3-19-2020

Big Data and Occupants' Behavior in Built Environments: Introducing a Game-Based Data Collection Method

Alenka Poplin
Iowa State University, apoplin@iastate.edu

Big Data and Occupants' Behavior in Built Environments: Introducing a Game-Based Data Collection Method

Abstract

Energy-related human behavior in buildings is difficult to define and quantify, yet critical to our understanding of total building energy consumption. It substantially influences energy consumption and saving. In the United States, residential and commercial buildings account for more than 70% of the total electrical energy consumed in the country. This paper explores the implementation of an online energy game, e-footprints, which aims to collect data about occupants' energy consumption and saving, and summarizes the feedback related to the first prototype of the user interface. The game was tested with 110 international students. The study focuses on the visualization, aesthetics, and usability of the e-footprints energy game, as these are the important elements of a player's interaction with the user interface and greatly influence the game play and the data that can be gathered. The paper concludes with a summary of the findings and general recommendations that may be useful for others using serious online urban planning games.

Comments

This accepted article is published as Poplin, A. 2020. Big Data and Occupants Behavior in a Built Environment: Introducing a Game-Based Data Collection Method, *Journal of Urban Planning and Development (JUPD)*,146(2) (June 2020), published online on March 19, 2020; doi: 10.1061/(ASCE)UP.1943-5444.0000552. Posted with permission.

Cite as: **Poplin, A.** 2020. Big Data and Occupants Behavior in a Built Environment: Introducing a Game-Based Data Collection Method, *Journal of Urban Planning and Development (JUPD), Special Issue on Data Science & the Built Environment*. Volume 146, Issue 2 (June 2020), published online on March 19, 2020, American Society of Civil Engineers, DOI: 10.1061/(ASCE)UP.1943-5444.0000552.

Big Data and Occupants Behavior in a Built Environment: Introducing a Game-Based Data Collection Method

Alenka Poplin, Iowa State University

Abstract. Energy-related human behavior in buildings is difficult to define and quantify, yet critical to our understanding of total building energy consumption. It substantially influences energy consumption and saving. In the United States, residential and commercial buildings consume more than 70% of the overall consumed electrical energy in the country. This paper explores the implementation of an online energy game *e-footprints* that aims to collect data about occupants' energy consumption and saving, and summarizes the feedback related to the first prototype of the user interface. The game was tested with 110 international students. The study focuses on the visualization, aesthetics and usability of the *e-footprints* energy game as they are the important elements of the player's interaction with the user interface. They greatly influence the game play and the data that can be gathered with the help of the online game. We conclude the paper with a summary of the findings and general recommendations that may be useful for other engaging online serious urban planning games.

Keywords: online geogame, game-based simulation, data about human behavior, energy consumption and saving

Introduction

Online serious games have been increasingly developed and implemented for urban planning, public participation in planning, civic engagement and architecture. They can be played either online through the Internet or any other computer network or offline by downloading the application on a device. As the browsers became more sophisticated, the developers started creating online browser games that use a web browser as a client. Such games can be used in a variety of urban planning phases and can enable one to visualize the current situation in the city and/or future developments (Gordon and Manosevitch 2010, Billger et al. 2017); facilitate discussions on the issues relevant to the citizens, public officials or other stakeholders (Gordon and Schirra 2012, Thiel and Fröhlich 2017); visualize and discuss the proposed plans and changes in the city (Gordon et al. 2011, Poplin 2012, Poplin et al. 2017); learn and reflect upon urban issues (Gordon and Baldwin-Philippi 2014, Devisch et al. 2016, Poplin and Vemuri 2018); foster negotiation and consensus building in urban planning (Saad-Sulonen and Botero 2010, Vemuri et al. 2014, Poplin and Vemuri 2018); and/or connect citizens in an online virtual platform enabling them to submit their suggestions for urban designs or comment on the proposed urban planning alternatives (Foth et al. 2009, Hacker and Matchin 2009, Poplin 2014). Some of the efforts concentrate on creating immersive playful environments for learning about cities and urban planning aimed to attract youth and children (Tóth and Poplin 2013a, Tóth and Poplin 2013b, Tóth and Poplin 2014, de Andrade et al. 2016). Most of these efforts in developing serious games for urban planning, in their initial stages, focus on the question "How to design an online game that can support one or several of the urban planning processes?" In the process of designing an online game, the design of the user interface, its visualization, aesthetics and usability play an important role. The designed user interface represents the first contact with the user/player and may substantially influence the decision about her further use of the game. It also has an impact on the frequency with which players visit/play the same game and whether they keep on returning to the game or not.

The central research focus is built on the question how to design an online game, game that can be played in a web-browser, and will enable one to collect big volumes of data about occupants' behavior in built environments. Big data in this context refers in particularly to the volume of data (Keller et al. 2012, Fuller 2015, De Mauro et al. 2016, Thakuriah et al. 2017) as it can be potentially collected online, 24/7 from every location with Internet connection and a device with a web browser. Its focus is on human behavior related to energy consumption. Annual Energy Outlook 2014 with Projections to 2040 reported that in 2013 residential and commercial buildings consumed more than 40% of the United States total energy and more than 70% of the electrical energy, resulting in a national energy bill of $410 billion (USDepartment of energy (EIA) 2014). Additionally, low energy buildings often fail to meet expected performance, with occupant behavior (OB) contributing decidedly towards building energy consumption and indoor environmental quality (Sun et al. 2014, Hong et al. 2015a, Schakib-Ekbatan et al. 2015). Occupants interact with building systems in a variety of ways by opening and closing windows, changing blinds, adjusting thermostats, controlling lights, all of which influence the energy consumption of the building (Hong and Lin 2013, O'Brien et al. 2013, Sun et al. 2014).

This paper has three main goals: a. It explores an implementation of an online game *e-footprints* that aims to collect data about occupants' behavior related to energy consumption and saving, and b. It summarizes the feedback related to the first prototype of the user interface, and c. Discusses take-aways for the development for other online serious games for collecting data about human behavior in a built environment. The developed *e-footprints* energy game is an example of a game-based environment that may help to collect big data about occupants' behavior in a built environment. The paper introduces at first experimentally developed analogue version of *e-footprints* energy game and the results of the initial test of its first prototype. The game prototype was tested with the help of an online survey that involved 110 international university students. The main goal of the test was to gain a better understanding of the elements of the user interface, in particular the visualization and aesthetics and how appealing are they to the young generation of players, which is often the most demanding and critical generation of players. The results of this test were the foundations for the next step of game development that lead into the development of an operational, web-browser version of the second game prototype. This paper summarizes the results of the empirical study, reflects upon the take-aways for the development for other online serious games for collecting data about human behavior in a built environment, and concludes with a discussion on further research directions.

