Designing a Consumer Framework for Social Products Within a Gamified Smart Home Context

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Abstract. The most effective strategy for homes to save energy is by decreasing their electricity consumption. Home Energy Management Systems connect appliances that improve households' energy performance to thermal comfort. These systems need to take into account human behavior regarding saving energy and thermal comfort. This paper proposes a three-step framework that integrates the Smart Residential Load Simulator (SRLS), Adaptive-Network based on Fuzzy Inference System (ANFIS), and a gamification structure to develop an interface designed to reduce energy consumption without losing thermal comfort. Finally, a gamified mock-up for mobile devices is displayed for a household with high energy consumption levels and a temperature setpoint of 23 °C. This proposal integrates the concept of social products to empower the interaction between devices and end-users.

Keywords: Gamification · Smart home · Social products · ANFIS · Gamified homes · Gamified interfaces · HMI

1 Introduction

Household appliances, like televisions, interior lighting, electric stoves, coffee makers, washing machines, geysers, refrigerators, clothes irons, and thermostats, have different energy consumption patterns according to their operating periods, power ratings, and the specific characteristics of each appliance [1]. The Residential Energy Consumption Survey (RECS) conducted by the U.S. Energy Information Administration (EIA) [2] provides data on energy-related characteristics and usage patterns of a representative

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sample of U.S. homes. The most current available survey is from 2015, and it is the 14th edition of the RECS analysis. This database contains 5,686 observations with 759 variables and represents 118,208,250 U.S. homes.

Residential buildings in the U.S. represent approximately 20% of total energy demand and 36% of total electricity consumption [3]. According to RECS, 85% of residential buildings have thermostats in their homes [4]. A growing fraction of these thermostats are connected to the Internet. They offer many features that enable greater information and control. Installation of connected thermostats can reduce energy consumption up to 35% of the peak load and raise overall energy efficiency by 5% through small changes in behavior [3]. Although it is possible to achieve such reductions by interactions between the end-user and the connected thermostat, successful reduction infrequently occurs because users do not entirely accept the connected device, leading to insufficient energy behavior [5–13].

An important parallel trend is the widespread availability of smart household appliances, which has been made possible by the ubiquitous Internet of Things. Such smart appliances can facilitate routine tasks, adjust visual and thermal comfort, and provide building security [3, 14]. In [15], a simulation framework is proposed to manage a smart home's home appliances and lighting systems. Home energy management systems build the interconnection of appliances to manage households' peak power demand and comfort. Research focuses on scheduling optimization of the household appliances to reduce the electricity bill and generation cost; multi-objective optimization models for household electricity consumption and load peak of the utility grid; and analysis of the economic benefit of energy storage [16]. The Smart Residential Load Simulator (SRLS) for Energy Management in Smart Grids is an example of a validated tool. It is based on MATLAB-Simulink-Guide toolboxes that model household appliances, wind and solar power generation, and battery sources based on the ambient temperature and household activity levels in a day [17].

Human factors nevertheless remain a significant determinant in achieving lower energy consumption. Hence, the Universal Thermal Climate Index (UTCI) is a one-dimensional quantity that reflects the human physiological reaction to the actual thermal condition and is categorized as thermal stress [18]. An individual can have no thermal stress within an air temperature range from 9 °C to 26 °C. Therefore, the air conditioner setpoint in a home can be 26 °C without experiencing thermal stress. However, before allowing the temperature to exceed that setpoint, it is essential to understand the three categories of thermal adaptation:

- Behavioral adjustment (personal, technological, and cultural responses).
- Physiological adaptation (genetic and acclimatization).
- Psychological dimension of thermal adaptation: Refers to an altered perception of, reaction, and sensory information due to experience and expectations [19].

