The Human Factor – Introducing Game Mechanics to Computerized Home Automation Systems

User experience as a method for reducing consumption in domestic buildings

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Abstract. A method of integration of game mechanics and game dynamics into a user interface for a home automation system as means of reducing the inhabitant’s environmental footprint is described and detailed up to the point of proof of concept. In detail, the paper describes the game framework and the method in which the competitive game could be balanced between different dwellings to ensure a fair game. A unique and intuitive method of control via smartphone is described that aims at making the interaction with the device and game more intrusive and friendly. This method is prototyped and tested to the stage of proof of concept.

Keywords. Gamification; domotics; user interface; domestic energy reduction; layered reality.

INTRODUCTION

Domestic use is responsible for a large portion of the worldwide consumed resources, namely electricity and water. For instance, in 2001 the USA housing sector alone was responsible for the consumption of 14% of the 2001-yearly production of electricity consisting of HVAC, home appliances and hot water. [1] While substantial research is aimed at reducing the energy consumed by domestic systems and appliances as well as improving the thermal capabilities of the buildings envelope, little attention has been given to the behavior of the inhabitants. Acknowledging that, even in similar houses, dweller’s behavior and profile have a substantial impact on the consumption of energy and other resources (Santín, 2010) (Figure 1), this paper presents a possible way for altering the behavior of users.

Considering the growing technological development and use of home automation systems (domotics), untapped potentials for interaction between houses and their habitants occur. Specifically, the drastic reduction in component price for sensors, actuators and wireless connectivity, as well
as the vast popularity of smartphones, is acting as a fertile breeding ground for new application and methods of controlling the living environment. This paper focuses on the design of a user oriented home automation interface to actively reduce resource consumption in a domestic building. The solution suggested addresses the issue of increasing user motivation to reduce their environmental footprint specifically, by means of embedding a serious game into the human-machine interface. The work consists of a game framework as well as a proof of concept demonstration of the method in which the user would interact with the systems.

**GAME AS A GAME-CHANGER**

While we are accustomed to see games used primarily for fun and as a pastime, a new type of game had increasingly emerged in recent years, generally referred to as “serious games”. Michel and Chen (2005) had defined serious games as “games that do not have entertainment, enjoyment or fun as their primary purpose”. Seeing the overwhelming popularity of computer based game software, a sub-branch had been created within the domain of serious games. The purpose of these computer games is to reach and capture the attention of players to other means such as education, problem solving or norm changes. Ritterfeld, Cody and Vorderer (2009) have narrowed the definition for serious computer games into “any form of interactive computer-based game software for one or multiple players to be used at any platform that has been developed with the intention to be more than entertainment”. The reason games are sought by educators is that they can be used as a tool to alter behavior. Serious games in particular have been found by Klimmt (2009) to have potential for creating social and behavioral changes, and he has isolated mechanisms which are likely to be most effective to achieve the desired change. He had divided the reasons for which the mechanisms would be effective to 15 groups. Several of them, such as the ability of a serious game to be an effective method of convening information in an enjoyable manner, the serious game’s ability to increase level of acceptance by creating a social network were key drivers in the design of the proposed game.

In this paper, the use of game mechanics is tackled as a source of motivation as well as an educational method for altering people’s behavior. The game framework is presented as human computer interface in home automation systems and aims to turn the daily activity of living into an engaging layered-reality serious game, in which the game’s ‘levers’ are the day-to-day actions done in the house in fields related to the resource consumption.

**HUMAN-HOME INTERFACE**

The game framework as human computer interface in home automation systems relates on the one hand to the human behavior and on the other hand to a number of aspects of dwelling impacting the consumption of resources, namely energy, water and waste.

**Energy, water and waste**

Regarding energy management, it is most significant and relatively simple to monitor the house’s energy balance: the frequency and extent to which the appliances are being used, the usage of the comfort system, the domestic hot water production and lighting are the most crucial factors in this category. If the house is producing energy (e.g. wind, solar collectors or thermal collectors), or is connected to a

![Figure 1](image-url)

User behavior has a significant impact on consumption.
grid that charges different fees for energy according to the hour of the day, there is a significant difference not only to the amount of energy used, but also to the time of consumption. Monitoring is done by smart grid monitors that can give real-time usage data to the interface. In order to provide a more accurate feedback to the user, the domotic system should monitor the consumption of each device separately. As Mallaya (2011) showed in his research, this can be done by listening for interferences over the power line, rather than by connecting a sensor to each device separately. Secondly the interface is monitoring the amount of fresh water consumed in the household, for which it is proposed the use of meters on the house’s main inlet and the separated outlets. The third aspect, which is also the most difficult to monitor is the household’s waste management. It monitors by putting electronic weights at the bottom of the recycle bins and trash cans, which provides data on the amount of trash in the bin and when is it emptied. In this way the interface monitors usage patterns, as well as identifies changes in ratios between organic, non-sorted garbage and separated, recyclable waste.

