# End-User Development and Gamification to Foster Sustainability in Smart Homes

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**Abstract**

This paper proposes a reflection on the design of a system for controlling and managing a green smart home through end-user development. Such a design stemmed from user research carried out with people living in Italy, considering their specific problems related to energy costs and consumption, given the limited energy availability in this country. To explore diverse perceptions of smart home sustainability and end-user development for smart home control, we decided to organize a survey involving people living in other countries. Interesting findings convinced us to integrate adaptive and adaptable gamification mechanisms into the system to foster participation in end-user development and enhance sustainability awareness.

**Keywords**

Sustainability, End-User Development, Gamification, Design Trade-offs, Green Smart Home

## 1. Introduction

The United Nations Sustainable Development Goals (SDGs)[1] are at the heart of the 2030 Agenda for Sustainable Development, which proposes a shared model to achieve peace and prosperity for the world community and the planet. Among these goals, SDG 12 "Responsible production and consumption" is a call to action to ensure sustainable consumption and production patterns, SDG 13 "Climate action" recalls that it is urgent to combat climate change and its impacts, and SDG 9 "Industry, innovation and infrastructure" asks to foster sustainable innovation. These are the goals we are addressing in the frame of EUD4GSH, an Italian project focused on the development and management of Green Smart Homes[2]. In particular, we are in charge of studying and implementing a digital twin for green smart homes that could help users monitor their energy consumption, enhance their ecological footprint awareness, and thus manage their smart homes in a more sustainable way. To enable household members to participate in shaping smart home behavior, End-User Development (EUD) tools based on conversational agents and augmented reality are integrated with the digital twin [1].

To design and develop the digital twin, we adopted a Human-Centered Design (HCD) approach, starting from user research through surveys and interviews with users and domain experts, to iterative prototyping interleaved with evaluations with Italian household members. The preliminary results are very positive, but led us to reflect on further aspects related to the sustainability challenges.

To achieve the SDGs, in his recent book "Design for a Better World" [2], Donald Norman advocates transforming HCD, which focuses on people and their immediate needs, into Humanity-Centered Design, to focus on the entire ecosystem of people, living things, and environment and take a long-term perspective that considers the impact of any intervention on society and planet. This led him to add a new design principle to the basic principles of Human-Centered Design: "Design with the community and as much as possible support designs by the community". This principle aligns with the goals of

*Joint Proceedings of IS-EUD 2025: 10th International Symposium on End-User Development, 16-18 June 2025, Munich, Germany*

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[1]https://sdgs.un.org/goals

[2]https://giove.isti.cnr.it/eud4gsh/index.html

participatory design research, which aims to promote the participation of domain experts and end users in designing solutions to their own problems. Taking a step further, [3] suggested that meta-design augments participatory design by designing socio-technical environments that support end users at both design and use time. These environments exploit EUD methods to foster users' participation in system adaptation when their needs change or unforeseen requirements emerge, often due to changes in the surrounding conditions that could not have been foreseen. EUD for smart homes is usually supported by trigger-action programming (TAP) that allows the creation of automations for smart home automatic control [4, 5, 6, 7, 8, 9, 10]; in our case, also thanks to the digital twin features, EUD is enhanced with automation sustainability evaluation to prevent excessive energy consumption and inform users about their ecological footprint.

However, humanity-centered design points to the importance of enabling sustainable communities that consider and address multiple human needs, welcome people of diverse backgrounds and perspectives, and focus on anticipating and adapting to change from a long-term perspective[3].

In this position paper, we revisit our design approach, which was originally centered on Italian households and their specific challenges regarding energy consumption and rising costs, due to the country's limited energy availability. We decided to broaden the discourse by adopting a humanity-centered design perspective. By surveying people living in other countries, we explored their perceptions of smart home sustainability and EUD for smart home control. Our findings led us to study how to make the system suitable for a broader community in its future versions. Considering the literature about persuasive technologies for behavior change [11][12] and gamification techniques in particular [13], we hypothesize that tailored gamification, combined with EUD, could foster rich ecologies of participation and enhance sustainability awareness.

