Shining a Light on Energy Use: Combining AR and Physicalisation to Represent Household Energy Consumption

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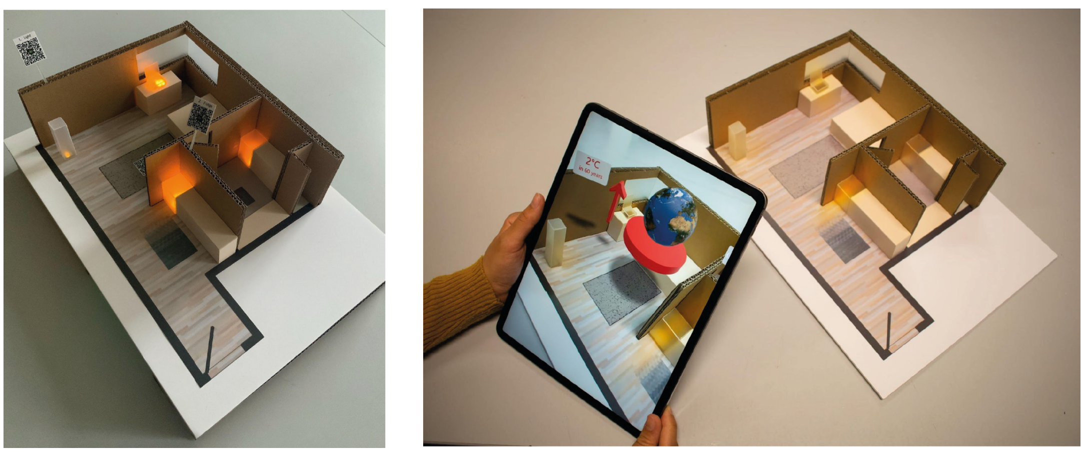

Figure 1: Left: Full model with LEDs. Right: Interaction with AR.

Abstract

Typically, energy consumption is recorded through a series of measurements, and while the potential impacts of it are discussed, the interconnection between causes and effects is often not clearly illustrated. Our project focuses on representing household energy consumption through data physicalisation and Augmented Reality. The demo consists of a studio maquette containing four household electronic devices: a laptop, washing machine, fridge, and lamp. The energy consumption of these devices is represented through the brightness of the device. To enhance the viewer's experience and show, we use AR storytelling to show the impact of this data on the climate. Motivating the user to make positive improvement to their household energy consumption behaviour.

*These authors developed this demo as a team during a semester project.

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CCS Concepts

• **Human-centered computing** → *Visualization techniques.*

Keywords

Data visualization, Data physicalisation, Energy consumption, Household energy usage

1 Introduction and Background

In today's age of increasing environmental challenges, understanding the causes and effects of energy consumption, as well as reducing it, have become paramount concerns [3, 8]. Although not the largest polluter, individuals can still contribute to slowing down climate change, as almost 20% of greenhouse gas emissions stem from energy usage in personal residences [12]. This requires individuals to change their behaviours regarding energy consumption.

As the first step towards behaviour change is to create awareness [17], we developed a hybrid data experience that combines Augmented Reality (AR) storytelling with a *data physicalisation* (Figure 1). Physicalisations are physical objects that represent data through their geometric, behavioural, and material properties [9, 11]. Previous work has shown that physicalisations enhance the engagement with data, can trigger emotional responses, and make data easier to understand [4, 11, 22]. Furthermore, physicalisations can be used to represent the story of the data and their qualitative values, not only numerical data [18], and trigger reflections [16].

However, as physicalisations can represent the overall narrative of the data, they also require a higher degree of data curation than visualisations [21], meaning that details get lost and the accuracy of the data decreases [20]. Moreover, from data science, it is known that people have difficulties understanding what happens based on the data (e.g., what do these numbers mean in the real world?) [6]. The disconnect between data and real world experiences has been found with traditional visualisations as well [19].

As our aim was to inform people about their energy consumption and motivate them to positively contribute to the environment, we combined data physicalisation with AR. This way, we could use physicalisation's strength of engagement and reflection, and narrate details that cannot easily be physicalised using AR [7]. AR was chosen as for its narrating abilities and high immersion [5, 10], whilst still allowing the viewer to see the data physicalisation in real life (something that is not possible in Virtual Reality).

With our work, we explore the idea of combining physicalisation and AR to make viewers aware and motivate them to change their behaviour. This way, we contribute to the fields of data physicalisation and immersive analytics, and give a demonstration of how these fields can contribute to each other.

2 The Data Experience

Our project aims to make household energy consumption more vivid and relatable by using different means for representing data. In this context, an architectural model (maquette) was constructed, which enabled the physicalisation of an apartment, with furniture, appliances, and devices included. This approach allows the viewer to see and touch each device in context [23], making the experience more tangible and realistic.

2.1 Data Physicalisation

The maquette is made using low-fi and easily accessible materials, including cardboard, cartons, and semi-transparent plastic sheets. This way, others can easily create their own maquettes, and quick changes to the apartment can be made (e.g., adding another room with more appliances).

