Building Information Monitoring via Gamification

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Abstract: For efficient facility management it is of high importance to monitor building information, such as energy consumption, indoor temperature, occupancy as well as changes in building structure. In this paper we present a novel methodology for monitoring information about building via gamification. In our approach, the employees of a facility record the states of building elements by playing a competitive mobile game. Traditionally, external sensors are used to automatically collect information about the building usage. In contrast to that, our methodology utilizes personal mobile phones of employees as sensors to identify objects of interest and report their state. Moreover, we propose to use crowdsourcing as a tool for data collection. This way the users of the mobile game are collecting points and compete with each other. At the end of the game the winning team gets the reward. We utilized various gamification strategies to increase motivation of users to collect building data. We extended the traditional 3D BIM model with temporal domain to enable tracking of building changes over time. Finally, we run an experiment with real use case building in which the employees used our system for the duration of three months. We studied our approach and our motivation strategies in a post-experiment study. Our results suggest that gamification can be a viable tool for building information monitoring. Additionally, we note that motivation plays a critical role in the data acquisition by gamification.

1 INTRODUCTION

Efficient management of buildings is a challenging task because of big amount of required information. This building information may contain data about the usage of a building such as rooms occupancy, utilization of natural ventilation, usage of air condition, heating preferences, direct sun exposure, load of computing hardware, and many other factors. Automatic heating systems, ventilation, power systems, building insulation, shading systems and network infrastructure should be set up in a way to fulfill the needs of the facility users (employees) and at the same time to optimize the energy usage. Therefore, the acquisition and monitoring of the building information, including its usage by employees, is necessary for efficient facility management.

Typical problems in facility management are overheated offices, big energy loss due to the opened windows with enabled heating at the same time, improper lighting of the working area and others. In order to tackle these problems the information about the building elements and their properties is necessary. The most common methodology for building data acquisition is the installation of monitoring devices which can automatically monitor electric power usage, heating status, temperature, air quality, and other metrics (Amaxilatis et al., 2017; Määttä et al., 2017; Sayed and Gabbar, 2018). Many new buildings already have these devices installed during construction. However, numerous old buildings would require additional installation of these devices. The installation of monitoring devices to existing building sometimes require invasive operation on walls, electric cables and other appliances. Additionally, these devices are not always well accepted by the employees of a facility. Therefore, traditional data acquisition by monitoring devices is often not a feasible solution. The alternative methodologies for building information acquisition include estimation from materials, equipment, or occupancy data (Edirisinghe et al.,

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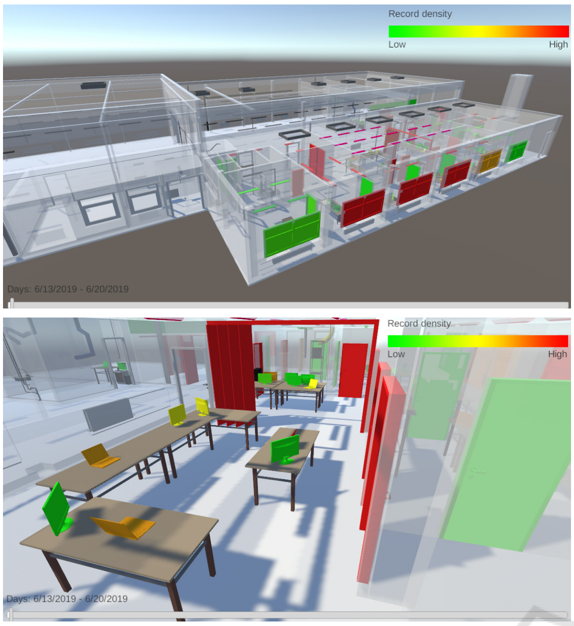


Figure 1: WebGL visualization of collected building information. Data, collected by our mobile game, can be interactively mapped to 3D BIM model and visualized. Various properties can be mapped to color coded visualization for facility management to provide a clear overview of building behaviour over time.

2017) and interviews with facility staff. A drawback of these alternative methods is that they provide limited or subjective information.