## 2. An EUD-enabled Digital Twin of Green Smart Homes

We designed and developed a digital twin for a green smart home environment as a responsive web-based application suitable for PCs, tablets, and smartphones [14, 15, 16]. The goal of the application is to support smart home inhabitants in managing energy more efficiently, improving their comfort, and introducing environmental awareness. To this end, the digital twin exploits Home Assistant[4] to gather energy consumption data from home appliances and applies Artificial Intelligence (AI) to such data for predicting and simulating energy consumption.

The home page (depicted in Figure 1) is constituted by a map of the smart home showing the configured devices. Each appliance is represented by a clickable icon that grants access to its control panel. On the same screen, further information is provided. First, real-time information about the home's current power demand and the number of active devices is displayed. Secondly, the ecological footprint of the users is visualized to help them assess their environmental impact by calculating $CO_2$-equivalent emissions from the past month and comparing them to the average emissions of an Italian household. To enhance understanding, the footprint is contextualized through relatable comparisons, such as the equivalent distance a car would travel or the number of phone charges the emissions correspond to. Thirdly, a list of all devices, their current status, and their energy consumption is provided.

Another section of the application offers insights into the home's energy usage. Users can visualize energy consumption at different granularities, ranging from an hourly breakdown for a single day to daily or monthly consumption trends. Also, they can compare energy usage across different days or months, either for the entire household or specific devices. And finally, an energy forecast for the upcoming hours based on past consumption patterns is provided. This forecast is generated using an LSTM-based deep learning model [17], trained on real consumption data.

A further section of the application allows users to access a list of all automations created through EUD techniques. Selecting an automation reveals a detailed card displaying its triggers and actions. If applicable, the system suggests optimized scheduling options to improve energy efficiency and

[3] https://sustain.org/about/what-is-a-sustainable-community/
[4] https://www.home-assistant.io/

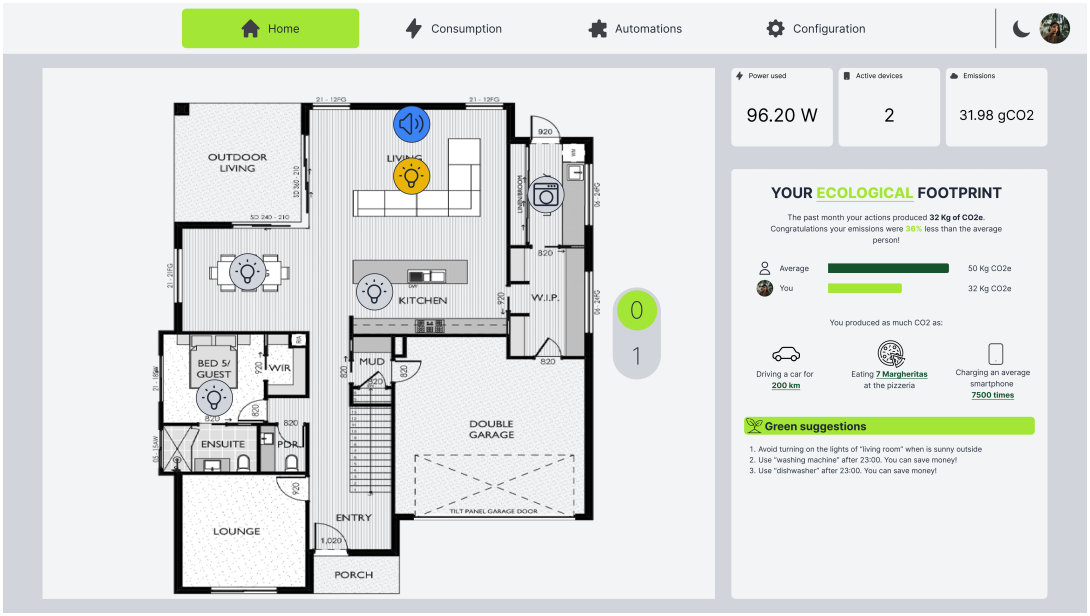



**Figure 1:** Home page of the digital twin.

cost savings. These suggestions are generated by analyzing the automation's original activation time in relation to the configured energy plan and exploring, through AI-based simulations, alternative schedules that minimize costs. Before presenting a suggestion, the system ensures that no conflicts arise with existing automations.

