Sensified Gaming – Design Patterns and Game Design Elements for Gameful Environmental Sensing

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ABSTRACT
Participatory Sensing, i.e. collaboratively taking sensor measurements with mobile devices in a Citizen Science fashion, has become increasingly popular. Because such scenarios often require a critical mass of users, applying gamification to different areas in order to increase user engagement has been proposed. However, existing attempts often default to the standard points, badges, and leaderboards and fail to recognize the potential of exploiting game design elements beyond creating user engagement. We propose not to think of Gamified Participatory Sensing when designing such systems, but rather of *Sensified Gaming*. To this end, this work presents a collection of design patterns and game mechanics that can be used to identify or design suitable games, into which participatory sensing tasks can be embedded. We identified four core tasks from participatory environmental sensing and sensor networks research, reviewed hundreds of design patterns and map each of the 63 selected patterns to the core tasks.

ACM Classification Keywords
H.5.3. Information Interfaces and Presentation (e.g. HCI): Group and Organization Interfaces; K.8.0. Personal Computing: General – Games

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Game Design Patterns; Participatory Sensing; Gamification; Mobile Games; Mobile Sensing; Design; Environmental Sensing; Task Support; Non-expert Sensing; Serious Games

INTRODUCTION
In Participatory Sensing [15], users with personal mobile devices (e.g. smartphones) collaboratively collect information at different locations and upload it for a joint cause. Applications cover a wide range, including urban issue tracking [27], real-time monitoring of road congestion, weather conditions, air quality [19] or noise pollution [32]. Of the many tasks and systems that exist, practically all depend on a certain level of participation and user engagement to function. Gamification has been proposed as an approach to provide incentives for participation [35, 42, 9, 44, 2]. However, often attempts at gamifying such systems are executed half-heartedly or fail to recognize the potential of gamification techniques beyond standard PBLs (points, badges, leaderboards). In this paper we propose the concept of *Sensified Gaming* as an alternative way of thinking as opposed to gamified Participatory Sensing: The idea is – rather than gamifying a task – to think of designing a game in the first place, that secondly also is suitable to support a sensing task. Depending on the application case, Participatory Sensing has various requirements (e.g. moving around, being outside, visiting certain locations of interest, etc.). This paper focuses on the research question what the crucial elements to create *Sensified Gaming* are, i.e. how to support participatory sensing in games. For this, we (1) identify core tasks from the field of participatory sensing and (2) collect and map game mechanics that are suitable to embed these tasks, presenting a set of design patterns.

PARTICIPATORY SENSING
Participatory Sensing is one of many similar concepts that overlap to a certain degree: *Citizen Science*, *Volunteer Monitoring*, *Crowd Sensing*, *Citizen Observatories*, *Amateur Science*, *Community Science*, just to name a few. They all have in common that a group of (often untrained) people collaboratively works on (parts of) a joint task. The tasks itself and the platforms that are used differ between the individual concepts. Participatory Sensing, as defined by Burke et al. [15], emphasizes distributed sensing done by everyday users with the personal mobile devices they carry and control in the public sphere. In this work, we focus on such settings: environmental sensing with smartphone sensors (or other personal devices connected to them), in the real-world (e.g. a city) by ordinary (i.e. non-expert) people. Still, the presented core tasks generalize to a wide range of applications.

Core Tasks
We have identified four core tasks as requirements environmental sensing:

- *Coverage*
- *Touch POI*
- *Rendezvous*
- *(Correct) Sensing*

Coverage

Since the goal of Participatory Sensing generally speaking is to crowdsource a task to people in a public space, achieving suitable coverage of that area is an obvious requirement. This is especially true for applications in which a map is constructed from individual measurements or observations, like in environmental sensing. Here, coverage is meant both in time and in space, i.e. ascertaining that sufficient measurements are recorded across the area of interest continuously over time.