In order to address the above mentioned problems we propose a novel approach for building information monitoring based on gamification. In our approach the employees in the building play a competitive mobile game in which they collect points by scanning building elements and reporting their status. At the end of the game period the team with the highest score wins valuable prizes. The critical factor in data acquisition by humans is motivation. We hypothesize that the gamification approach may increase the motivation of facility employees to provide information about the building via their mobile devices. Additionally, we introduced advanced challenges in the game to boost the motivation of users. Our approach can serve as an alternative methodology for monitoring buildings, energy usage tracking, maintenance reporting, construction process tracking, or communication with users about building changes, problems and requirements. Moreover, our method is based on the Building Information Modeling (BIM) and the acquired information is coupled with BIM objects in the 3D model of the building. By this way the changes in the building and the behaviour data can be tracked and stored in relation to the 3D positions of respective building elements and their representations in BIM.

The relation of 3D objects in BIM model and the collected building information over time can be used for efficient 3D visualization. We demonstrate an example of such visualization on the web where the data can be quickly and efficiently visualized by color coding on 3D objects (Figure 1). Such a visualization can be especially useful for overview of building performance and for decision making process.

In this paper the results of the ongoing research project *"SCI_BIM: Scanning and data capturing for Integrated Resources and Energy Assessment using Building Information Modelling"* are presented. The overall aim of the project is to increase resources as well as energy efficiency of buildings by coupling of various digital technologies and methods. By using laser scanning and Ground Penetrating Technology, a digital twin (BIM model) of an existing building is generated. Through gamification, the users of the building are integrated into the process of collecting data about the building and the user behavior is tracked.

Information about building usage and about its thermal properties over time can lead to lower costs, efficient utilization of resources and lower ecological footprint. Therefore, the methods for building information acquisition and monitoring are of high importance. The presented research provides an alternative methodology to obtain information about existing building without installation of additional sensors and therefore can contribute to increasing efficiency of facility management. An additional benefit of our methodology is increased awareness of users about energy efficiency in their working place. Moreover, the proposed method can be extended in future to engage users into energy saving by influencing their behavior.

2 RELATED WORK

2.1 Building Monitoring

Several methodologies have been presented in past research to address the problem of building information monitoring. The most common approach is to install monitoring devices into the building (Sayed and Gabbar, 2018; Zhao et al., 2013; Amaxilatis et al., 2017; Määttä et al., 2017; Coates et al., 2017; Chen Yongpan et al., 2010). These methods can record vast variety of data including air quality (Chen et al., 2014), electric power usage, heating, ventilation, and air conditioning (HVAC) operation, temperature, occupancy and many others. Occupancy monitoring received a special attention in previous research because the utilization of building and its equipment can be directly related to the presence of people. Akkaya et al. (Akkaya et al., 2015) surveyed monitoring systems based on internet of things (IoT) devices. Occupancy can be also estimated in a non-intrusive way from HVAC systems (Yang et al., 2012) or from utilization of computer network infrastructure (Melfi et al., 2011). Alternative methodologies for building information monitoring include estimation from materials, equipment data or maintenance data and interviews with facility staff (Edirisinghe et al., 2017).

2.2 Building Information Modeling

Defined by National Institute of Building Sciences (of Building Sciences, 2020), BIM is a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward. Moreover BIM is *"a shared digital representation of physical and functional characteristics of any built object..."* which is created with object-oriented software, consisting of parametric objects that represent building components (Volk et al., 2014; ISO Central Secretariat, 2016). BIM can stand for the model itself – Building Information Model or for the process - Building Information Modeling (Lévy, 2011).

2.3 BIM with Temporal Data

BIM models play an important role in the facility management. Therefore, building monitoring data can be coupled with BIM representation to achieve well defined organization of data and its understandable visual representation. A framework for building information management based on BIM was presented by McArthur (McArthur, 2015) and Demian and Walters (Demian and Walters, 2014). BIM with monitoring data can be also utilized to detect failures in the facility management (Motamedi et al., 2014). The extension of BIM with structural sensors and collected data was proposed by Rio et al. (Rio et al., 2013). Visual programming approach for processing big BIM data, including temporal information, was presented by Preidel et al. (Preidel et al., 2017).

