3D interaction in Intelligent Buildings

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Abstract

The efficiency of an Intelligent Energy Management System(IEMS has a direct co-relation with how energy data is presented. Despite the effort put in design, current solutions still have serious problems in terms of data energy representation to users. Research has shown that interfaces are one of the major sources of human errors, due to its complexity. IEMS user interfaces are not capable of providing all necessary energy information, in a clear and understandable way, to help users in decision-making process.

This work explored the usage of a tree-dimensional interfaces for IEMS to fill the existing gaps in data energy visualization. In particular, we studied how to take advantage of a rich graphical representation of energy related information to provide better control over an IEMS and assist in the decision making processes.

To prove our hypothesis we implemented a solution that combines concepts of energy data visualization, user behavior transformation and BIM technology, to represent three-dimensionally the facility. An evaluation showed that people were capable of using and understanding the system, therefore, certifying that we had achieved our initial objectives.

Keywords: Energy Management, Data Visualization, Energy Management Systems, 3D, 2D, Virtual Reality.

1. Introduction

Intelligent Energy Management Systems (IEMS) monitor and optimize energy consumptions in Facilities to improve its efficiency and comfort of occupants [5]. This systems consists of two major components: an Energy Management System (EMS) and a Building Automation System (BAS). The first one supports energy management processes by monitoring, managing and optimizing how much energy facilities are using [30]. The second manages mechanical and electrical equipment such as ventilation, lighting, power, and emergency systems. BAS systems are also capable of gathering data regarding the status of the facility. Combining these two systems allow IEMS systems to take advantage of the management logic of EMS and actuation capabilities of a BAS, integrating them in one single system to create autonomous building management processes.

Besides managing and optimizing consumption, IEMS systems efficiency is related with users ability to understand the displayed data to assist them in their decision making process [6, 22]. Recent results demonstrate that IEMS can lead energy savings up to 10%-15% [12, 16, 17]. The observed reductions are related mostly to the usage of interfaces capable of providing graphical feedback to users.

Visualization has long been seen as a way to affect users behaviors, namely, it can be seen as a tool to motivate end-users to reduce consumptions, by empowering users with the capability to monitor and control energy consumptions. Optimal design of such visualizations is considered crucial to achieve and generate maximum savings to end-users [31].

Solving the problems related with energy data visualization on IEMS interfaces is challenging. They need to integrate large amounts of information, from different types and sources, which must be presented in such way that must be easy to understand by users. Researches showed that current solutions are more focused on displaying information and not how to display it [2]. By not representing energy data in a clear and understandable form, users become confused when it comes to choosing which action should they take [33].

Based on several studies regarding IEMS systems and energy data visualization, there is a clear problem regarding the interfaces of these systems and principles to create them [42, 38, 13]. The majority of researches points out the complexity of interfaces as main problem, and lack of spatial context to help users to understand what is going on in the

facility that they are monitoring. Different studies state that still exists a clear lack in current literature concerning which principles should be followed to create a interface to these systems [13, 40].

The definition of principles to guide the creation of interfaces for these systems would promote the creation of better and more understandable interfaces by users, and ultimately, more user friendly interfaces [13]. Furthermore, interfaces that are easier to use will have a direct impact on the efficiency of IEMS systems, and ultimately the reduction of consumptions by users.

Therefore, this work intends to solve the existing problem related to energy data visualization over IEMS interfaces. In order to fulfill this goal, we combine the concepts of Energy Data Visualization, and tri-dimensional representation. This work proposes a tri-dimensional interface for an IEMS, capable of presenting an augmented 3D representation of the facility, to help users to perceive what is going going in the facility in real-time.

The next chapter addresses the analyzes of relevant work made in these areas, in terms of Intelligent Energy Management Systems, Energy Data Visualization, or Virtual Reality Environments. Chapter 3 describes our proposed solution, which was tested and the results are discussed at chapter 4. Finally, chapter 5 present our conclusions of this work.

2. Background
In this section we will discuss the state-of-the-art regarding the main topics of this work.

2.1. Intelligent Energy Management Systems
Intelligent Energy Management Systems (IEMS) are systems capable of monitoring and optimizing energy consumptions of facilities, by improving the facility efficiency and comfort of its occupants [5]. To achieve the stated objective this systems are composed by an Energy Management System and a Building Automation Systems, that are capable of taking advantage of the management logic of an EMS and the gathering and actuation capability of a BAS system to create autonomous building management processes [30].

To achieve the desired levels efficiency this systems must present a large variety of heterogeneous data to the end-users, specifically, building managers and owners. That information is typically related to consumptions, gases levels, humidity, etc, which help managers to analyze how and where energy is being used, identifying energy-saving opportunities or forecasting energy consumption demand. Also, this systems are capable of detecting anomalous situations, performing improvement actions, and measuring energy saving strategies outcomes, as it happens in decision support systems [20, 1, 15].

