Features and Checklists to Assist in Pervasive Mobile Game Development

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***Abstract*—Pervasive games are a recent form of entertainment that aims at bringing the game experience out of a game device. However, this area still lacks consensus on definitions and formalisms as researchers explore pervasive games from several viewpoints, from game studies to context-aware computing. Practical guidelines for mobile game developers are even scarcer. Firstly, this paper critically analyses the definitions of pervasive games found in the literature. Secondly, it proposes a set of pervasive features and checklists that can help both the task of classifying a preexisting mobile game and the task of designing a new mobile pervasive game. This paper ends with an example of applying checklists and features in a pervasive mobile game that we have developed.**

Keywords—pervasive mobile games, pervasive features, context-aware games, pervasive computing, development process

I. INTRODUCTION

In a nutshell, we understand that pervasive games are games that aim at bringing the game experience out of the game device to the physical world. Yet in practice, it is not as simple as it might sound.

According to the Oxford English Dictionary [1], "pervasive" means: *"having the quality or power of pervading; penetrative; permeative; ubiquitous"*. This could suggest that pervasive games are games pervading something (real-world perhaps) or "spread" somewhere, but there are various interpretations and scopes for defining what "pervasive games" mean. Several works in the literature present "pervasive games" as a concept encompassing different kinds of games that use mobile devices (*e.g.* phones, tablets, PDAs), custom hardware (*e.g.* sensors, augmented-reality peripherals), and even non-technology games (*i.e.* games that are not based on computing devices).

The research field on "pervasive games" is young. As far as we are aware, no one knows precisely when and where the term "pervasive games" was coined. According to Montola and co-authors [2], this term was probably coined in the year 2001, when important "alternate reality games" (ARGs) were launched, as *The Beast* [3]. The first game explicitly labeled as "pervasive game" was *Pervasive Clue* [4], dating back from 2001. Around that time, the *Pirates!* game [5] had been deployed as an example of "game based on ubiquitous computing". Shortly after, the company *It's Alive!* Deployed *Botfighters* [6], a commercial location-based mobile phone game that uses the real-world as the game arena.

The reader that starts to explore this field might get confused by the variety of approaches and scopes regarding discussion about "pervasive games". A reason is that several researchers have explored this field using different lenses. The end result is that a definite conceptualization of pervasive games is still lacking in the literature. The subtlety and ambiguity arising from the "pervasiveness" concept contribute to this situation.

The authors of the present paper have embarked on this quest several years ago motivated by the idea of developing pervasive games with mobile devices. As computer scientists this means we were interested in coming up with tools and concepts to help in software development of pervasive games. We are also interested in the technological aspects of pervasive games and their implications, meaning how technology supports or makes it possible to create pervasive games.

Instead of coming up with another definition for pervasive games, we opted to study pervasive game projects and extract from them features that make those games unique. As the scope of pervasive games in the literature is too broad, we limited the scope of our study to "pervasive mobile games" – context-aware games that necessarily use mobile devices. We believe that this can be a more pragmatic step towards providing support for pervasive mobile game development.

This work presents our first results in finding important features in pervasive mobile games (*pervasive features*), along with a first attempt at defining checklists to help in finding those features in games or introducing features in new pervasive game projects.

This work is organized as follows: Section II presents an overview of pervasive games that includes common approaches and definitions found in the literature. Section III presents our considerations on pervasive game definitions and other works related to identifying important features in pervasive games. Section IV presents the features and corresponding checklists that we have identified. Section V presents a case study that describes: 1) how pervasive features occur in a game developed by the first author (*Pervasive Word Search*); and 2) checklist questions that apply to this game. Section VI presents conclusions and final remarks. The Appendix presents the complete checklist of each pervasive feature.

II. PERVASIVE GAMES

While browsing the literature on pervasive games, we noticed that this field is highly interdisciplinary and that the approaches to pervasive games can be loosely divided into two broad groups: "cultural" and "technological" approaches.

With "cultural approach", we refer to approaches originated in areas such as design, game studies, and social studies. In cultural approaches, authors tend to use the term "pervasive" in its original literal sense [1] to indicate that some game aspects defy concepts that are considered central in traditional game definitions. The ideas behind definitions in cultural approaches are more concerned with aspects of gameplay and the game itself, not emphasizing technology, pervasive computing and relating ideas. In cultural approaches, a pervasive game may exist and not use technology at all [2].

In "technological approaches", authors often discuss pervasive games as applications of pervasive and ubiquitous computing. Another noticeable aspect is the confusion of using the terms "pervasive" and "ubiquitous" in pervasive game definitions, as Nieuwdorp [7] pointed out. We regard "pervasive" and "ubiquitous" as synonyms, although this is not unanimous as Nieuwdorp [7] points out.