The end-users must also be prepared to accept connected products and the operating decisions that they make; this acceptance can be improved by personalizing Human-Machine Interfaces (HMIs) and making social products. Social products come from the S^3 product development reference framework proposed by [20], in which each S means Sensing, Smart, and Sustainable products:

1. Sensing: A system can detect events, gather information, and measure changes throughout sensors that allow the observation of physical or environmental conditions.
2. Smart: The complementary consolidation of physical parts, smart components, and connectivity to make intelligent and accessible products to interface with different gadgets.
3. Sustainable: Social, environmental, and economic elements that create a balanced and optimized performance. The social aspect contributes to the product by gathering people's satisfaction.

Consequently, social products can be supported by understanding the varieties of behavior and usability problems when adopting connected devices, and including household energy users in planning, implementing, and monitoring energy usage [20]. Hence, Ponce et al. [10] recommend including social factors in the design process by implementing a gamification strategy to send stimuli to shape consumer behavior towards energy reduction.

Social products acceptability has the following characteristics [21]:

- Users comprehend that when they buy a connected product, they can leverage its advantages.
- The products align with users' current and dynamic lifestyles.
- The appliances and devices are quick and cheap to acquire.
- The products diminish or eliminate physical demands for operation; users do not require experience, high user-knowledge levels, or regular intervention of experts for installation, troubleshooting, and maintenance.
- The usability of the products considers end-user skills; products do not decay or perform unpredictably.
- The products take into account users' requirements.
- The products take into account privacy and security characteristics, so that users' information is secure and private.

Gamification is developing and creating positive experiences using game mechanics, behavioral economics, and design thinking in non-game contexts to motivate, engage, and educate individuals to solve real-world or productive activities problems [22, 23]. The Octalysis framework proposed by Chou [24] analyzes and builds strategies to make engaging applications. Table 1 shows the extrinsic and intrinsic motivations regarding energy applications [25].

- Extrinsic motivation: People are motivated because they want something they cannot get, and earning it infers outer recognition or even monetary prizes. Includes factors of external control, identification, and integration.
- Intrinsic motivation: The activity is rewarding on its own without a particular purpose to succeed. This motivation considers autonomy, competence, and relatedness [26].

In [8, 11, 27], the authors propose a three-step framework that allows the interface designer to display personalized interfaces to engage, teach and motivate end-users to

Table 1. Gamification elements for extrinsic and intrinsic motivations.

Extrinsic motivation	Intrinsic motivation
Offers, coupons	Notifications
Bill discounts	Messages
Challenges	Tips
Levels	Energy community
Dashboard	Collaboration
Statistics	Control over peers
Degree of control	Social comparison
Points, badges, leaderboard	Competition

save energy at home through a fuzzy logic decision system gamification structure. In [28], a multi-sensory system is proposed on an ANFIS by including Alexa and cameras to track older adults and check their daily status and mood to improve their quality of life by promoting social inclusion and physical exercise.

Conventional analytical mathematical modeling algorithms sometimes encounter problems when dealing with vague or uncertain information. Thus, using linguistic rules (IF-THEN), Fuzzy systems have the strength and ability to reason as humans, without employing precise and complete information. However, a problem arises: transferring human knowledge to a fuzzy logic system and how to tune the fuzzy logic system. Several proposals have been made, such as the combination of artificial neural networks with fuzzy systems. Artificial neural networks can learn and adapt from experience, potentially complementing fuzzy systems. One of the essential techniques is ANFIS, an adaptive neuro-fuzzy inference system proposed by Jang [29]. ANFIS is based on adaptive networks, a superset of feed-forward artificial neural networks with supervised learning capabilities, as Jang stated in [29] and [30].

This paper proposes to use the SRLS simulator to determine the daily energy consumption in Concord, California. Based on the result, ANFIS is used to determine what type of gamification motivation is required to reduce energy consumption without losing thermal comfort.

2 Methodology

The data was collected from the RECS database and analyzed using R Studio. The weather file for Concord, California was analyzed using Energy Plus to obtain the cooling design day. The RECS's exploratory data analysis obtained the characteristics of a typical home in California, and the most common household appliances were analyzed in the SRLS. The information was then fed into the ANFIS, representing input values of energy consumption and temperatures in July. Output is provided as gamified motivation where lower values are related to intrinsic motivation and higher values are related to extrinsic motivation.

