A systematic review on software engineering in pervasive games development

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Abstract

A digital pervasive game can be defined as a game in which the gaming experience is extended to the real world. This is possible due to the use of sensor-based mobile devices. Developing digital pervasive games involves additional requirements, such as dealing with ubiquitous computing challenges. Part of these requirements affect directly the design and development processes of pervasive games. Software Engineering techniques should be adapted to increase the overall quality of game software. The main objective of this paper is to present a systematic review of this area in order to capture the state of the art research in Software Engineering for Pervasive Games. A standard systematic review methodology using digital databases for research was applied and 100 relevant studies were found within 1304 obtained from searches. We were able to identify the main topics of pervasive games research area in the last five years, the most relevant research methodologies, topics and challenges in terms of numbers for pervasive games research field.

Keywords: Pervasive games, Software engineering, Game development, Systematic review

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1 Introduction

From the union of pervasive computing and digital games, the pervasive games area arises. According to [Montola et al. 2009], pervasive games are a curious form of culture, as they exist at the intersection of urban phenomena, such as cities culture, mobile technology, fiction, reality, and performing arts combining different contexts to produce a new kind of games.

Unlike traditional games, which take place in a virtual world, pervasive games combine the physical and virtual worlds by integrating information and communication technologies of mobile devices to generate new types of gaming experiences [Kuehn and Sieck 2009]. The more context information of player context could be captured, the integration of the game with the real world will be greater. [Buzeto et al. 2012] says the ubiquitous computing (or "ubicomp", for short) vision of an enhanced computed environment becomes a closer reality each day. Thus, it is necessary to develop better ways to create games of this type.

As shown in [Trinta 2007], a generic definition of context, defined by [Dey 2001], would be "...any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and the application itself".

For a pervasive game, [Becam and Nenonen 2008] mentions some information that might be part of the context, for example, weather information such as temperature, wind, humidity, rain and clouds, and man made urban phenomena like pollution, traffic, movement people, and public transportation. Some context information may be also calculated, such as sun's position simply by knowing the location of the player.

These are just a few examples, but any information that can be captured to enhance the player's experience is part of the context, such as location, screen size, screen layout (vertical or horizontal), ambient light, among others. All these information is easily captured by current smart phone devices.

Thus, context awareness is an important feature for pervasive games, i.e. games that adapt themselves to different context conditions. Even [Becam and Nenonen 2008] mentions that the use of context data by a game is a sufficient condition for it to be considered a pervasive game.

Pervasive games's features arises many challenges that must be addressed in its development. [Wietrzyk and Radenkovic 2007] presents challenges such as high turnover, cheating, heterogeneity of devices and platforms, network costs and disconnections.

Also, [Thomas 2006] presents some key philosophical concepts that must be taken into account when designing pervasive games. Additionally, in [Guo et al. 2010], there is a description of a framework, called "TeMPS", named for the four identified perspectives and that are also part of the pervasive game design: temporality, mobility, perceptibility and sociability. Finally, [Chatzigiannakis et al. 2010] lists some factors that are required for the implementation of a pervasive game.

With this, we can see a lot of challenges that must be tackled in the process of creating a pervasive game. It is important to note that, depending on the game genre, some features may lose importance over others. For instance, in a massive multiplayer pervasive game, communication issues are often treated with greater importance than interface issues.

That said, the purpose of this study is to conduct a systematic review aiming at identifying the techniques that have being used in pervasive games development. A systematic review is a specific methodology of research, developed in order to gather and evaluate the available evidence pertaining to a focused topic [Biolchini et al. 2005]. Thus, the choice of this kind of study helps us to understand the initiatives made in this area in recent years.

In the next section, we will present how the systematic review was performed and how the results were collected, which was based on a previous work [Brereton et al. 2007]. In section 3, findings based on our review requirements will be presented in statistical format. In Section 4, an analysis of key areas found in the review will be made. Section 5 finishes up the paper, conclusions and future work of this research are presented.

2 Review methodology

Just as [Ampatzoglou and Stamelos 2010], our systematic review was divided into three main phases: planning, conducting and reviewing documentation. Each of these phases has been subdivided into sub-phases, according to the purpose of each.

The planning phase is where we define the review objectives, who should be sought and how to validate the studies to be obtained. As sub-phases this stage, we had:

- **Research questions specification:** Here, we defined the heart of the review, and specified which issues the results should answer;

- **Review protocol development:** At this stage, we determined which search engines and databases would be used, the cri-

teria for inclusion and exclusion of studies in the review, the works quality assessment, which data would be extracted from each job and classification for selected studies;

- **Review protocol validation:** At this time, we revised the protocol defined in the previous phase in order to ensure their consistency.

The next phase is the conduction, where the protocol is performed. At the end, a list of items is obtained with all necessary data extracted and classified. Sub-phases of this step were, as follows:

- **Primary studies selection:** At this stage, we perform searches in established mechanisms in review protocol;

- **Studies quality assessment:** Here, studies which were not consistent with the quality criteria were excluded;

- **Extraction of required data:** With selected studies, we extracted important data defined in review protocol;

- **Data synthesizing:** At this point, we set up tables and comparison charts with the extracted data.

The last phase was the documentation, in which the synthesized data could be compared with other studies such as [Ampatzoglou and Stamelos 2010], who made a systematic review of the software engineering application in traditional games development. Sub-phases of this phase were:

- **Write the report of the review**: The synthesized data were organized in the form of a report;

- **Validation Report:** The report was submitted for review from other contributors to verify its quality.

In the following subsections, we describe in detail each sub-phase of the review planning and execution, showing what decisions were taken in each moment described above.

2.1   Research questions

Since this study objective was to identify the software engineering techniques that have being used in pervasive games development, the research questions followed the same idea from the previous review presented in [Ampatzoglou and Stamelos 2010]. The questions were as follows:

1. What is the intensity of research activity in software engineering methods for developing pervasive games?

2. What research topics of software engineering are being addressed in pervasive games field?

3. What research approaches in software engineering researchers use in pervasive games field?

4. What empirical methods of research in software engineering researchers use in the field of pervasive games?

To answer the first question, we extracted the year of each publication. As a result we had a graph showing the evolution year by year of the publications number in this area. Coupled with this data, we were able to compare the evolution of research in software engineering published in [Glass et al. 2002] and software engineering for games, shown in [Ampatzoglou and Stamelos 2010].