Nieuwdorp [7] used a similar division ("game studies" x "technology") to analyze the discussion on pervasive games available in the literature. We use the division "culture x technology" as a starting point for analyzing some subtle issues present in pervasive games, and we include in our analysis some works that are newer than the ones considered by Nieuwdorp [7].

As a first look, we classify the approaches we found on pervasive games in 5 categories (Table I), according to the authors' viewpoint(s).

TABLE I. VIEWPOINTS ON PERVASIVE GAMES

Viewpoints	References
game studies and technology dichotomy	[7]
cultural, theater, technology	[8]
technology, ubiquitous & pervasive computing, sensors	[9]–[14]
computer-augmented game	[4], [9], [15]
cultural or game studies approach	[2], [16], [17]

Besides the different approaches for "pervasive games", there are some patterns, which are:

- The idea of "games coming back to real-world", which suggests that computer games are the dominant form of gaming, and pervasive games appear as an alternative to this scenario;
- Spatial mobility on a physical "open" environment, the "game world boundary" is not "well-defined", sometimes it can be unconstrained;
- The players use mobile devices (*e.g.* smartphones, tablets, custom hardware);
- Focus on promoting social interaction among the players;
- The physical world (places, objects) is integrated as part of the game, combining it with the virtual world;
- Emphasis on "mixed-reality", a term that commonly arises in pervasive gaming discussion, meaning the integration of virtual and physical domains in the game. In general, authors consider those terms as synonyms, with exceptions as noted by [9].

A. Cultural approaches

Montola and co-authors [2] defined a pervasive game as *"a game that has one or more salient features that expand the contractual magic circle of play socially, spatially or temporally."* Another example comes from Peitz and co-authors [18], who stated that *"pervasive signifies that the gameplay is pervasive"*.

In the definition by Montola and co-authors [2], the spatial expansion indicates that the game no more has a specific place to occur, the game now may happen anywhere. The boundaries of the play space become not well defined, or undefined. It is a metaphor for "the world as a playground". The temporal expansion indicates that the concept of "game session" is not well defined: now the game may be blended with everyday activities. This relates to the idea of a process that exists in parallel to the "real life", and may require player attention anytime. The social expansion obscures the definition of players and non-players. The players may take part in a game not knowing in advance who the other players are. Another possibility could be non-players participating in the game unintentionally, as in our prototype *Pervasive Word Search*, which uses nearby Bluetooth devices to generate game content. The owners of those devices have no idea that they are "being part" of a game. Another example of this expansion might be of a game happening on some place and by-passers joining the game to experience it.

The definition that Montola and co-authors [2] propose is very broad, encompassing simple mobile phone games to "artistic events" with complex infra-structure. Examples of the latter include *Can you see me now?* [19] and *Uncle Roy all around you* [20]. This definition is broad enough to consider games that do not use computing-based technology as pervasive games, which means that technology (electronic, computing devices and peripherals) acts as a facilitator, and not as a requirement. In this sense, Montola and co-authors [2] defined two categories to classify pervasive games that use technology – *"technology-supported games"* and *"technology-sustained games"*.

In technology-supported games, the technology acts as a complement to the game. For example, technology may work as a mere tool (*e.g.* players using mobile devices to make calls) or as some physical object that has a specific role in the game, which players can go after or manipulate.

In technology-sustained games, the technology is central to the game. Without using the technology, the game does not exist. In this case, technology shapes the game completely. An example is a game that uses GPS sensors to obtain location. As computer scientists, these are the kind of games that we are interested in.

Davies and co-authors [17] also present pervasive games as expanding the magic circle, although their discussion focuses on the physical expansion only.

Jane McGonigal [8], [21] proposes pervasive games definitions based on cultural aspects, theater, and technology. She proposes a broad domain of "pervasive play and performance". Pervasive play consists of "*mixed-reality games that use mobile, ubiquitous and embedded digital technologies to create virtual playing fields in everyday spaces"*. According to her, the "performance" aspect enables players to maximize their play experience by performing instead of just participating in the game, thus becoming "game actors".

B. Technological approaches

Technological approaches place more emphasis on the underlying technological aspects needed to realize pervasive games. There is a variety of definitions, but they form two broad groups:

- As applications of pervasive/ubiquitous computing, or context-aware applications.
- "Computer-augmented" games.

The following sub-sections analyze these two groups.

1) Computer-augmented games. The vision of "computer-augmented" games considers the notion of existing real-world (physical) games being "upgraded" with some sort of computing. An example of "real-world, physical game" would be "Capture the flag". The difference to the "games as pervasive computing applications" approach is subtle. Schneider and Kortuem [4] also share this concern (emphasis added):

> "We define a Pervasive Game as a live-action role playing *game that is augmented with computing and communication technology in a way that combines the physical and digital space together*. In a Pervasive Game, the technology is not the focus of the game but rather the technology supports the game. Although technology is ubiquitous in a Pervasive Game, its role is a supporting one and thus the technology is kept as unobtrusive as possible."