**Interaction with the users**

Within the game framework, specific objectives have been tackled in order to properly interface the user. Firstly, in order to encourage the users, the proposed game aims at rewarding the real-life positive behavior. Considering the similarities of the purpose, precedents can be found in games to support the user during e.g. a diet or a fitness program, such as the Nike+ iPhone app, or the Ford Fusion dashboard design. These are cases in which the individuals are aware of a situation in which they require external help for self-improvement, and willingly comply with the rules applied by the system. Secondly, in order to allow a constant and immediate feedback, the interface was designed to relay on the usage of a smartphone as the main communication device between home automation and individual user. The frequent interaction with smartphones enables users to be provided with instant feedback on their performance and at the same time suggesting ways for self-improvement. Another benefit of using smartphones as actuators and monitors is the abundance of sensors and connectivity options they are equipped with – this ensures a more intuitive and easily embedded solution for actuation and representation of feedback. This real-time feedback improves the user’s ability to connect action and cause, thus enhancing the educational process. Thirdly, peer pressure, a major force in motivation and norm adaptation, also plays a role in the proposed game – the system is deeply embedded within social networks and is designed to allow for competitions to be held between users and status symbols be acquired and presented as social capital.

The game described in this paper is designed as a training tool that would allow a household’s transition into a more sustainable way of life, and is designed to stimulate players to a period of about three months – the period of time considered to be sufficient to make a behavior change into a habit [2]. Naturally, the enthusiasm from games tends to wear off after a while. In order to prolong the period of time the users are engaged to play with the system, various game mechanics were used by applying the flow model theory by Csikszentmihalyi (1997), and appealing to the four different types of players according to Bartle’s model (1996).

**Intuitive house actuation via location based control**

An important part of how much the system and game interface would be adopted by users is determined by how intuitive and useful it is believed to be by the habitants.

The usage of smartphones as human-machine interfaces in combination with several stationary 3d cameras, such as the ones used in the Microsoft Kinect controller, allows the system to accurately track the users and better interpret their desires. This ability enables accurate tracking of the user’s posture and the center of their focus. Once the focus is established the smartphone can act as a “point and shoot” remote: If the user points at the TV with his
smartphone, as one would do with a conventional remote, the display would automatically adjust itself to show only the controls that are relevant. The same would apply for lighting, comfort, appliances, windows, blinds, etc. In this way, users are allowed to keep old habits in a new fashion.

**GAME DESIGN AND IMPLEMENTATION**

**Goals and objectives**
The aim of the game is to positively alter users’ consumption in terms of reduction of used resources (energy, water and waste) for a long enough period (three months) that it becomes a new habit. Also the design aims to provide the users with new knowledge and knowhow to improve their skills to assist achieving the game’s goals.

The game’s objective from the player’s point of view is to become the most energy efficient player. This needs to be reflected on the player’s level and ranking and be visible within the social network. In addition, the player aspires to get as many trophies and achievements as possible to further motivate and justify the reason for playing.

The game interface coexists in several different environments (Figure 2); the first and most useful for the user is the control environment - it is displayed as an HTML page on a mobile device, allows direction dependent actuation and immediate simplified feedback on the effect the actuation has on the system. Its goal is to provide instant feedback in order to improve skill by trial and error. The next environment is the game overview screen, which consists of a set of views in which the players can note their progress and be able to compare it with others. This game environment provides the player with continuous feedback on progress they make in the game. Another environment in which the game exists is the social feed, which allows the players to extend the level of interaction to include social networks and compare with others. Lastly, the score acquired in the game can be transformed into tangible redeemables which in turn are converted to real-life objects of benefits.

**Rules and gameplay**
The game is designed to be open ended. It is based on the continuous metering of household usage. Efficient usage is rewarded and decline in performance is punished. The player cannot lose; however effort is needed to be maintained in order to preserve the acquired assets.

The game’s reward system is designed to keep the player involved by positive reinforcement for both reduction of usage and sustaining of low consumption. Actions done by the players are registered and interpreted by the game and are reward-
ed by the game engine based on a quantifiable level of compliance with the performance on the game’s Key Performance Indicators (KPIs). The rewards are visualized by a virtual environment and are redeemable in the form of an in-game currency which is exchangeable to real-life money equivalent based on the product’s business model.