Touch POI

This core task subsumes activities that require going to a point-of-interest (POI), i.e. a specific location (or one of a set of locations). The reasons for this can be diverse. In scenarios with low-cost sensors, especially air quality sensing, the need for regular (re-)calibration of sensors is present [14]. Calibration can be carried out by co-locating a sensor with a high-precision reference device or station whose readings are used for calibration. Scenarios with user-generated reports may also require measurements at certain locations to verify data points or complement automatic data cleaning approaches [12]. Another need to travel to a certain location may be data offloading [30]. Especially in data heavy sensing tasks, e.g. if high-volume data like video or high-frequency data of many sensors is recorded, the need to move data off the participant's device may arise regularly. This may require offloading traffic to a wi-fi network in case the participant does not have a data plan or wireless service reception is bad. The same is true for situations with no connectivity in which the collected data needs to be uploaded within a certain time to be of value.

Rendezvous

Calibration can not only be carried out against high-precision data (so-called *ground truth*), but also against other already calibrated devices. Such an approach was e.g. presented for low-cost gas sensors by Hasenfratz et al. [23]. They proposed a multi-hop calibration scheme in which the sensors exchange measurements collected during a rendezvous in order to improve their individual calibration "on-the-fly". Other similar approaches exist [45], among them one that additionally incorporates privacy protecting measures [34]. Other reasons for co-locating participants may be the desire to collect redundant readings, the need to collaboratively collect readings (e.g. for verification), or again for data offloading.

(Correct) Sensing

In participatory sensing with low-cost sensors, the potential for systematic error that leads to low-quality or even useless data is high [13]. As usually non-experts perform the tasks, ensuring the correct execution of the measurement process is important. Aspects of a correct sensing procedure with smartphones include correct body posture, device orientation, environmental constraints (good weather, being outside, remaining motionless, etc.), sufficient measurement duration, data annotation as well as the correct sequence of the steps.

SENSIFIED GAMING

We argue that gamification can do much more for Participatory Environmental Sensing applications than 'merely' provide incentives for participation. Different mechanics can be used to support the presented core tasks. As it is important that the various mechanics are not looked at individually but rather in the context of their interplay, we encourage the notion of "sensifying a game" rather than "gamifying a task". This section attempts to more closely define the term *Sensified Gaming* and place it on the continuum of existing nomenclature.

Mobile Games are (video) games that are played on mobile devices, as phones, tablets, smartwatches, and the like. As we focus on support for smartphone-based sensing applications, Sensified Gaming naturally (but not necessarily) entails Mobile Gaming. At the same time, since sensing clearly pertains to the real world, we touch the field of *Pervasive Games* [31]. Depending on the definition, Pervasive Games can narrowly be seen as a combination of game reality and physical reality within the gameplay or more broadly as games that have "*one or more salient features that expand the contractual magic circle of play spatially, temporally, or socially*" [37]. A deep discussion including a classification has been presented by Hinske et al. [24]. One sub-class that is certainly closely related are *Location-based Games*.

The distinction between gamified applications and games is often made according to the underlying design goals [18, 33]: In *Gameful Design*, game-like thinking is applied to a design process without the actual inclusion of game elements. *Gamification*, as defined by Deterding et al. is "*the use of game-elements in non-game contexts*", explicitly excluding full-fledged games [18]. *Serious Games*, in contrast, are "*full-fledged games for non-entertainment purposes*". More fine grained distinctions of Serious Games exist, again characterized along the difference in design goals. Marczewski [33] sub-categorizes them into *Teaching Games / Games For Learning*, *Simulators*, *Meaningful Games / Games For Good* and *Purposeful Games*. Of these, none perfectly accommodates our notion of Sensified Gaming. While the term Purposeful Games covers it best, there are notable differences, e.g. that sensing itself does not directly affect the real world, as the definition of purposeful games entails. Also, the player does not really need to know that playing the game achieves something in the real world – at least from a classification point of view[1]. Finally, *(Full-fledged) Games* are the ones that are designed purely for entertainment.

