

The Rallye Platform: Mobile Location-based Serious Games for Digital Cultural Heritage

Jean Botev, Sandra Camarda, and Claude Ohlhoff

University of Luxembourg, 4364 Esch-sur-Alzette, Luxembourg
`firstname.lastname@uni.lu`

Abstract. This paper presents the Rallye Platform, a software ecosystem that enables various mobile location-based serious games such as digital treasure hunts. Such games are an effective way to engage audiences in a cultural heritage context on-site, and beyond traditional museum spaces. We devised and employed the platform to develop two long-running deployments –the Légionnaires Rallye and the Minett Stories Rallye– in support of two major multimedia exhibitions in Luxembourg running between July 2021 and May 2022, which doubled as test cases for qualitative and quantitative analysis. The evaluation shows that the applications helped promote the physical exhibitions, engaged players, and sparked curiosity about the respective subject areas and historical contexts. Various changes implemented between the deployments further improved the user experience, and the mobile web applications were used even beyond the end of the exhibitions by students and other groups to explore the history and geography of the urban space.

Keywords: Serious Games and Gamification · Location-Based Learning · Mobile Learning · Cultural Heritage · Digital Storytelling.

1 Introduction

For the past decades, museums have experienced a paradigmatic shift towards inclusiveness and participation, putting in place outreach strategies aimed at making exhibitions more experiential and interactive [19,2]. Expanding the museum beyond its walls helped reformulate the relationship between cultural heritage institutions and their audiences [16]. Additionally, the affordances of new digital technologies have increased the possibilities of providing enriching learning experiences. From an educational point of view, emotional involvement, enjoyment, and engagement are proven conditions to facilitate the acquisition of skills, the understanding and retention of information, and the improvement of knowledge [6,7,8,20]. Serious games, particularly those that provide task-based activities involving quizzes and puzzles, are particularly suited to be employed in cultural heritage settings [13]. Providing contextualized content, location-based systems are seen as an effective solution to enhance cultural experiences both inside and outside the museums [1,5,9,12,15]. The urban space becomes the game board where players are invited to explore historical locations and

cultural heritage sites while contextually solving cognitive tasks [18]. Mobile devices, employed as interfaces for gameplay, allow the interchange between the physical and virtual world, functioning as gateways to access various types of textual and audiovisual sources. Such kinds of pervasive games [11] can enrich and augment the visitors’ experience representing both tangible and intangible heritage while transcending spatial and temporal barriers.

Storytelling represents another fundamental component in conveying information related to cultural heritage sites [14,17]. Location-based serious games can facilitate forms of both linear and non-linear storytelling, where the position and interaction of the player with the physical environment (for example, reaching a historical point of interest) triggers and advances the narrative and the game itself. Such forms of location-aware storytelling, where stories are generated interactively based on the user’s location, can result in a more enjoyable and stimulating educational experience [10].

Starting from these assumptions, we built on the familiar concept of the treasure hunt game (Rallye, in Luxembourgish) to develop a solution to extend immersive multimedia exhibitions toward the urban space. With the Rallye platform, we created a tool that helped us realize and deploy games for two educational projects related to historical themes and national heritage.

Before discussing the details of the two concrete deployments in Sect. 3, we introduce the platform and its components in the following Sect. 2. We then discuss qualitative and quantitative results in the context of the evaluation of the test cases in Sect. 4 and conclude in Sect. 5 with a summary and outlook. The terms rallye, treasure hunt, and game are used interchangeably in this paper.

2 The Rallye Platform

The Rallye platform was built to develop, deploy, and manage location-based web applications that engage players in games, such as digital treasure hunts, around historical locations. The concept resulted from an interdisciplinary collaboration between the Luxembourg Centre for Contemporary and Digital History (C²DH) and the VR/AR Lab of the University of Luxembourg. It was first developed during the early stages of preparing a temporary multimedia exhibition called *Légionnaires on the history of the Luxembourgers in the French Foreign Legion* at the Musée Dräi Eechelen in Luxembourg City (30 June 2021 to 27 February 2022) [4]. Players were given an interactive map and a series of riddles or hints that had to be solved in sequence to reach several secret locations. Each location, or point of interest (PoI), was related to a particular historical event, building, landmark, person, or group.