Complex data requirements are the typical outcome of IEMS tasks. Although, that data is related with the need of obtaining information from heterogeneous data sources, that are often unreliable. The poor integration of IEMS's data storage systems with analytic tools is another problem regarding these systems [1].

These problems transform itself into confusing user interfaces, which force users to throw away large amounts of data and bypass system controls [39, 19]. This leads to one of the main concerns of this work, which is the lack of standards to display information over EMS interfaces.

2.2. Energy Data Visualization
Energy Data Visualization is the process of presenting collected and processed data to users. It is possible to measure the effectiveness of a visual report in terms of interactivity between human and machines, by amount of time required for a user analyze and interpret the reported data. [21].

It has an outstanding capability to help users to perceive what is going on in the facility and consequently lead them take actions to conserve energy [31]. This idea of visualize data about energy has already prove its usefulness to: i) monitor and manage power usage, (ii) analyze and predict energy consumptions, (iii) provide real-time feedback to help users reacting to patterns of consumption, which leads to an increase of sustainability through energy conservation, (iv) imparting information in an innovative and understandable way, (v) being publicly accessible, and (vi) providing unambiguous and interesting visualization [31].

Researches about this subject date back to early 70's, when Ronald Bittle and his team made an experiment where they put post cards every day with the daily consumptions for an household, which lead to a decrease of consumptions by 1-9% [31]. In 1978, Clive Seligman and John Darley extended that experiment, when they used large posters to show the energy consumption in a medical institution. As result they proved that the display of visual information has a direct effect in energy conservation and user's behaviors, in this case, they achieved a cut down in consumptions [36]. Later in 1992, visualization started to migrate to computer-based monitor, which have shown reductions up to 12.9% [36]. There are many other researches about this subject [17, 28]. Typically, the conclusions of these researches point that providing feedback to users is related with a decrease in consumptions. Showing cut downs up to 10%-15%, and effects in user's behaviors.

Economic and environmental benefits are well known as motivating factors to conserve energy. Although, in practice, it is challenging to motivate

users to assume behaviors and habits to conserve energy [31]. This happens due to: i) a lack of awareness and knowledge of their precise energy consumptions, ii) inability to perceive which actions or steps to follow to conserve energy, iii) unwillingness to sacrifice comfort to reduce energy consumptions [31]. Designing tools and ways to visualize that energy data is a non-trivial problem from a software engineering perspective [31]. In particular, there are no clear criteria to guide visualization design for this critical application domain [31, 13].

In 2007, Corinna Fisher researched about the state of the art regarding interfaces capable of giving feedback to users [13]. In her research she concluded that there are a clear lack in the literature concerning which principles should be followed to create a interface to these systems. Based on the literature she identified some likely features for successful feedback (meaning both effective to stimulate energy conservation and satisfying to users). Such feedback must be:

- Based on the actual consumption of the facility

- It is given frequently

- Involves interaction and choices from users

- Involves appliance-specific breakdown

- It is given over a longer period

- Should allow historical and normative comparisons

- The data is presented in an clear and understandable way to users

2.3. Perceptions of Energy

To perceive the real importance of energy data visualization is important to analyze how consumers perceive and understand energy. This notion brings direct implications for creating effective design for feedback systems.

In their research Kempton and Montgomery found that cost is a simple measure that consumers tend to easily understand. This means showing energy consumption based on its cost, is a clear measure to users, as it affects them directly [24]. Although, despite cost being an useful indicator and motivator for reduce consumptions, it is an indirect measure, and easily can lead to misleadings when analyzing the bills [14].

The lack of understanding on energy usage is directly connected to the actions that users wrongly make, trying to reduce consumptions. An example is how many people incorrectly think that setting a thermostat off on a winters evening would result in less energy used because. Although they don't perceive that the house needs to reheat when it is switched on again, which consumes much more energy than just maintaining the temperature [41].

2.4. EMS's data visualization

An EMS is not just a tool to control the devices of a facility by itself. It can also be seen as a system capable of providing energy data feedback to users. Helping them to perceive the status of the facility that they are monitoring and what is going on.

The problem regarding this subject is that the state of the art is pretty obsolete. Most of the information about this subject is about which data should be represented, and how to control devices. There is a clear lack on the literature regarding how to represent that data to facilitate the tasks of users. Most systems are still representing the facility in a 2D perspective, which transmit less information about the building and the system, and it is pretty inefficient when compared with 3D navigation and visualization. Some of the existing solutions don't even represent the facility.