One could argue that while defining these classes according to the design goal makes sense, thinking too much about the task when designing a serious game may result in a badly designed, unenjoyable or shallow game. Another issue of designing such a purposeful game with the task being the first thing in mind is that the resulting game almost automatically will be tailored to the people who are expected to work on the task anyway. The fear that a badly designed system may be counter-productive was e.g. expressed by the developers of the citizen science game *Floracaching*, who "*... don't want glitches in the technology to demotivate this important group of contributors, potentially preventing them from submitting future data*." [9]. In contrast, the target user group of Sensified Gaming is gamers that don't need to have any motivation

[1] Whether it is right to deceive or coerce a participant into working on a task without knowing it is a question of its own.

regarding the underlying purpose. While technically, the ultimate design goal of *Sensified Gaming* is in fact supporting a Participatory Sensing task, we argue that this should not make a difference and propose to still put entertainment first in the design process. Overall, we introduce the term *Sensified Gaming* as a simpler way of saying "*Digital Purposeful Pervasive Mobile Games for Participatory Sensing that are designed to be full-fledged games.*"

Gamified Participatory Sensing

There are some success stories of lightly gamified Participatory Sensing systems, but all with the focus on motivation/engagement and – with one notable exception – not taking into account additionally supporting any of the core tasks. Ueyama et al. for instance present a system of badges, points and leaderboards (PBL) to supplement monetary incentives, the core goal being to reduce the cost spent on monetary incentives [44]. This work was continued by Arakawa et al. [2]. PBLs are also the core of the gamification design for the participatory noise pollution monitoring system *NoiseMap*, whose authors could show an increase of recorded measurements in a comparison of different prototypes with varying degree of gamification [42]. In this app, the sensing task is still clearly central and it is not intended to be a full-fledged game. The exception mentioned above also is in the field of noise pollution sensing: *NoiseBattle* and *NoiseQuest* [35] are two game prototypes addressing different player types (the types *Killer* and *Explorer* according to Bartle [3]). Both games are designed not only to encourage participation but also to increase coverage in the game area by making players explicitly explore the area respectively battle for control of cells in a grid by measuring ambient noise with smartphones. Unfortunately, the games seem to have been research prototypes that were never publicly released. A notable commercial project that incorporates players collecting information in urban environments is the pervasive game *Ingress*[2], which managed to attract an enormous player base of several million people around the world. While this manuscript was undergoing review, the game *Pokémon GO*[3] was released by the same company, quickly surpassing *Ingress*'s success and being played massively all over the world, players having walked a total of 4.6 billion kilometers so far [28]. This shows the great potential of such location-based games and indicates that they will become of interest to a broader audience.

To the best of our knowledge, game design elements have today not been used further to support the presented core tasks. While Flata et al. presented so-called *calibration games* [21], their notion of calibration does not relate to the calibration of mobile environmental sensors, but rather to the adjustment of input devices such as eye-trackers.

GAME DESIGN PATTERNS

Design patterns [1] were introduced within the discipline of architecture for easy knowledge transfer between professionals and non-specialists. These patterns encode design practices as problem-solution pairs with accompanying information and interrelate to form hierarchies or nets. This design patterns concept has spread from architecture to several other areas, e.g. programming [20] and interaction design [20, 8, 16].

Design patterns are an example of explicitly creating a design language [40], as a way of understanding a design discipline through the relevant elements and materials, how these elements can be structured, and in which situations specific elements and choices of structures are appropriate. Specifically, they let those involved in the process consciously consider and discuss what the implications of design choices would be for the final design. Design patterns are not complete design languages in themselves since they focus on the basic elements and do not describe the steps of a design process.

The idea to use design patterns for game design was introduced by Kreimeier [29] in the context of computer games and has since then been generalized to all types of games [7, 6], resulting in a pattern collection of nearly 300 gameplay design patterns [5]. These patterns differ from the original structure by replacing the problem-solution pair with a causes-consequences pair describing how the pattern can occur in a game design and how it can affect the gameplay and player experiences. The reason for the change was because the patterns are intended to support both the design and analysis of games and also to allow the use of specific patterns as design goals. In 2009, Björk started a wiki to collect more patterns, and has up to this point assembled an extensive (and still growing) gameplay design patterns collection [4]. The selection of patterns in this work is largely based on that collection.