To answer the other questions, it was necessary to associate each paper with a software engineering research area, a research approach, and an empirical research method. The classification was chosen based on the Computing Classification System, where we used the 2008's version for comparison with this study [Ampatzoglou and Stamelos 2010] and [Glass et al. 2002]. These questions are explained in sections 2.4.1 and 2.4.2.

2.2   Search process

The process of searching for a systematic review should first identify the main sources of possible data. Being a new area, there are no specific conferences or journals in software engineering area for pervasive games. However, we performed searches using the traditional software engineering and "entertainment computing" areas, so as did [Ampatzoglou and Stamelos 2010]. Thus, dominant publishers that can be chosen where they can be picked relevant papers are ACM (Association for Computing Machinery), IEEE Computer Society (IEEE) and Springer.

The best way of searching papers in these databases is by the automated search available in correspondent digital libraries. Thus, we chose ACM[1], IEEE[2], Springer[3] and, additionally, Scopus[4], Science Direct[5], and Engineering Village[6] aggregators, which could return relevant results not observed in the first group.

The search in each of these digital libraries was based on keywords, which were defined according to the research questions specified. Our search string was defined with three basic components that comprise the chosen topic: "games", "software engineering", and "pervasive computing". Thus, in all search engines we created strings with these three components, where keyword "game" should appear in the paper title. At least one keyword related to software engineering (engineering, software design, or development) should appear in the abstract. Finally, words related to pervasive computing (ubiquitous, pervasive, context-aware, context sensitive, or location based) should also appear (at least one) in the abstract.

Regarding languages, this review included English, Spanish and Portuguese languages, so that relevant research done in other languages could also be found. Nevertheless, the majority of studies found were written in English. With the criteria of how and where they would be made searches defined, it was possible to collect the relevant papers in the three languages chosen. At this stage, 1304 papers were returned that may or not be directly addressing the central research theme of this review. Thus, inclusion and exclusion criteria were used to filter those works and reduce this set to relevant papers only. These criteria are described in section 2.3. The list of 1304 papers found in our searches can be viewed at (`http://systematicreviewer.herokuapp.com/reviews/1/public`).

2.3   Inclusion and Exclusion criteria

Despite all items returned by the search having all the chosen keywords, it was expected that many of them do not directly address issues related to software engineering for pervasive games. At this point, the inclusion and exclusion criteria defined in our review protocol in planning step, would guide the choice of the really relevant items.

The exclusion criteria used following rules:

- **Based on the title:** The simplest criteria, where the title of each paper was read and judged important or not to the review area;

- **Based on the abstract:** If the title was not enough, we read the summary to verify paper adherence to the review;

- **Based on full text:** Finally, if the title and abstract were not enough, we read the whole paper to get a clear view of work and judge if the item should included in the review or not.

In this process, some auxiliary criteria helped to quickly delete non-relevant paper to review. They were:

- **Artificial intelligence theme:** Papers have focused on the use or development of mechanisms for artificial intelligence;

- **Social impact of gaming theme**: Papers assessing or applying games giving a social context to it;

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[1]https://dl.acm.org/
[2]http://ieeexplore.ieee.org/
[3]http://link.springer.com/
[4]http://www.scopus.com/
[5]http://www.sciencedirect.com/
[6]http://www.engineeringvillage.com/

- **Game-based learning theme:** Papers oriented to implement games as a way of learning and pedagogical focus on criteria for evaluation;

- **Networks theme:** Focused on developing and evaluating communication in games, not necessarily as a way to help in the development;

- **Computer graphics theme:** Works with rendering of scenes or performance improvements in graphics generation thematic;

- **Short paper or poster (less than 4 pages):** Even though the paper would fit the theme, short papers (or porters), less than 4 pages, were excluded from the review.

Inclusion criteria used the following rules:

- **Identifying relevant studies:** This criteria is equivalent to performing the search in mechanisms as defined in Section 2.2;

- **Related topics of software engineering research:** First it was checked if the paper theme is related to software engineering;

- **Journal paper:** It was verified if the paper was published in a journal;

- **Full Conference paper:** In this criteria, it was verified if the paper was published in a conference as a full paper;

- **Workshop paper:** Papers published in workshops were also considered.

After applying the first exclusion criterion (based on the title), the initial sample (1304 papers) was reduced to 604 papers. Evaluating based on the second criterion (based on abstract), 193 papers left. Evaluating based on full text (third criterion), 100 papers were finally selected (shown in appendix A). At the final stage, the auxiliary exclusion criteria were also used to evaluate the papers, and duplicated ones were excluded. Using these inclusion and exclusion criteria ensured the quality of the final set of 100 papers, allied to the bases that were used to find them. A possible issue in our study was the decision to included workshops papers in our selection stage, but the inclusion of such papers is justified to the extent that it is expected that future research trends are and that soon they are published in journals or conferences. Figure 1 illustrate this execution of search process.
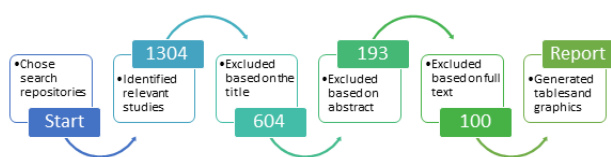

Figure 1: *Search process execution*

2.4 Data collection

With the items returned from the selection stage, and filtered by the inclusion and exclusion criteria, the next step was to extract important data from each paper to answer the questions formulated in the planning stage. For this, data listed below were extracted from the papers:

- **Type:** If the paper was published in a journal, conference or workshop;

- **Published:** What is the conference or journal name in which the paper was published;

- **Publisher**: What publisher is responsible for the paper;

- **Year of publication:** In what year the paper was published;

- **Country and continent:** Which country and continent authors (their affiliation) belong;

- **Research topic:** What research topic the paper is about, as defined in section 2.4.1;

- **Research approach:** What kind of research approach was used in the paper, as explained in section 2.4.2;

- **Research method:** The research method of the paper, as listed in section 2.4.2.

In the following subsections, we detail the choice of topics, approaches, and methods for papers classification, given the first items are extracted are self-explanatory.

2.4.1 Classifying topics

Topical classification of the papers were chosen based on [Ampatzoglou and Stamelos 2010]. In this research, the classification used was defined by the ACM, the ACM CCS[7] (Computing Classification System), which is already used in several conferences and journals. However, as [Ampatzoglou and Stamelos 2010] is a paper from 2010, the 2008 version of the classification scheme was used. In our research we used two versions of ACM CCS: the 2008 version, aiming to compare with the results from [Ampatzoglou and Stamelos 2010] and the 2012 version, being the latest version.