In his work, Shepherd, showed the importance of designing interfaces capable of achieving an effective user interaction with the system, with special regard to visualization software [37]. His and other works stated that data visualization is influencing how systems are representing facilities and nowadays it is observable a switch from the typical 2D representation to the 3D, as these types of representations allow successful completion of explanatory and analytical tasks [37, 9].

An idea that is gaining strength to solve this problem is to combine EMS systems with VRE. The purpose of this association is creating a virtual environment where users can monitor the status of facility and simultaneously interact with an augmented 3D building. A major advantage related with the usage of VREs, is to be able to design interfaces capable of representing the surrounding environment, making a lot easier to create a conceptual model of the facility than when 2D representation is used [25].

In terms of effectiveness is not possible to define which of the two representations can the better one. 3D systems are more time-consuming and its advantages are more relevant for dealing with large environments with different types of information, when users intend to perform some complex job, rather than the standard ones. 3D interfaces require more practice to achieve the same efficiency as 2D ones for solving simple tasks but are a better and faster tool to achieve complex goals [9].

2.5. 3D reality and interaction for Building Data

Building Information Modelling (BIM) is the current trend in projects derived from association between construction and computer industry. This technology contributes to an efficient integration

and management of engineering information [8]. BIM model provide a central point to communicate, share information and ideas between the different parties involved in a project [23]. These models allow to generate and manage digital representations of physical and functional characteristics of a facility during its entire life cycle, improving collaboration, information management and advanced simulation [11].

BIM is being used as a structured digital storage for all information regarding the building during its entire life-cycle. This includes all spatial and geometrical information used to create 3D models, as well as data regarding the structure and elements present in the facility. As the model stores geometrical information, this allows the 3D representation of the facility, which can be augmented with the representation of its status, based on the state variables stored in the model [12, 16].

Although, the usage of BIM models still presents some issues. This file format is still not recognized as a standard, so the usage of this models still presents interoperability issues [18]. Complexity of the models has direct effect in the existing BIM viewer's rendering capability. When the models are complex, the navigation turns too slow to be considered real-time data visualization (the frequency of refreshing should be about 20Hz) [27]. In some cases real time representation viewers hide objects or incorrectly present them to allow real time visualization [23]. Also, the it is necessary to perform a large number of conversions and transformations to use them as 3D models in the typical game engines, as Unity3D, Unreal, etc. In the majority of times this conversions lead to quality and information losses [4].

3. Implementation

Here we will present our approach - first by explaining the scenario in which it will be used. After that, we will see an overview of our architecture, before specifying each vital component of the solution.

Our typical user will want to perceive what is going on in each room of the facility, without the need of being physical present to perceive its status. To do so they need to quickly realize what are they seeing, in this case, which one of the rooms are they monitoring, and in a simple way they must perceive if the elements of the room are consuming or not. This means that the interface must be user-friendly for reducing the time that it takes to make the simplest of tasks. Providing them a way to compare historic data is also a must to have, as they need to compare between periods [13], to perceive if they are reducing costs and consumptions.

Therefore, this works proposes a solution that aims to make use of BIM models for rendering building geometry. This geometry is then augmented with graphical energy data, in the sense that is compliant with the principles of User Behavior Transformation. In other words, we intend to facilitate user's interaction with the system, solving the complexity problems of existing solutions. Also, for enhancing the visual rendering of the building, our solution will run on top of a game engine, which has proven to be a more effective technique for rendering complex models [4, 27].

3.1. Architecture Overview

Our solution is divided in two different parts, 3D viewer and web-application, which renders the viewer component. This division was necessary because the game engine, Unity 3D, does not fully support charts, and we wanted to provide a way to search and compare historic data. Another reason to the division is that with a web-application we could provide a way for users to access the system in every type of device that they wanted. So we exported the viewer from Unity game engine and later integrated it in a web-application.

This means that in fact we needed to have two different architectures. The layered-module architecture for the viewer, logical, presentation and network layers [3]. While the web-application has a Model View Controller (MVC) architecture, where in fact the Model in this application is the viewer that is integrated in the application.

As stated before, our viewer's architecture has a layered-module architecture, logic, presentation and communication layers. The Logic layer handles and manages all information related with the facility. First, it maps all information from the BIM model to an internal representation. Then, the communication layer sends the energy data of the facility, which is parsed and stored by each room inside our data model.This allow us to augment the facility that is being rendered with data about energy and the BIM model.

The Communication layer is responsible to update, in real-time, the information regarding energy data of the facility. This layer is connected to an external server, that stores all information regarding the facility gathered data from sensors. After fetching and receiving the information from server, this layer sends that data to the Logic Layer, which stores it by room. The way how that information is stored in the server, and the server itself, is out of the scope of this work. Bearing that in mind, we implemented a simple version of a server that is sending energy data to our application, to simulate the connection between our application and a server.