This definition by Schneider and Kortuem [4] is probably one of the first attempts at coining a definition for pervasive games, and it shares some similarities with Montola and co-authors' definition [2] when regarding the role of technology in pervasive games. However, although Schneider and Kortuem [4] mention that technology is not the focus of the game, without technology the game they present would not exist.

Other authors like Magerkurth and co-authors [9] have followed this same idea (emphasis added): *"an emerging genre in which traditional,* ***real-world games are augmented with computing functionality****, or, depending on the perspective, purely virtual computer entertainment is brought back to the real world."*

Magerkurth and co-authors [9] go further in this regard and consider as pervasive games what they categorized as: "smart toys", affective gaming, augmented table-top games, and augmented reality games. Smart toys are traditional children toys fitted with sensors that enable computing. Affective gaming deals with using emotions and physiology as game inputs. Augmented table-top games are traditional board games equipped with touch-screens, sensors, and tangible objects. Tangible objects are manipulable physical objects possessing computing properties. Augmented reality games draw virtual content over the real-world, using special glasses, helmets, or mobile devices (as virtual windows), for example.

We consider the "computer-augmented game" vision broader than the ones based on pervasive and ubiquitous computing concepts (as it includes "toys"), although considering "toys" as "games" is up to debate.

2) Pervasive computing, sensors, and related topics. Several researchers relate pervasive games with topics as pervasive computing, sensors, and context-aware applications.

One of the first games to define itself as "based on ubiquitous computing", or "aiming at constructing a context-aware experience" was *Pirates!* [5], back in 2001. Later, researchers related to the *Pirates!* project have decided to coin the term "ubiquitous games", as those games *"explore the possibility of taking the functionalities that ubiquitous computing offers and applying them to computer games"* [22].

Linner and co-authors [10] view pervasive gaming through a related lens, regarding them as *"applications interweaved into the real world, an emerging field for context-aware multimedia applications"*.

The focus on sensors, wireless networking, and mobility motivates several researchers. For example, Capra and co-authors [11] define pervasive games as extensions of traditional computer games through those technological means:

> "Through a combination of personal devices, positioning systems and other multimedia sensors, combined with wireless networking, a pervasive game can respond to a player's movements and context and enable them to communicate with a game server and other players."

Benford and co-authors [14] share a similar view by declaring that what characterizes pervasive games in a unique way is the combination of pervasive computing technologies with the public nature of playing in those games.

Hinske and co-authors [13] present another definition with focus on pervasive computing, but more concerned in incorporating elements from game studies:

> "Pervasive Games are a ludic form of mixed reality entertainment with goals, rules, competition, and attacks, based on the utilization of Mobile Computing and/or Pervasive Computing technologies."

3) Other technological views. Walther [12] considers pervasive games as a system that exists in a space that presents four characteristics: distribution (embedded computing, ubiquitous infra-structure), mobility, persistence ("always-on" availability), and "transmediality" (ways to consume media, media production by users). He presents then a rather abstract definition of pervasive games: "*Pervasive gaming implies the construction and enacting of augmented and/or embedded game worlds that reside on the threshold between tangible and immaterial space, which may further include adaptronics, embedded software, and information systems in order to*

facilitate a 'natural' environment for gameplay that ensures the explicitness of computational procedures in a post-screen setting" [12].

III. Considerations on Pervasive Game Approaches

As computer scientists, we are more interested in the technology approaches as they regard issues related to computers, technology and software. Some technology approaches to pervasive games seem to use game as an opportunity to apply computer science research, leaving the game issues to the background. In this sense, we consider the approach by Hinske and co-authors [13] a balance between computer science and game studies issues.

From these cultural approaches we understand that the authors seem to imply that those games have a property that makes those games different from traditional digital games – *pervasiveness*. However, we see that defining pervasiveness as an objective criterion is a difficult task – the term is just too subtle and ambiguous. It seems to us that it is more effective to explore features that help games become "pervasive". Nieuwdorp [7] also ended her research work considering that "what makes a game pervasive" is more practical than trying to come up with an ultimate definition of pervasive games. With this in mind, we present our first attempt at exploring pervasive features in Section IV.