Within the classification of ACM CCS trees we selected areas related to software engineering. Table 1 shows the selected topics of ACM CCS 2008 to classify papers:

Table 1: *ACM CCS 2008 software engineering topics*

ID	Topic
D.2.0	General / Miscelaneous
D.2.1	Requirements / Specification
D.2.2	Design tools and techniques
D.2.3	Coding tools and techniques
D.2.4	Software/program verification
D.2.5	Testing and debugging
D.2.6	Programming environments
D.2.7	Distribution, maintenance and enhancement
D.2.8	Metrics
D.2.9	Management
D.2.10	Design
D.2.11	Software architecture
D.2.12	Interoperability
D.2.13	Reuse

Table 2 shows the topics chosen from the ACM CCS 2012 to classify the papers. In this case, we chose the sub-tree called "Software and its engineering" of ACM CSS 2012 and its sub-trees.

2.4.2 Research approaches and methods

According [Glass et al. 2002], papers can be characterized according to their approach and search method. Our work uses the same approach, and the classification from [Glass et al. 2002] was used in our review, as well as in [Ampatzoglou and Stamelos 2010].

The main categories of scientific approach listed in [Glass et al. 2002] are:

1. **Descriptive:** Research which describes a system, a tool or method. Literature reviews are also fall into this category;

2. **Exploratory:** Research in which the problem is still not clearly defined. This kind of research helps determine the best research design, method of data collection and selection of subject;

3. **Empirical:** Results which were produced through direct or indirect observations of real subjects.

If an empirical approach used was used, there are three main methods that can be used to observe the ongoing research and their results [Wohlin et al. 2000]. They are:

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[7]http://www.acm.org/about/class/

Table 2: *ACM CCS 2012 software engineering topics*

ID	Topic
1	Software organization and properties
1.1	Contextual software domains
1.2	Software system structures
1.3	Software functional properties
1.4	Extra-functional properties
2	Software notations and tools
2.1	General programming languages
2.2	Formal language definitions
2.3	Compilers
2.4	Context specific languages
2.5	System description languages
2.6	Development frameworks and environments
2.7	Software configuration management and version control systems
2.8	Software libraries and repositories
2.9	Software maintenance tools
3	Software creation and management
3.1	Designing software
3.2	Software development process management
3.3	Software development techniques
3.4	Software verification and validation
3.5	Software post-development issues
3.6	Collaboration in software development
3.7	Search-based software engineering

1. **Experiment:** A task is assigned to a set of individuals perform in a controlled environment. The results are derived from observations during execution inspecting the task or questions from individuals after the tasks;

2. **Survey:** A questionnaire is placed for a range of subjects respond directly or via internet. The results are derived from the responses raised by individuals;

3. **Case Study:** A project, activity, or task is monitored with respect to the method under study.

Each paper was evaluated primarily with respect to the research approach. When the paper is framed in empirical approach will be evaluated which method of research was used in the work.

2.5 Data analysis

The 100 papers resulting from the searches were assessed according to each of these criteria in order to obtain the following statistics:

- Number of studies published per year (to answer Question #1).

- Number of papers published in journals, conferences and workshops, to obtain the locations of most active publishing (yet answering the Question #1).

- Number of studies that each country and continent has produced in recent years (also to answer Question #1).

- The topics of software engineering addressed by most researchers in this area (to answer Question #2).

- The number of studies following each approach and research method (responding to the Questions #3 and #4).

3 Results

In this section we present the results of the statistical analysis of the selected items set and evaluated according to the criteria defined. Some of these statistics are compared with [Ampatzoglou and Stamelos 2010] to get an idea of the evolution of research in software engineering for pervasive games in parallel with the development of research in software engineering for games.

Table 3 shows the quantities of papers per year and by publication type (workshop, conference, or journal). There has been a growth in number of publications related to software engineering for pervasive games in recent years and a predominance of publications in conferences, which were published 71% of the papers chosen. In Section 4, by Figure 2, we did a comparison of these figures with those of [Ampatzoglou and Stamelos 2010] and [Glass et al. 2002].

Table 3: *Papers by year and type*

Year \ Type	Workshop	Conference	Journal	Total
2004	0	2	0	2
2005	0	2	0	2
2006	2	3	1	6
2007	1	7	2	10
2008	1	6	1	8
2009	0	11	0	11
2010	0	12	1	13
2011	3	11	4	18
2012	2	8	6	16
2013	1	9	4	14
Total	10	71	19	100

Table 4 shows where most studies were found in this review, whether conferences or journals. In this table are included only those that had more than on published paper. More than half (60) of the papers were published in different places, showing that the idea posed at the beginning of this study that there is no particular place to work in software engineering applied the pervasive games was correct. All paper data an your classification can be found in `http://systematicreviewer.herokuapp.com/reviews/1/all_papers`.

Table 4: *Main journals and conferences*

Name	Papers
Personal and Ubiquitous Computing	7
International Conference on Advances in Computer Entertainment Technology	6
International Conference on Digital Games Research Association	5
Nordic Conference on Human-Computer Interaction	2
International Conference on Digital Game and Intelligent Toy Enhanced Learning	2
International Conference on Interaction Design and Children	2
International Conference on Intelligent Environments	2
International Academic MindTrek Conference	2
International Conference on the Foundations of Digital Games	2
Computers in Entertainment	2
Conference in Games and Virtual Worlds for Serious Applications	2
Workshop on Network and System Support for Games	2
International Symposium on Mixed and Augmented Reality - Arts, Media, and Humanities	2
International Conference on Fun and Games	2

Table 5 shows the number of papers per publisher, which shows that almost half of the papers came from ACM publications, followed by IEEE and Springer. It is worth mentioning the presence of DIGRA[8] (Digital Games Research Association), an association focused on research in games which ended up good presence among the resulting papers, suggesting that it may be a trend publications of the issue addressed here in its conferences or journals.

Table 6, we have statistics publications by country, according to the affiliation's country of principal author in each paper. Here, we see that most research activity in this area is in Germany, accounting for 15% of searches, followed by the USA (11%) and the UK (10%). In this table also the countries with only one publication in the period were omitted.