To better customize the digital twin application, the users can configure their personal profiles by setting privacy and preferences. Preferences are grouped into four categories: health, money-saving, security, and comfort. Users can rearrange these categories to reflect their priorities, with the highest-ranked item being the most significant.

## 3. Widening User Research for Green Smart Home Design

To investigate how sustainability is perceived outside of Italy, we designed and distributed a survey to 23 individuals residing in 13 different countries over four continents. The questionnaire assessed participants' perspectives on environmental sustainability, their management practices for smart devices, their knowledge of home automation, and the potential impact of persuasive and engaging techniques like gamification to foster more responsible energy use.

The participant group consisted of 16 males (69.57%) and 7 females (30.43)%), with ages spanning from 18 to 61 years (mean: 33.91, standard deviation: 13.16). Respondents live in France (21.74%), Iran (17.39%), Bolivia (13.04%), and Norway (8.70%), while the remaining reside in other nations like Canada, China, Hungary, Japan, Luxembourg, the Netherlands, Sri Lanka, and the United Kingdom.

Regarding smart devices in their homes, 9 out of 23 participants responded that they do not use them because of high costs, lack of needs, security and privacy concerns, ecological preoccupation, and no interest in the matter. The other 14 participants in the study used up to 10 devices (3 individuals) or up to 3 devices (11 individuals). Among these 14 subjects, 5 of them (35.71%) managed their devices through their smartphone only, one just with their tablet, while the remaining 8 people (57.14%) used them with a combination of smartphones and other tools (PCs, laptops, smart speakers, and tablets). When asked if they were interested in having a centralized system to manage all their smart devices, 28.57% of them were very interested, 42.86% were somewhat interested, 21.43% neutral, and the remaining 7.14% were not very interested.

We decided to explore the participants' attitudes towards tools that allow the creation of automations, such as Google Assistant, Amazon Alexa, Apple Siri, and Home Assistant. 57.14% of the respondents (8

out of 23) declared to use them, and specifically, most of them used Google Home (3 subjects out of 8) and Apple Siri (3 out of 8), while only one participant used Amazon Alexa and the other one used Baidu and Xiaomi speakers, and Apple Shortcut. The 8 participants also answered one multiple-response question about what motivates them to create automations for their smart homes. Four respondents answered that it happens when they change their habits (e.g., going on vacation or seasonal changes), three mentioned the case when they need to connect a new device, and 3 people pointed out that it happens when they want to experiment with new features. It is particularly interesting that three participants declared that they are used to creating automations to schedule appliance activation to reduce energy costs, while 2 respondents answered that they create them when the system suggests it.

All 23 questionnaire respondents were inquired about environmental consciousness and waste reduction. 60.87% of them (14 subjects) expressed concern, with 13.04% being very concerned and 47.83% concerned, a neutral stance was held by 26.09% (6 subjects), while the remaining 13.04% were either unconcerned (4.35%) or very much unconcerned (8.70%). The majority of respondents (65.22%) were somewhat interested in a system that monitors energy consumption and provides energy-saving recommendations, followed by 13.04% who were very interested. Meanwhile, 8.70% expressed low interest, 8.70% remained neutral, and 4.35% were not interested at all. Furthermore, 52.17% indicated they would alter their energy consumption habits if provided with more precise information, whereas 39.13% remained uncertain, and 8.70% stated they would not make changes. Regarding interest in a system that recommends optimal times for device usage to minimize energy costs, 26.09% were very interested, 56.52% were somewhat interested, 13.04% were neutral, and 4.35% were not very interested. The 52.17% of respondents reported having never encountered issues related to excessive home energy consumption, while the remaining 47.83% had experienced such problems only occasionally. Interestingly, despite the majority of respondents never encountering issues, when asked about their interest in an alarm system to prevent excessive consumption, 56.52% of the 23 participants expressed moderate interest and 17.39% indicated high interest, while 17.39% showed neutral interest and 8.70% low interest.