3 Proposed Framework

This framework proposes three steps (Fig. 1):

- Knowledge base: Exploratory data analysis of the RECS database and the weather file. Extrinsic and intrinsic motivation of gamification features used for energy savings. SRLS provides insights into daily consumption based on the home and appliances' location and characteristics.
- ANFIS: This step analyzes the energy consumption in a home and the air temperature of a specific location. The output value is related to the gamified motivation that helps the user engage in activities.
- Evaluation: The end-user interacts with the HMI, which provides continuous feedback to the user and the knowledge base to determine whether the user is engaged or if adjustments are required.

3.1 Knowledge Base

RECS Database. The IECC Climate Code [31] classified the country into eleven zones. The mean kWh in the U.S. in 2015 was 11,029 kWh, with a standard deviation of 7,050 kWh. Figure 2 displays different boxplots for each zone and their total site electricity usage in kWh; the blue dashed line represents the average annual electricity consumption for a U.S. residential utility customer. The present work focused on the IECC climate zone 3C and in the Pacific Census Division. This zone 3C has a mean of 5,684 kWh with a standard deviation of 3,171 kWh.

Zone 3C is below the national average; hence, this paper aims to propose a strategy that promotes household reduction. Table 2 displays the type of home's main characteristics and the most common appliances in that zone.

Modeling a Home in California. SRLS was used to simulate and analyze three cases on a typical summer day.

The first case analyzed the most common appliances of Table 1 without any photovoltaic generation. The second case analyzed the appliances that consume less than 3 kWh. The third case considered case 1 with photovoltaic generation to analyze the energy and cost reductions. Table 3 summarizes the characteristics of the household appliances and PV generation used for each case and the type of home in each case.

Besides, Table 2 shows the seven household appliances selected for case 1, the summer season, and the electricity price based on an electricity bill for Concord, California. This SRLS simulator requested the temperature for a single day. July 21st was the cooling design reported at the Statistic Report of the annual weather file (stat file) [32]. Moreover, the tool requested the family characteristics, which were considered in Table 1, with adults' presence during the day, with their dishwasher and clothes washer.

ANFIS and Gamification Structure. Although zone 3C was the lowest zone with total site electricity usage, the present work proposes a gamification strategy to promote energy reduction by promoting the adoption of PV panels and increasing the setpoint to reduce energy consumption without losing thermal comfort. 1 °C can save about 6% of the electricity [33].