2.4 Gamification

A gamification approach for energy conservation in buildings was proposed by Papaioannou et al. (Papaioannou et al., 2017). The authors created a system which monitors the energy utilization by specific users and provides personalized recommendations how to improve energy efficiency. Their approach also utilizes IoT devices. An augmented reality game for educating children how to save energy was proposed by Osello et al. (Osello et al., 2015). Similarly to our research the authors used QR codes to identify the objects. Augmented reality can also be used as an intuitive interface to building management systems (Jang et al., 2019). The surveys of gamification were presented by Seaborn and Fels (Seaborn and Fels, 2015), Hamari et al. (Hamari et al., 2014) and Deterding et al. (Deterding et al., 2011).

3 BUILDING MONITORING BY CROWDSOURCING

Our methodology utilizes a competitive mobile game to monitor information about building elements. In this game the employees of a facility compete with each other to collect points and win the final prize. All data about building elements need to be coupled with BIM model of the building to ensure continuous update. Therefore, the crucial part of the game is the identification of objects in relation to their BIM representations. For this purpose we use QR codes which are printed on a paper and sticked to the elements of the building. For the target use case in our experiment we generated 184 QR codes. We developed an automated approach for QR code generation from BIM model. This automated QR code generation approach works as follows: For each element of BIM model which should be monitored we generate an individual QR code. The QR code is generated from json representation which includes the identifier of object, the type of object and verification string. The verification string serves as a checksum of the other data to verify authenticity of the QR code. By this way our mobile application can identify if the QR code was generated by our software or if it was faked. The example of QR codes installation in a target room can be seen in Figure 2.

Once the BIM objects can be identified in the real building we need to monitor their states. This is done by users who are playing our game. We used three gamification strategies in this game:

1. Collections of points
2. Competition with colleagues
3. Advanced challenges

Collection of points motivates users to monitor building elements by giving them certain amount of points for each scanned element. Our system allows a facility manager to set up various point amounts for

Figure 2: An office with installed QR codes for identification of objects.

Table 1: Types of target building elements which were monitored during our experiment. The right column indicates the amount of points which a user earns when reporting the state of the element.

Building element	Points
Window	3
Door	2
Light	1
Desktop computer	1
Laptop	2
Fan	1
Air Condition	1
Printer	1
Window shade	2

different elements (Table 1). This setting can be done on the server side and it changes the game behavior in real time. Variable point rewards for different elements enables on-demand increase of monitoring priority for specific building elements. For example if a heating data is of importance for facility management, the points for scanning heater can be higher than for scanning other elements.

Our second gamification strategy enables users to compete with their colleagues. Additional motivation in this strategy is the final prize which the winning team receives. The users are grouped in the teams of size three. Assignment to a specific team is chosen by each user at the first login screen (Figure 3).

The third gamification strategy, advanced challenges, was added in the middle of experiment to explicitly increase the motivation of users. With advanced challenges, the users can collect additional points by scanning multiple items in a given period. Challenges require scanning of items of specific type (e.g. 3 windows, 2 doors etc.) or exactly specific items (e.g. door number 3. QR codes also contain names and IDs of elements). Challenges can be time limited (e.g. 3 windows in 2 minutes) or time unlimited (in the whole day). Each day a user gets four daily challenges randomly selected from the pool. In our experiments we designed 15 challenges in total.

Every time a user reports the state of building element, the data is sent to the server. Due to the coupling of QR codes with BIM object identifiers, the BIM model can be continuously updated. As all the data is collected on the server, the building can be monitored in real time via web interface (Figure 1). An important aspect of the data collection is privacy of users. To ensure the maximum privacy the system only collects the minimum necessary data. This includes the ID, type and status of building element, time stamp and nickname of the user who scanned the element. The nickname of the user is required to count her points on the server side. For privacy reasons our mobile game does not store any photos, device identifiers, location or personal information.