When asked about desirable features in a sustainable smart home, respondents prioritized the use of renewable energy sources and energy consumption reduction via artificial intelligence. Some participants also highlighted the importance of improving security and privacy, as well as optimizing water consumption.

Participants' knowledge of applications that include gamification elements was also examined, with 3 respondents reporting not using gamification-based applications, while the other 20 declared to use mostly Duolingo, Khan Academy, Strava, and Forest. Regarding the use of gamification as a strategy for helping users with energy conservation, 56.52% believed it could be effective for them if well-designed, 26.09% stated that it would increase their motivation to save energy, and 17.39% found it not compelling.

## 4. Tailored Gamification to Foster Cultures of Participation

Given the results obtained through the survey, it appears clear that priorities and needs are different for citizens of other countries, so we decided to extend the digital twin with gamification elements aimed at encouraging and engaging users from a more global perspective. We decided to foster cultures of participation [18] by providing inhabitants of smart homes with additional motivation to customize and adapt their smart environment, reflecting their preferences, objectives, and daily practices.

In the new digital twin home page, by clicking on the medal icon located in the top right corner of the navbar of Figure 2, users can open a popup (Figure 3a) from which they can access the gamification features of the system. The gamified interface is designed around two fundamental concepts: Achievements and Challenges. Achievements work similarly to digital badge systems, where users earn permanent badges by completing predefined actions. These serve as long-term milestones, recognizing user engagement and progress. Unlocked achievements (Figure 3b) are displayed with their name, unlocking criteria, and obtaining date, while hidden achievements (Figure 3c) only present the steps that a user needs to do to obtain them. The surprise element of knowing the title of an achievement and its corresponding badge could incentivize users to complete the required steps. The gamification

popup will display the three most recently earned achievements, allowing users to view the complete list by clicking the “Other Achievements” button.


**Figure 2:** Home page with gamification elements.

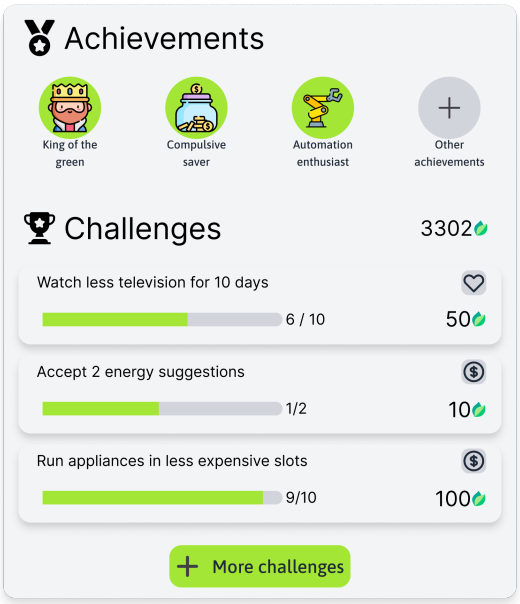
Challenges are structured as single-activity tasks that users can voluntarily join and complete to accumulate points. Each challenge defines a specific activity that users must complete (e.g., running appliances during off-peak hours) and sets a required frequency for completion (e.g., 10 times). Upon successfully fulfilling a challenge, users are rewarded with points in the form of leaves, the amount of which is proportional to the challenge difficulty. Through the popup, users can quickly keep track of their progress and access additional challenges. Figure 4 illustrates the application’s gamified profile page, where users can customize their preferences by ordering the categories Health, Money saving, Security, and Comfort from the most to the least important. Here, users can explore both personal and group challenges. Personal challenges are tailored to individual users, while group challenges are more demanding tasks that require collaboration among multiple participants to complete. Both challenge lists are dynamically generated based on the user’s preferences, ensuring a personalized and engaging experience. For example, a user who prioritizes health will be more frequently presented with challenges that promote a healthy lifestyle, whereas a user focused on saving money will receive recommendations for cost-saving activities. To help users understand why a challenge was presented, each of them is associated with a small icon that indicates which preference is primarily supported by the challenge.