In the Communication Layer we also have a manager component that makes the connection between

web-application and viewer. It receives requests form the web-application and calls the desired function inside our viewer application. This was necessary to limit the number of external entry points to our viewer application, which means that any external calls are handled by this component.

Finally, our Presentation layer his divided in two parts, navigation system and options of the viewer, which includes augmenting the model representation. The first one is implemented over the game engine. Our solution implements two different cameras, one that orbits around the facility, as it is seen in many CAD softwares, and a second one that gives total freedom for exploring the facility. Regarding augmenting the model, we implement two different features, one where the rooms become colored boxes, where the color represents how much the room is consuming. The second feature is also a colored representation of elements, in this case the objects of the room. In this feature the color also have a meaning, it represents if the object is powered on and how much is consuming. This representation by colors intends to give the users a simple and faster way to perceive what is going on inside each room. Figure 1 illustrates the architecture of the solution.

Our web-application has a MVC architecture, as previously stated, where the Model is the viewer component itself. Our interface has two different views. A page for rendering the viewer component, which allows the user to see a 3D representation of the facility and a sidebar to select different options over the viewer. These options are in fact calls to the Communication Manager that passes the call to Presentation Layer of viewer, and enables the selected view over the facility. Our second view is an analytics system solution to allow the exploration and comparison of historic data. The views of our interface are managed by the Viewer and Dashboard controllers. This means that the views directly related with the viewer are managed by the viewer controller and the views related with the visualization of historic data and comparisons are handled by the dashboard controller.

3.2. Viewer Application

Addressing the lack of spatial context was the main reason that lead us to implement a 3D facility viewer, thus helping users to perceive the facility status. To implement such system we took advantage of the best tools to render 3D models - game engines.

This option solved us simultaneously two different problems. The first one, as stated, was the lack of spatial context and building easy recognition. Second, handling complex models. Game engines can handle complex models for animations, games,
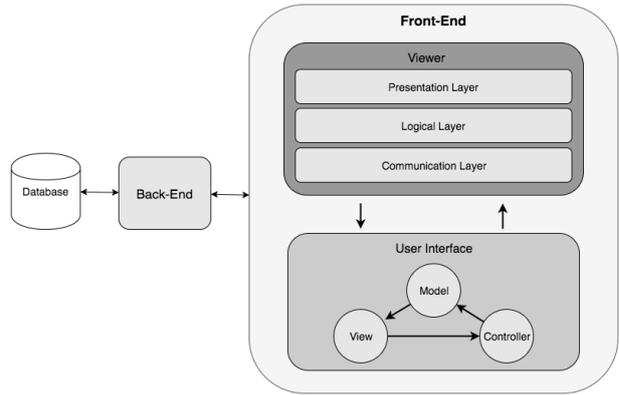

Figure 1: Illustration of the architecture of our solution

etc, which makes them the perfect choice to render and augment complex 3D models.

Nowadays there are various choices to these types of systems. We searched for the most widely used, better capabilities and community support, founding three different ones that we tried. In the end we chose the one that suited us better. First, we tried libGDX, however, it proved itself too low level for a fast development of our system. Later we tried JMonkeyEngine, which seemed very promising at the beginning. Although it still lacks some key features that we desired, such as the capability of integrating BIM models or a related model. In the end we chose the Unity3D game engine. It is one of the best game engines nowadays. Also, this engine allowed to use BIM models, after a conversion, as model to represent the facility.

To use BIM models, as basis to our representation of the facility, we needed to transform it into a readable model by the game engine. That transformation was made in the CAD software, where we exported the BIM model to FBX (Filmbox) format file. Later, this model is imported by the game engine. Although, this transformation brings a problem, which was that some informations of the original model were lost during the conversion.

To implement our 3D facility viewer we used UnityScript from the game engine Unity3D. It is a programming language modeled after Javascript, that's why their syntax are very similar. Although, UnityScript provides some capabilities that Javascript by its own do not support, such as the concept of classes or inheritance between them. To be running the scripts must be assigned to an object inside the Unity3D editor. To do that we created an empty and invisible object that runs the main scripts our system.

The system starts by importing the 3D model, to create an internal representation of the facility. It is parsed according each one of the rooms, which are

represented as a FacilitySpace. For each space we associate the objects inside the room that consume energy, as a FacilityObject, with the FacilitySpace that represents the room. This way we can create an internal representation of all spaces of the facility an electric objects inside it.