Methodology

After having identified the core tasks, we surveyed literature and online sources for game design elements that are fitting to build (or identify) games suitable for Sensified Gaming. Björk's wiki [4] is with currently 536 entries the by far largest collection and was therefore the main source for the mechanics presented in this work. Other pattern collections [5, 17, 25] mostly contained subsets of the set of mechanics found in this wiki. A small number of patterns was added from these sources, as well as individual ones that we did not find in any collection but rather came up with ourselves in the process of discussing the core tasks and the concept.

The pattern analysis was conducted by three researchers who were familiar with the patterns approach, the pattern collections used in the analysis, and the principles of participatory sensing. One of the researchers did the initial selection of relevant patterns based on whether the pattern could substantially support at least one of the core tasks. The selection was then reviewed by the two other researchers, suggesting additional patterns to be included. Patterns that are generally suitable for all types of games but that were classified by us as not being especially relevant regarding the core tasks were left out to provide a more condensed collection. This includes patterns such as tension or the "usual suspects" points, badges, leaderboards and achievements. However, this does not mean that we think other patterns should not be used in Sensified Gaming, but rather that they do not indicate specific suitability. Finally the patterns were categorized with input from all three researchers following the principles of thematic analysis [10].

[2] https://www.ingress.com/
[3] http://www.pokemongo.com/

Pattern Collection

All of the selected mechanics are shown in Table 1, divided into categories. The table features the name of each design element[4] and one column for each of the core tasks ('×' indicates special suitability for the respective task). In addition to these, we added a column for *Sustained Engagement* to the table, which is used to denote mechanics that especially encourage "replayability" (rather then generally motivate, which would basically be any game mechanic). This section elaborates on the elements in our collection and their categorization.

Prerequisites

There are some design elements that are important, if not crucial to sensified games. Since typically a central instance that coordinates players is needed, having *Game Servers* is more or less mandatory. Since the system presents the game state and controls the interactions with other players before a possible meeting in the real world, we usually have *Mediated Gameplay*. *Dedicated Game Facilitators* are responsible for this mediation. They keep track of the game state and guide the players through the game world, e.g. by *Game Element Insertion*, controlling non-player characters or by giving information to the players. As the measurements take place in the real-world, *Hybrid Gameplay Spaces* are a direct consequence. *Persistent Game Worlds* are not a necessity, but can enable a deeper and more complex interaction by enabling players to play asynchronously.

Modes

There are different modes of gameplay that can be used. Some of them are conflicting, so they can not be used at the same time but it is possible to switch between them in different parts or stages of a game. A possibility that e.g. lets players embed playing into other everyday life activities is some sort of *Pervasive Gameplay* or *Casual Gameplay* with many *Lull Periods*. When someone is waiting for the bus they can just start the game to kill some time. *Attention Demanding Gameplay* is fitting for more thrilling games (or phases of a game) when players want to devote themselves more. *Massively Single-Player Online Games* with *Asynchronous Gameplay* could be used if users just play by themselves instead of with others. Further modes are presented in the category *Social* below.

Exploration / Expansion

This category mostly covers mechanics that motivate players to move around the world (both game and physical) and are therefore especially suitable to support the core task of reaching coverage. Possibilities to *free-roam* around the world and/or increasingly discover it through *Game World Exploration* promote player movement, e.g. to discover locations of other game elements. Mechanics such as *Fog of War* can be used in different ways to motivate travel to certain areas: If discovered areas on a map are e.g. covered again after a certain time, regular movement around the (entire) world is stimulated. Techniques like *Area Control* (for regions) or *Capture* (for items) also promote player movement, but do so by addressing the desire to increase the zone of influence. This can

[4]For the sake of better readability, we omitted the textual description of the mechanics in the table. It can be found in the running text of the paper and in Björk's wiki [4].