Online serious games for data collection about occupants' behavior in a built environment: research focus

One of the most difficult tasks people can perform,
however much others may despise it, is the invention
of good games. (- C.G. Jung)

Energy-related human behavior in buildings is difficult to define and quantify, yet critical to our understanding of total building energy consumption (Hong et al. 2015a). Humans interact with their built environment in order to satisfy their thermal, visual and acoustic needs and preferences. These interactions are typically grounded in the Humphreys' principle of adaptation (Hong et al. 2015a, Hong et al. 2015b), which states that if a change occurs such as to provide discomfort, people react in ways which tend to restore their comfort (Humphreys 1997). Parson (1993) distinguishes among the following three main adaptive responses: behavioral, physiological, psychological. A behavioral response is any type of action performed to maintain or restore a state of comfort when the indoor environmental conditions cause discomfort. Such activities may include turning on or off Heating, Ventilation, and Air-Conditioning (HVAC) equipment, opening or closing windows, using shades and/or blinds, adjusting thermostat settings, using fans, caulking, using plastic on the windows and/or doors, etc.

This paper concentrates on the behavioral response. A physiological response is any type of unconscious reaction which allows the human body to adapt thermally to the indoor environment. Example of that would be shivering when cold or sweating when very warm or hot. A psychological response is any type of individual reaction to the indoor environment due to discomfort, strain, pressure, motivation or adaptation to the environment. It may involve the cognitive and cultural variables of each individual with respect to their perception of the indoor environment (Parson 1993).

In the past, this type of behavioral comfort-driven responses of occupants has been modeled and simulated based on some limited evidence/data gathered from field studies. Such studies often use questionnaires as a research method. The problem with using questionnaires is that the occupants often enter the preferred and not the actual response. Some people quickly respond without too much premeditated thought. Existing models of the human-building interaction include assumptions based on some generic input data assuming that the occupants behave in a set way according to standard deterministic design conditions such as preferred temperature, ventilation rates, thermostat set points and other threshold values (Hong and Lin 2013, Sun et al. 2014, Hong et al. 2015a, Hong et al. 2015b). Traditionally, in building energy modeling (BEM) programs, occupant behavior inputs are deterministic and less indicative of real world scenarios, contributing to discrepancies between simulated and actual energy use in buildings (Hong et al. 2015a). The inclusion of the adaptive comfort model (de Dear and Brager 1998) into European EN 15251 (2007) and U.S. standards ASHRAE 55 (2010) has promoted interest in: (1) the prediction of occupants' actions performed by individuals to restore their personal comfort, and (2) the quantification of the energy impact of their behavior to understand the factors driving the difference between predicted and actual building energy use (Hong and Lin 2013, Sun et al. 2014, Hong et al. 2015a, Hong et al. 2015b). Of particular importance are the actions of turning on/off HVAC equipment, adjusting thermostats, lights, windows and blinds, and moving into/out of spaces.

Research described in this paper explores the first prototype implementation of a game-based environment that aims to capture data about behavioral comfort-driven responses of occupants within the built environment. The main research questions that drive this research is how to design and implement a digital online serious game for collecting big data about occupants' in built environments? Serious games are games developed for more than just fun, they are more often games developed for non-entertainment purposes (Abt 1970, Michael and Chen 2005, Ritterfeld et al. 2009). They have been used in many application areas including urban planning, civic engagement in urban planning, education, energy, military and/or management. Serious games may include learning elements; they may be designed as "puzzles to solve, just like everything else we encounter in life" (Koster 2004, p. 34). They may include powerful learning tools and are increasingly used to transform the way people learn and what learning means and how it is available to them (Malone 1981, Lepper and Malone 1987, Malone and Lepper 1987, Mitchell and Savill-Smith 2001, Gee 2003, Squire and Jenkins 2003, Squire et al. 2005).

Creating an online game for data collection can be challenging. Successful games for data collection have been developed in the domains of objects tagging as for example image tagging (Hacker and Matchin 2009), music tagging (Lepper and Malone 1987, Turnbull et al. 2007, Law and van Ahn 2009, Mandel and Ellis 2009) knowledge extraction (Siorpaes and Hepp 2008), computer vision (e.g. object detection) and labeling (Carlier et al. 2012) and ranking predictions through image search (Bennett et al. 2009, Law 2011). These exemplary games are often called Games with a Purpose

(GWAP) and are digital games in which the players' actions in the game contribute to a real-world purpose outside of the game. Most of these games are based on kinds of “validation” mechanisms. Their advantage is that they are generating useful data for scientific purposes as a by-product of their gameplay. The issues researchers, game developers and designers face with serious and GWAP games is that “the task to be solved may mismatch with the game mechanics, thus decreasing the playability of the game and failing to attract people and engage them in the execution of the task” (Galli 2014, p. vi.), which is a general issue with serious games and needs additional research in better understanding of their design that can bring players into the state of flow (Csikszentmihalyi 1990).

Developing an online serious game, that can be used in a web browser, also involves the process of creating the digital appearance of the game and the user interface. Game design requires a collaboration across disciplines and several iterations in refining the game concept and the game story. It is challenging due to the technology involved, which often enables additional functionalities (in comparison to non-digital games) and the ability to access such games online. Additional challenges in creating online serious games represent the design of the user interface and particularly the visualization, aesthetics and usability of the designed user interface. The novel design principles have been advocating for play-centric and human-centric game design (Fullerton 2008, Brathwaite and Schreiber 2009, Rogers 2014, Schell 2015). One of the key ideas of the play-centric approach is that “ideas [about the game and game design] should be prototyped and tested early. Immediately after brainstorming ideas, we encourage designers to construct a playable version of their idea.” (Fullerton 2008, p. 11). They should be tested in the early stages of the game development with its potential users/players. This paper summarizes a response to an early prototype of the game-based simulation titled the *e-footprints* energy game.

Prototype of the *e-footprints* energy game for collecting data on occupants behavior in built environments

The prototype of the game *e-footprints* was developed in a research project which started as an initiative of a small number of researchers from various disciplines at Iowa State University. The main goal of the research was to explore the possibilities of game-based environments and their use in various phases of data collection. The prototype of the game *e-footprints* focuses on creating an immersive simulation of built environments which invites players/citizens to experiment, explore, and make their decisions about this environment in order to feel comfortable in the simulated home environment. The first prototype is represented by a set of visualizations of the envisioned user interface and an activity diagram demonstrating the levels of the game which coincide with the levels of data collection (Figure 2).

Level 1: Data collection. In the first step, the potential players have to register and create their own password. The registration page asks them about their gender and their age group. In the next step the player can choose among four types of housing available to her (Figure 1). It invites them to choose the house/residence similar to the one in which they currently live. These steps represent the first phase of data collection related to the information about the players and their house style. After finishing this first level of the game and the first level of data collection, the game takes the player into a simulated room environment.