## 5. Discussion

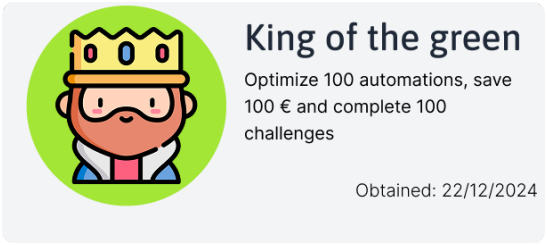
The survey we carried out involving people who reside in several different countries and the consequent extension of our system with gamification mechanisms allowed us to reflect on the fact that accommodating everyone’s preferences can be an issue. This confirms that adaptive and adaptable configurations should be preferred over a *one-size-fits-all* approach.

From this perspective, tailored gamification has been proposed to address some design trade-offs, such as the need to balance individual preferences and habits with the potential that collaborative decision-making can provide for promoting sustainability.

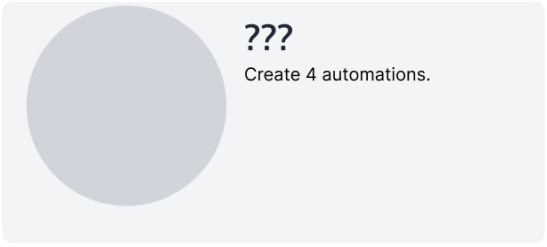
Furthermore, design trade-offs that may arise when a digital twin like ours is used in a single-user environment can differ from those emerging in a shared environment where multiple users are willing to control the home-connected devices and appliances. Individuals co-habiting a smart home may