We designed the platform as a generic software ecosystem; the modular, container-based architecture is built with modern event-driven back-end technologies such as Node.js and allows for the easy addition of different activity types, multimedia content, or interaction modes. We chose the non-relational database MongoDB to process all data because of its flexibility and efficient query operations on geospatial information.

Aside from the server-side technologies, which constitute a back end for hosting treasure hunts in arbitrary locations and about different historical themes, the platform further consists of two front-end components providing interactive access to the different stakeholders: the game, i.e., the treasure hunt itself, in the form of a mobile web application, and a web-based staff tool providing various management functionalities, such as statistics and editing capabilities. One of the paramount design guidelines was to make the user interfaces simple, intuitive, and adaptable to provide a great user experience regardless of the level of digital literacy.



Fig. 1: Légionnaires Rallye web application, landing page on mobile device.

2.1 Mobile Web Application

Following a search-and-find game pattern, the user has to physically reach a string of fixed-point destinations in the game area. An anonymized cookie allows for saving the game progress and language preferences. From the landing page, the player chooses a preferred language from a set of options (see Fig. 4a and Fig. 1 offering three or four different options, respectively); this can also be changed at any point later through the game menu. Before starting the game, users must consent to store the anonymous cookie and allow the app to access their location (cf. Fig. 3a).

A tutorial containing the game instructions and some tips on how to follow such a trail of PoIs shows an interactive map marking the treasure hunt area and the user’s current position. When starting the game, players are given a riddle/hint and an interactive map that displays their location as they move around, for instance, as shown in Fig. 3b or Fig. 4c. The player’s current geographical position is tracked and displayed on the interactive map using the mobile device’s GPS localization data throughout the game.

Assuming the player correctly guessed the solution and is heading towards the right location, within a larger radius from the destination, a pulsating circle will appear on the map, signalling that the target is close. The closer the PoI, the more frequent and vivid the rings of the pulsating circle will be. Finally, upon arriving at the destination, an animated pin drops on the map, followed by an image and a text explaining the historical significance of that specific site (cf., for example, Fig. 3c). Reaching the first location will unlock the second riddle, and so on.

The pulsating circle signaling that a location is nearby will only appear if the player is at that particular stage of the hunt; simply roaming around the area will not reveal the position of the other secret locations on the map. As the player solves the riddles and discovers the PoIs, a progress bar indicates the advancement. The discovered locations will now appear as greyed-out markers on the interactive map.

To allow players to finish the game within a reasonable time, the locations are all in walking distance from each other. From the moment they start the game, players have two weeks to finish the hunt; after this period, the game progress is deleted, and they will have to start anew.

The last hint takes the players to the museum or venue, where they can continue the experience by visiting the exhibition. As an incentive, upon successfully finding all secret historic locations, players receive a unique code that can be redeemed at the museum’s reception for a small reward (cf. Fig. 3d) and share their achievement on social media. The completion codes are randomly generated and stored anonymously on the server. The players can now also revisit all discovered locations in the form of a gallery view (cf. Fig. 4b).

The rationale behind a realization as a web application is maximum diffusion and availability without the need to install a dedicated app. While connection issues might slow the game, free Wi-Fi is available in most urban areas nationwide, so users do not need to rely on their data plans for access. Furthermore,

running the business logic server-side allows for better control and fast deployment of updates in case of any issues or bug fixes. The adaptive design adjusts locally and dynamically to different screen sizes, resolutions, and orientations, while the back end detects whether a qualifying mobile device is used; if not, a dedicated page indicates to switch the device.

No personal data is collected or stored, but generalized statistics are provided to monitor the status. These data are visualized and made available through the web-based interface discussed in Sect. 2.2.

2.2 Staff Tool

To facilitate the management and maintenance of a game instance, the Rallye Platform provides an online front end with different access types and feature sets (cf. Fig. 2). For instance, a visual editor allows for creating and editing trails and PoIs, while different statistics interfaces provide real-time status information or technical details about platforms and browsers.

In order to accommodate the different stakeholders, we have created three access levels that gradually provide additional functions, detailed in the following with respect to each role.

Front Desk. The front desk role only provides access to the completion certificates generated at the end of the game (cf. Fig. 2a). Since the idea is to offer on-site award prizes for the first few users successfully completing a rallye, local staff needs to be able to verify the code on the user’s device. The certificate list provides various sorting options, temporal filters, or the direct search for specific certificate numbers. After the prize is handed out, staff can validate the code as used, updating the status to ”redeemed”. The validation can also be reversed.