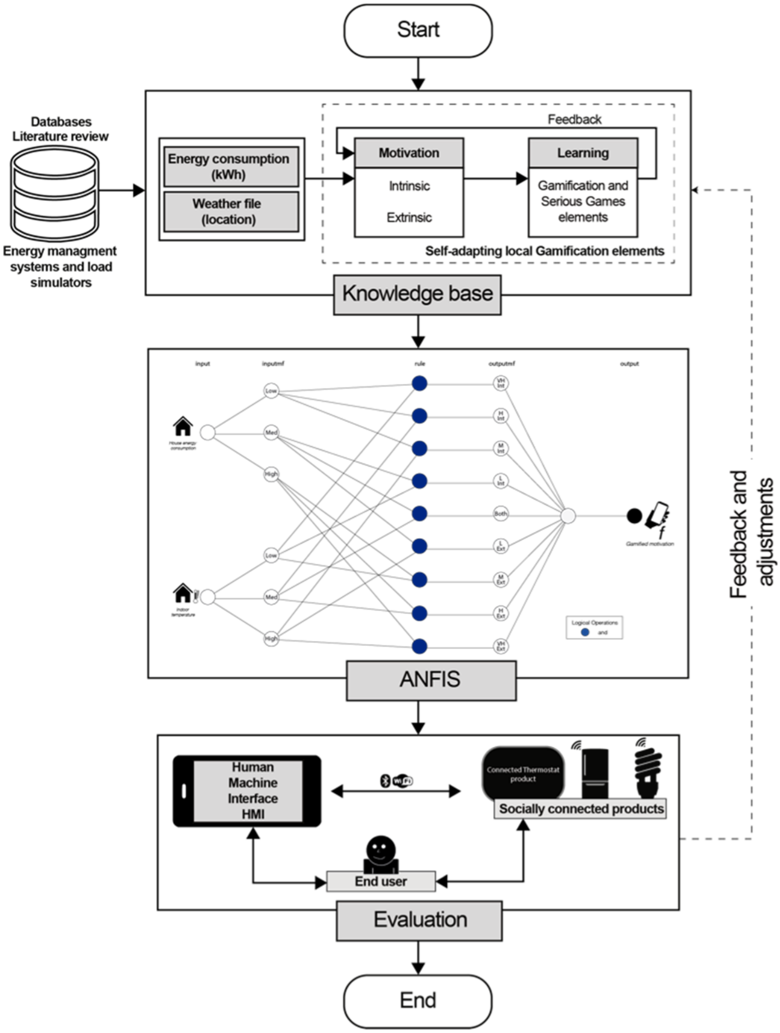

Fig. 1. Proposed framework.

The ANFIS decision system is proposed. There are two input variables, kWh and temperature, and gamified motivation is the output variable. Gamified motivation considers both the intrinsic and extrinsic motivations by following this premise:

- The home that consumes more energy with setpoints based on the outdoor temperature that requires setpoints below 21 °C, requires extrinsic motivation for outer recognition and external rewards. The home that consumes less energy with setpoints above 23 °C can be related to intrinsic motivation as the house uses less kWh than the other in similar conditions. This activity is rewarding on its own. On the other hand, the average home and setpoint below 23 °C and above 21 °C have both motivations. This

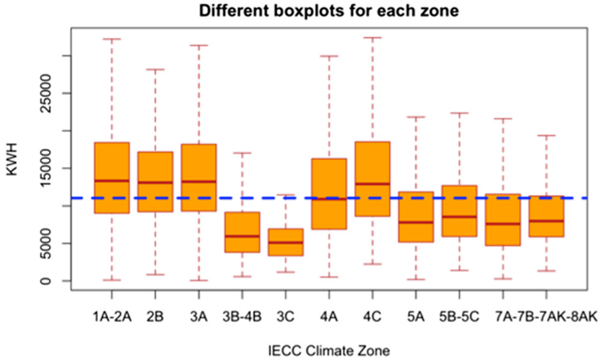

Fig. 2. Boxplots for each IECC Climate Zone and their site electricity usage in kWh.

Table 2. Main characteristics of the type of home and most common appliances in zone 3C

Home characteristics	Most common appliances
Floor area: 165.14 m^2 The average number of rooms: 3 The average number of windows: 34	Stove
Average site electricity usage: 5,864 kWh	Dryer
Average electricity cost: $1,605 USD	Lights (average of 40 CFL)
87% of the homes were built before 1989	Dishwasher
Single-family detached house	Refrigerator
Three household members	Washing machine
Three weekdays someone is at home	Air conditioner and programmable central thermostat

type of home may be motivated by external recognition or autonomy, competence, and relatedness elements.

The ANFIS simulation was done using the Neuro-Fuzzy Designer of the MATLAB toolbox.