3.1 Temporal BIM Model

In our methodology we enhanced traditional BIM model of the building with temporal data to enable coupling of collected monitoring information with 3D representation of the building. We store temporal data in a separate file. The binding of records from this file with building elements in BIM model and with real objects (tagged by QR codes) is achieved by using unified building element identifiers. These identifiers were created manually during the reconstruction of BIM model. Then, they were propagated into the QR codes generation and event reporting. The creation of our temporal BIM model, coupled with real building, was done in three steps:

1. **Manual Remodeling from Point Cloud.** We obtained a point cloud model of the building by laser scanning and photogrammetry methods. Then, the model was manually remodeled from point cloud to create its BIM representation (Figure 4).
2. **Automatic Generation of QR Codes and Their Installation in Real Building.** QR codes encode the building element identifiers from manual remodeling. This way they guarantee the coupling of real objects with BIM model.
3. **Storing Temporal Events Referenced by Building Element Identifiers into External File.** Each record is stored as a separate row in this file. In our implementation we read the object identifier from QR code. Nevertheless, the connection between temporal data and BIM model can work also without QR codes and even the traditional monitoring devices can be used. Example of our temporal data storage is show in Figure (Figure 4).

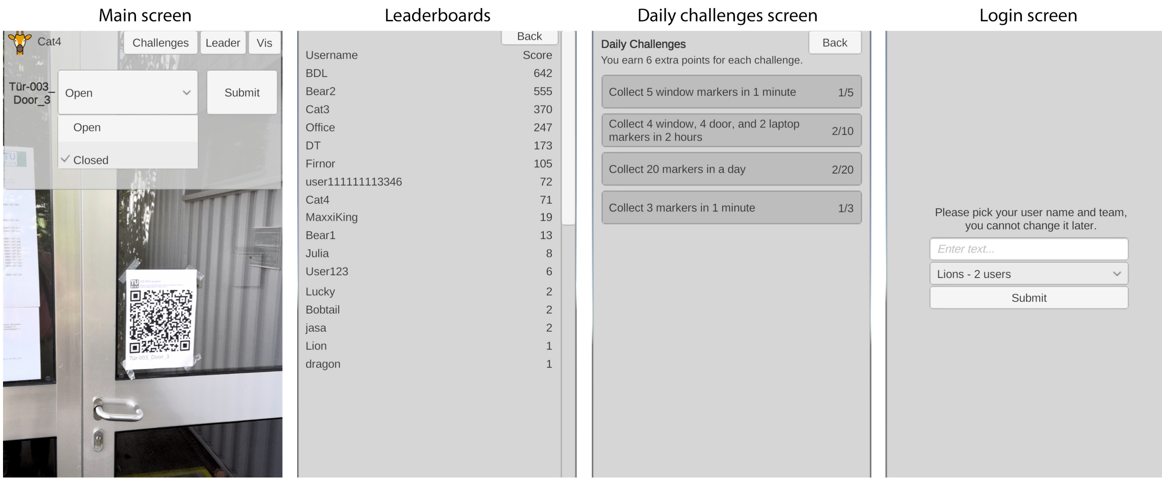
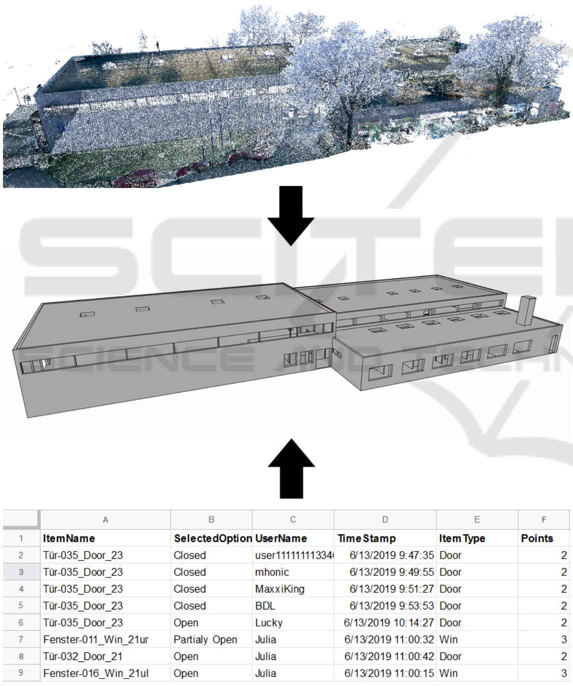