Moderator. The moderator role provides two other essential functions. On the one hand, detailed real-time statistics, e.g., on how many people play the game, how long it takes them to complete it, and whether they stop at a specific point of the hunt. To a certain degree, this allows for addressing potential issues with the content (particularly if users tend to get stuck at a specific point of the hunt). On the other hand, moderators have access to a visual editor for creating and editing trails or individual PoIs, allowing them to build content easily.

Administrator. In addition to the front desk and moderator options, the administrator role provides an interface for accessing further device-related statistics (cf. Fig. 2b), such as browser types, platforms, or browser platform distribution, which are especially useful for prioritizing bug fixes or designing automated tests. The statistics can again be filtered to provide more detailed information about a specific period.

LÉGIONNAIRES STAFF TOOL frontdesk

Certificate validation - Front Desk

When patrons present their certificate, use this table to validate it and mark it as redeemed. For convenience, you may search for the certificate by directly entering the code in the box below. **A certificate can only be redeemed once. To prevent patrons from using the same certificate twice, validate the certificate shown by pressing the green button.**

Sort by: ▼ Date - Most recent to most dated ▼ From: Select a start date... To: Select an end date...

Reset Filters C

CERTIFICATE NUMBER	ISSUE DATE	STATUS	ACTIONS
GbRQF4hkdpHV	19/02/2022	✓ Redeemed	Undo validation
TTbTOV8C6DWA	04/02/2022	✓ Redeemed	Undo validation
SlwJKM_V6WZr	16/10/2021	✗ Not redeemed	Validate
2qVuPW7owJB	14/08/2021	✓ Redeemed	Undo validation

(a) Front desk interface, certificate validation.

LÉGIONNAIRES STAFF TOOL admin

Dashboard - Device Statistics

On this page essential statistics about what devices are used to play the rallye.

Device browser and platform

Used Browsers

All Time

Browser	Percentage
Apple WebKit	3%
Chrome	35%
Edge	1%
Facebook	3%
Firefox	10%
Opera	0%
Safari	39%

Used Platforms

All Time

(b) Administrator interface, device statistics.

Fig. 2: Légionnaires Rallye staff tool, desktop screenshots (browser content only).

3 Deployments / Test Cases

Based on the Rallye platform introduced in Sect. 2, we developed and deployed two treasure hunts to accompany temporary multimedia exhibitions in Luxembourg.

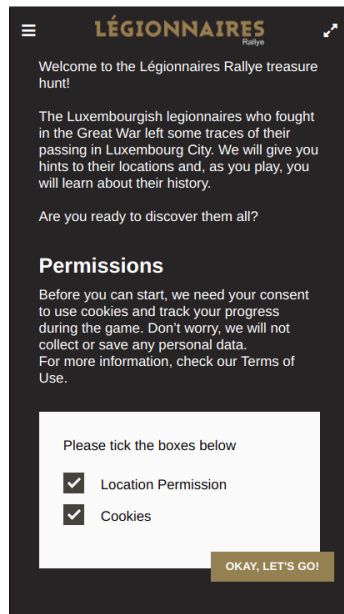
The Légionnaires Rallye, in the context of the eponymous exhibition at the Musée Dräi Eechelen in Luxembourg City, running from July 2021 to February 2022, constituted the first test case. The second test case was the Minett Stories Rallye developed for the exhibition *Remixing Industrial Pasts: Constructing the Identity of the Minett* on the former ironworks of Belval in Esch-sur-Alzette, running from February to May 2022. As discussed in Sect. 1, both follow the same rationale to promote the events and transcend the exhibitions' physical space, giving them a transmedia dimension beyond the museum walls.

Application development began in 2020, and the chronological sequence allowed us to develop specific aspects between deployments further. We will discuss the individual implementations and their differences in the following sections.