After creating this virtual representation, the system gets energy data from server, by making a request to the web service, which returns all required energy data as in the JSON format. That information is parsed and stored inside each FacilitySpace element, and for each object is also stored inside the FacilityObject element the device's consumption. After these two steps we have a notion about the facility and its consumption. With that information we were able to create visual representations for the consumption. It allowed us to create a box representation for each space, according to its dimensions, which has a color. That color, in fact had two purposes, to create a visual representation of the consumption and easily provide a way to compare rooms, as the rooms that are represented in red are consuming more than the ones that are represented as a green box. The objects inside each space are also highlighted with colors that follow the same logic. Although, in this case, to provide a more real representation, the object is not rendered as a box, but its defining mesh changes color.

When these steps are completed the system enters in a loop cycle, waiting for events, such as request form the web-application, for highlighting objects or rooms, or events from the navigation system, which are processed by the navigation model. From time to time, the system sends new requests to the server to update the stored energy information.

The navigation model can almost be defined as a single component. It is implemented as a module outside of the main architecture of the viewer, and its scripts are not assigned to the main object as the others, but to cameras. Its connection to the architecture is made through the main script, when users change the camera, which means that the main script needs to switch which of the camera scripts are enabled. By default it is the "Orbit Camera" script. This camera is based on the view of various CAD softwares, it orbits around the facility, which is in the center of the screen. Also the camera allows zooming the facility. The other camera that we implemented is called "Normal camera", typically in games is called "God View". It is characterized by allowing total navigation to users all around the model. It allows, panning, zooming and rotating over the camera itself. As it has no restrictions allows a 360 degrees and unlimited possibilities to explore the model. For tests purposes we also implemented a 2D camera, to test how much time a user spent to do a task with a 2D view compared to 3D representation.

3.3. Web-application

The web-application of our system follows the typical Model View Controller (MVC) architecture. This software architectural pattern is typically used for implementing user interfaces of web-applications. It divides the application into three interconnected pieces, to separate internal representations of information from how that it is presented or displayed.

The Model component of the architecture typically stands for the logic components, as it manages the data. In our application this is implemented by the viewer from Unity3D, which is called through the exposed API. The View can be any representation of information, in this case web-pages, charts, etc. We implemented this part as the pages that render information regarding the facility and representation of the viewer to be used by users. Finally, Controllers are components that accept input from the View and translate it to actions to be call in model or view components. It was implemented by the Dashboard and Viewer controllers that manage the interface of our system.

This architecture was implemented using Javascript, SCSS and Angular JS, a typical framework to implement MVC web-aplications. This tool itself is already designed as an MVC system. It forces us to define views and controllers that manage those views. We also used another framework, ChartJS, that was used to render the charts regarding energy data.

According to the requirements of our system we must provide way for the users see what is going on inside the facility, which was achieved with the viewer component. At the same time, we also want them to have a way to compare between periods and see historic data. To achieve that we studied some possible implementations, such as 3D graphics for historical data, 2D charts, etc. We came to the conclusion that the best way to provide historical data was through charts, which are easy to read, by showing them, according the perceptions of energy to users, time, energy units and above all costs.

As it is now obvious, our system implemented two major functionalities, the viewer, handled by the Viewer controller, and representation of historic data, managed by the Dashboard controller.

The viewer controller manages all user requests to the 3D facility viewer, as it sends the user's request to the exported API. In this case, it requests to the 3D viewer to show some selected space, highlight objects or spaces. It also receives information from the viewer regarding the facility, such as rooms, objects and floors, to be displayed as information in

the interface.

To summarize, the viewer controller allows the following actions:

- 3D navigation and exploration over the rendered facility on the viewer

- Selection of spaces, directly in the viewer or from a list presented in the interface

- Selection of different navigation cameras

- Views to explore real-time data, such as rooms and objects consumptions

The objective of dashboard was to provide a tool that allows historical and normative comparisons in our system. This helps users to navigate though historic data, to perceive the impact of their actions in consumptions and if they are improving their results or not. It renders historic data, by requesting it to the server, allowing users to query over that data, through the selection of time periods. It is composed by two different sections, the current energy data, and a section to see comparisons between periods. The first one, shows energy data regarding the current year, month and day to allow the users to easily perceive the energy values of the current period through different chats, such as line, pie and bar charts. In the second section, user choses a period to compare its values, then the data from the period is rendered, also as charts, showing users the values as consumptions and costs, to help them to find patterns and perceive variations in the values .

3.4. Evolution of the interface

As stated before, to develop an interface that is well accepted by the final users, their involvement on the development stage was crucial. The chosen methodology to create this interface is based on user centric co-design, which combines a continuous involvement of the final users with interface development concerns.