	Mechanic	**Coverage**	**Touch POI**	**Rendezvous**	**(Correct) Sensing**	**Sustained Engagement**
Prerequisites	Game Servers	×	×	×		
	Mediated Gameplay	×	×	×	×	
	Dedicated Game Facilitators	×	×	×	×	
	Hybrid Gameplay Spaces					×
	Persistent Game Worlds	×				
Modes	Pervasive Gameplay	×				
	Asynchronous Gameplay	×	×			
	Attention Demanding Gameplay			×		
	Casual Gameplay	×				
	Lull Periods	×	×		×	
	Massively Single-Player Online Games	×				
	Real-Time Games			×	×	
Exploration / Expansion	Area Control	×				×
	Capture	×				×
	Expansion	×				×
	Game World Exploration	×				×
	Fog of War	×				×
	Free-roam / Open World	×				×
	Configurable Gameplay Areas	×				×
	Physical Navigation	×			×	×
	Artifact-Location Proximity	×	×			
	Real Life Activities Affect Game State	×	×	×		×
Location / Proximity	Player-Location Proximity	×	×			
	Player-Artifact Proximity	×	×			
	Bases		×	×		
	Game Items	×				
	Pick-Ups	×				
	Resource Locations	×		×		
	Point of Interest Indications	×	×	×		
	Events Timed to the Real World	×		×	×	×
	Geo-fencing	×	×	×		×
	Location-Fixed Abilities		×	×		
Social	Instances			×		
	Massively Multiplayer Online Games	×		×		×
	Multiplayer Games			×		×
	Synchronous Gameplay			×		
	Late Arriving Players			×		×
	Player-Player Proximity		×	×		×
	Common Experiences			×		×
	Game Element Trading			×		×
	Mutual Goals			×		×
	Symbiotic Player Relations			×		×
	Collaborative Actions			×		
	Cooperation			×		
	Privileged Abilities/Orthog. Differentiation			×		
	Team Strategy Identification			×		
Sensing	Feelies				×	×
	Unlocking				×	×
	Mimetic Interfaces/Physical Enactment				×	
	Minigames				×	
	Tutorials				×	
	Reputation				×	
Engagement	Predetermined Story Structures	×	×	×	×	
	Alarms			×	×	
	Dyn. Diff. Adjustm./Challeng. Gameplay					×
	Notifications			×		×
	Replayability	×				×
	Ubiquitous Gameplay	×				×
To consider	Extra-Game Input	×			×	
	Inaccessible Areas	×	×		×	
	Player Physical Prowess					×
	Unmediated Social Interaction			×		
	Extra-Game Consequences				×	

Table 1. Design patterns for Sensified Gaming, mostly selected from Björk's wiki [4] according to their suitability to support the core tasks in participatory environmental sensing.

either happen continuously or during an explicit *Expansion* phase in a game. Most of these elements also encourage players to come back to play the game, as they address a sense of accomplishment. A bit of an exception to this are *Inaccessible Areas*, which are described further below.

Physical Navigation can help to increase coverage and – depending on the sensing task – may also be used to support correct sensing. *Artifact-Location Proximity* is a mechanism that can be used when, for example, sensors are not embedded in personal smartphones but rather in seperate devices or real-world items that are not carried by the player continuously. An example are environmental sensors that are built into rentable public city bikes [14]. A game element could entail moving the bikes in the real world so that they then take measurements at different locations even after the player has moved on.

Location-based / Proximity

Instead of motivating to explore and roam the world, attempts can also be made to guide or lure players to specific locations. The mechanics in this category are mainly suitable for *touching POI* by encouraging players to travel to certain places. Indirectly, by that many mechanisms also support player *rendezvous*, as (randomly or deliberately) guiding people to certain locations in parallel greatly includes the probability of co-location. In both cases, an effect of this can be increased coverage, provided the locations in question are spread around the world accordingly. Basis to attract the user to special places are the *Player-Location Proximity* and *Player-Artifact Proximity*. Special places in the game can e.g. be *Bases* or locations of *Game Items* (*Pick-Ups* or *Resource Locations*), which in turn can in the real world be locations that feature ground truth reference stations for calibration or wi-fi hotspots for data offloading. Such places can be made even more interesting to players if they feature *Location-Fixed Abilities*. *Point of Interest Indications* can lead players to special locations. To also increase temporal coverage, *Events Timed to the Real World* can be used. A possibility would be to e.g. only allow certain actions at specific points in time, under certain weather conditions, etc. *Geo-fencing* is a way to trigger certain actions when a player crosses a certain perimeter, a mechanic that can be used in various ways for the core tasks, e.g. to alert players that they are close to a location of interest or entering an area of *Attention Demanding Gameplay* (see *Modes* above).