The literature regarding specific features of pervasive games is scarce. Koivisto and Wenninger [23] proposed six pervasive features to support pervasiveness in MMORPGs through mobile phones: "Communication access", "Event notifications", "Asynchronous gameplay", "Synchronous player-to-player interaction", "Passive participation", and "Parallel reality". Some issues regarding the features we present in Section IV relate to topics they discussed in their work. For example, our *Daily Life Interleaving* feature relates to their "Event notifications" and "Asynchronous gameplay" features. Our *Social Communication* feature relates to their "Communication access" feature. Our *Device Independence* feature relates to their "Synchronous player-to-player interaction" feature. The "Passive participation" feature that they discuss refers to players observing the game without actually playing it. The "Parallel reality" feature that they discuss refers to the game creating a mixed-reality (integrating the physical and virtual worlds).

Guo and co-authors [24] investigated how pervasive games differ from traditional digital games by characterizing "important aspects" of pervasive games into a conceptual framework, which is similar to what we propose.

They referred to these "important aspects of pervasive games" as "perspectives", proposing four of them: temporality, mobility, perceptibility, and sociality. For each perspective, they propose a set of properties (referred as "options") that characterize the perspective. As an example, there are three options for their "mobility" perspective: "*1) Games are played fixed in one place as most traditional computer games are; 2) Games can be played in large-scale outdoor places anywhere (often also played in everyday life); or 3) Games can be played where the player must move in one place and need physical actions to change gesture, posture, and etc due to requirements of gameplay"* [24].

Our work is different from the work by Guo and co-authors [24] in several ways. For example, we identified other important aspects in pervasive games than they did (*e.g. Uncertainty Handling Policy* and *Cross-mediality*, discussed in Section IV). Also, their discussion is geared towards design studies independent to technical implementation, whereas we are more concerned about technological (computing) aspects.

IV. Checklists and Pervasive Features

The scope of the discussion about "pervasive games" is too broad. Hence, in order to find important features ("pervasive features") in these kind of games, we defined boundary criteria (Table II) that encompass the types of games that we wanted to explore (the "pervasive mobile games").

Table II. Boundary criteria for pervasive mobile games. The asterisk denotes mandatory conditions

No.	Description
1*	Games using mobile devices (*e.g.* smartphones, tablets)
2*	Games that are context-aware
3	Games that access remote data on the move
4	Multi-player games

Condition 1 is mandatory because many pervasive games have activities in open areas or at least not confined to the static nature of using desktop computers. Condition 2 is mandatory because context-aware applications are able to create the integration between the virtual and physical worlds that many pervasive games present. We see this as an essential characteristic of pervasive games. Condition 3 relates to the ability of pervasive games to access remote resources while players are located anywhere. However, not all pervasive games use networking, hence Condition 3 is optional. Condition 4 relates to the social nature of pervasive games by integrating players in a co-located or global fashion (or both). In case of players not being co-located, Condition 4 implies Condition 3. As not all pervasive games are multi-player games, Condition 4 is optional. Games that are "portable" or "mobile" are out of the domain. A "portable game" satisfies Condition 1 only. A "mobile game" satisfies Conditions 1 and (3 and/or 4).

Using these boundary criteria, we conducted a literature review and selected 24 pervasive games for analysis. Due to space constraints, the reader can be referred to our preliminary research report [25] for information about those games, including their descriptions and references. We also added to that research report the first author's experience in developing mobile games using sensors.

This analysis of pervasive game projects resulted in an initial list of 16 relevant features, which the first author proposed in his PhD dissertation [26, Appx. B]. The first author also presented in that work the idea of having checklists to help designers in identifying pervasive game features. In the present paper, we improved that work with a more structured view of those features, especially when we look at relationships among them. Moreover, we improved the analysis of how features and checklists can be used in a real game (Section V).

The pervasive features and checklists that we present are our first attempt at identifying relevant pervasive game

characteristics that contribute to the uniqueness of this kind of game. We do not claim that we have identified all possible features – there will always be room for further research, especially if we investigate design theory and carry out extra inspections using more games and designers. Each feature is related to a set of other features, what renders structure to the space of pervasive game features. Fig. 1 represents a feature relationship matrix, where the features are represented by their acronyms. The Appendix presents the checklist of each feature. Each subsection title refers to the feature acronym and its corresponding checklist table found in the Appendix.

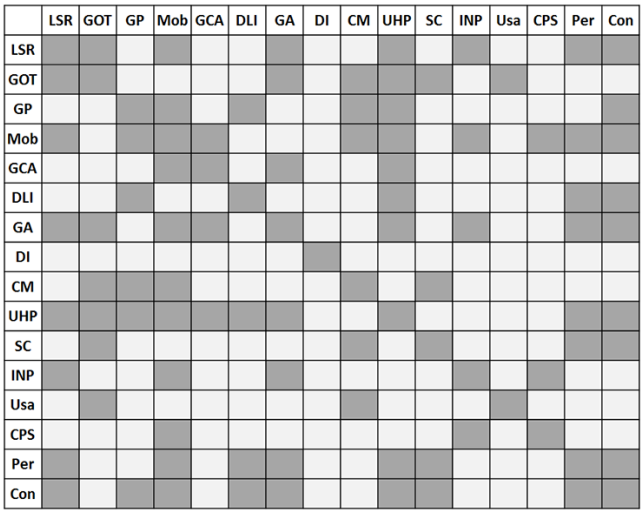

Fig. 1. Feature relationship matrix

A. Device Independence (DI, Table III)

This feature relates to the possibility of playing the game in multiple platforms.