The interface development process consists on the following steps:

1. Promoting questionnaires with users to identify who they are, to create a target group that will follow all the design process.

2. Getting to know what tools they use nowadays, their pros and cons, to perceive where our solution can improve the current tools.

3. Getting to know what are their necessities, in this case, their requirements for the solution.

4. Create a first version of the system as a low-fidelity prototype based on the conceptual model. This low-fidelity prototype integrate all

requirement to discuss with users how they prefer the aesthetically aspects and how they want to execute the tasks in the interface.

5. Iterate over the low-fidelity prototype based on what was discussed before with users.

6. Specifying and applying usability tests to evaluate the prototype in terms of interactions between screens. The metrics that are usually used consist of spent time, error and number of help requests that are needed to complete a task.

7. Re-iterate over the prototype to meet the expectations of users, and the problems that they pointed out, and if necessary re-test the prototype and re-iterate again.

During this process the interface faced various major changes. In a first phase we do not had the system as a web-application. It was all made inside Unity3D and had some functionalities that we thought that users wanted and in the end they were removed, such as third person view or showing sensors location. The first interface can be seen in Figure 2.

Figure 2: Illustration of the early interface

Later we perceived that users not only wanted a way to navigate through the facility but also through historical data, this lead us to change the system to a web-application, as Unity3D still do not fully support rendering charts. This shift in the interface was also due to the need of having an application that could run in all different devices. Also, creating the interface outside of Unity3D helped us to create a more user-friendly and aesthetically clean interface than the one that we were creating inside Unity3D. In this phase in introduced the web-application architecture, and in specific the areas of dashboard and viewer.

In the end minor changes were made due to the results of user tests to our system. They pointed out different aspects in the navigation system, the way how we highlighted the objects and showed the dashboard, as at the beginning they found that was
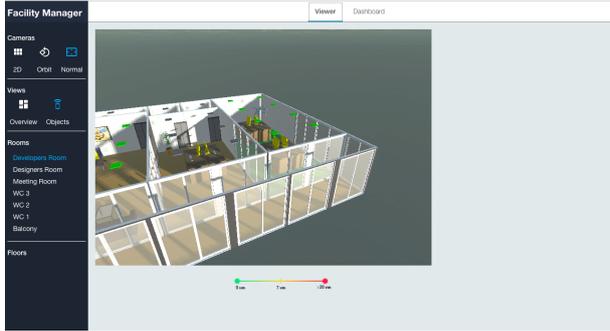
Figure 3: Final version of the interface, after addressing some comments by users during the tests-labels were added to views and cameras, and the spectrum bar of consumptions also changed.

a little confusing how we showed the charts. The final version of our interface can be seen in the figure 3 and 4, viewer and dashboard respectively.
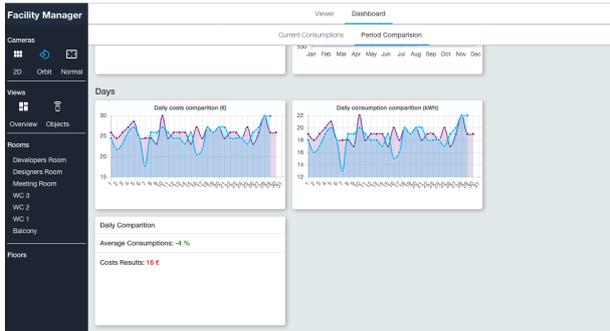

Figure 4: Final version of the interface, after fixing the errors related with the representation of historic data. Current results became separated from the comparison values.

4. Results

Based on Nielsen and Molich principles [32], we defined a batch of tests to evaluate the usability of our interface. The test group was composed by different types of users, facility owners and managers, which we considered expert users, and home owners, users with less experience that typically do not use complex systems to manage consumptions. This versatility of the group helped us to understand experts opinions about our interface, if it is capable of improving their performance when executing their daily tasks. It also helped us to conclude about how easy our interface was for users that never used such type of system, and how long they need to learn to use it.

To evaluate the usability of interface, users tested our solution and commented out loud what they were doing and their problems. The session of evaluation consisted in three different parts:

1. **Initial form** to trace testers profile (e.g. age, gender, studies, etc.), this intends to define the features of each user and the group test

2. **Tasks** a set of actions to perform with the application that covered all the possible solutions to a certain problem

3. **Final questionnaire**, aimed at usability and qualitative assessment of the system.

4.1. Evaluation Results

After filling the first questionnaire we delivered the tasks' guide to testers. The guide was composed by 6 tasks, with subtasks, that tested the different features of our system.