Social

Multiplayer Games form the principle basis for games with social interaction, by enabling *Synchronous Gameplay* for multiple players. Especially *Massively Multiplayer Online Games* seem suitable to support interaction in pervasive games as they increase the chance of finding other players in the vicinity. Supporting *Late Arriving Players* is almost a necessity, as players should be able to independently start, join or leave a running game. *Instances* can help to reduce technical requirements like server load and can facilitate the formation of closer social groups.

Player-Player Proximity is an element that can be used for encouraging calibration rendezvous. In order to bring users together at the same time and place, *Common Experiences* can be used. Players can e.g. be brought together by *Mutual Goals*, *Collaborative Actions*, that increase a sense of community or *Game Element Trading* that requires real-world proximity. Also, elements that support *Team Strategy Identification*, like *Symbiotic Player Relations*, e.g. by *Orthogonal Differentiation*, can be used to bring players together.

(Correct) Sensing

An interesting and until now relatively unexplored area is the use of game design elements to ensure the sensing task being triggered and carried out correctly. Whether and how mechanics can be used strongly depends on the concrete sensing application and the employed sensor(s). If for example sensing requires using external sensors, gadgets, or smartphone extensions such as e.g. clip-on air quality sensors for smartphones [11, 43], they could also be shipped with the game and act as *Feelies* to increases the game experience. To reduce cost and improve data quality, it would also be a possibility to give out sensors only after *Unlocking* to the best performing players as an in-game reward. The players with the best coverage, social interaction and most accurate simulated measurements unlock the sensor, which they then receive as hardware. Another approach could be to offer sensors of different quality and cost as tangible game items that can be bought with real-world currency. A related example for this is the *Pokémon GO Plus* wristband[5], that acts as a physical accessory to the digital game. Such wearables could easily also house sensing capabilities, act as tangible or *Mimetic Interfaces* or real-world items that e.g. boost game stats. Smartphone sensors such as accelerometer, light sensor, proximity sensor, etc. can provide information on the way the player handles the measurement device or on his physical activities, which can in turn be used to monitor if the user handles the device correctly. Another possibility to e.g. ensure a certain device orientation is the use of *Minigames*. The sensing itself could be a small *Minigame*, like balancing a virtual marble on the screen to steady the phone. If desired, in-game *Tutorials* can be used to enable the players to learn how to use the sensors correctly. In contrast to manuals, players benefit from getting immediate feedback. Tutorials can take different forms, they could e.g. also be embedded in training missions. If the game behavior that involves sensing has an effect on *Reputation* (either of the players themselves or their game avatars), data quality can possibly be increased. Aside from comparing the quality of the measured data to that of other players, the game could also try to verify that the players are real persons. In both cases players will probably be more eager to make more accurate measurements.

Engagement

This section covers mechanics that provide the player with reasons to play the game (more often), i.e. to sustain engagement. *Replayability* is very important for these types of games. To be able to collect a lot of data, it is important to keep up the interest of the player. *Predetermined Story Structures*, such as Adventures or Quests, can be used to keep the game from getting boring by constantly supplying new content. As an added benefit they also can be used for all of the core tasks: to bring players together or to certain places, to increase coverage or to task them with a certain procedure. Through *Dynamic*

[5] http://www.pokemongo.com/en-us/pokemon-go-plus/

Difficulty Adjustment players can be kept in flow and steadily have *Challenging Gameplay* which would provide an incentive to collect even more sensor data. Since players carry their smartphones with them most time of the day anyway, *Ubiquitous Gameplay* should be possible. If the player is running the game anyway, she can be alerted to phases of *Attention Demanding Gameplay* and "pulled into to the action" by *Alarms*. If not, *Notifications* may remind them that the game still exists.