B. Uncertainty Handling Policy (UHP, Table IV)

This features relates to how the game handles noticeable boundaries, breaks, or gaps among technology components (*i.e.* seams). This also includes handling breaks in the smoothness of user experience, due to inherent technology limitations in precision, accuracy, availability and other uncertainties. Some researchers [19], [29] have identified five general strategies to handle these issues:

- Remove: designing activities so that limitations never appear in the game. This includes using improved technologies (which is not always possible) or designing activities that fit the technology limitations into them;
- Hide: anticipating issues and "correcting" them before the player has a chance to face it. Contrary to the remove strategy, in this case the limitations appear in the game, but are "corrected" before the player notices them;
- Manage: includes having fall-backs to use when the primary mode of operation fails. In other words, the game adapts to the circumstances by having several modes of operation;
- Reveal: consists of presenting the limitations to users and letting them decide how to act. For example, mobile phones display the operator signal strength in the user interface;
- Exploit: means acknowledging the existence of issues and integrating them into the game as a feature.

The case study in Section V provides examples on using the *hide* strategy.

C. Local Space Redefinition (LSR, Table V)

This feature relates with how the game is able to change the meaning of the places where the game are played. By changing meaning, we denote augmenting value to places, incorporating the place (or objects belonging to the place) as game objects, integrating live (human) non-player characters, or making the players perceive the place with alternative viewpoints. This is different from just "being on a place", or using some property (like location) without referring to the local context.

D. Game Object Tangibility (GOT, Table VI)

This feature relates to how the game uses the mobile phone (and other environment elements) as tangible objects, instead of being mere terminals. As tangible objects, we mean that the device has a purpose (a role in the game) and the players manipulate devices as game objects instead of terminals (*e.g.* "only "phones). The device could also be disguised as another object through shells and other resources, as in REXPlorer [27].

E. Game Pacing (GP, Table VII)

This feature relates to how technology influences or limits the pacing of the game (or *vice versa*). For example, if pacing is high some sensor technologies might not work well [28], [29].

F. Involving Non-players (INP, Table VIII)

This feature relates to integrating non-players into the game. Some games might use this to create ambiguities about who is playing and who is not, creating what Montola and co-authors [2] have defined as "social expansion". This idea also relates to players having to discover who the other players are and meet them (physically). By doing so, players might have to approach strangers on public places, and then proceed to complete game activities. It is important to notice that involving non-players in the game might raise ethical issues.

Non-player participation can be passive or active. An example of passive participation is our prototype *Pervasive Word Search*, which uses other people's Bluetooth devices as a source of content. An example of active participation is *Uncle Roy all around you* [20], which uses actors to represent non-player characters.

G. Usability (Usa, Table IX)

This feature corresponds to traditional usability issues from Human-computer Interaction focused on mobile devices. Usability is a big research field, and detailing it is out of the scope of this work.

However, an aspect that caught our attention relates to designing activities that do not require players to constantly look at the mobile device screen. This relates to using multiple modalities for interacting with the player. For example, games

may explore audio and haptics feedback, as we did in [31], [32]. This issue especially concerns pervasive games as players might be moving in game activities. In this case, looking at the device screen might risk their safety, or may make them miss part of the game experience. Some authors refer to this approach as "design for 'heads-up' experience" [27]. Other examples of this concern are in [29] and [30].

H. Daily Life Interleaving (DLI, Table X)

This feature relates to how the pervasive game is able to become diffuse through daily life, enabling the player to integrate gaming sessions with other non-game activities.

I. Game Autonomy (GA, Table XI)

This feature relates to the game as being an independent system that does not require preparation for game sessions (like configuring the physical location) or in-game management by a support team. At the other end of this spectrum are *event games* – pervasive games that happen at specific time and physical places, for a specific duration, generally requiring dedicated infra-structure and a support team that works to keep player experience as smooth as possible, possibly intervening in the game to handle issues so players do not notice them.

J. Mobility (Mob, Table XII)

This feature relates to aspects of mobile computing – using wireless connections on mobile devices – and aspects related to the physical size of the game area, which may require players to move through far distances to complete game activities.