Figure 3: The screens of our mobile application for building information monitoring. Login screen is shown to the users only once at the first run of the application. After they pick a user name, it stays the same for the rest of the game.



	A	B	C	D	E	F
1	ItemName	SelectedOption	UserName	TimeStamp	ItemType	Points
2	Tür-035_Door_23	Closed	user11111111334	6/13/2019 9:47:35	Door	2
3	Tür-035_Door_23	Closed	mhonic	6/13/2019 9:49:55	Door	2
4	Tür-035_Door_23	Closed	MaxxiKing	6/13/2019 9:51:27	Door	2
5	Tür-035_Door_23	Closed	BDL	6/13/2019 9:53:53	Door	2
6	Tür-035_Door_23	Open	Lucky	6/13/2019 10:14:27	Door	2
7	Fenster-011_Win_21ur	Partialy Open	Julia	6/13/2019 11:00:32	Win	3
8	Tür-032_Door_21	Open	Julia	6/13/2019 11:00:42	Door	2
9	Fenster-016_Win_21ul	Open	Julia	6/13/2019 11:00:15	Win	3

Figure 4: From top to bottom: Scanned point cloud from our target use case building, BIM model which was manually remodeled from point cloud, and temporal data stored in a spreadsheet and linked to the BIM representation. ItemName is the unified identifier which links the temporal data to specific BIM objects.

3.2 Mobile Game

We developed a competitive mobile game to investigate our methodology for information monitoring. The main screen of the game shows camera image in real time to allow user to scan a QR code (Figure 3). Once the QR code is decoded the mobile application allows user to select the state of the scanned building element. The states of various types of objects can differ. Therefore, we store the object types and their possible states on the server and load them each time the application starts or resumes. Every object type can have its own states. For example the heater can have the values from 1 to 6 and the window can have the states *open*, *partially open* and *closed*. When a user selects the state of scanned object she can press the submit button and send the data to the server. By this action the user earns points for given object type.

We used Unity3D to implement our mobile game and we built it for iOS and Android platforms. The server side utilizes Google Sheets to store the information about building elements. The information is transferred via Google API. Storing information in Google Sheets enables fast processing by any 3rd party software, human readability and interactive visualization of data.

3.3 Visualization of Crowdsourcing Data

In order to visualize the collected building information we developed a web application which utilizes WebGL. As the data is coupled with BIM representation of the building, we can visualize it in 3D. The visualization shows color coded values on the 3D BIM model directly to the facility manager. Additionally, the visualization is interactive and a facility manager can see various properties mapped on the model. The web application also contains time axis by which a manager can control the time period of data to be visualized. In our implementation data from one week window (starting with a selected date) are aggregated for visualization but this window can be set to arbitrary length. The web visualization always works on the real-time data stored on the server so even new events can be observed in real time. The screenshot from our WebGL visualization can be seen in Figure 1.

4 USE CASE EXPERIMENT

4.1 Experiment Design

The experiment was designed to study the user perception of our gamification methodology. Our main research question was whether our gamification approach is seen by the users as equivalent or better than traditional building monitoring with sensors in certain aspects. We used six metrics to compare our methodology with traditional sensor-based approach: general user preference, practicality, enjoyability, time demand, privacy, and cost. These metrics were subjectively reported in a final post-experiment questionnaire using two-alternative, forced-choice approach. In this approach the users were instructed to indicate their preferred method of information monitoring amongst two options: (1) Gamification approach and (2) monitoring sensors. After the general preference question the users were asked to explain their choice in an open question. In addition to the general preference, the users indicated which method do they consider more practical, more enjoyable, less time consuming, better in terms of privacy and better in terms of costs. If the frequencies of user preferences for our method are better or comparable to the preferences for monitoring sensors from certain aspects, we might consider our approach successful.