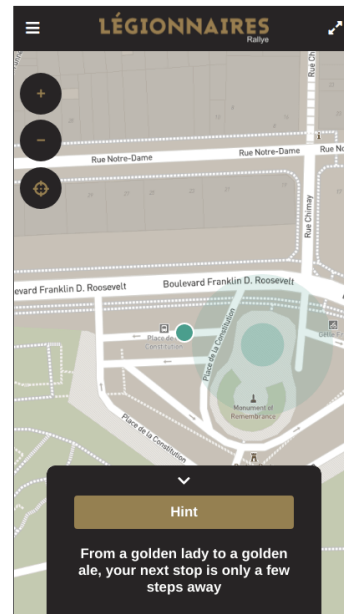
3.1 Légionnaires Rallye

The exhibition *Légionnaires* was the outcome of a collaboration between the C²DH and the Musée Dräi Eechelen, bringing together the results of a quinquennial investigation on the Luxembourgers in the French Foreign Legion conducted at the University of Luxembourg as well as the work of local specialists, public historians, and international experts. The exhibition also represented the last phase of *Éischte Weltkrich*, a digital public history project on WWI in Luxembourg. Highly visual and interactive, the project employed a multimedia and transmedia approach using multiple channels to delve into individual accounts and micro-histories. The Légionnaires Rallye treasure hunt constituted one of these channels, expanding the exhibition to the city and inviting tourists and local citizens to discover the history of the Luxembourgish legionnaires in the places that marked their passage.

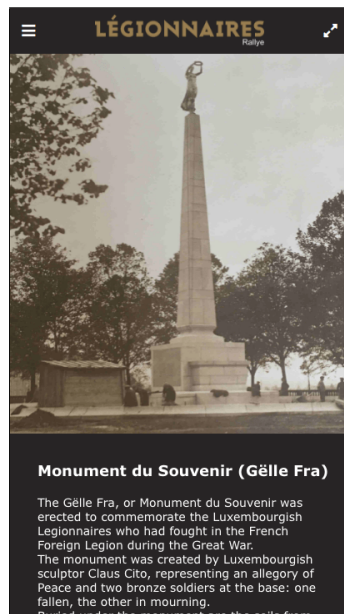
The game area was restricted to the core of the city center where ten salient historic locations (PoIs) were identified. Players were given a fairly challenging single hint or riddle leading them to each secret location. The pulsating circle signalling the target's proximity on the interactive map was set at a radius of 50 meters from the PoI (cf. Fig. 3b). To allow some leeway, the pin icon that drops on the map upon reaching the destination and the subsequent informative image and text (cf. Fig. 3c) were set to appear within a radius of 10 meters. Given the length of the trail, users were allowed to stop and resume the game at any point. As an incentive for finishing the treasure hunt, however, we set a temporal constraint of two weeks, after which any progress would be deleted, and the game reset. Additionally, mystery boxes containing various prizes were promised to the first five players who would reach the final destination. Smaller rewards (a dedicated enamel badge) were also envisioned for the remaining players.



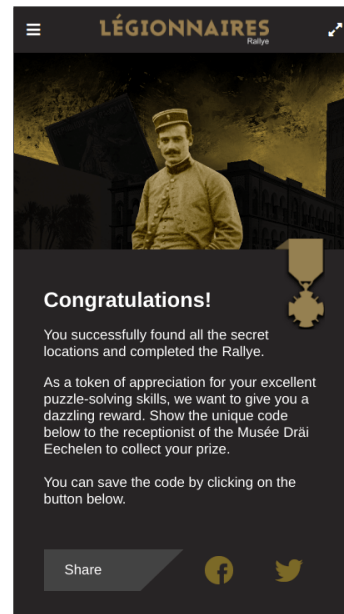
(a) Welcome screen, permissions.



(b) Map screen, hint extended.

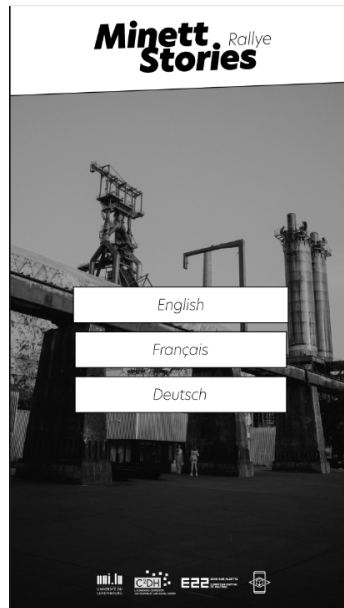


(c) PoI screen, description.