The rewards in the game are given in two forms: points and trophies. Each of the two is corresponding to KPIs in three different fields of resource conservation: energy improvement, water consumption reduction and waste management.

• **Points** - The player can gain points in two different methods: First, a reduction and sustenance of low consumption patterns and second, meeting challenges (single or multiplayer). Points are accumulated and determine the level a player is at (logarithmic incremental thresholds, reflect difficulty in moving from one level to the other. Players collect points in three hour intervals for energy and water performance, while points for waste are distributed once a week (00:00) and reflect the effort within the last 7 days. In addition, points are distributed upon completion of a challenge, regardless of time. To gather points for everyday consumption, the monitored data is constantly in comparison with a virtual energetic reference model of the house. This model consists of a benchmark equivalent of the house which is altered by house specific information and meteorological data. The difference between the assumed average household consumption of the model and the actual measured performance of the user is translated to points. The larger the deviation, the more points the user gains. The measurement takes place in correlation with the actual user taking the action (recognized via optical means) and counted to their balance. The points are calculated per quarter of an hour, based on the presence of the player in the house. Points are given only during the time that the user is in the house. The gained points are automatically accumulated, even if the user doesn’t show interest or involvement in the game. They can be used as a personal reference for users who are only interested in quantification of data. Extra points can be gained by taking on challenges, offered by the game engine, implied by the users upon themselves or later in the game in groups.

• **Trophies** - In addition to points, a parallel reward system that consists of trophies is implemented to enable the players to collect proof of competence in various fields. These would be granted on successful completion of challenges (both social and personal). The trophies would be visible to the player and the social surroundings in form of feed updates, player profile alteration and unique rewards within the mirroring virtual environment in the form of species that represent the effort. Trophies are designed to keep users engaged and motivated by introducing a collecting game into the scheme, as suggested by Kim’s guidelines for gamified process (Kim 2009). The trophies are used as part of the challenges module of the game to shift user’s focus into specific goals set by specific needs that are determined by the game designer, the service providers or induced by the game to improve the user’s performance on a specific topic. The trophies management system is capable of real-time online update so that new trophies can be added or some trophies may become available only for a short period of time. The trophy system contains three sets of trophies- one for energy related challenges, the second for water related ones, and the third for waste related ones. As oppose to points, which are gathered regardless of the user’s active intervention trophies are only given as a result a conscious decision of the player to engage in a challenge. All challenges and tournaments are defined by both an explicit target and a timeframe. The timeframe needs to be long enough to get reliable data, but at the same time not too long for the players to lose interest in it. The suggested
timeframes are between 3 days and a month. The reward intensity should be reflected by it – long challenges should reward better than short ones. Once a challenge is met, a trophy is unlocked, and points are given in regard to the difficulty level. Players are offered the chance to pick a trophy to their liking, enabling choice and customization within the same worth level.

- **Virtual reality as mirroring feedback** - In order to improve the connection between cause and effect in this serious game, a visual virtual representation mechanism was conceived. An island would act as a mirror, representing the reality within a virtual environment (Figure 3). The two main outputs of the game, points and trophies would be displayed in it. Points determine the livelihood and size of the island, and trophies its biodiversity. The three different consumptions are translated into a simulated environment which is comparable in social media. Each player is given an editable procedurally generated island. These islands are visible to other players in the form of a screen saver that shows a rendered flight between the islands as a screen saver (on all devices). The players can fly around their own island as well as other players’ islands within their social network. During these flights they would be exposed to trophies acquired by their friends.

At first stage, the island is a rocky wilderness, and the actions of the player create life within it. The island would represent the progress in the game in a way that from a glance one could tell how well the player is doing. The energy balance would be translated into vegetation – the more CO2 the player saved, the more trees and plants would be generated on the island. The water balance would be represented by the amount of rivers and waterfalls as well as aquatic life (fish etc.) that would be generated on the island, and waste would be represented by the fertility of the land, by flowers, grass and animals. Trophies would be represented as the biodiversity of the island.

**Fair play**

Different houses in different environments function in different ways. Thus, comparing their performance for scoring purposes might prove to be difficult due to the fact that the same rules must apply to all players, and all need to be judged by the same criteria. Otherwise, players would get frustrated after a short while. This is avoided by creating an internal consumption simulated model of each house within its automation system, in order to create a baseline simulation of the expected energetic performance (Figure 4). Once the model is created, the interface measures the variations from the set point on a scale of relative difference from it. To further increase the accuracy of the ‘zero’ model, a questionnaire is filled out, surveying the dwellers’ habits and routines, their environment and type of household.