Additionally, we studied the motivation factor for building information monitoring by facility users. For this purpose we used a four-alternative, forced-choice approach. The users were asked to indicate which strategy was the main source of their motivation amongst the following options: Collection of points, competition with colleagues, advanced challenges, and other. Finally, we studied the usability of our mobile application using system usability score (SUS) (Brooke, 1996) and we also analyzed the rate of reported states over time. The user preference questions, motivation questions and system usability questions were assembled into final post-experiment questionnaire. The employees of the building who participated in our game were asked to fill in this questionnaire at the end of the experiment.

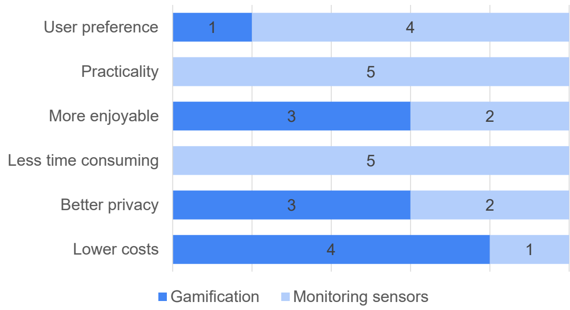


Figure 5: Frequencies of user answers to the preference questions. Each row indicates the number of users who preferred our gamification approach (dark blue) and the number of users who preferred monitoring sensors (light blue) from specific aspect.

4.2 Target Building

The target use case for our study was a university facility. The working group had 26 employees in the time of study. 11 of them participated in our experiment using their personal mobile devices. The users monitored building information in 13 offices of the target building. The types of monitored building elements can be seen in Table 1. We did not monitor the status of heating because the experiment was conducted in summer.

4.3 Procedure

We studied the proposed gamification methodology in a target use case building in the duration of three months. In the preparation phase we attached our generated QR codes to the building elements. During our experiment, traditional monitoring devices were also installed in the building so the users could directly compare using of these devices and our gamification strategy. The employees, working in the use case building, installed our mobile game on their devices. We conducted an initial briefing workshop where we explained how the game works, how is the data collected, which traditional monitoring devices are installed and what is the purpose of the study. Then, the competition started. At the end of the study the users were asked to fill in the post-experiment questionnaire. The three user groups with the most collected points won the final prizes in form of goodies.

5 RESULTS

Eleven participants were playing our game during the experiment. As the participation in the experiment was voluntary, only 5 out of 11 participants answered

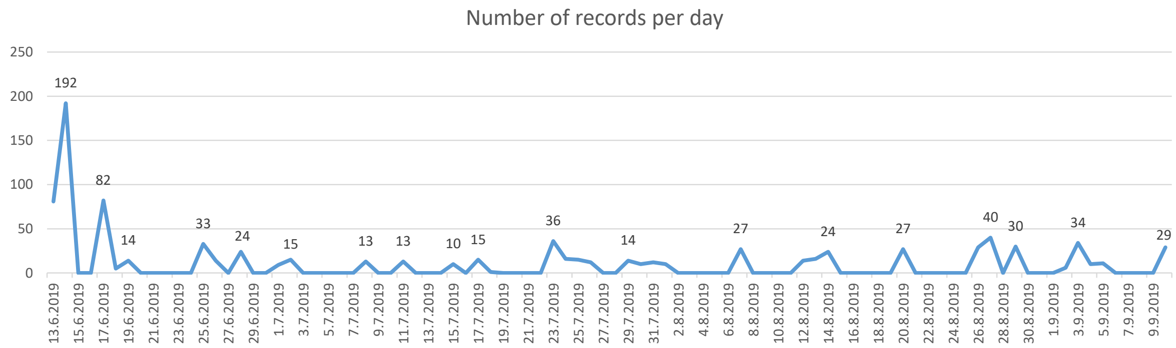


Figure 6: Frequencies of data reporting by our mobile application per day during the experiment. Measured values on the y axis indicate the amount of scanned QR codes (i.e. reported items). The data labels are only show on the peak days for clarity.