The first task was the identification of consuming equipments using 2D representation. Its objective was to understand how long users take to identify spaces and the state of its elements. By analyzing table 1 it is observable that, on average, users took 58.59 seconds to perform the task, with a relatively big standard deviation of 14.17 seconds.Despite being a simple task the time to complete it was too big. We think that these values are related with the facility being rendered in 2D, which takes longer to identify spaces. Another factor could be related is that was users first real interaction with the system.

The following task was similar to the first one, but in this case the facility was rendered in 3D. Testers had to identify another space and the state of its elements. It presented a faster execution, some users reduce their time by half, and reduced number of errors. The average time consumed to execute the task was 41.86 seconds with a standard deviation of 8.86 seconds. These better results helped us to prove our point regarding representation of the facility. 3D showed better results than 2D, as it was easier and faster for users to identify spaces and status of objects.

After comparing representations, we intended to test consumptions identification. The third task was determining consumption of an equipment in a

task	avg clicks	stdev clicks	avg time(s)	stdev time(s)	avg error	stdev error
1	5.29	1.80	58.59	14.17	0.71	0.62
2	5.86	2.11	41.86	8.86	0.42	0.50
3	7.42	1.64	60.81	8.60	0.35	0.49
4	8.04	2.63	54.28	21.44	0.58	0.88
5	9.75	2.17	96.72	17.81	1.17	0.92
6	87.71	1.65	91.23	19.29	0.17	0.38

Table 1: Tests results by task

specific room and comparison between rooms consumptions. All users were able to identify consumptions, although some errors occurred.First, when was asked the consumption of a computer, some users clicked in the element trying to perceive if any action occurred. Although, the consumption of the computer was in the sidebar of the room. A similar error happened when asked to make a visual query over the rooms, highlighted with colors, to find which ones were consuming the least. Some users tried to click the room to see their specific values. In fact this error was pleasant surprise as it showed us that users were getting engaged to the interface and asking for more functionalities, wanting to see specific values of consumptions in rooms. After the tests we implemented this functionality of clicking the space and opening its sidebar informations, not just in the rooms list like we implemented in the version that users were testing.

The fourth task was similar to the third one, being more focused in the perception of energy data in 3D. This task had almost no errors and the time for completing it reduced when compared with the previous task. This lead us to think that users easily identified the consumptions in 3D, Also, as they had done a similar task before, they even got faster to complete the visual query to the consumptions of spaces.

The fifth was analyzing monthly historic data. Testers were asked to select a period and find the month that had higher consumption in the current year and in the selected period. This task was the one that presented more problems. In a first instance it was our fault because the first interface that we used to present the analytics was very confusing to users. We presented the current consumptions and the comparisons of periods inside the same page, divided by years, months, and days. After the tests we change it according the user's feedback. Current values of consumptions switched to a single tab and the comparison between periods in another tab.

Finally, the sixth task was also about data analyzes, in this case analyzing daily consumption. It presented fewer errors and times. This was related to the fact that users already have made some of the steps in the previous task. Although the interface was still very confusing, and after the tests we needed to change it.

4.2. Questionnaire Results
After executing the proposed tasks and taking notes about the metrics to test users, we asked users to answer a final questionnaire.

As we refereed earlier, the results of this questionnaire were used to evaluate our system to validate our solution according the System Usability Scale (SUS).

Table 2 show the SUS scores. Our overall SUS Score is 80.47, which means that we had a good system, and the solution is on the right track.

Regarding the domain specific questions users seemed to like the 3D representation of facility, 41.7% gave an appreciation of 4 and also 41.7% the maximum classification. When asked about data presentation on the viewer, 54.2% of users gave us a classification of 4, and 29.2% the maximum, 5. 37.5 % of users considered that had no difficult to user the system, and 54.27% had almost any difficulty. When asked if energy data was easy to search, the majority of users were divided between 3, 4 and 5, 29.2%, 33.3%, 37.5% respectively. We expected this division due to the problems on dashboard. The tests that we made after fixing this problem to validate if it was solved do not counted for these statistics, but showed us that the problem was solved.

4.3. Discussion
The overall results of the tests were good, some of them even better than we expected and proved that our efforts to build a simple and user-friendly interface were well applied. Tests showed that are still some finetunings to be made (mainly related with historic data presentation and and augmenting the facility with information), although the overall feedback of users was very positive. The usability of the system was proven, with all users being able to complete all tasks. Also, according to the SUS methodology, our solution had very good results, 80.47 points. Although, we know that is there much to explore and improve.