(a) Popup of gamified features




(b) Unlocked achievement




(c) Hidden achievement

**Figure 3:** Gamification elements

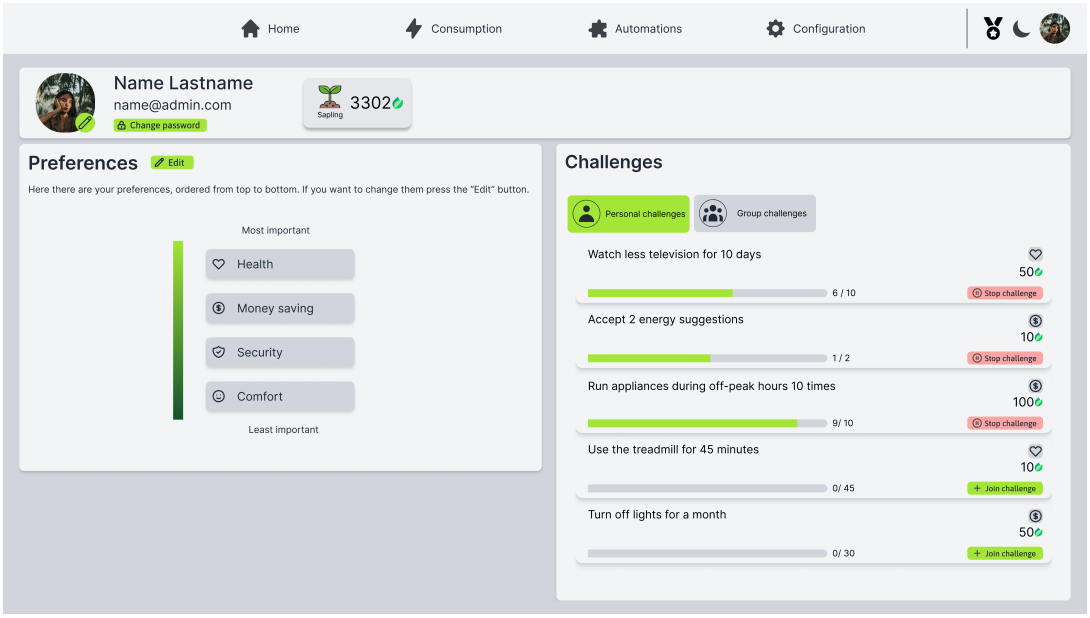



**Figure 4:** User profile page with gamification elements.

have diverse priorities and be influenced by cultural background, financial resources, work/life balance choices, or personal values. Some users may prioritize energy savings, while others may value comfort more. The digital twin presented in Section 2 has been designed and developed for countries where energy availability is limited, like Italy. In regions where energy supply is not a limiting factor, a system like ours must be configured to emphasize other aspects, such as environmental sustainability or energy cost, and this requires EUD features enabling customized installation and configuration of the smart home. Gamification could, in turn, support the personalization of goals a user or a household may desire to achieve.

Gamification should also take into account that, in a household setting, the actions of a single person can benefit multiple individuals. Consequently, assessing the merit of a single resident based on

their measured energy consumption and resources may disadvantage those who more frequently take responsibility for operating energy-intensive appliances, such as washing machines or dishwashers. A person in this situation should not be blamed for consuming more, as their consumption is equally distributed among all those who benefit from their actions. The idea of providing group challenges beyond the personal ones, proposed in our approach to gamification in smart homes, aims to address this aspect.

## 6. Conclusion

This position paper explores the use of tailored gamification to engage users in smart home management by accommodating the preferences and habits of people residing in different countries, thus with different perceptions and needs with respect to sustainability goals. However, several other issues remain to be addressed in the future. Some of them are mentioned below.

The introduction of digital twins in smart homes and the adoption of EUD for the automation management empower the users, but, at the same time, can expose them to an overwhelming decision-making process that can lead to what can be defined as participation overload [19]. While on the one hand, the integration of AI-based features that allow users to receive suggestions on optimizing energy consumption and resolving conflicts between different devices is undoubtedly an advantage, on the other hand, there is a risk that, due to laziness or a sense of incompetence, users may avoid trying to understand the reasoning behind specific suggestions and accept them without learning from the process. An advanced system like the one we propose should provide users with a gradual learning process that informs them about the pros and cons of their decisions, including those guided by AI, by offering explanations and alternative options to support decision-making rather than replacing it. Another issue worth discussing is that while smart devices provide a valid solution for creating and managing a more sustainable home environment, their adoption and use can pose environmental issues. The production and disposal of electronic devices contribute to e-waste, and they often rely on cloud infrastructure, which is one of the most energy-consuming aspects of today's digital landscape. To foster a sustainable approach to smart home management, the lifecycle of smart devices and appliances should incorporate modular and repairable features and strategies to reduce their impact on the planet's resources. Another relevant issue is the trade-off between user privacy and personalization. In the long run, a shared smart home can benefit from the adaptation to the behaviors of its inhabitants. However, tracking user behaviors may compromise privacy, even if the tracking's main objective is to learn from the user's behavior. Insights derived from occupancy patterns and appliance usage could inadvertently reveal sensitive information.

In future work, we will assess how customizable gamification strategies can be aligned with the evolving values and preferences of different users sharing the same household. Combined with the benefits of providing EUD tools, a digital twin like the one we developed has the potential to impact long-term engagement and promote sustainable behavior.

## Acknowledgments

This work has been supported by the Italian MUR PRIN 2022 PNRR Project P2022YR9B7, End-User Development of Automations for Explainable Green Smart Homes, funded by European Union - NextGenerationEU.

## Declaration on Generative AI

During the preparation of this work, the authors used Grammarly and ChatGPT in order to: grammar and spelling check. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for the publication's content.

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