the post-experiment questionnaire (2 females and 3 males, in age from 25 to 31). The users were asked about their preference between gamification and monitoring devices in terms of general judgment, practicality, which one is more enjoyable, less time consuming, better in terms of privacy and better in terms of costs. The resulting frequencies of user preferences can be seen in Figure 5. In terms of general preference, the users preferred monitoring devices more than our gamification strategy. As we analyze the specific aspects of user preferences we can see that this preference was based on the users seeing monitoring sensors more practical and less time consuming than using gamification method. On the other hand, the participants preferred our gamification strategy before monitoring sensors in terms of enjoyability, privacy and lower costs.

Our second research aim was to investigate which of the used gamification strategies was the main source of motivation. Collection of points and competition with colleagues was each chosen by two distinct users as the main source of their motivation. Surprisingly, the advanced challenges were not stated as the main source of motivation by any user. Nevertheless, it might have motivated users but it was not perceived as more motivating than collections of points and competition with colleagues.

In order to evaluate usability of our mobile application, we utilized SUS questionnaire (Brooke, 1996). The average system usability score, calculated according to Brooke, was 75.5 in a range from 0 to 100 where 100 means the highest usability score.

The answers to the open question support the preference votes of participants. The users who preferred electronic sensors commented that they have less work to do. One user, who preferred gamification approach, explained his preference by better privacy because the monitoring sensors allow certain level of surveillance.

In order to further analyze the motivation of users and usage of our mobile application, we plotted the frequencies of data reporting onto a time axis (Figure 6). This plot shows the amount of QR codes scanned by users per each day during the 3 months period of experiment.

6 DISCUSSION

The main goal of our experiment was to validate the proposed gamification strategy for building monitoring in a real scenario. Eleven people used our application during 3 months on a voluntary basis. 943 records about states of building elements were gathered during this period. The distribution of reporting activity can be seen in Figure 6. As we can observe in this figure, some days were populated by high activity while some others report no scanning at all. During our experiment as well as after data analysis we found that motivation plays a critical point in our gamification strategy. The initial motivation was very high, leading to the peak of 192 records per day, because all users were interested in the application and they were eager to compete with each other. However, after one week, the number of records per day dropped rapidly. The second version of the application, containing advanced challenges, was released on 22.7.2019. The activity was again partially increased after this release. There were also additional unrelated peaks of activity during the whole period of experiment. We should note that the experiment was conducted during the summer time while some of the users might have been on holidays for part of the time. Moreover, the data reporting by our mobile application was not part of the work duties of employees. We hypothesize that the motivation could be higher if data collection was done by facility staff, like security and cleaning personal, as part of their work responsibilities. As our application was accepted and regularly used by our participants, our experiment suggests that gamification strategy can be a valid tool for building monitoring. However, the motivation plays an important role in this process and the results are highly dependent on human factor. During the experiment, we also motivated participants extrinsically by the reward for the three best user groups with the highest number of collected points. At the end of the experiment the winners obtained the prizes in form of goodies.

We used the post-experiment questionnaire to compare our method with monitoring devices in terms of user preference and to study the main source of motivation for data collection by users. In terms of general preference monitoring devices were preferred more by users. The main reason for this preference was that with monitoring devices, the users had no additional workload for collecting the building information. On the other hand, the gamification approach was judged by the users as more enjoyable, with better privacy and lower costs. From the answers to open question and from personal discussions with users we saw that people would like to secure their privacy. They felt uncomfortable with having installed monitoring sensors because they were afraid of unwanted surveillance. On the other hand they trusted our mobile application because we informed them during bootstrapping meeting that we do not collect any personal data, any location information or any occupancy information.

Based on the results from the study and frequencies of data records we hypothesize that gamification approach could serve as a complementary approach to traditional building monitoring, especially in places where the motivation of users could be extrinsically increased. It could be particularly utilized in buildings where installation of sensors is not practical, where the amount of users is high and where the rate of data capturing is not of highest importance.