Figure 1. Select the type of a house you live in

The simulated room environment is central to the *e-footprints* energy game. The room is designed as an interactive online room in which the player/user can adjust the temperature, open up/close the window, turn on/off the air conditioner, and turn on/off the fan. The outside temperature is visible to the user at the top right corner of the screen; it gives her an idea of the temperature outside the house and a feeling for the time of the year/season and time of the day. The player can explore the room and chose the temperature conditions of the room that are the most comfortable for her, given the season and the time of the day. The data being additionally collected is the temperature the players sets in the room and her reaction to the extreme heat "random event". She has the possibility to choose among several options as her reaction to the extreme heat: open/close the window, turn on/off air conditioning, turn on/off the fan and/or adjust the blinds. Figure 2 summarizes the activity diagram of the game play with the data collection levels clearly marked, along with the decisions available to the player on each step of the game play.

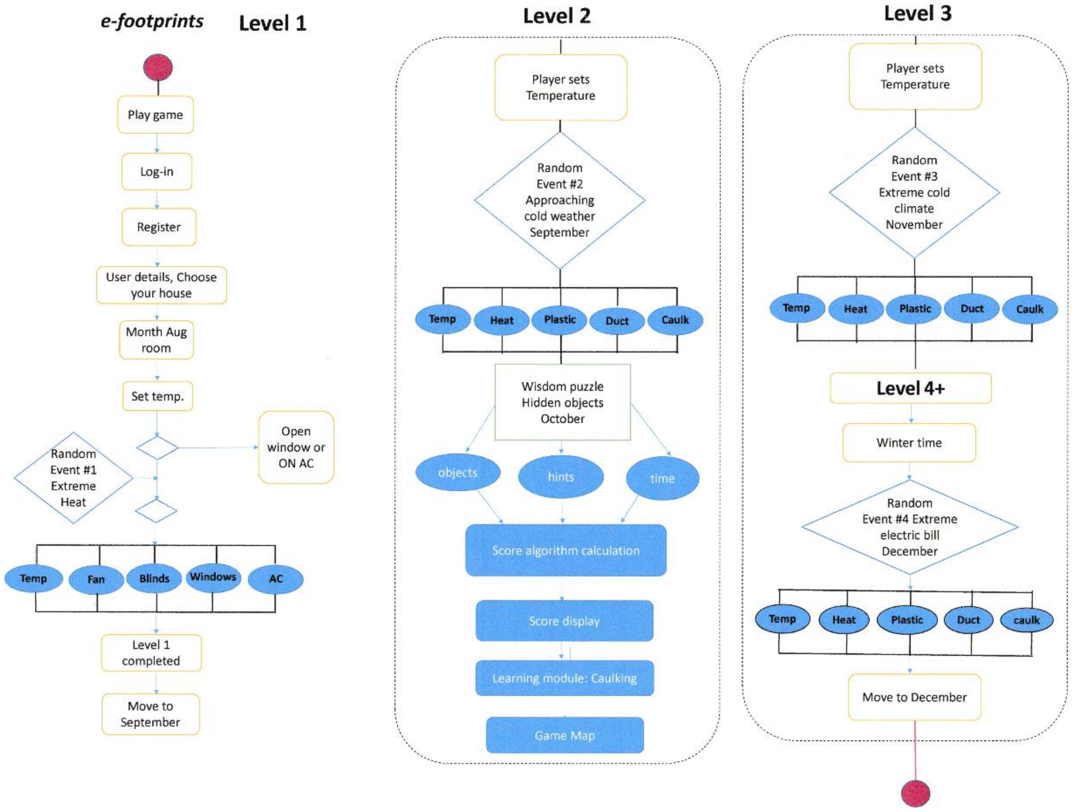

Figure 2. Levels of data collection implemented in the *e-footprints* energy game

Level 2: Data collection. Level two includes random event two in which the player experiences approaching cold weather and the associated result of getting cooler. The player then has some options in how she wants to react to the changes in temperature. Her options include changing the temperature in the room, install plastic on the windows and/or doors to insulate them, sealing the ducts or using the method of caulking the windows. Her decisions and preferences are recorded and saved in the back-end of the game. Additionally, a wisdom puzzle is introduced for the first time. Wisdom puzzles in the *e-footprints* energy game are designed as learning tools throughout which learning can be expanded and deepened by the players. The first wisdom puzzle aims to teach, in a fun and entertaining way, about caulking and which tools are needed for caulking. The player has to find four hidden objects needed for caulking and can also read more about the advantages of caulking in terms of energy saving. The time needed for the player to accomplish this task is measured by a melting cube and the player gets points for the completion of this task. The points are calculated in an algorithm that takes into account how many hints did the player use to solve the wisdom puzzle and how fast was she able to find the four hidden objects. An example of a wisdom puzzle is presented in Figure 3.

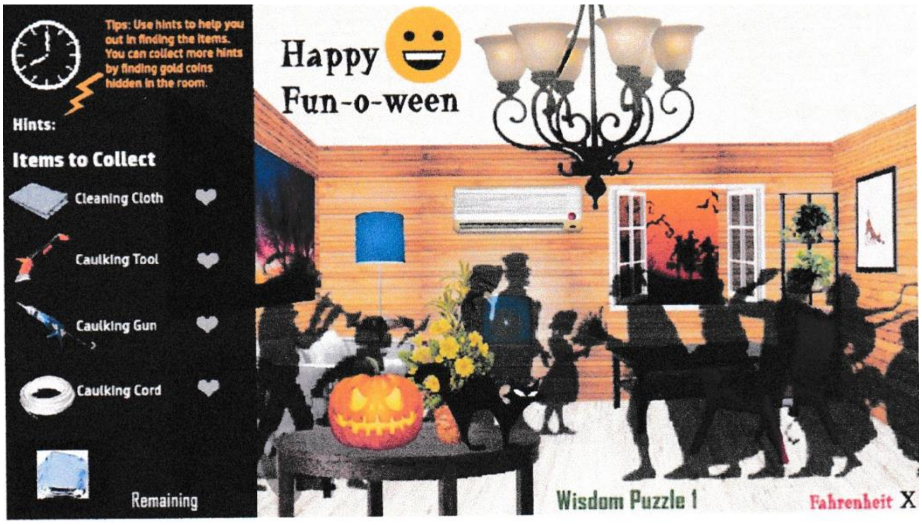

Figure 3. Wisdom puzzle about caulking with the ghosts of Halloween

Level 3+: Data collection. The third, and all the next game levels (3+), introduce a new set of random events and wisdom puzzles. The third level introduces the extreme cold weather random event with the same options to solve the problem as the random event on Level 2. The aim of the game is to capture and save the players’ choices after they have been exposed to the option of caulking on Level 2. Will more players choose this option as a possible reaction to the extreme cold event? Level 4 introduces an extreme electric bill random event. The player can respond to this random event by, again, choosing among five options given by the game (Figure 2).