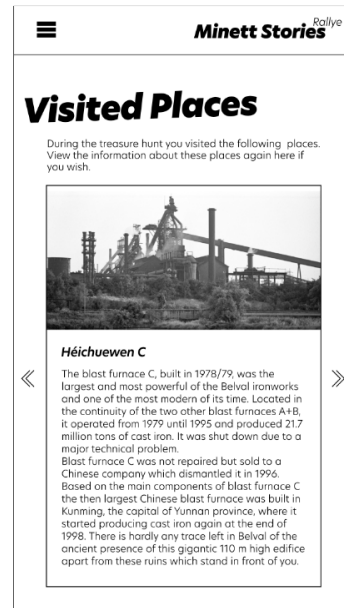


(d) Completion screen, code.

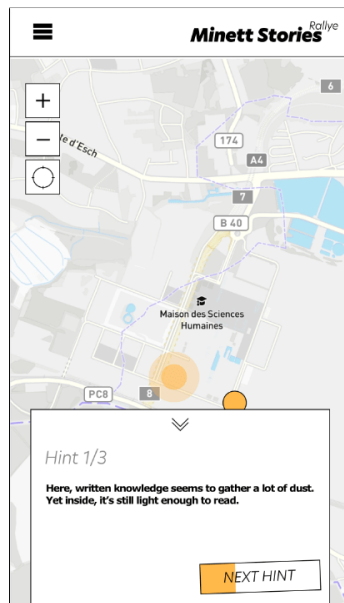
Fig. 3: Légionnaires Rallye web application, screenshots (browser content only).



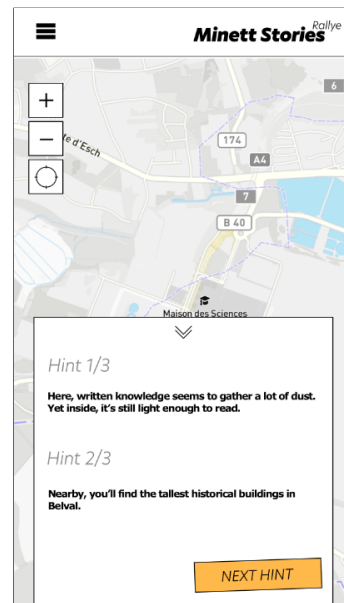
(a) Landing screen, languages.



(b) Final screen, gallery view.



(c) Map screen, hint extended.



(d) Map screen, hints extended.

Fig. 4: Minett Stories Rallye web application, screenshots (browser content only).

3.2 Minett Stories Rallye

The Rallye platform was subsequently used in the frame of another project involving a different location and historical theme. The Minett Stories Rallye accompanied the opening of the temporary exhibition *Remixing Industrial Pasts: Constructing the identity of the Minett* (27 February 2022 to 15 May 2022), which was part of the European Capital of Culture Esch2022 programme. The exhibition explored the region’s industrial past and was set in the Massenoire, a repurposed industrial hall within the former steelworks complex of Belval. The redevelopment project that over a period of twenty years converted the brownfield into a business and cultural center (today hosting the University of Luxembourg’s main campus) radically transformed the landscape, erasing many old structures and buildings.

The game allowed to rediscover that past taking the players on a journey through the landmarks and relics of the former ironworks. The team of historians involved in the Remix project provided a new visual identity and a list of locations that mirrored the thematic structure of the exhibition for a total of nine PoIs (including the exhibition hall, where once a material known as *masse noire* or “black matter” was produced to close the tapholes of the blast furnaces). This new instance offered the opportunity to address a series of issues identified in the original Légionnaires Rallye, particularly concerning flow and balance between player challenge and frustration. This was achieved by significantly narrowing the distance between the PoIs, with a game area reduced to roughly one square kilometer. The reduction and compacting of the game area required an adjustment of the PoI radius down to 30 meters instead of 50 meters. The activation range was also halved to five meters. Most importantly, a three-tiered difficulty level was introduced so that, if a riddle was too obscure, every 30 seconds, players could unlock additional hints, with the third and last hint openly revealing the position of the secret location. While still providing a challenge for the players willing to embrace a hard mode, we allowed those experiencing difficulties to complete the game still and learn from the trail. Due to time constraints, the Minett Stories Rallye language options were reduced to three (English, French, and German).

