hypothesis 2 | Significant (p-value <0,05) | Yes |
| Hypothesis 3 | Significant (p-value <0,05) | Yes |
| Hypothesis 4 | Not significant (p-value >0,05) | No |

# 7 Discussion

Although the GAFCC model was originally developed for educational environments, its application in the +Lugar Covid-19 platform required careful consideration. The motivations present in formal education, such as academic obligations and content mastery, differ significantly from those driving voluntary actions in public health, which are generally motivated by altruism, citizenship, and concern for collective safety. Despite these differences, the GAFCC model shows potential for application in public health, particularly because it is grounded in universal motivational elements such as goals, access to information, feedback, challenges, and collaboration. These pillars were adapted in the platform to encourage actions like risk mapping, simplified system use, recognition for contributions, and the promotion of collective efforts.

The success of gamified strategies in public health depends on the active and voluntary engagement of the population Harris and Crone [2020]; White *et al.* [2023]. The GAFCC model has demonstrated significant potential as a guide for promoting collaborative behaviors, which are essential in situations such as pandemics Saleh Al-Omoush *et al.* [2021]. Its flexibility to adapt to user motivations, through elements like points, badges, and rankings, helped attract volunteers and explore the effectiveness of the “Access" and “Collaboration" components. Because it is grounded in various motivation theories, such as Flow, Self-Determination, and Behavioral Reinforcement, the GAFCC model is supported by principles that transcend the educational field. This theoretical foundation allows for a deeper understanding of human behavior across different contexts, making the model a powerful tool for designing gamified interventions aimed at public health.

Regarding the assessment of acceptance and use of the platform, due to the pandemic context and the lack of sufficient time for effective widespread adoption, this study aimed to understand the factors influencing the intention to use the platform among the young and adolescent participants of the research. Therefore, the construct “Use Behavior" was suppressed from the analysis. Another modification made to the UTAUT application procedure was the omission of correlation analyses for the moderator constructs: Gender, Age, Experience, and Voluntariness of Use. The moderator constructs were presented descriptively to contribute to the participant characterization.

The distribution of participants according to their experience with collaborative platforms reflects the use of some adolescents and young people from the community with the +Lugar platform. This group is already involved in other research and outreach projects conducted at the Institute of Collective Health of the Federal University of Bahia and the Gonçalo Moniz Institute (Fiocruz Bahia), which incorporate the +Lugar platform and other collaborative tools in their activities.

Regarding the assessment of platform acceptance and usage, the descriptive data analysis indicated that the majority of respondents have high levels of performance expectancy, effort expectancy, social influence, facilitating conditions, and behavioral intention to use the platform. However, through the analysis of the Spearman correlation coefficient, it was possible to identify that only the factors of effort expectancy and social influence significantly impact the intention to use the platform. Consequently, performance expectancy and facilitating conditions do not show a positive and significant correlation according to the testing of this coefficient.

The confirmation that Effort Expectancy (EE) positively impacts Behavioral Intention (BI) to use the +Lugar platform is a significant finding, especially given the profile of the participants (young people from vulnerable communities). This suggests that, for participatory mapping and crowdsourcing solutions to be effective in these contexts, ease of use and interface simplicity are essential. The perception that the platform does not require much effort to use, or that it is intuitive, increased users' willingness to actively engage with it. This highlights the importance of user-centered design that minimizes the learning curve and avoids cognitive overload, reinforcing the practical relevance of the "Access" component of the GAFCC model.

The positive influence of Social Influence (SI) on Behavioral Intention (BI) to use the platform highlights the power of the community context in the adoption of health technologies. This result is particularly relevant for initiatives in vulnerable communities, suggesting that interpersonal relationships and the approval of peers or community leaders may be more decisive than in other contexts. The perception that friends, family members, or community authority figures support or use the platform emerged as a potentially decisive factor for user participation. This validates the importance of the "Collaboration" component of the GAFCC model and suggests that the design of future solutions should incorporate collaborative strategies.

Contrary to Hypothesis H1, Performance Expectancy (PE) did not show a significant impact on Behavioral Intention to use the platform. This finding is noteworthy, as PE is generally a strong predictor of technology adoption in the UTAUT model. A possible explanation for this deviation is that, during the evaluation period, the young participants may not yet have had the opportunity to fully perceive the tangible benefits and direct impact of their contributions on Covid-19 mitigation or community decision-making.