Data privacy considerations. During the game design, special attention was devoted to data privacy. The first level of data collection collects data about the age, gender, and the type of the house in which the player lives. The players also enter their E-Mail address. This data is not personalized and will – in the further analysis – be used as an aggregated dataset. The research is looking into data patterns and not an individual preferences and choices. The player can skip this stage and still play *e-footprints* energy game anonymously, however this is not explicitly encouraged by the game. On the following levels of data collection (2+), the data collected registers the player's choices in the built environment and their chosen actions and reactions to the extreme events presented to them in the game. Again, this data will be used for the analytical purpose of the study that concentrates on human behavior in built environment. The main idea behind is to define so called "personas" with typical behavior and use the parameters of these personas for further development of an agent-based system that will enable simulations of human behavior. We will explore patterns of typical behavior and search for co-relations with data collected on the first level such as age, gender, type of the house. A general types of human behavior will be generated based on the collected data. The raw dataset will not be shared or reviled to a third party. The game can be played online and there is no risk for the players associated with playing the game.

Testing the first prototype of the *e-footprints* energy game: research methodology and results

Participants

The participants of the survey were 110 international students. Testing of the first game prototype is intentionally focused on this group of the millennials that are demanding in respect of game visualizations and aesthetics. They were also quickly available for the first feedback on the designed prototype needed to be executed in very early stages of the game design. Among them, there were 103 undergraduate students and 1 graduate student; six students did not provide information about their university program. Four age groups participated in the survey: 4 students were 17 years old or younger, 79 students were between 18-20 years old, 19 in the age category 21-23, and one in the category 24-26 years old (Figure 4). Among them were 26 female, 73 male and 5 other gender. The countries of origin were Burma, Bolivia, Brazil, Canada, China, Dubai, Ecuador, Egypt, India, Indonesia, Iraq, Kenya, Kuwait, Malaysia, Mongolia, Nigeria, North Korea, Oman, Pakistan, Puerto Rico, Riyadh, Russia, Spain, South Korea, South Sudan, Taiwan, Uganda, and United Arab Emirates.

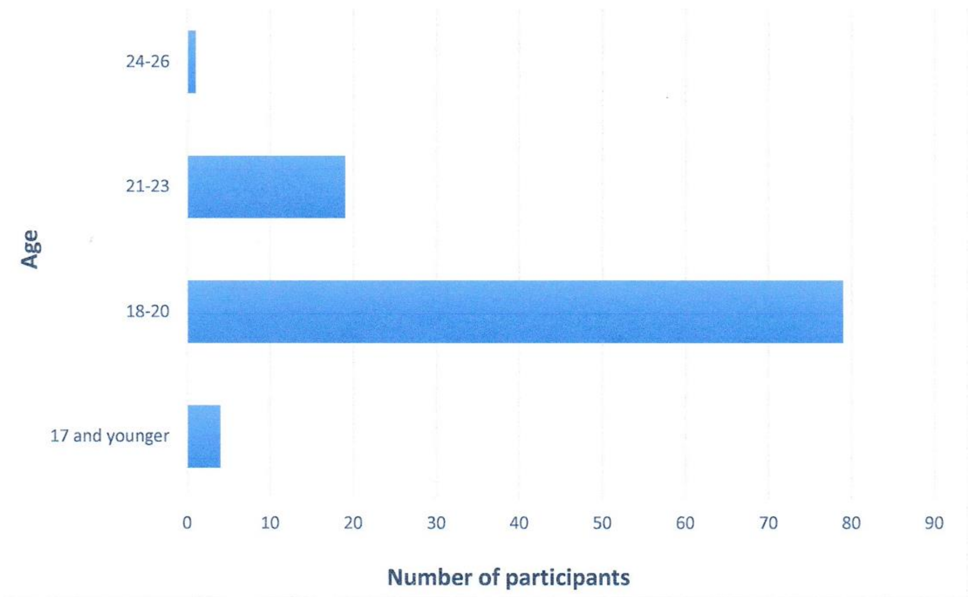

Figure 4. The age of the survey participants

Material

The material used included the online survey and the graphics designed for the first prototype of the *e-footprints* energy game. The online survey was designed as an online questionnaire in Qualtrics open source software, which includes a database and enables one to store the data collected, executing the online survey. The graphics of the *e-*

footprints energy game shown to the students in the online survey included four pictures which represented the design of the game user interface and its graphical visualization. The needed materials also included their personal devices for accessing the online survey such as personal computers, tablets or smart phones.

Procedure

The international students gathered in a lecture hall which has a big screen, a projector and audio equipment. The chairs in the room have a small table attached to them so that the students can place their laptop or a mobile device on them. The leading experimenter (the author of this article) introduced the game project, explained its main goals, and the goals of this survey. The goals of the project were to develop an online energy game which simulates a home environment and enables one to collect data about the occupants' behavior in built environments. The lead experimenter then asked the students to follow the link of the online survey sent to them via email. From here on in the process of the evaluation they were able to concentrate on the four graphical visualizations of the game as presented in the online questionnaire. The students were allowed to respond to the online survey at their own pace; there was no pressure for them to finish it in a particular time frame.

Empirical results of the testing *e-footprints* energy game and its further development

The survey participants were asked to evaluate the visualization and aesthetics of the room, the whole image, and comment on the usability of the designed user interface. The first picture shown to the students was the graphics of the room (Figure 5) with the following instructions: *"Imagine you are playing an online game at your home. This particular online game takes you into a living room. The outside temperature is 65˚F /18˚C, and it is in the middle of the day in October."*

Figure 5. Introducing the room in the *e-footprints* energy game

The more specific results for every question are summarized in Table 1. The main conclusion is that there is a potential for improvements of the graphics. The issue of the missing ceiling was a topic among many participants; over 40% of the users suggested changing the open roof, and additionally over 24 % seemed to somewhat agree about the need to change the (lack of) ceiling (64% altogether).

# Field	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree	Total
1. I find the design of the room attractive	11 10.09%	36 33.3%	26 23.85%	24 22.02%	12 11.01%	109
2. The furniture is similar to mine at home	10 9.09%	22 20.00%	34 30.9%	23 20.91%	21 19.09%	110
3. The colors of the room are appealing	16 14.55%	28 25.45%	32 29.09%	23 20.91%	11 10.00%	110
4. There is no ceiling; this needs to be changed	45 40.91%	24 21.82%	22 20.00%	14 12.73%	5 4.55%	110
5. The emoticon makes the scene fun	15 13.89%	24 22.22%	34 31.48%	16 14.81%	19 17.59%	108

Table 1. Responses related to the graphics introducing the room in Figure 5

The students were asked to evaluate the graphics and aesthetics of the whole image and not just the room (Figure 5). The image was perceived as aesthetically pleasing by 39% of the students and 33% are neutral about this topic. The colors were considered pleasing for 44% of the international students and 42% are neutral. The students confirmed that they perceived too many objects on the image (for 55% of the students) and that there is too much detail included on the image (44%). Table 2 summarizes the results of the empirical study.