By comparing the data gathered from the sen-
user’s response to a series of questions covering lifestyle, usage, climatic variables and technical information about the house (Figure 5). Then the data is sent to the game’s servers and a simulated energetic model of the house is generated and combined with matched statistic data. Over time, it is recommended a fuzzy logic neural network make adjustments to the benchmark to better represent the physical environment, so that any inaccuracy in the fitting of the benchmark and coefficients would be canceled out after a period of time. Score is then given according to the relative distance on an array between the actual measured consumption data (received from the sensors monitoring the house) and the best and worse practice settings of the benchmark. The factors that are normalized are the building’s active and passive efficiency, the inhabitant’s behavior and scheduling, and the climatic environment in which the dwelling is located.

**Game framework**

In order to maintain high level of interest and motivation, the game is designed in several phases that gradually allow the player to advance to different playing modes and challenges. The game is designed to always give the players challenges that are not too hard nor too easy, based on their current level. Doing so would prevent the player from getting bored or frustrated by challenges which are out of the spectrum of their skill. There are 6 different game modes the users are advancing at, unlocking each as they improve.

1. **Tutorial** - In this phase player learns to use the different ‘lever’, while at the same time the benchmark is created and adjusted by the game core.
2. **Sandbox** - In this single player mode the users learn the outcome of their actions by trial and error.
3. **Self-challenge** - This is a stage where the players select challenges and try to meet their goals.
4. **Social challenge** - Same with phase 3, but measured against a group of peers from social...
5. **Team challenge** - group vs. group of players on cumulative reduction of footprint, over social networks.

6. **Tournament** - high gain player vs. player mode, in which the users play against strangers within their level range.

**INTUITIVE CONTROL AND PROTOTYPES**

A proof of concept prototype was created for the ‘point and shoot’ remote control system (Figure 6). It was based on an iPhone as the actuator, a Kinect sensor as the external reference camera and a laptop and wireless network that acted as a server. The phone ran a JavaScript based webpage which acquired real time sensor data from the device’s compass and accelerometers, and sent it to the server via WIFI. The server cross-referenced the phone’s absolute orientation data with data acquired from the Kinect sensor, in which the location of the phone in 3D space can be determined. Combined together, a vector is plotted that indicates where the user is pointing the phone at. Once a ‘hit’ is detected, the server sends the current data from the selected device to the JavaScript client, which in turn hides the previous set of switches and presents the current one. If the user changes the value of a control, the phone sends the command to the server which in turn uploads it to Xively’s servers (formerly Pachube), from where the data can be transferred to a home automation system.

**CONCLUSION**

Initially, domestic consumption was mapped and potential for reduction in various fields was identified. Then, the home automation system was targeted as the interface between the inhabitants and the appliances, and where the potential for improvement was greatest. The contemporary home automation system serves as a hub, binding all mechanized operation in the house. Therefore, embedding a system that would promote resource consumption reduction in it would be most effective. The main concept explored in this work was guided by the notion that the most effective method to reduce demands in a domestic environment is to improve the method through which the inhabitants are experiencing the interaction with the appliances. It seems to be the missing piece in the ‘sustainable home’ puzzle - While appliance manufacturers put...
their emphasis on improving the performance of the machine, the user is neglected. This work aimed at changing the paradigm of communication with the home appliances – instead of the conventional one-sided communication of giving operation commands, a bilateral communication that would be established. It reacts to the users' action in corresponding stimuli, encouraging them to change their behavior. When it comes to desired behavior alteration agents, a new and prominent player in the field could be the serious game.

To make the system more accepted and intuitive, a method for context aware remote controlling was developed and a prototype for analyzing user intent was programmed and tested as a proof of concept. The key innovation and contribution of this work to the field of building technology, revolves around making of connections between previously unrelated topics, and unifying them in an unconventional yet meaningful way. The work binds research in the fields of comfort design, behavior science and design of interaction into a single product. Combined together, an alternative method was developed to the way domestic automation systems are controlled today. It is our belief that the new method proposed is capable of effectively motivate the inhabitants to conserve resources.

OUTLOOK
Due to the framework of a masters’ graduation thesis, the project was developed until it had reached the stage of proof of concept. The path from the current stage to a viable market product is long and would require further market research and adaptation, development of the sensor unit and machine compatibility, building a viable business plan and improving playability through trial and error.

Some issues were disregarded in the work, such as privacy and personal security. The implication on people’s feelings towards a system that is constantly watching them could have negative effect on acceptance. Furthermore, automation systems in general and the proposed system in particular create new vulnerability points in home security. Hack-


[1] www.eia.doe.gov/emeu/reps/enduse/er01_us.html