In Table 7, we have the statistic of works by research themes in ACM CCS 2008. From these data, in section 4 will be a compari-

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[8]http://www.digra.org/

Table 5: *Papers by publisher*

Publisher	Papers
ACM	41
IEEE	25
Springer	21
DiGRA	6
Elsevier	1

Table 6: *Papers by country*

Name	Papers
Germany	15
USA	11
United Kingdom	10
Finland	9
Sweden	6
Greece	5
Italy	5
Netherlands	5
China	4
Brazil	4
Portugal	4
Japan	3
Taiwan	2
Canada	2
Australia	2
Ireland	2

son with systematic reviews [Ampatzoglou and Stamelos 2010] and [Glass et al. 2002]. The main areas used as research subjects were "Design" with 29% of the cases and "Design tools and techniques" to 25%.

Table 7: *Papers by research topic (ACM CCS 2008)*

Topic	Papers
D.2.0 - General / Miscelaneous	8
D.2.1 - Requirements / Specification	6
D.2.2 - Design tools and techniques	25
D.2.3 - Coding tools and techniques	17
D.2.4 - Software/program verification	1
D.2.10 - Design	29
D.2.11 - Software architecture	10
D.2.12 - Interoperability	2
D.2.13 - Reuse	2

In Table 8, we have the statistic of papers by research themes in ACM CCS 2012. Based on these data we make a further analysis of each research topic in section 4. It should be noted that the most researched areas are "Software Designing" and "Extra-functional properties", with 33% and 20% of papers, respectively.

Table 8: *Papers by research topic (ACM CCS 2012)*

Topic	Papers
Designing software (3.1)	33
Extra-functional properties (1.4)	20
Development frameworks and environments (2.6)	16
Software development techniques (3.3)	16
Contextual software domains (1.1)	4
Software development process management (3.2)	3
Software system structures (1.2)	3
Software functional properties (1.3)	2
Software verification and validation (3.4)	1
Software post-development issues (3.5)	1
Collaboration in software development (3.6)	1

Table 9 shows the classification according to the research method used in the papers. In this case, there is a great use of empirical approaches, with 62% of the cases, showing that the research in this area tend to be based more on practice than on theory.

Table 9: *Papers by research approach*

Research Approach	Papers
Descriptive	25
Empirical	62
Exploratory	13

From the papers that use empirical approach, the classification was made according to the research methods listed on Table 10. The most widely used empirical method was case study, with 46.7% of the cases.

Table 10: *Papers by research methods*

| Empirical Research Methods	Papers
Case study	29 / 62
Experiment	15 / 62
Survey	18 / 62

4 Discussion

In this section, we present answers and discussion related to the research questions shown in section 3. The results are compared with studies [Ampatzoglou and Stamelos 2010] and [Glass et al. 2002]. We chose them since their works are closely related with the themes developed in this study. The work of [Ampatzoglou and Stamelos 2010] would be a subset of [Glass et al. 2002] and our study could be understood as a subset of [Ampatzoglou and Stamelos 2010]. Each subtopic below corresponds to the discussion of each of the research question.

4.1 Research intensity

The results in Table 3 show that interest in research in software engineering for pervasive games has increased in recent years. Figure 2 shows a comparison of the growth of this area in his early years with the growth reported by [Ampatzoglou and Stamelos 2010] in the areas of software engineering for games and traditional software engineering.

This figure shows the growth of the area over the years. To achieve this growth, the rate was calculated each year by dividing the number of papers found in the current year by the number of papers found in the first year of the sequence. Thus, the three areas start at value 1 (one).

We notice that the area of software engineering for pervasive games have quite a similar growth with engineering software for traditional games, with only a slightly higher rate of growth. The two areas have rates higher than the traditional software engineering growth. Despite the comparative chart does not showing, in three subsequent years the curve again increases (2009 to 2011) and there is a small fall in the following two years (2012 and 2013), as can be attested by the data in Table 3.
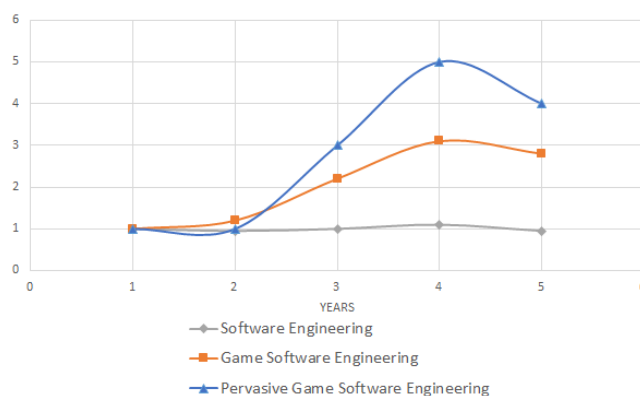
Figure 2: *Scientific domain research activity increase*

We can also compare with [Buzeto et al. 2012], a study that shows the pervasive games developed in recent years, focusing only in papers that describe some aspects of the game, showing how many of these papers were published each year. Figure 3 shows a higher growth papers showing pervasive games than those that focus on software engineering for the same. There is an intersection between the sets of papers in two studies, but most of the considered publications are different. It is noteworthy that, in the graph, were placed only years where two studies have numbers.
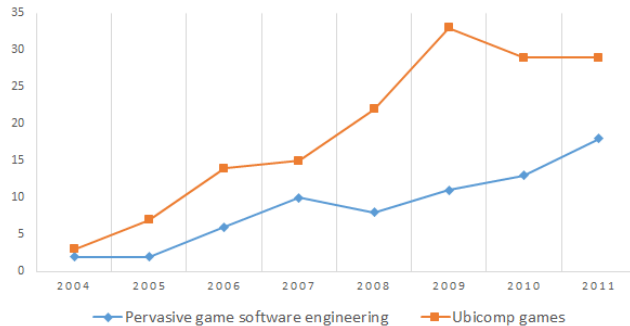
Figure 3: *Comparision with [Buzeto et al. 2012]*

4.2 Research topics

In this section we discuss about the major research topics addressed in review selected papers. We will also do a comparative analysis with the results obtained by [Ampatzoglou and Stamelos 2010] and [Glass et al. 2002].

According to Table 8, the topics most discussed, following the ACM CCS 2008 were "Design" (D.2.10) at 29% of papers and "Design tools and techniques " (D.2.2) at 25%. On the other hand, important software engineering topics such as "Testing and debugging", "Programming environments" and "Distribution, maintenance and enhancement" were not even addressed. The topics "Software/program verification", "Interoperability", and "Reuse" are underexplored, with small number of publication.