# Field	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree	Total
1. The image is aesthetically	19	24	36	18	12	109
pleasing	17.43%	22.02%	33.03%	16.51%	11.01%	
2. The colors are	14	30	42	13	11	110
aesthetically pleasing	12.73%	27.27%	38.18%	11.82%	10.00%	
3. There are too many	19	36	26	20	7	108
objects on the image	17.59%	33.33%	24.07%	18.52%	6.48%	
4. There is too much	13	31	39	15	10	108
detail on the image	12.04%	28.70%	36.11%	13.89%	9.26%	

Table 2. Responses related to the graphics and aesthetics of the user interface in Figure 5

The usability of the proposed user interface was evaluated very positively. The majority of the students would intuitively know very well how to use it. More than 70% of the students strongly agree and somewhat agree that it is clear how to adjust the temperature, how to open the window, and that it is easy to read the text on the image. Table 3 summarizes the empirical results.

# Field	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree	Total
1. It is clear how to adjust the temperature	51 46.36%	31 28.18%	20 18.18%	4 3.64%	4 3.64%	110
2. It is clear how to open the window	47 42.73%	40 36.36%	15 13.64%	4 3.64%	4 3.64%	110
3. The text in the middle of the image is easy to read	48 44.44%	37 34.26%	12 11.11%	9 8.33%	2 1.85%	108
4. The text in the upper corner is easy to read	27 25.71%	35 33.33%	16 15.24%	21 20.00%	6 5.71%	105

Table 3. Responses related to the usability of the user interface presented in Figure 5

Improvements of the visualizations and aesthetics. Based on the testing results we focused on the improvements of the visualization and the digital, online implementation of a prototype that can be tested using web browser. Our second prototype includes a Rhino 3-D model of the room and a more clean and professional design. Figure 6 demonstrates the improvements done in conceptualizing the main interactive room. The room has the ceiling, less objects, less detail and the colors were changed. Additional tests needs to be done in order to be able to understand how appealing is this room to the players.

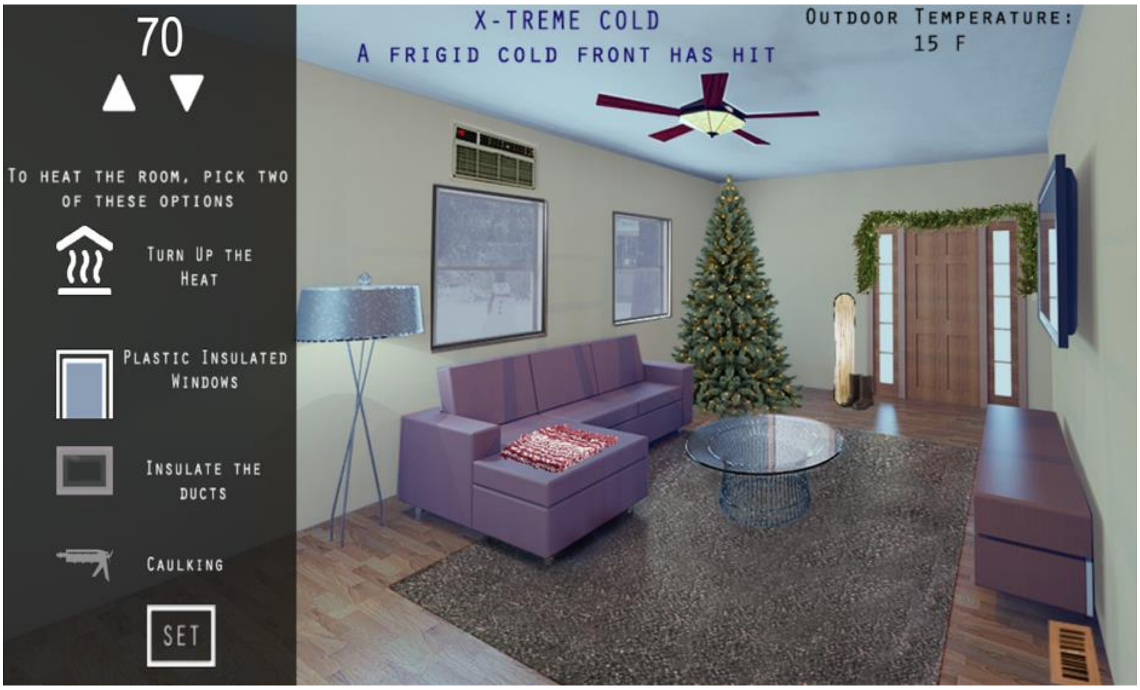

Figure 6. New design of the room with an extreme cold random event

Further envisioned changes include the option for the players to choose the furniture and other objects in the room and drag&drop them into an empty room space. This option is a direct response to the survey in which the participants claim that the proposed furniture has not been similar to the one they have at home. The *e-footprints* energy game aims to achieve immersive environment in which the players' feel immersed into their own home.

Implementation of the online prototype. After the first testing of the user interface and visualizations we implemented a new version of the *e-footprints* energy game that ca be tested in a web browser. The front-end was implemented with Hypertext Markup Language (HTML), Cascading Style Sheets (CSS), Java script and JQuery which enables to add complex functionalities to the web pages, and Bootstrap that made the web pages platform independent from programming. The data collection, the back-end of the *e-footprints* energy game was implemented with the help of Structured Query

Language (SQL) server and Visual Studio 2015. The implemented database enables one to store the players' responses in the tables that are then joined into one common table responding to the game play of each individual player. ASP.net and Ajax enable the communication between the front-end and back-end. Ajax was used to code the logic that enables the game to send the values from the front-end to the back-end. Windows 10 server is used to launch the *e-footprints* energy game. The current version of the online game can be tested online using the Chrome internet browser following the link http://efootprints.design.iastate.edu/.

Lessons learned and research challenges applicable for online game-based data collection about human behavior

The main goal of this experiment was to get immediate feedback on the first design of the prototype of *e-footprints* energy game. Such an approach has been recommended in the game design community and may lead to higher quality of game design in general, which we followed in this research project. The presented results accomplished for the *e-footprints* energy game demonstrated the need for the changes in the graphical visualization and aesthetics of the initial prototype. The second prototype was developed based on the results of the testing. However, what are the results gained from developing and testing one prototype that can be generally concluded and be useful for other game-based simulated environments created for collecting data about human behavior? What are the main research challenges? The list of important features and research challenges to be considered in the online game design for urban planning and data collection about human behavior includes the following elements:

Big data game-based online collection. The game presented in this paper is unique as it deals with data about human behavior that it is in its nature difficult to capture. To the knowledge of the authors of this article, no comparable games exist which makes this contribution unique. Researchers in human modeling and simulation and artificial intelligence (Normoyle et al. 2012) that use games mostly concentrate on the collection of player metrics which basically records the moves of the player and her decisions in the game without intending to focus on modeling human behavior by collecting this data. Examples may include the number of times a certain weapon was used or the percentage the player spent performing a certain activity which is then analyzed by the game designers (Ambinder 2009). Some of them focus on experimental design in such a way that they can actively collect players metrics related to the designed scenario in which they also concentrate on data uncertainty (Chaloner and Verdinelli 1995, Settles 2012). Special concern needs to be dedicated to ethics of collecting data online with or without players’ knowledge and permission. Also, data privacy is a valid concern for online game-based data collection applications.