The maquette was exhibited during a two-day university exhibition in [XX], Germany. For this context, the decision was made for the apartment to reflect the living conditions of the average exhibition attendee: students and young professionals, who live in studio/small apartments or shared housing. To increase the overlap with attendees who do not live in shared housing, we decided to model a small studio apartment. For the electronic devices, we selected a light, fridge, washing machine, and computer. Besides being appliances that are commonly found in German housing, these devices have a deeper meaning: the laptop represents the growing trend of remote work and home-based digital activities, the washing machine symbolises essential domestic chores, the fridge is a constant energy consumer vital for food preservation, and the lamp is an example of daily lighting needs. Moreover, these devices consume different amounts of energy, making it interesting to represent this difference. Additionally, they are frequently used.

The maquette included these appliances, made out of semi-transparent material, as well as other elements, such as furniture, to avoid rooms looking unrealistically empty.

To demonstrate the intensity of power consumption, LEDs were used. The brighter the LEDs, the more power-consuming the corresponding device is. For example, in Figure 1 the lamp shines a lot less bright than the laptop positioned on the desk. Each LED module was placed inside one of the four devices to light them accordingly. This is the reason why these devices were modelled out of a transparent material. The intensity and the corresponding LED brightness were determined after we calculated the energy consumption per device per year, as listed in Table 1.

For these numbers, it is important to note that they serve as indicative usages. In an ideal, personalised setting, the usages are based on the user's actual consumption. However, as our demonstrator was displayed at an exhibition, we made the calculations based on the average usage of the appliances in Germany.

2.2 AR Narrative

Next to the data physicalisation, we developed an AR experience for a tablet, using Adobe Aero. A tablet was chosen (rather than an HMD), as this is cheaper and more realistic to how people would interact with AR at home. As data on their own are often difficult to understand –what are the implications of these numbers?– [6] the AR showed users a narrative of what happens to the environment based on current energy consumption and usage. Figure 2 shows some stills of the AR experience. A video of the full narrative can be found with the supplemental materials.

The AR experience consists of three parts, that are accessed by scanning the respective QR codes incorporated in the model (Figure 1). The first two parts are examples of different devices (the lights and refrigerator). As the user scans these respective QR codes, they get to see a cloud representing the CO_2 emissions hovering over the device (Figure 2, a). The size of the cloud represent the amount of CO_2. Besides the cloud, the user gets to see the annual average CO_2 emission (e.g., 408 kWh per year for the fridge). The third part shows the sum of the estimated energy usage of a residence, and its consequences when households continue this consumption behaviour (see Figure 2, b–f). Here, all the devices' CO_2 emission clouds come together, showing the overall sum of the data. After that, the impact of the data is shown: the user gets to see that the earth's temperature will be rising by two degrees Celsius in sixty years [15]. This results in an intensified the global water cycle [1, 2], that is represented by showing large waves, rain and storm to the user. In addition, the expected costs due to climate damage are presented. The AR story eds with a big flood, after which the user is informed that conscious electricity consumption can already have a big impact.

3 Exhibition and Future Work

The maquette and AR experience were presented during a two-day exhibition, during which eight visitors interacted with the prototype. It could be observed that visitors could smoothly use AR, easily recognise the 3D objects and understand the context. As feedback, visitors emphasised that they liked the different, easy to understand and engaging explanation of the data. Moreover, they

Table 1: Energy consumption per device. The consumption data for the fridge-freezer, washing machine, and light bulb are taken from [14]. The consumption for the computer is based on [13].

Device	Fridge-Freezer	Computer	Washing Machine	Light Bulb
Consumption per year	408 kWh	384.71 kWh	65.52 kWh	36.5 kWh
Assumption	assuming 24h/day operation	assuming 10-hour use per day	based on the average consumption at 40°C using a 2kg load	assuming 4 hours a day

Figure 2: (a) a CO_2 emission cloud showing the emission of a refrigerator, (b) impact of residencies on CO2 emissions, (c) resulting rising temperature, (d) resulting rising sea level, (e) resulting increase in humidity, and (f) resulting extreme weather conditions.

appreciated that they could see the effect and impact of current consumption behaviour.

Despite the positive reactions, a larger user study needs to be conducted to evaluate our work. Moreover, for future work it would be interesting to make a similar representation of larger polluters, such as big companies. By expanding beyond personal energy consumption, a more comprehensive representation of the environmental consequences of human practices can be offered.

4 Conclusion

This work introduces a data representation of energy household consumption that combines data physicalisation with AR. Using a maquette of a small studio, the energy consumption of four devices is represented through the brightness of the device, using LEDs. This gives the user a quick overview of which devices consume the most. However, it does not illustrate 'the bigger picture' or the consequences of these data. Therefore, this physicalisation is accompanied by an AR narrative, that shows the impact on the climate. Using the combination of AR and physicalisation, our work aims to contribute to the fields of immersive analytics and data physicalisation, by showing how these fields can benefit from each other and work together in one representation.

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