Figure 4 shows a comparison of these numbers with those of software engineering for games and the traditional software engineering. Each column represents the number of publications in software engineering theme showed in Table 1. It also indicated a similar trend with that of traditional games, except the themes "Design tools and techniques" (D.2.2) and "Design" (D.2.10), where pervasive games has well greater numbers and "Requirements / Specification" (D.2.1) where traditional games grew more.

With respect to ACM CCS 2012 topics, Table 8 shows that the most discussed topics in the papers were "Designing software" (3.1) and "Extra-functional Properties" (1.4). Themes like "Formal language definitions" (2.2), "Software libraries and repositories" (2.8) and "Software maintenance tools" (2.9) were not mentioned.

4.2.1 Contextual software domains

This topic was addressed by four papers [S5, S12, S57, S89]. First, [S5] presents an analysis of the mixed reality games paradigm, showing the main characteristics of this kind of games. In [S12], the author focuses on the issues related to location-based games. Characteristics such as scalability, heterogeneity of multimedia data, replication and consistency are addressed in [S57] as a way to support context-aware games. Finally, [S89] redesigned the classic game "Snake" as a context-sensitive game, by proposing a location-based version of the this game, in which users can control the snake by walking.

4.2.2 Software system structures

Three papers were about software system structures [S37, S74, S83]. For instance, the work [S37] proposes a middleware for crossmedia games; [S74] identified patterns of interaction design

for augmented reality games; and [S83] developed an architecture for collaborative ubiquitous games.

4.2.3 Software functional properties

Only two papers address the theme of software functional properties [S10, S79], which address topics like synchronization, functionality, real-time schedulability, among others. In these works, the idea was working features that aided in the purpose of each game, first a report tool for crossmedia games [S10] and elements to support learning from the game [S79].

4.2.4 Extra-functional properties

One of the more often approached studied areas, extra-functional properties was setted to 20 papers [S9, S16, S17, S28, S36, S41, S42, S52, S53, S54, S55, S60, S61, S73, S78, S80, S81, S88, S94, S96]. In most cases the paper focuses on usability issues, as in [S16] that addresses the use of non-visual interfaces in pervasive games, [S55] investigates the applicability of usability and gameplay heuristics in pervasive games, [S41] that makes recommendations for design of interfaces for pervasive games based on augmented reality and [S94] that addresses user interfaces for pervasive games and its implication in development.

There are also other non-functional properties addressed in the selected papers. [S52] is concerned with increasing the user immersion. They suggest a mapping of the real life player's avatar in the game. [S54] establishes interoperability standards for pervasive games. [S73] investigates the perception of the players on the sharing of in-game content. [S80] suggests a game that influence on energy savings in the work environment of the player. [S96] seeks to reveal the ambiguity of the system or infrastructure to a player, by introducing additional and deliberate ambiguity in how information is presented and revealed to players.

4.2.5 Development frameworks and environments

Sixteen papers addressed the topic development frameworks and environments [S3, S11, S15, S21, S26, S35, S43, S45, S46, S47, S49, S56, S76, S87, S92, S98]. Most suggest frameworks supports the development of pervasive games. Some of them focus on specific types of pervasive games, as [S3] which suggests a framework based on cloud gaming related to obesity and [S15] establishes a framework for exercise games. Still others have a more general theme such as [S43, S45, S47, S49, S87] that create frameworks for developing games with pervasive characteristics. Finally, some addressing certain aspects of pervasive games, as [S21] proposes a framework for the use of RFID (Radio-Frequency IDentification) in pervasive games, [S46] with a framework that focuses on the use of sensors and actuators in pervasive games and [S76] provides a framework that provides generic contexts for pervasive games.

4.2.6 Designing software

The vast majority of papers addressed issues relating to design pervasive games [S1, S6, S18, S20, S22, S23, S25, S29, S30, S33, S34, S38, S48, S50, S51, S59, S62, S63, S64, S66, S67, S68, S69, S70, S71, S72, S84, S85, S86, S90, S91, S93, S100]. Of these 33 selected papers, much of the work develops a pervasive game and shows aspects of its design, which varies greatly depending on the game goal. For example, [S1] develops the design of a game to show possible design problems in this type of games, [S22] addresses the design of a game for rural tourism, [S29] and [S30] incorporate elements of the real world in design of pervasive games and [S91] shows the design of a game that evolves according to the media types that the player interacts.

Other papers discuss more general aspects of designing pervasive games, such as [S48] lists design guidelines for the location sensitive games based on classic board games, [S69] shows that design challenges for developers and players, [S89] shows theoretical implications and methodological of location-based pervasive games design and [S90] sets design standards regarding the gameplay of pervasive games.
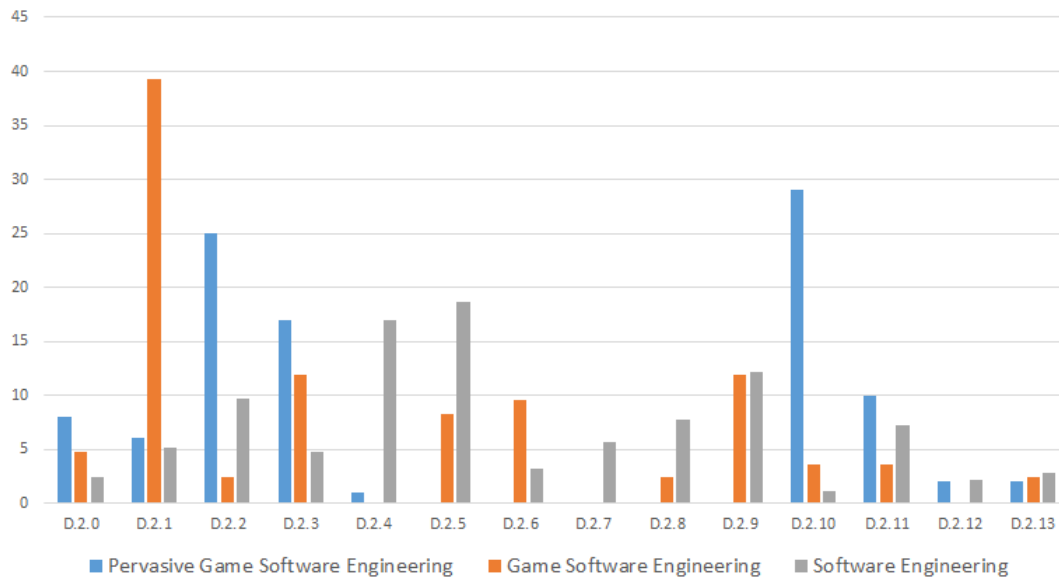
Figure 4: *ACM CCS 2008 Research topics*

Finally, [S68] shows a report of the state of the art concerning design aspects of pervasive games, making a systematic study of the major projects of current pervasive games and extracting and comparing its key design features.