4 Evaluation

The user tests conducted on a sample of players, as well as other metrics such as success rate and completion time, revealed an overall appreciation of this mode of asynchronous engagement. While the discussed test deployments were specifically aimed at promoting physical exhibitions, the platform enables the creation of stand-alone applications and games for exploring various contexts. This type of location-based game can thus offer a variety of possibilities for developing digital cultural heritage projects, strengthening the connection between the landscape and its stories while allowing players to discover history through an interactive experience that is both entertaining and educational. Although the games were not specifically intended to provide an alternative to the restricted

museum visits during the COVID-19 pandemic, they offered the opportunity to access part of the exhibition content outdoors in safety.

4.1 Quantitative Results

While anonymous, the usage data provide a plethora of information and valuable insights into how the web applications were used.

User Growth Development. The plot in Fig. 5 shows the number of new users for the Légionnaires Rallye and the Minett Stories Rallye over time, for the duration of the exhibitions (shaded in the respective color) and beyond, until the cut-off date in November 2022. Around both exhibition openings (June/July 2021 and February/March 2022), the amount of new users peaks, and also the stabilization or increase following subsequent promotional initiatives is clearly discernible. Later spikes in January and March 2022 for the Légionnaires Rallye and October 2022 for the Minett Stories Rallye stem from groups using the web application well past the end of the exhibitions.

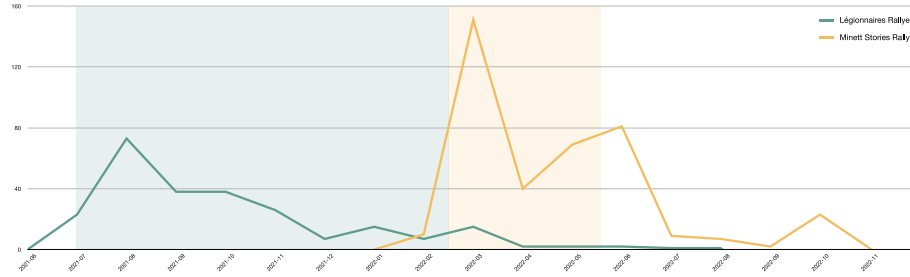


Fig. 5: User growth for both deployments; actual exhibition periods are shaded.

Completion Rates. The completion rate of the Légionnaires Rallye was alarmingly low, with high drop-out rates at the initial PoIs. This can only partly be attributed to unforeseen circumstances, such as the extreme flooding across Western Europe in the summer of 2021 that hit Luxembourg with devastating effects shortly after the web app’s launch. While the torrential rain prevented people from playing for several weeks, the low completion rate is probably due to the relatively high difficulty of the riddles. Without the possibility to short-track and get further help within the application itself, few mustered the perseverance required to solve the puzzles. Another deterrent was represented by the length of the trail connecting the PoIs. While the gaming zone was confined to an urban area of circa five square kilometers, reachable on foot or by public transport, the game required crisscrossing the city center for several hours. Five of 223 players who started the Légionnaires Rallye game completed it. The Minett Stories Rallye, on the contrary, was more successful, with 393 players overall, of which

49 players succeeded, i.e., the completion rate was about 12%. The reasons for the positive reception are to be found in the influx of people visiting the area because of the Esch2022 events, in an effective promotional campaign, as well as in the game design improvements, namely a shorter duration of the session play, the delimitation of the game zone to a much smaller area, and the introduction of the three-tiered hint system that significantly lowered the game difficulty.

Device Statistics. The device statistics (cf. screenshot in Fig. 2b) provide interesting insights into the platform and browser distribution. Notably, around half of the players were using iOS devices, i.e., iPhones or iPads (45% for the Légionnaires Rallye, 52% for the Minett Stories Rallye). Fig. 6 furthermore shows the browser distribution for each platform, with the platform-native browsers (Chrome/Android and Safari/iOS) dominating and only Firefox or Facebook’s app-internal browser as third-party browsers achieving more significant shares. The remaining 11% (Légionnaires Rallye) and 6% (Minett Stories Rallye) of the browser software could not be allocated.