Modelling human behavior using Agent-Based Modelling (ABM) and Machine Learning. ABM and artificial intelligence (Epstein and Axtell 1996, Axelrod 1997) has been be increasingly implemented and used to study patterns of players’ behavior. In an ABM, humans are represented/simulated with the help of agents whose models are designed and coded based on the knowledge of the actual behavior and reactions of humans in a variety of situations. Machine learning (Mitchell 1997, Bishop 2006) can further on help to study patterns in the collected data. It can help identify and build mathematical models based on sample data in order to be able to make predictions or decisions without being specifically trained or programmed to perform certain tasks. Combined with data mining it can focus on exploratory data analysis. Machine learning was coined in 1959 by Arthur Samuel who was a pioneer in computer games and artificial intelligence (Samuel 1959).

Meaningful choices and meaningful experiences. The ability to be able to make meaningful choices is crucial for the players. Iten et al. (2017) found that meaningful choices were often characterized by a combination of different options from which the player had to choose one - they can be moral, strategic or emotional. Being able to choose between these types of options and knowing that these choices would have consequences lead to choices that were experienced as meaningful. According to Rogers, Woolley et al. (2017) meaningful game experiences can be related to the depth of the story and its characters; experiences which most distinguished meaningful from fun experiences were those that involved moral choices and dilemmas. The fact that games ask players to choose between certain options puts the responsibility in their hands and makes them think about the choice at hand. In further development of *e-footprints* energy game, the ability to choose the furniture, the location of the furniture and the colors may enable the player to create the room she wants to see and feels comfortable with. The ability to choose has, in general, further implications on the player's attitude towards the created environment in the game. It may increase the feeling of immersion and ownership (Oliver et al. 2015, Rogers et al. 2017).

Conclusions and further research

This paper summarizes the empirical results gained from an online survey of the user interface designed for the first prototype of the *e-footprints* energy game, a game that concentrates on collecting data about players'/occupants' behavior in a built environment. This game is a unique contribution to the online methods for collecting data about human behavior that can be used by many internet users across continents. It was designed to collect high volume of data about human behavior in built environment. The focus of the study presented in this paper was on the visualization of the first prototype of the *e-footprints* energy game, aesthetics of the graphical images, and the usability of the presented user interface. All these elements substantially impact the game play and the players' ability to repeatedly return to the game. Only with a high quality user interface and its functionalities that players like and are willing to return to, an online game can be successful.

The empirical results demonstrate that additional resources in improving the graphical visualization and aesthetics of the *e-footprints* energy game need to be devoted in the next stages of the game development. The game is currently in the phase of redesign and further development. This phase includes a complete redesign of the graphics included in the *e-footprints* energy game which will also slightly change the functionalities of the game. We are working on the new graphical style of the game, choices of new colors, changes of the text and its style, and the visualization of the room itself. The mechanics of the game will allow for more meaningful choices for the player; being able to choose the type of the room objects and their placement would enhance this game and the players' immersion into the built environment. This step of testing in the initial phase of development was crucial for the next steps of prototyping of the *e-footprints* energy game.

This paper is a continuation of the research on data analytics and urban planning games. In general, the community game-based data collection is a growing research area and represents a unique potential for further research, development and implementation. It may bring together computer scientists, architects, machine learning experts, urban planners, urban informatics researchers and experts and geoinformation scientists. It is a truly an interdisciplinary effort to design and develop a successful serious online game.

There is a need for a more systematic approach to the topic. Establishing a specific conference, dedicated workshops or seminars on the topic would be very valuable. Collaboration with computer scientists who could advise on the recent trends in the implementation of such games, and game designers who could contribute their knowledge about successful methodologies and techniques of the design would bring insight and improvements of participatory methods needed in urban planning. Novel ways of data collection still need to be discovered; ways in which data collection becomes fun, playful, engaging and truthful in the ways data has been presented and analyzed. Research has a ways to go to improve our understanding of the player-game interaction, the design of the user interface, the dynamics of games, and how to create and stimulate the feeling of "flow" for the players. The masses of collected data can enable to study the patterns in the collected data, employ analytical methods such as machine learning and data mining and improve our understanding of human behavior which can then consequently lead to smarter buildings in our future oriented smarter cities.

Data Availability

c. Some data, models, or code generated or used during the study are available from the corresponding author by request. Items available: the complete results of the online survey performed to evaluate the first prototype of the *e-footprints* energy game.

Acknowledgements

Thank you to Santhi Buddhabathini for her valuable contribution in implementing the *e-footprints* energy game and to architecture undergraduate student Evan Harris for the design of the 3D visualizations of the second prototype of the game. Thank you for the feedback on the prototype implementations to the interdisciplinary mixed group of researchers working on the Presidential Interdisciplinary Research Initiative (PIRI) project titled Big Data and Sustainable Decision-Making in the Cities. This work was partially funded by the PIRI project, Iowa State University. I appreciate the support given by Marina

Reasoner by organizing the testing with 110 international students. Thank you to Stephen Poplin for his edits and language improvements of this text.

References

Abt, C. (1970). Serious Games. New York, The Viking Press.

Ambinder, M. (2009). Valve’s approach to playtesting: The application of empiricism. Game Developer’s Conference.

ASHRAE/ANSI Standard 55-2010. (2010). Thermal Environmental Conditions for Human Occupancy. Atlanta, GA, American Society of Heating, Refrigerating, and Air-Conditioning Engineers.

Axelrod, R. (1997). The Complexity of Cooperation: Agent-Based Models of Competition and Collaboration Princeton, NJ, Princeton Univ. Press.

Bennett, P. N., Chickering, D. M. and A. Mityagin. (2009). Learning Consensus Opinion: Mining Data from a Labeling Game. World Wide Web (WWW) Conference. Madrid, Spain, ACM 978-1-60558-487-4/09/04.

Billger, M., Thuvander, L. and B. S. Waestberg. (2017). "In search of visualization challenges: The development and implementation of visualization tools for supporting dialogue in urban planning processes " Environmental and Planning B: Urban Analytics and City Science **44**(6): 1012-1035

Bishop, C. M. (2006). Pattern Recognition and Machine Learning, Springer.

Brathwaite, B. and I. Schreiber (2009). Challenges for Game Designers. Boston, MA, USA, Course Technology, Cengage Learning.

Carlier, A., Marques, O. and V. Charvillat. (2012). Ask’nSeek: a new game for object detection and labeling. Computer Vision - ECCV 2012. A. Fusiello. Florence, Italy, Springer-Verlag Berlin Heidelberg**:** 259-258.

Chaloner, K. and I. Verdinelli (1995). "Bayesian experimental design: A review." Statistical Science **10**: 273–304.