4.2.7 Software development process management

Only three papers were classified in this category [S14, S82, S97]. [S14] focuses on the use of design patterns for the pervasive games implementation; [S82] provides a standard for converting computer games to pervasive games based on technologies such as WSN (Wireless Networks System), RFID, GPS (Global Positioning System), among others; and [S97] discusses the use of prototyping since the beginning of pervasive games development.

4.2.8 Software development techniques

In this category, sixteen papers [S2, S4, S7, S8, S13, S19, S24, S27, S31, S32, S44, S58, S75, S77, S95, S99] were identified. [S7] shows the development of a pervasive game based on wearable technologies, [S13] explains how to focus on openness and portability in game production, [S27] shows the benefits of using Geocaching in the creation of pervasive games, and [S75, S77] addresses the use of prototyping techniques in developing pervasive games.

4.2.9 Software verification and validation

The paper [S39] was placed in the software verification and validation category because it addresses the evaluation of a pervasive game using experiences suggesting two methods for evaluating games of this type and applying these two approaches in a location-based game (The methods complement each other: one, OPOS, gathers quantitative data, the other, GroupSorter, gathers qualitative data).

4.2.10 Software post-development issues

In [S40], the CityZombie game was created and used to assess technical and gameplay aspects. This study investigated aspects of the location, documenting how the use of positioning technologies (CellID and GMS) influenced the gaming experience. This is the motivation to put it in this category.

4.2.11 Collaboration in software development

In [S65], the authors created a pervasive game for elderly socialization and exercise. In this application development, sections of participatory design, where two involved with the implementation

came into contact with the target audience of the game, thus characterizing a collaborative development technique.

4.3 Research approaches

Table 9 showed the quantities of papers by research method. In 62% of cases, thus the majority of searches, an empirical approach was used. In this section, we compare these numbers with the ones obtained by [Ampatzoglou and Stamelos 2010] and [Glass et al. 2002].

A discrepancy is noted with respect to the two other studies, to the extent that the proportion of empirical research is greater than the other two, while the number of exploratory studies is lower. This can be explained by the fact that most research is focused on the pervasive game development for evaluating specific features. When the proportion of descriptive research, the number is right next to the other researches.
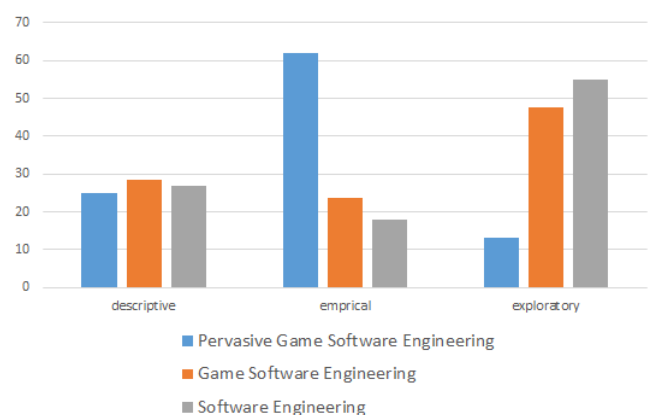

Figure 5: *Research approaches*

4.4 Research methods

Table 10, in Section 3, shows the numbers of papers by the empirical methods used. In this case, we counted only those papers that used empirical approaches. The most used method was the case study, with 46.7%. Again, we compare these numbers with the studies [Ampatzoglou and Stamelos 2010] and [Glass et al. 2002].

As in research approaches, analysed in Section 4.3, there was a discrepancy in the empirical methods, although smaller. Here, the most common method used was case study, while in [Ampatzoglou

and Stamelos 2010] was survey and in [Glass et al. 2002] was experiment. What can explain this is the same reason mentioned in the previous subsection, since much of the work is based on presenting the implementation of a pervasive game and the characteristics of its development.
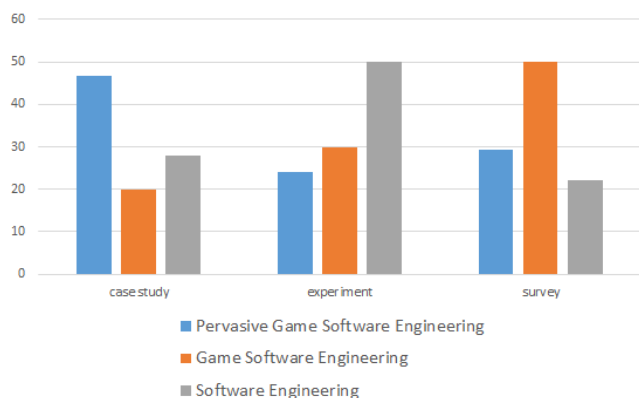

Figure 6: *Empirical research methods*

5   Conclusions and future work

The purpose of this paper was to summarize the state of the art in the use of software engineering techniques for pervasive games development. For this, a systematic review, a formal process of collecting primary studies, data extraction and analysis of the extracted data was used.

The results show that there is a growing interest in research in this area in recent years. Also show that in most cases the papers were published in conferences and there are no predominant conferences or journals that publish most papers on software engineering for pervasive games, having several journals and conferences with just one paper. Groups like DiGRA tend to unify such initiatives, but even there, there is no area focused only on pervasive games.

Regarding topics of interest, it became clear that the design area of pervasive games is still a fertile field, with many studies being developed. This can be corroborated by the idea of ubiquitous/pervasive computing is a recent development and it is in constant evolution. Creating games for these environments is challenging, especially when it comes to designing them. It is worth mentioning the area of user interface for pervasive games, showing the concern of researchers in creating new interfaces for this type of immersive game. Underexplored areas were "Software/program verification", "Interoperability", and "Reuse". Important fields of software engineering have not been addressed in the papers, as "Testing and debugging", "Programming environments" and "Distribution, maintenance and enhancement"

Within the research approaches, the most widely used form was empirical, and methods within this approach results tell us that research is focused on the creation of games intended to validate aspects therefore are often created case studies to characterize the idea that the author set out to do. Game design and interaction features implemented are revisited and reported on papers.