The perceived usefulness of a platform like +Lugar, which involves risk mapping for public health, may be viewed as a more collective and long-term benefit, making it less immediate in terms of perceived individual performance improvement. Furthermore, the nature of the task may have been perceived more as an act of citizenship and collaboration than as a tool that would directly enhance their personal performance in a specific task, as is often the case in corporate or educational contexts. This suggests that, in civic engagement for public health, the perception of collective utility and social impact may serve as distinct motivators from individual performance expectancy.

Similarly, Facilitating Conditions (FC) did not emerge as a significant predictor of Behavioral Intention to use the platform in our study, contradicting the assumption that the availability of resources and technical support is crucial for technology adoption. One interpretation of this result is that, for the target population, basic access to resources such as smartphones and internet connectivity may already be considered a given or a common reality, which reduces its predictive power as a variable influencing intention to use.

Alternatively, the assistance and support provided by the "Building Healthy Communities in Brazilian Urban Slums" project, within which the study was conducted, may have mitigated any perceived shortcomings in facilitating conditions, making them less of a concern for participants during the evaluation phase. This suggests that when basic infrastructure needs are met, or deficiencies are offset by external support, other factors such as ease of use and social influence take on a more prominent role in shaping the intention to use.

Due to the pandemic context experienced during the execution of this research, conducting this study with young people who were already part of the "Building Healthy Communities in Brazilian Urban Slums" project was essential for the feasibility of this study. The engagement of young people and adolescents in this community in activities with the +Lugar platform had already been observed in the ethical approval process in the early stages of the project. The results highlight the impact of gamification on the engagement of vulnerable communities in participatory mapping and crowdsourcing initiatives to combat Covid-19.

## 7.1 Limitations and threats to the validity

The choice of action research for this study, although fundamental to investigating the applicability of gamification in a real scenario of combating Covid-19 in vulnerable communities, imposes certain important limitations that must be recognized. One limitation to consider when analyzing the results presented in this study is the non-generalizable nature of this research modality. Besides the action research having a non-generalizable scope, the group of young participants in this study also took part in other research related to the field of epidemiology and other areas within public health, such as ecology and entomology. This involvement could influence their perception of the established determining constructs in the assessment of platform acceptance and use.

As is characteristic of the action research approach Tripp [2005], the results obtained in this study are deeply embedded in the specific reality of the participating community, which contributes to the internal validity of the proposal, that is, its contextual adequacy. However, this imposes limitations on external validity. This restriction on generalizability is evidenced, for example, by the fact that the participants were previously engaged in community health projects. This involvement could influence their perception of the established determining constructs in the assessment of platform acceptance and use. Furthermore, the small sample (n=20) and the predominance of young men (70%) reflect local dynamics but do not allow for capturing nuances related to gender or underrepresented age groups.

Another observation is that action research and the voluntary nature of participation can influence participant engagement. Although we employed the GAFCC model to motivate participation, the level of engagement of the 20 young people may not be representative of a broader population because participants engaged in action research studies may already have a greater inclination toward collaboration and innovation, which could lead to an overestimation of the potential for engagement in a large-scale implementation.

The application of the GAFCC model in public health presents significant challenges. Elements such as goals, feedback, and collaboration, which naturally align with pedagogical objectives, need to be adapted to collective realities and broader narratives. Moreover, measuring outcomes in public health is more complex, as it involves multiple behavioral factors. Another challenge lies in the diversity of the target audience: unlike educational settings, where users tend to share similar motivational profiles, public health initiatives involve heterogeneous populations, which can reduce the effectiveness of standardized gamified strategies, such as rankings. However, the target audience of this study did not allow for the evaluation of this approach in a context with diverse motivational profiles.

# 8 Conclusion

This research demonstrates that the overall objective, evaluating the use of gamification to support participatory mapping and crowdsourcing approaches in practices aimed at combating Covid-19, was notably achieved. Based on the findings presented throughout this study, it is evident that the GAFCC model is significantly adaptable and can be applied in public health contexts, extending its utility beyond the realm of education.

Given the non-generalizable nature of the research methodology used, it is evident that the work conducted can be valuable for conducting new studies that assess the feasibility of implementing the GAFCC model in various healthcare contexts. It can also serve as a basis for the development and adaptation of new gamification design models tailored to this domain.