user/task	1	2	3	4	5	6	7	8	9	10	SUS Score
1	5	1	4	1	5	1	4	1	5	1	97.5
2	4	2	4	1	5	1	5	1	4	2	87.5
3	3	2	2	2	4	2	4	2	4	2	70
4	4	2	4	1	4	2	4	2	4	1	80
5	3	2	4	1	4	1	4	2	5	2	80
6	4	2	3	2	3	3	4	1	4	1	72.5
7	4	2	2	3	4	2	3	3	3	1	65
8	4	1	5	1	4	1	5	1	5	1	95
9	4	1	4	1	4	1	4	1	4	5	77.5
10	4	1	5	1	4	1	4	1	4	1	90
11	4	2	4	1	4	2	5	1	4	2	82.4
12	4	2	3	2	4	2	4	2	4	2	72.5
13	4	4	5	1	4	1	5	2	5	1	85
14	4	3	3	1	4	2	3	3	4	1	70
15	4	2	4	2	5	1	4	2	5	2	82.5
16	5	2	4	1	5	2	4	1	4	2	87.5
17	4	2	4	1	4	2	4	2	4	1	80
18	3	2	2	2	4	2	4	2	4	2	70
19	4	2	4	1	5	1	5	1	4	2	87.5
20	3	2	3	2	3	2	4	2	4	2	70
21	4	2	4	1	4	2	4	2	4	2	80
22	4	1	4	2	4	2	4	2	4	2	77.5
23	3	2	4	1	4	1	4	2	5	2	80
24	4	2	4	1	4	2	4	2	4	1	80
total											80.47

Table 2: Summary of SUS results

Regarding our previously defined objectives we can say that all of them were achieved. Bellow we make a more careful analysis of the results of this work and future work. The main objective, creating an tri-dimensional interface for monitoring consumptions was successfully achieved, with only minor points to be correct and improved. User tests showed us that our 3D interface was easy to use and navigate through the facility, and the visual queries over the model were well implemented an easy to understand.

5. Conclusions

The emerging interest regarding smart homes and building created a need for more advanced Intelligent Energy Management Systems, capable of providing detailed information regarding facilities. Interfaces of existing solutions provide lots of energy informations, although, how it is represented turn their interfaces very confusing to simple users, and even the easiest task can become very complex in these systems [2, 33].

Creating interfaces for such systems is always a challenging task, as the effectiveness of an IEMS is directly connected to users decisions. Therefore, interfaces of these systems have great importance to their performance, thus, focusing on is usability and acceptance by users should by a priority. Although, as we have seen in this work, that is not the case for existing solutions, which are very complex and not user-friendly. A major factor that contributes to the complexity of these interfaces is the lack of guides to create such interfaces [13, 40] . Therefore it is imperative to clearly define which should be the features that such system must contain to be successful.

In contrast with other solutions, our implementation was designed to render energy data in such way that should be easy for a non-expert user to understand it. Our approach is innovative in a way that we explored the usage of virtual reality to create an interface for an IEMS. Tri-dimensional representation of data, typically, have faster and better recognition by users, so we decided to explore it in the context of representing facilities. We proposed a solution that augments 3D rendering of facilities with energy information gathered by the IEMS, to be easier for users to understand energy data, and perceive what is happening in real-time.

Another merit of this work is that we made a survey on the state-of-the-art regarding principles to create an interface for render energy data. Based on several researches we could provide a list with some of the main features that such interfaces must contain to be successful.

To validate our hypothesis, we implemented an interface of the proposed solution, running on top of a game-engine, to render the facility in 3D. The interface was later validated with users, to check how well accepted our solution was. The tests proved that our interface worked and can be easy to use. Some problems emerged during tests, which were later fixed, to meet users needs and expectations. The system allows users to explore the facility, perceiving its consumptions in real-time, by augmenting the representation of the facility with energy data. We think that this type of interfaces can help to solve some of the major problems of IEMS interfaces, such as lack of spatial context and complexity of IEMS interfaces.

Our initial goal of creating a tri-dimensional interface for IEMS was achieved, although we understand that there is much to explore and improve. This solution really works, despite of having minor flaws that need to be perfect, we did create a system capable of helping users to understand consumptions.

5.1. Future Work

Regarding the current implementation, there are still several issues that need intervention:

- Manage devices from the interface - as we explained, this work main focus was the motorization of the facility. Although, ideally this interface would allow the users to control their devices through the interface, by powering them on or off

- Our work was more focused on electric consumptions, but there are other metrics relevant to monitoring facilities, such as occupation, humidity, pressure, etc. An interesting work, is to find how to integrate them in this type of interfaces

- Study other ways of augmenting the facility with energy information, such as animating objects, and perceive which of them are easier for users to understand

- Study better ways to integrate BIM models with game engines, as we stated and proved, it is possible, but not perfect. Models are still losing information, and it is necessary to convert the model to be used by the game engine.

- An interesting work is finding how to represent historic data in the 3D interface, and which are the best ways to achieve that.

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