As future work, this study could be repeated to validate the trends found here or perhaps to meet new trends in software engineering for pervasive games. Another suggestion is to make a more in-depth comparison of the technical aspects of each approach found, its characteristics and remaining challenges. We also suggest the deepening of the themes found in some studying and creating specific work of each subtopic as a contribution to this research area.

Acknowledgements

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Appendix A. Studies included in review

[S1] A case study in pervasive game design: The songs of north (2004). Nordic Conference on Human-Computer Interaction.

[S2] A case study of exploding places, a mobile location-based game (2011). International Conference on Advances in Computer Entertainment Technology.

[S3] A cloud-based serious games framework for obesity (2012). International Workshop on Cloud-Based Multimedia Applications and Services for e-Health.

[S4] A location-based multiplayer mobile game to encourage pro-environmental behaviours (2011). International Conference on Advances in Computer Entertainment Technology.

[S5] A ludological view on the pervasive mixed-reality game research paradigm (2011). Personal and Ubiquitous Computing.

[S6] A Narrative Architecture for Story-Driven Location-Based Mobile Games (2011). New Horizons in Web-Based Learning.

[S7] A new approach on wearable game design and its evaluation (2006). Workshop on Network and System Support for Games.

[S8] A Pac-Man Game on Campus Using GPS Location Information and Shortest Path Algorithm (2010). International Conference on Digital Game and Intelligent Toy Enhanced Learning.

[S9] A Pervasive Augmented Reality Serious Game (2009). Conference in Games and Virtual Worlds for Serious Applications.

[S10] A report on the crossmedia game epidemic menace (2007). Computers in Entertainment.

[S11] A ubiquitous solution for location-aware games (2012). International Conference on Entertainment Computing, ICEC.

[S12] A vertical view of social structure on location-utilized mobile games (2010). International Conference on Advanced Communication Technology, ICACT.

[S13] Addressing openness and portability in outdoor pervasive role-playing games (2013). International Conference on Communications and Information Technology.

[S14] Ambient displays and game design patterns (2010). European Conference on Technology Enhanced Learning.

[S15] An adaptive game-based exercising framework (2011). International Conference on Virtual Environments Human-Computer Interfaces and Measurement Systems.

[S16] An exploratory study on non-visual mobile phone interfaces for games (2008). Brazilian Symposium on Human Factors in Computing Systems.

[S17] An in-game reporting tool for pervasive games (2009). International Conference on Advances in Computer Entertainment Technology.

[S18] Believable environments: generating interactive storytelling in vast location-based pervasive games (2006). International Conference on Advances in Computer Entertainment Technology.

[S19] Blowtooth: A provocative pervasive game for smuggling virtual drugs through real airport security (2012). Personal and Ubiquitous Computing.

[S20] Boxed pervasive games: An experience with user-created pervasive games (2009). International Conference on Pervasive Computing.

[S21] Building Your Own Tangible Virtual World: A Design of an RFID-Based Tabletop Game Platform (2010). International Conference on Digital Game and Intelligent Toy Enhanced Learning.

[S22] Burgomaster and Pedro - A pervasive multi-player game for rural tourism (2009). Conference in Games and Virtual Worlds for Serious Applications.

[S23] Capturing the response of players to a location-based game (2011). Personal and Ubiquitous Computing.

[S24] Chamber of Mirrors: A Socially Activated Game Exploits Pervasive Technology (2012). Pervasive Computing.

[S25] Combining Storytelling Tradition and Pervasive Gaming (2013). International Conference on Games and Virtual Worlds for Serious Applications.

[S26] Context-aware multimedia provisioning for pervasive games (2005). International Symposium on Multimedia.

[S27] Creating scalable location-based games: Lessons from Geocaching (2013). Personal and Ubiquitous Computing.

[S28] Design and evaluation of player experience of a location-based mobile game (2010). Nordic Conference on Human-Computer Interaction.

[S29] Design for coincidence: Incorporating real world artifacts in location based games (2008). International Conference on Digital Interactive Media in Entertainment and Arts.

[S30] Design for emergence: Experiments with a mixed reality urban playground game (2007). Personal and Ubiquitous Computing.

[S31] Designing and creating environment aware games (2008). Consumer Communications and Networking Conference.

[S32] Designing pervasive games for learning (2011). International Conference Design, User Experience, and Usability. Theory, Methods, Tools and Practice.

[S33] Designing pervasive health games for sustainability, adaptability and sociability (2012). International Conference on the Foundations of Digital Games.

[S34] Design-in-play: Improving the variability of indoor pervasive games (2012). Multimedia Tools and Applications.

[S35] Developing multiplayer pervasive games and networked interactive installations using ad hoc mobile sensor nets (2009). International Conference on Advances in Computer Entertainment Technology.

[S36] Enabling emergent behaviour in location based games (2010). International Academic MindTrek Conference.

[S37] Evaluating a middleware for crossmedia games (2008). Computers in Entertainment.

[S38] Evaluating design constraints for proximity-based games in a real urban topology (2013). International Conference on Multimedia and Expo Workshops.

[S39] Evaluating player experience for children's outdoor pervasive games (2013). Entertainment Computing.

[S40] Experiences from the development of the pervasive game cityzombie (2010). International Conference on Game and Entertainment Technologies.

[S41] Experiences with AR plots: design issues and recommendations for augmented reality based mobile games (2013). Communications in Mobile Computing.

[S42] Experiencing a process to create a multimedia game and validating results application in a socio-cultural environment (2010). International Conference on Design of Communication.

[S43] FAR-PLAY: A framework to develop Augmented/Alternate Reality Games (2011). International Conference on Pervasive Computing and Communications.

[S44] FIASCO: Game interface for location-based play (2004). Conference on Designing Interactive Systems.

[S45] FRAP: A framework for pervasive games (2009). Symposium on Engineering Interactive Computing Systems.

[S46] Game Development Framework Based Upon Sensors and Actuators (2008). On the Move to Meaningful Confederated International Workshops and Posters.

[S47] Gamework – A Framework Approach for Customizable Pervasive Applications (2012). International Conference Game and Entertainment Technologies.