We did not evaluate the statistical significance of our findings because the sample size was too small to infer any general conclusions. Instead, we see our results as user-based indications about acceptance, validity and usage of our gamification approach.

Finally, an interesting option to note is the data collection by manual user reporting to Excel sheet or paper. Two employees, working in the target use case, explicitly asked for this option because they did not have appropriate mobile device, they wanted to participate in the data collection and they considered the option of direct data entering as more efficient. We allowed them to collect data this way during the time of experiment. However, in contrast to their assumption of higher efficiency, they entered only 21 records and they reported states of building elements only three days out of total duration of the experiment. The sample size is too small to draw any conclusions in this case, however we hypothesize that efficiency of using mobile application is higher than with manual reporting.

6.1 Limitations and Future Work

Despite the acceptance of our gamification strategy by participants, our investigation had several limitations. One of the main constraints and critical point of the proposed methodology is the motivation of users. As we can observe in frequencies of data reporting per day (Figure 6), some days are not covered by data. Therefore, the motivation would need to be increased to increase frequency of scanning and thus cover the required data rate. Both extrinsic and intrinsic principles can be used to increase motivation in this case. Moreover, an important point in bootstrapping the data collection is to motivate more people to install the application and join the data collection. In our experiment 11 out of 26 employees agreed to participate. If this number was higher, the data rate coverage might have been higher too. The resulting guideline for future experiments with gamification in building information acquisition is to invoke a strong extrinsic motivation at the bootstrapping of the data collection to increase the amount of participants. Additionally, other gamification aspects can be added to the application in the future to increase motivation. These strategies may include levels, personalized profiles, special skills or new measurement features (e.g. sound loudness measurement, illumination measurement, etc.).

The main limitation of our post-experiment evaluation was small amount of participants who filled the questionnaire. Our sample size for this questionnaire was only five people. For this reason conclusions about statistical significance of our results could not be drawn. In future work we aim at repeating this study with improved version of our mobile application, bigger user group and stronger emphasis on motivation of participants.

In this paper we did not evaluate the quality of gathered monitoring data. In the future we plan to compare the frequency and quality of our collected data to sensor data. We expect this comparison to reveal additional insights on practicality of our approach for building monitoring. We hypothesize that more users would help to increase monitoring frequency and data quality.

One of the avenues for prospective future work is the usage of mobile application to not only collect information about the building but to also actively affect the energy efficiency of the building by actions of users. For this purpose gamification can be again used in form of collection of points for actions which positively affect energy status (e.g. closing windows while air condition is on). In this case the application can provide the users with hints how their behavior can efficiently improve their working environments.

7 CONCLUSION

In this paper we have presented a novel approach for building information monitoring via crowdsourcing and gamification. The core of our methodology is the mobile application which allows employees of the building to use their mobile devices as sensors and report the information about building elements in time. The users can then collect points for information reporting and compete with each other to win the prize. We enhanced the 3D BIM model of a building with temporal data to store the gathered monitoring information. On top of data model in our method we built a webGL application to visualize collected data in real time on the 3D model. We conducted a three-months experiment in the use case building and we evaluated our gamification approach using post-experiment questionnaire.

The findings from our experiment indicate that while monitoring devices are preferred way for building information collection, our gamification approach can be also accepted and valid methodology for this task. The main benefits of our method in comparison to monitoring devices is higher privacy and enjoyment factor. One of our main findings is that motivation is a critical aspect in user-oriented data collection and it needs to be specifically addressed from the very beginning of the project. A vital future utilization of gamification in facility management could be to not only passively monitor data but to actively influence energy efficiency by user actions. As future outlook, the proposed concept will enable the maintenance of digital twins throughout the life cycle of buildings (the structural changes of building elements are automatically adopted in the BIM model). We believe that continuation of research on this topic will allow alternative building monitoring approaches, like gamification, to be more practical and closer to the deployment in real-world scenario.

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