K. Cross-mediality (CM, Table XIII)

Cross-media games are games delivered through different devices or media, and each device offers a different mode of participation. This means that each device has a distinct role in the game. This is different from a game being available on multiple platforms, with the same functionality.

L. Persistency (Per, Table XIV)

Persistency refers to maintaining game state to be accessed through different game sessions over time. This feature is a requirement for games that aim at simulating a parallel world that evolve by itself. This includes all games that have social networking or community aspects. However, not all pervasive games require persistency.

M. Social Communication (SC, Table XV)

This feature relates to how the pervasive game is able to innovate in fostering social communication, acting as a medium for people to communicate. It includes means for communication between co-located people, distributed people, or both.

N. Conformance to Physical and Social Settings (CPS, Table XVI)

This feature relates to ethical and privacy concerns, conforming to social conventions, safety concerns (*e.g.* protecting players from harm while moving around), and adequacy to physical settings (*e.g.* relying on audio feedback on noisy places).

O. Connectivity (Con, Table XVII)

Connectivity may exist in global or local scope. Global scope refers to connecting to remote peers that are not in the same physical place. Local scope refers to connecting peers that are co-located. The connectivity scope directly relates to the space scope of the game. Global connectivity makes it possible for activities to happen in very different places, possibly very distant. In this case, the game space scope can be big. Local connectivity restricts activities to happen in places with more restricted size. This feature influences all pervasive features where obtaining remote information may be required.

P. Game Content Adaptability (GCA, Table XVIII)

This feature relates to pervasive games that are context-aware – generating content through sensors. It relates to how those games are able to adapt the gameplay regardless of the environment, while keeping the same (or expected) functionality.

V. CASE STUDY

This section describes how the pervasive features occur in a pervasive mobile game developed by the first author. We also outline which checklist questions are relevant to applying those features in the game. The full questions that this section references are in the checklist tables located in the Appendix.

Pervasive Word Search is a single-player pervasive mobile game developed by the first author in 2011 using the features and the checklists presented in this paper. In this section we present the most important requirements used to develop this pervasive game. The main goals we had were: 1) a game that could be played in current smartphones; 2) a context-aware game that retrieved as much content from the environment as possible using current smartphones; 3) a game that required no special setup (regarding infra-structure).

The goal of *Pervasive Word Search* is to find the letters from a word that the game draws. The player must explore the environment surrounding him to find the letters. While exploring the physical world, the player may interact with some game zones – the dark, open, and wireless zones. The "dark zone" is a place with "low" ambient light. An "open zone" corresponds to an outdoor area. A wireless zone corresponds to a place with a certain number of WiFi access points and Bluetooth devices. Interacting with these zones is an important part in this game.

The player is able to get letters by capturing colors with the device camera and interacting with the wireless and dark zones. For example, Fig. 2 illustrates a user playing the game with the word "REYNOLD" and points the device to a tennis shoe to capture a "gray" color – thus getting the letters "g", "r", "a", and "y", and eliminating "r" and "y" from the target word. The game identifies a finite set of colors: red, yellow, orange, green, purple, blue, pink, black, white, and gray. The player goes to wireless zones to get letters that do not exist in the basic color names (like "f", considering names in English). The player has a finite time to find all letters. Interacting with the game zones changes the game clock behavior. For example, if a wireless zone has lots of devices, the game clock runs slower. If the player is inside an open zone, the game clock runs faster. For more specific details on this game, the reader should refer to [26, Ch. 2.6].

A. Pervasive Features and Checklist Questions

1) Local Space Redefinition. The game defines conceptual zones – open zone, wireless zone, and dark zone. In this

Fig. 2. A player capturing a "gray" color in *Pervasive Word Search*.

regard, players are able to perceive physical places as "game zones" when they go to places that match the requirements of a specific game zone. Relevant question: LSR3.

2) Mobility. The game requires the players to wander around the physical world to find sources for letters. The game area is not limited. Relevant questions: Mob1, Mob3.

3) Uncertainty Handling Policy. The game applies the general strategy *hide* to handle uncertainties. For example:

- The colors are represented with a limited set of options. Similar "colors" are grouped with the same name (*e.g.* all variations of "red" are considered as "red");
- Bluetooth and WiFi queries are slow operations. It is also possible that some queries miss some devices, or return false positives. Thus, the game does not require real-time response to use this data. The interaction with those sensors is indirect – the game queries the sensors in the background and announces the results when they are ready.
- Game zone representation is ambiguous – the game does not display zone maps. Instead, the game just informs if the player has entered or left a game zone (*e.g.* the wireless, dark, and open zones).

Relevant questions: UHP1, UHP2.