Csikszentmihalyi, M. (1990). Flow: the psychology of optimal experience. New York, Harper and Row.

de Andrade, B. A., de Sena, Í. S. and A.C.M. Moura. (2016). Tirolcraft: The Quest of Children to Playing the Role of Planners at a Heritage Protected Town. Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection. EuroMed 2016. Lecture Notes in Computer Science. I. M. e. al., Springer, Cham.

de Dear, R. and G. S. Brager (1998). "Developing an adaptive model of thermal comfort preference." ASHRAE Trans **104**(1): 27-49.

De Mauro, A., Greco, M. and M. Grimaldi. (2016). "A Formal Definition of Big Data Based on its Essential Features." Library Review **65**(3): 122-135.

Devisch, O., Poplin, A. and S. Sofronie. (2016). "The Gamification of Civic Participation. Two experiments in improving the skills of citizens to reflect collectively on spatial issues." Journal of Urban Technology **23**(2): 81-102.

Epstein, J. M. and R. L. Axtell (1996). Growing Artificial Societies: Social Science from the Bottom Up Cambridge, MA, MIT Press, Cambridge, MA.

Foth, M., Bajracharya, B., Brown, R. and G. Hearn. (2009). "The Second Life of urban planning? Using NeoGeography tools for community engagement." Journal of Location Based Services **3**(2): June 2009, pp. 2097-2117.

Fuller, M. (2015). "Big data: New science, new challenges, new dialogical opportunities." Zygon **50**(3): 569–582.

Fullerton, T. (2008). Game Design Workshop: A playcentric approach to creating innovative games. Burlington, MA, USA, Morgan Kaufmann Publishers, Elsevir Inc.

Galli, L. (2014). Methodologies and Tools for Games with a Purpose Design and Gamified Applications. Dipartimento di Elettronica, Informazione e Bioingegneria. Milano, Politecnico di Milano, Italy. **PhD:** 277.

Gee, J. P. (2003). What video games have to teach us about learning and literacy. New York, Palgrave Macmillan.

Gordon, E. and J. Baldwin-Philippi (2014). "Playful civic learning: Enabling lateral trust and reflection in game-based public participation." International Journal of Communication **8**(28).

Gordon, E. and E. Manosevitch (2010). "Augmented Deliberation: Merging Physical and Virtual Interaction to Engage Communities in Urban Planning." New Media and Society **13**(1): 75-95.

Gordon, E. and S. Schirra (2012). Playing with Empathy: Digital Role-Playing Games in Public Meetings, Brisbane.

Gordon, E., Schirra, S. and J. Hollander. (2011). "Immersive Planning: a Conceptual Model for Designing Public Participation with New Technologies." Environment and Planning B: Planning and Design **38**(3).

Hacker, S. and A. L. Matchin (2009). Eliciting User Preferences with an Online Game. SIGCHI Conf. on Human Factors in Computing Systems. Boston, ACM, New York.

Hong, T., Sunb, H., Chen, Y., Taylor-Lange, S. C. and D. Yan. (2015a). "An ontology to represent energy-related occupant behavior in buildings. Part II: Implementation of the DNAS framework using an XML schema." Building and Environment **94**: 196-205.

Hong, T. and H.-W. Lin (2013). Occupant behavior: impact on energy use of private offices,in: First Asia Building Simulation Conference ASim. First Asia Building Simulation Conference ASim. Shanghai, China.

Hong, T., D'Oca, S., Taylor-Lange, S. C., Turner, W.J.N., Chen, Y. and S.P. Corgnati. (2015b). "An occupant behavior modeling tool for co-simulation." Energy Buildings.

Humphreys, M. (1997). " An adaptive approach to thermal comfort criteria." Nat. Vent. Build. Build. Senses Econ. Soc.: 129 - 139.

Iten, G. H., Steinemann, S.T., K. Opwis. (2017). To Save or To Sacrifice? – Understanding Meaningful Choices in Games. CHI PLAY'17 Amsterdam, Netherlands

Keller, S. A., Koonin, S. E., and S. Shipp. (2012). "Big data and city living – What can it do for us? ." Significance **9**(4): 4-7.
Koster, R. (2004). A theory of fun for game design Scottsdale, Arizona, USA, Paraglyph Press.

Law, E. (2011). Attribute Learning Using Joint Human and Machine Computation. Pittsburg, PA, Carngeie Mellon University. **PhD:** 30.

Law, E. and L. van Ahn (2009). Input-Agreement: A New Mechanism for Collecting Data Using Human Computation Games. SIGCHI Conference on Human Factors in Computing Systems. Boston, MA, USA, CHI '09 Proceedings of the SIGCHI Conference**:** 1197-1206.

Lepper, M. R. and T. W. Malone (1987). Intrinsic motivation and instructional effectiveness in computer-based education. Aptitude, learning, and instruction: Vol. 3. Cognitive and affective process analyses. R. E. Snow and M. J. Farr. Hillsdale, NJ, Lawrence Erlbaum**:** pp. 255-286.

Malone, T. W. (1981). "Towards a theory of intrinsically motivating instruction." Cognitive Science **4**: pp. 333-369.

Malone, T. W. and M. R. Lepper (1987). Mining learning fun: A taxonomy of intrinsic motivations for learning. Aptitude, learning, and instruction. R. E. Snow and M. J. Farr. Hillsdale, NJ: Erlbaum. **3**.

Mandel, M. and D. Ellis (2009). "A Web-based game for collecting music metadata." Journal of New Music Research **37**(2): 151-165.

Michael, D. and S. Chen (2005). Serious Games: Games That Educate, Train and Inform, Course Technology PTR.

Mitchell, A. and C. Savill-Smith (2001). The Use of Computer and Video Games for Learning: A Review of the Literature, Learning and Skills Development Agency, (www.isda.org.uk/files/PDF/1529.pdf).

Mitchell, T. (1997). Machine Learning, McGraw Hill.

Normoyle, A., Drake, J., Likhachev, M. and A. Safonova. (2012). Game-Based Data Capture for Player Metrics. AAAI Conference on Artificial Intelligence and Interactive Digital Entertainment.

O'Brien, W., Kapsis, K., A.K. Athienitis. (2013). "Manually-operated window shadepatterns in office buildings: a critical review." Building & Environment **60**: 319–338.

Oliver, M. B., Bowman, N. D., Woolley, J. K., Rogers, R., Sherrick, B. I. and M.-Y. Chung. (2015). "Video Games as Meaningful Entertainment Experiences." Psychology of Popular Media Culture: 1-16.

Parson, K. C. (1993). Human Thermal Environments: the Effects of Hot, Moderate and Cold Environments on Human Health, Comfort and Performance, Taylor & Francis.

Poplin, A. (2012). "Playful public participation in urban planning: A case study for online serious games." Computers, Environment and Urban Systems, Elsevier **36**(3): 195-206.

Poplin, A. (2014). "Digital serious game for urban planning: B3 – Design your Marketplace!" Environment and Planning B: Planning and Design **41**(3): 493-511.