This study has also demonstrated that the implementation of a gamification design model to support the use of participatory mapping and crowdsourcing approaches in practices aimed at combating Covid-19 in vulnerable communities is a significantly viable procedure. Through the proposed solution, it was possible to obtain spatially distributed indications regarding the presence of Covid-19 transmission predictors in a participatory manner, as well as real-time notification of users' proximity to publicly marked areas under the perceived risk of Covid-19 transmission.

These findings represent a significant advance in the understanding of the use of gamification as a strategy for social mobilization in public health, providing important directions for future implementations in similar scenarios. In addition, adapting the GAFCC model to this context reveals valuable insights into the personalization of the user experience and motivation for active participation.

## 8.1 Future works

Although the small sample size (n=20) is considered appropriate for action research, which focuses on the depth of intervention in specific contexts, future studies could benefit from larger and more diverse groups in terms of age, gender, and history of community participation. Such adjustments would not only make the results more generalizable, but also allow researchers to test whether findings such as the non-significance of Performance Expectancy and Facilitating Conditions hold true in more heterogeneous populations. This would also enable the exploration of nuanced relationships across different user profiles, including those with diverse motivational drivers. Additionally, they would enable analyses of how demographic factors moderate the effects of gamification and allow for greater sophistication in the statistical models employed.

Longitudinal studies are also recommended to investigate the sustainability of user engagement over time, as well as the real impact of their contributions on community health indicators. This approach will allow for a deeper understanding of the effectiveness of gamified participatory strategies, providing insights for improving interventions in similar contexts.

Furthermore, it would be valuable to explore the specific impact of narrative elements and avatar personalization on user motivation and participation. Given the co-design approach used for avatars in this study, future research could quantitatively and qualitatively assess how these elements contribute to a sense of belonging, self-expression, and lasting engagement within gamified public health platforms.

Finally, comparative studies should also be carried out in order to perform a comparative analysis of the GAFCC model with other existing gamification models and frameworks in various public health scenarios to assess their relative effectiveness. The GAFCC model shows strong potential for adaptation to a variety of epidemiological and public health scenarios beyond Covid-19, including the prevention and control of zoonotic diseases such as leptospirosis, as well as urban arboviruses like Zika, Dengue, and Chikungunya. By actively engaging the population through gamified and collaborative strategies, this approach can enhance participatory surveillance systems and support faster, more effective responses. Moreover, understanding the spatial distribution of transmission predictors can inform targeted prevention strategies and evidence-based decision-making in diverse environmental and epidemiological contexts.

# Declarations

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## Authors' Contributions

Conceptualization, Murilo G. A., Marcos E. B. and Isa Beatriz C. N.; Methodology, Murilo G. A., Marcos E. B., Isa Beatriz C. N. and Ricardo L. B.; Validation, Murilo G. A., Marcos E. B., Isa Beatriz C. N. and Ricardo L. B.; Formal analysis, Murilo G. A., Marcos E. B., Isa Beatriz C. N., Ricardo L. B. and Vaninha V.; Resources, Federico C., Marcos E. B., Ricardo L. B. and Hussein K.; data curation, Murilo G. A.; Writing—original draft preparation, Murilo G. A., Ailton R. and Ana Maria A.; Writing—review and editing, Murilo G. A., Ailton R., Ana Maria A., Vaninha V., Marcos E. B. and Ricardo L. B.; Supervision, Federico C., Hussein K, Ricardo L. B. and Frederico A. D., Project administration, Federico C., Hussein K and Ricardo L. B.; Funding acquisition, Federico C., Hussein K. and Ricardo L. B. All authors have read and agreed to the published version of the manuscript.

## Competing interests

The authors declare no conflicts of interest.

## Availability of data and materials

The dataset and user study materials generated and analysed during the current study are openly available in a public repository. The user study form is accessible at GitLab repository (user study form)[5]. The dataset used in the validation process is available at GitLab repository (dataset)[6].

## Further relevant information

**Approval by the Ethics Committee**: This study was approved by the Research Ethics Committee of the Collective Health Institute/Federal University of Bahia (CEP/ISC/UFBA), with CAAE number 68887417.9.0000.5030, and by the National Research Ethics Committee (CONEP) linked to the Brazilian Ministry of Health under approval numbers 2.245.914–2.245.914.17–3.315.568.

**Statement on the Use of Generative AI Tools**: Generative Artificial Intelligence tools were used to enhance the writing. All AI-generated content was reviewed and validated for accuracy and consistency. All authors read and approved the final version of the manuscript.

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