4) Game Pacing. The pacing is compatible with the uncertainty handling policy. The game uses Bluetooth and WiFi network queries, which are slow operations, as part of the gameplay. In order to accommodate these operations gracefully, the game does not have activities that require fast responses from players. Relevant questions: GP1, GP2.

5) Game Autonomy. The game is autonomous as it does not require special setup in order to play it. Relevant questions: GA1, GA2, GA3.

6) Game Object Tangibility. The smartphone is a device to capture letters in the physical world, but the game does not assign a specific role to the device. In this regard, this feature does not apply to this game.

7) Game Adaptability. All the content that the game uses is generated from sensing the environment (except for the target word that comes from an internal database). The game can be played at any place where there are wireless networks, Bluetooth devices and colored objects. Relevant questions: GCA2, GCA4.

8) Involving Non-players. Non-players are passive from the game point of view. They participate in the game as sources of content, as their Bluetooth devices broadcast names that can be sources of letters. Relevant questions: INP1, INP3.

9) Social Communication. The game does not require players to approach/interact with those people. In this regard, this feature is not applicable to the game. However, if the player goes to areas with lots of people, the game clock might run slower, which would make the game "easier".

10) Connectivity. The game queries Bluetooth and WiFi networks, but does not establish remote connections. As the game uses networks only as a source of content, this feature does not apply to the game.

11) Device Independence. The game is limited to Nokia smartphones running Symbian/Qt (the game was developed in 2011). Relevant question: DI1.

12) Daily Life Interleaving. The game requires a dedicated game session, so this feature is not applicable.

13) Cross-mediality. The game offers just one mode of participation, so this feature is not applicable.

14) Persistency. The game does not store data between game sessions, so this feature is not applicable.

15) Usability and *Conformance to Physical and Social Settings.* Evaluating these features requires other studies involving several users and specific usability research techniques, which is not in scope of the present paper. Hence, they were not evaluated for this game.

VI. CONCLUSIONS

Pervasive games are a recent form of entertainment that propose bringing the game experience out of a game device. This means a shift from traditional digital games to a games that incorporate elements of context-awareness, integration of physical and virtual worlds, mobility, playing in unconstrained game areas, increased social interaction, among others.

Research on pervasive games has attracted people with different backgrounds, as computer science, game studies, design, and theater, which produces a rich discussion about this topic but also a confusing scenario. The end result is that the discussion on pervasive games is too broad, especially regarding formal definitions of pervasive games.

The authors of the present work were interested in developing pervasive games using mobile devices. As a first step towards this goal, we approached the area to find out what pervasive games were and to find guidelines about pervasive game development. After discovering the broadness of the research field on pervasive games, we started investigating this area to find features that contribute to the uniqueness of this kind of game. We also started this investigation because the literature on pervasive features is scarce. Also, from a Software Engineering point of view there are no dedicated works addressing guidelines and formalisms for pervasive games.

We started our research by limiting the scope of possible pervasive games to a subset of games we were interested in – the "pervasive mobile games". We have investigated 24 pervasive mobile games and included the experience of the first author in developing mobile games using sensors, which resulted in an initial list of 16 features and corresponding checklists. Our results represent a modest step in the area of pervasive mobile games, which requires deeper investigations.

In the current form, we see these results as a pragmatic roadmap to navigate on the sea of pervasive mobile games. These results can help game developers in the following ways: 1) a resource to spark novel game ideas; 2) a language to talk about pervasive mobile games and their characteristics; 3) a starting point to discover functional and non-functional requirements for pervasive mobile games; 4) a starting point to find other relevant features in pervasive mobile games. As future works, we foresee the need of refining and validating the features with more games and designers.

ACKNOWLEDGMENTS

The authors thank CNPq, FAPERJ, FINEP, and CAPES for the financial support to this work.

APPENDIX

This appendix presents the checklist of each pervasive feature that Section IV describes.

TABLE III. CHECKLIST FOR DEVICE INDEPENDENCE

No.	Question
DI1	Is it possible to play the "same" game on multiple mobile device platforms?

TABLE IV.CHECKLIST FOR UNCERTAINTY HANDLING POLICY

No.	Question
UHP1	Which strategy does the game use to handle technology limitations?
UHP2	How does the game handle technology limitations?
UHP3	Does technology correctly acknowledge physical world limits?

TABLE V. CHECKLIST FOR LOCAL SPACE REDEFINITION

No.	Question
LSR1	Does the game integrate physical places (or their elements) in the gameplay?
LSR2	Does the game give roles to physical places (or their elements) in the gameplay?
LSR3	Does the game help players to have alternative views of the physical environment?
LSR4	What physical resources does the game use as game elements?
LSR5	Does the game use "live characters" to reinforce the mixed-reality overlay?
LSR6	How do game activities affect the physical world?