Poplin, A., Kerkhove, T., Reasoner, M., Roy, A. and N. Brown. 2018. Serious GeoGames for civic engagement in urban planning: discussion based on four game prototypes. In: Yamu, C., Poplin, A., Devisch, O. and G. de Roo (eds) *The Virtual And The Real: Perspectives, Practices and Applications For The Built Environment*, p. 189 – 213, Routledge, Taylor & Francis Group, London and New York.

Poplin, A. and K. Vemuri (2018). YouPlaceIt!: Spatial Game for Building a Consensus. Geogames and Geoplay - Game-based Approaches to the Analysis of Geo-Information, Editors: Ola Ahlqvist and Christoph Schlieder. O. Ahlqvist and C. Schlieder, Springer (in press)**:** p. (pending).

Ritterfeld, U., Cody, M. and P. Vorderer, Eds. (2009). Serious Games: Mechanisms and Effects. New York and London, Routledge.

Rogers, R., Woolley, J., Sherrick, B., Bowman, N. D. and M.B. Oliver. (2017). "Fun versus meaningful video game experiences: A qualitative analysis of user responses." The Computer Games Journal **6**(1-2): 63-79.

Rogers, S. (2014). Level Up. The Guide to Great Video Game Design. West Sussex, United Kingdom, John Wiley and Sons, Ltd.

Saad-Sulonen, J. and A. Botero (2010). The urban mediator as a tool for public participation – A case of collaboration between designers and city planners. Digital tools in participatory planning. S. Wallin, L. Horelli and J. Saad-Sulonen**:** 59–78.

Samuel, A. (1959). "Some Studies in Machine Learning Using the Game of Checkers". IBM Journal of Research and Development." IBM Journal of Research and Development **3**(3): 210-229.

Schakib-Ekbatan, K., C¸akıcı, F. Z., Schweiker, M., A. Wagner. (2015). "Does the occupant behavior match the energy concept of the building? Analysis of a German naturally ventilated office building." Build ing & Environment **84**: 142–150.

Schell, J. (2015). The Art of Game Design. A Book of Lenses. Boca Raton, FL, USA, CRC Press, Taylor&Francis Group.

Settles, B. (2012). Active Learning, Morgan & Claypool Publishers.

Siorpaes, K. and M. Hepp (2008). "Games with a purpose for the semantic Web. IEEE Intelligent Systems." IEEE Intelligent Systems **23**(3): 50-60.

Squire, K. D., Giovanetto, L., Devane, B., S. Durga. (2005). "From users to designers: Building a self-organizing game-based learning environment. ." TechTrends: Linking Research & Practice to Improve Learning **49**(5): pp. 34-43.

Squire, K. D. and H. Jenkins (2003). "Harnessing the power of games in education." Insight **3**(5): pp. 7-33.

Sun, K., Yan, D., Hong, T. and S. Guo. (2014). "Stochastic modeling of overtime occupancyand its application in building energy simulation and calibration." Build ing & Environment **79**: 1-12.

Thakuriah, P., Tilahun, N.Y., M. Zellner. (2017). Big Data and Urban Informatics: Innovations and Challenges to Urban Planning and Knowledge Discovery. Seeing Cities Through Big Data. T. P., T. N. and Z. M., Springer Geography, Springer, Cham..

Thiel, S. and P. Fröhlich (2017). Gamification as Motivation to Engage in Location-Based Public Participation? Progress in Location-Based Services 2016. G. G. and H. H., Lecture Notes in Geoinformation and Cartography, Springer, Cham.

Tóth, E. and A. Poplin (2013a). Cooperative Learning Games – a Successful Tool for Promoting Children's Participation in Urban Planning? Future and Reality of Gaming (FROG) conference. Vienna, Austria.

Tóth, E. and A. Poplin (2013b). Pop-up Pest: An Educational Game for Active Participation of Children in Urban Planning. Real CORP 2013, International Conference on Urban Planning and Regional Development in the Information Society (CORP). Rom, Italy, CORP.

Tóth, E. and A. Poplin (2014). ParticiPécs – a cooperative game fostering learning about the built environment and urban planning. 17th AGILE Conference on Geographic Information Science (AGILE 2014), Workshop Geogames and Geoplay. Castellón, Spain., AGILE.

Turnbull, D., Liu, R., Barrington, L. and G. Lanckriet. (2007). A game-based approach for collecting semantic annotations of music. 8th Intl. Conference on Music Information Retrieval Vienna**:** 535-538.

UNI Standard EN15251. (2007). Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings Addressing Indoor Air Quality, Thermal Environment, Lighting and Acoustics. Brussels, European Committee for Standardization.

US Energy Information Administration (EIA) (2014). Annual Energy Outlook 2014 with Projections to 2040. US Department of Energy. Washington, DC.

Vemuri, K., Poplin, A. and P. Monachesi. (2014). YouPlaceIt!: a Serious Digital Game for Achieving Consensus in Urban Planning. 17th AGILE Conference on Geographic Information Science (AGILE 2014), Workshop Geogames and Geoplay. Castellón, Spain, AGILE.

Tables

Table 1. Responses related to the graphics introducing the room in Figure 5

# Field	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree	Total
1. I find the design of the room attractive	11 10.09%	36 33.3%	26 23.85%	24 22.02%	12 11.01%	109
2. The furniture is similar to mine at home	10 9.09%	22 20.00%	34 30.9%	23 20.91%	21 19.09%	110
3. The colors of the room are appealing	16 14.55%	28 25.45%	32 29.09%	23 20.91%	11 10.00%	110
4. There is no ceiling; this needs to be changed	45 40.91%	24 21.82%	22 20.00%	14 12.73%	5 4.55%	110
5. The emoticon makes the scene fun	15 13.89%	24 22.22%	34 31.48%	16 14.81%	19 17.59%	108

Table 2. Responses related to the graphics and aesthetics of the user interface in Figure 5

# Field	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree	Total
1. The image is aesthetically pleasing	19 17.43%	24 22.02%	36 33.03%	18 16.51%	12 11.01%	109
2. The colors are aesthetically pleasing	14 12.73%	30 27.27%	42 38.18%	13 11.82%	11 10.00%	110
3. There are too many objects on the image	19 17.59%	36 33.33%	26 24.07%	20 18.52%	7 6.48%	108
4. There is too much detail on the image	13 12.04%	31 28.70%	39 36.11%	15 13.89%	10 9.26%	108

Table 3. Responses related to the usability of the user interface presented in Figure 5

# Field	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree	Total
1. It is clear how to adjust the temperature	51 46.36%	31 28.18%	20 18.18%	4 3.64%	4 3.64%	110
2. It is clear how to open the window	47 42.73%	40 36.36%	15 13.64%	4 3.64%	4 3.64%	110
3. The text in the middle of the image is easy to read	48 44.44%	37 34.26%	12 11.11%	9 8.33%	2 1.85%	108
4. The text in the upper corner is easy to read	27 25.71%	35 33.33%	16 15.24%	21 20.00%	6 5.71%	105