[S48] Geogames: Designing Location-Based Games from Classic Board Games (2006). Intelligent Systems.

[S49] Handheld AR games — A triarchic conceptual design framework (2011). International Symposium on Mixed and Augmented Reality - Arts, Media, and Humanities.

[S50] Head Up Games: Combining the best of both worlds by merging traditional and digital play (2010). Personal and Ubiquitous Computing.

[S51] In-car game design for children: Child vs. parent perspective (2013). International Conference on Interaction Design and Children.

[S52] Increased game immersion by using live player-mapped avatar evolution (2011). International Conference on E-learning and Games.

[S53] Insectopia: Exploring pervasive games through technology already pervasively available (2007). International Conference on Advances in Computer Entertainment Technology.

[S54] Interoperability standards for pervasive games (2011). International Workshop on Games and Software Engineering.

[S55] Investigating the applicability of usability and playability heuristics for evaluation of pervasive games (2008). International Conference on Internet and Web Applications and Services.

[S56] Issues in the development of location-based games (2011). International Journal of Computer Games Technology.

[S57] Large Scale Mobile and Pervasive Augmented Reality

Games (2005). International Conference on Computer as a Tool.

[S58] Location and situation based services for pervasive adventure games (2010). International Conference on Computer Modelling and Simulation.

[S59] MuseUs: Case study of a pervasive cultural heritage serious game (2013). Journal of Computing and Cultural Heritage.

[S60] Mystery at the library: Encouraging library exploration using a pervasive mobile game (2012). Australian Computer-Human Interaction Conference.

[S61] On the design of Camelot, an outdoor game for children (2006). Conference on Interaction Design and Children.

[S62] OutRun: Perversive games and designing the de-simulation of eight-bit driving (2010). International Conference on the Foundations of Digital Games.

[S63] panOULU conqueror: Pervasive location-aware multiplayer game for city-wide wireless network (2010). International Conference on Fun and Games.

[S64] Participatory game design to engage a digitally excluded community (2011). International Conference on Digital Games Research Association.

[S65] Persuading older adults to socialize and exercise through ambient games (2012). International Conference on Pervasive Computing Technologies for Healthcare.

[S66] Persuasive design of a mobile energy conservation game with direct feedback and social cues (2009). International Conference on Digital Games Research Association.

[S67] Pervasive games in a mote-enabled virtual world using tuple space middleware (2006). Workshop on Network and System Support for Games.

[S68] Pervasive games research: A design aspects-based state of the art report (2013). Panhellenic Conference on Informatics.

[S69] Pervasive mobile games - A new mindset for players and developers (2008). International Conference on Fun and Games.

[S70] Place as media in pervasive games (2007). Australasian Conference on Interactive Entertainment.

[S71] Play it for real: Sustained seamless life/game merger in Momentum (2007). International Conference on Digital Games Research Association.

[S72] Playing for real: Designing alternate reality games for teenagers in learning contexts (2013). International Conference on Interaction Design and Children.

[S73] Playing games with information: Investigating perceptions of a mobile content sharing game (2012). Journal of Digital Information Management.

[S74] Pre-patterns for designing embodied interactions in handheld augmented reality games (2011). International Symposium on Mixed and Augmented Reality - Arts, Media, and Humanities.

[S75] Prototyping in PLACE: A scalable approach to developing location-based apps and games (2013). Conference on Human Factors in Computing Systems.

[S76] Providing generic context for mobile games on phones (2011). International and Interdisciplinary Conference on Modeling and Using Context.

[S77] Rapid prototyping of context-aware games (2006). International Conference on Intelligent Environments.

[S78] Realizing Large-Scale Street Games Using Heterogeneous Future Internet Technologies (2013). International Conference on Intelligent Environments.

[S79] Refreshing contextualised IT curriculum with a pervasive game project in Tanzania (2011). International Conference on Computing Education Research.

[S80] Saving energy at work: The design of a pervasive game for office spaces (2012). International Conference on Mobile and Ubiquitous Multimedia.

[S81] Sensing fork and persuasive game for improving eating behavior (2013). Conference on Pervasive and Ubiquitous Computing.

[S82] Shifting from a computer game to a physical game: A case study of ePet (2008). International Symposium on Computer Science and Computational Technology.

[S83] Soundpark: Towards highly collaborative game support in a ubiquitous computing architecture (2009). International Conference on Distributed Applications and Interoperable Systems.

[S84] The final TimeWarp: Using form and content to support player experience and presence when designing location-aware mobile augmented reality games (2012). Designing Interactive Systems Conference.

[S85] The space of digital health games (2012). International Journal of Computer Science in Sport.

[S86] Theoretical and methodological implications of designing and implementing multiuser location-based games (2011). Personal and Ubiquitous Computing.

[S87] Toward a mobile platform for pervasive games (2012). International Workshop on Mobile Gaming.

[S88] Traditional games meet ICT: A case study on go game augmentation (2010). International Conference on Tangible, Embedded, and Embodied Interaction.

[S89] Turning the classic snake mobile game into a location-based exergame that encourages walking (2012). International Conference on Persuasive Technology.

[S90] Understanding pervasive games through gameplay design patterns (2007). International Conference on Digital Games Research Association.

[S91] Unexceptional.net: A story about a unique pervasive game (2009). Consumer Electronic Society's Games Innovation Conference.

[S92] uOS: A Resource Rerouting Middleware for Ubiquitous Games (2013). International Conference on Ubiquitous Intelligence and Computing.

[S93] Urbanopoly - A social and location-based game with a purpose to crowdsource your urban data (2012). International Conference on Social Computing.

[S94] User interfaces for pervasive games: Experiences of a formative multi-method evaluation and its implications for system development (2007). Workshop on User Interfaces for All.

[S95] Using an RFID game to phenomenologically test a theoretical systemic model for describing ambient games (2009). International Conference on Digital Games Research Association.

[S96] Using deliberate ambiguity of the information economy in the design of a mobile location based games (2011). International Academic MindTrek Conference.

[S97] Using prototypes in early pervasive game development (2007). SIGGRAPH Symposium on Video Games.

[S98] Vs golf - Developing location-based multi-player games (2007). International Computer Software and Applications Conference.

[S99] W41K: Digitally augmenting traditional game environments (2009). International Conference on Tangible and Embedded Interaction.

[S100] Where is the answer? - The importance of curiosity in pervasive mobile games (2007). Conference on Future Play.