TABLE VI. CHECKLIST FOR GAME OBJECT TANGIBILITY

No.	Question
GOT1	Does the game specify a role for mobile phones in the game, or are they mere access terminals?
GOT2	How does the game transform mobile phones into game objects?
GOT3	Does the game use other physical objects (other than mobile phones) equipped with sensors or actuators as game objects?
GOT4	Does the game use mobile phones as multiple props?
GOT5	How does using tangible objects improve player socializing in the game?

TABLE VII. CHECKLIST FOR GAME PACING

No.	Question
GP1	Is the technology the games uses compatible with the game pacing?
GP2	Do game activities adapt their pacing to accommodate technology limitations in this regard?
GP3	Does the pacing of game activities require the player to focus exclusively on the game? For how much time?

TABLE VIII. CHECKLIST FOR INVOLVING NON-PLAYERS

No.	Question
INP1	Does the game involve non-players? How does it do it?
INP2	Does the game have activities where players need to find out who the other players are?
INP3	Does the game generate/use content that is based on other (non-player) people?
INP4	Does the game use actors for non-player characters?

TABLE IX. CHECKLIST FOR USABILITY

No.	Question
Usa1	Do game activities require players to focus on the device screen too much?
Usa2	Do game activities use various modalities to interact with the player?

TABLE X. CHECKLIST FOR DAILY LIFE INTERLEAVING

No.	Question
DLI1	Does the game provide a persistent game world?
DLI2	Are game activities designed to be interruptible?
DLI3	Do game activities require long time commitment from players?
DLI4	Which approaches or techniques does the game apply to blend with daily life?
DLI5	Does the game provide equal opportunities for playing in any time?
DLI6	How does the game communicate game-related events to players?

TABLE XI. CHECKLIST FOR GAME AUTONOMY

No.	Question
GA1	Is the game bound to specific places or local context?
GA2	Does the game require configuring the physical space for a game session?
GA3	Does the game require any kind of supervision when players are playing it?
GA4	Does the game require custom hardware, actors, or other kind of related resources?

TABLE XII. CHECKLIST FOR MOBILITY

No.	Question
Mob1	Does the game need to use networking while the players are moving? If yes, how does the game handle networking limitation issues?
Mob2	Does the game depend on specific locations to be played? Are players required to move between specific locations?
Mob3	What is the order of magnitude of the potential game area? Does the game require players to walk long distances?
Mob4	How does the game keep physical player locations consistent within the game world?

TABLE XIII. CHECKLIST FOR CROSS-MEDIALITY

No.	Question
CM1	Does it make sense for the gameplay to include multiple devices with different roles? Does the game allow different modes of participation?
CM2	Does the game balance the game experience for the various specialized devices?
CM3	When using devices for multiple platforms (*e.g.* desktop, mobile), do the game activities have compatible paces, so as not to break the gameplay?

TABLE XIV. CHECKLIST FOR PERSISTENCY

No.	Question
Per1	Do game sessions depend on previous sessions or stored data?
Per2	Does the game support internal social networks or communities?

TABLE XV. CHECKLIST FOR SOCIAL COMMUNICATION

No.	Question
SC1	How does the game use technology to provide means to improve communication among people?
SC2	How does the game transform the relationships among players?
SC3	Does the game stimulate players to approach/start interactions with other people?
SC4	Does the game use technology to foster community/social networks forming?
SC5	Does the game present emergent gameplay?

TABLE XVI. CHECKLIST FOR CONFORMANCE TO PHYSICAL AND SOCIAL SETTINGS

No.	Question
CPS1	How does the game handle player privacy?
CPS2	Do game activities possibly disturb non-players?
CPS3	Do game activities expose players (or non-players) to embarrassing situations?
CPS4	Do game activities conform to local social conventions/etiquette?
CPS5	Are game activities adequate to the physical setting of the game?

TABLE XVII. CHECKLIST FOR CONNECTIVITY

No.	Question
Con1	What are the connectivity requirements for the game? Global? Local? None?
Con2	How does the game handle uncertainties related to connectivity?
Con3	What is the desired space scope for game activities?

TABLE XVIII. CHECKLIST FOR GAME CONTENT ADAPTABILITY

No.	Question
GCA1	How does technology availability affect the game content and the player experience?
GCA2	Does context usage require players to move more in the physical world?
GCA3	Does context usage affect accessibility[a]?
GCA4	Are players able to play the game in various places without manual intervention/re-installation/re-adaptation/orchestration?

[a] We consider "accessibility" as how players are able to access the game, including: 1) social issues (*e.g.* people with disabilities, gender-biased content); 2) economic issues (*e.g.* expensive devices, services, or technology); and 3) technological issues (*e.g.* technical constraints, technology not widespread).

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