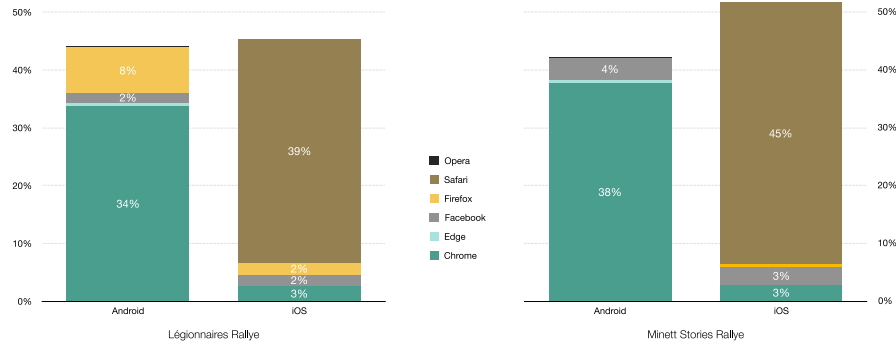


Fig. 6: Distribution of platforms and browsers for both deployments.

Language Selection. Both test deployments offered multiple languages to choose from. For the Légionnaires Rallye, most users played the game in English (33%) or French (30%), while 23% chose German and the remaining 14% Luxembourgish as a language. The Minett Stories Rallye did not include Luxembourgish as an option; the distribution of the remaining three languages among the players here was as follows: 37% French; 32% German; 31% English.

4.2 Qualitative Results

Complementing the quantitative data discussed in Sect. 4.1, we conducted a qualitative survey for the Minett Stories Rallye. Before the game went live, a group of 12 test users was asked to complete a questionnaire about their background and experience using the mobile web application. The survey was articulated in three main sections covering: 1) demographic segments; 2) game

experience (focusing on the appeal and educational potential of the content); 3) usability and performance. For the most part, the test group was composed of female participants (75%) between the ages of 30 and 60. The majority (42%) were Luxembourgers, followed by German, French, Dutch, Spanish, and Bulgarian nationals. Contrarily to the general quantitative statistics, 58% of the test group chose German as their language option, 25% French, and the remaining 17% played the game in English. Six users were educational professionals with expertise in game-based learning belonging to the organizations IFEN (*Institute de Formation de l'Education Nationale*) and SCRIPT (*Service de Coordination de la Recherche et de l'Innovation Pédagogiques et Technologiques*), both entities of the Luxembourg Ministry of Education. The questionnaire included five-point Likert scale questions, as well as multiple-choice and open-ended questions. This combined survey method provided more granular and nuanced feedback and a reliable measure of the game experience. All users completed the game within an hour or two, with 83% playing in a single session without interruptions. Players were given the possibility of completing the game alone or in a group. 58% chose to play alone and the remaining 42% played with friends and family.

75% of the test users found the first hints very difficult and, on average, needed to unlock one additional hint before guessing the secret locations. 25% needed all three hints.

In regard to the storytelling, 92% of the users read the texts with full attention, enjoyed the content, and felt driven to complete the treasure hunt.

While 83% of the users declared to have already a moderate to very good knowledge of the geography and history of the site, all testers unanimously stated that playing the game taught them something new and made them more curious about Belval. Additionally, 42% of the users felt more motivated about visiting the exhibition. Their feedback helped to further address some minor geolocation issues, adjust the difficulty of some of the hints, and improve the quality of the content.

Overall, the quantitative results confirm the effectiveness of the additional features and improvements such as the adaptive hint system. Concerning aspects related to UI and UX design, more than 75% of the test users found that the app navigation was easy or very easy, while the majority approved of the general app design (83% like it or like it very much, the remaining 17% answered neutrally, i.e., there was no negative feedback in this regard).

5 Conclusion

This paper presented the Rallye Platform, a software ecosystem that enables various mobile location-based serious games like digital treasure hunts. Such games facilitate learning, helping to retain and understand information, and are effective ways to increase emotional involvement, enjoyment, and engagement, while task-based activities involving quizzes and puzzles are particularly appropriate for cultural heritage.

Therefore, we devised and employed the platform to develop two long-running deployments supporting two national, physical multimedia exhibitions running between July 2021 and May 2022, doubling as test cases for qualitative and quantitative analysis. The evaluation shows that the changes implemented from the *Légionnaires Rallye* to the *Minett Stories Rallye* deployments further improved the user experience.

The mobile web applications remained active well after the end of the exhibitions and continued to be used by students and other demographic groups as educational activities to explore the urban areas and their history. Shifting the focus towards discovery and away from the game challenge significantly increased the completion rates, helping to promote the physical exhibitions and sparking curiosity about the respective subject areas.

We intend to continue development and possibly integrate augmented reality techniques and other collaborative aspects and features as explored, for instance, in *CollaTrEx* [3] or similar projects.

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