To consider

There are also some game elements which are not purely beneficial (or even intended) but should be kept in mind (see also *Discussion* below): As players move in the real world, they may encounter *Inaccessible Areas*. Private property should not be entered and the players thus not prompted to do so. Places that require an admission fee (e.g. a zoo) should maybe also be excluded. In addition, environmental measurements should typically only take place outdoors. If the game allows being played inside of buildings, it should possibly recognize this and hence not record sensor data or dismiss the recordings after the fact. Another thing to bear in mind is possibly varying *Player Physical Prowess*. Games should ideally be accessible to anyone and players with poorer physical abilities should not be demotivated by being tasked with something they can not compete in with other players. *Unmediated Social Interaction* should also be considered. As players encounter each other during the game, they may talk to each other, befriend each other, etc. Possible effects should be contemplated. The same is true for *Extra-Game Input* or *Extra-Game Consequences*. If the players know that the measurements could have consequences in the real world (e.g. air quality data is used for automatic traffic control), it could make them try to manipulate the data and play the real-world effect rather than the game, to for instance deliberately close off a street for traffic.

DISCUSSION

While this work attempts to provide building blocks for *Sensified Gaming*, there are of course general design considerations to be followed. There has been more than a decade of research on the design of pervasive games alone, and many lessons can be learned from previous work, like believable story-telling [22], wisely choosing technology platforms, carefully balancing single- and multi-player content of the game, and offering sufficiently diverse possibilities in the game to the players [39]. It should also be kept in mind that e.g. external sensing devices should fit the overall design of the game, as this can influence the players' perception and attitude towards them [26]. Another important aspect is that while supporting one of the core tasks, some of the mechanics may have adverse effects regarding another core task or (sustained) engagement.

An important aspect that should not be underestimated concerns the ethical issues connected to *Extra-Game Consequences*. Some vivid examples for this were encountered by people playing the recently released augmented reality app-based game *Pokémon GO*: There have been reports of people being robbed after being lured into a trap by muggers specifically targeting players of the game [46], as well as numerous cases of injuries and dangerous behavior. Also, inserting competitive game elements in a pervasive game could excite unwanted real-world interaction between players. Situations in which players could be tempted to compensate in-game inferiority by somehow engaging opponents in the real-world should not occur. It may be prudent to design games without shared resources that players compete for. But not only undesired interaction between rivaling players may be an issue, unforeseen problems involving people outside the game may also occur: As an example, a man attacked a *Pokémon GO* player, slashing him across the face, as he apparently thought the gamer was video-recording him on his phone [41]. While this surely is an extreme example, it pays to consider how the sensing procedure could be seen and possibly misinterpreted by bystanders. Such effects are possibly strongest and extremely hard to foresee if the game is played without bounds, i.e. by anyone, at any time and in any place. In contrast, so-called *event games* constrain the game environment to a certain playing time, game area, player group and/or limited hardware, allowing the game organizer to exercise more powerful control over the game [36]. Many ethical issues such as the use of public places and different aspects of privacy and security are discussed at length by Montola et al. in a report on Ethics of Pervasive Gaming in the *IPerG* project[6], which can also be read as a guideline document for reflecting individual game designs from the ethical point of view [38].

Overall, many things have to be considered to create games that are fun to play, deliver meaningful data and do not place players in harm's way. We would like to stress that simply selecting mechanisms from the list and combining them together is not what this work proposes as a design practice. As mentioned before, design patterns do not describe the steps of a design process. Rather, the selection and the accompanying discussion in this work can serve as a tool to facilitate building new games or identifying existing ones that could be suitable to be 'sensified'. Games are hard to design and good games even harder, that is why there are game designers. We believe that for the process to work best, game designers and sensing experts should ideally work hand-in-hand to successfully realize the concept of *Sensified Gaming*.

CONCLUSION AND FUTURE WORK

In this work, we presented the notion of *Sensified Gaming*, which proposes not to think of gamifying Participatory Sensing applications but rather embedding Participatory Sensing tasks into games that can support them. We highlighted the potential of exploiting game design elements beyond creating user engagement and presented a collection of game design elements that can be used to identify or design suitable games. For this, we identified four core tasks from participatory environmental sensing and sensor networks research, reviewed hundreds of game design elements from different collections and mapped our selection of 63 game design patterns to the core tasks. In future work, we will present the actual design of a sensified game according to this work and deploy and evaluate it to gain further insights.

[6] http://iperg.sics.se/index.php

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