Table 3. Characteristics of the household appliances and photovoltaic generation

Household appliances and PV generation	Energy Star	Case 1	Case 2	Case 3
Stove: - General Electric - Size: Two burners of 8” and two of 6” -Morning usage: 7 a.m., 40 min -Noon usage: 2 p.m., 60 min -Night usage: 8:30 p.m., 30 min		x		x
Dryer: - Loads per day: 1 - Minutes of load: 50	x	x	x	x
Lights: - Power (incandescent): 100 W - Power (CFL): 9 W		x		x
Dishwasher: - Miele G 6935 SCi - Number of loads per day: 1 - Minutes of the load: 50	x	x	x	x
Refrigerator: - Blomberg BRFB1045WH - Power: 32.6 W - Dimensions (m): 0.316 * 0.6 * 1.72	x	x	x	x
Washing machine: - LG WM9500H*A - Capacity: 5.8 cu. ft - Annual Energy Consumption: 120 kWh - Number of loads per day: 1 - Minutes of load: 30 - Water temperature: warm	x	x	x	x
Air conditioner: - Capacity: 9000 BTU - Energy Efficiency Ratio: 10		x		x
Photovoltaic Generation				x
Type of home				
Single-family detached house Area: 165.138 m^2 Number of rooms: 3 Size of each room: 7.42 m by 7.42 m Height: 2.75 m Numbers of windows: 34 Height of a window: 0.91 m Thermostat setpoint: 23 °C				

4 Results

Table 4 summarizes the energy (kWh) and cost ($) for the three cases. Case 1 consumed more Energy during Off-peak periods than the other peak loads, whereas Case 2 consumed more Energy during Mid-peak periods. Case 3 reflected the reduction of energy and costs due to the photovoltaic generation. 87.6% of the energy consumption came from the household appliances that consumed more than 3 kWh.

4.1 ANFIS

The result of the SRLS indicates that the home was consuming a significant amount of kWh and above the zone 3C. The ANFIS system suggested that this home required, for

Table 4. Results of each case.

	Case 1		Case 2		Case 3	
	Energy (kWh)	Cost ($)	Energy (kWh)	Cost ($)	Energy (kWh)	Cost ($)
Off-peak	18.34	4.83	1.86	0.49	18.12	4.77
Mid-peak	11.99	3.62	2.84	0.86	9.4	2.84
On peak	9.18	3	0.2	0.06	6.19	2.02
Total (day)	**39.51**	**11.45**	**4.9**	**1.41**	**33.71**	**9.63**

this specific day, an interface with very high extrinsic motivations. Figure 3 shows the ANFIS structure including, in the output, the type of gamified motivation to illustrate better which gamification elements should appear in the gamified interface. Figure 4 displays the Rule viewer, editor, membership function, and surface viewer. Table 5 displays the fuzzy rules for the ANFIS.

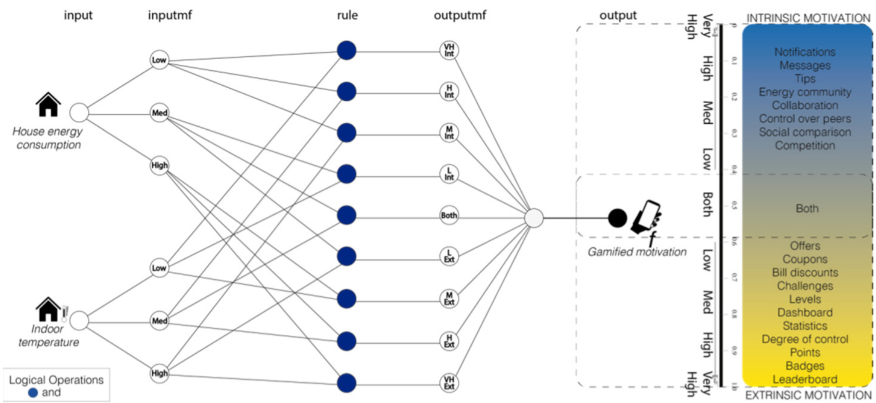

Fig. 3. Proposed ANFIS structure.

Figure 5 shows the HMI for a type of user with a home with high energy consumption and a medium indoor temperature setpoint. An option to reduce energy consumption is by increasing 1 °C, so a 6% of saving can be achieved. Besides, a PV system is included in the section of “My socially connected products” to generate interest to the user and see what is needed to install a PV system. As this type of user requires Very High extrinsic motivations, gamification elements, such as competitions and degree of control elements, are displayed. The degree of control appears as a comparison to others or the weekly savings in electricity and money.

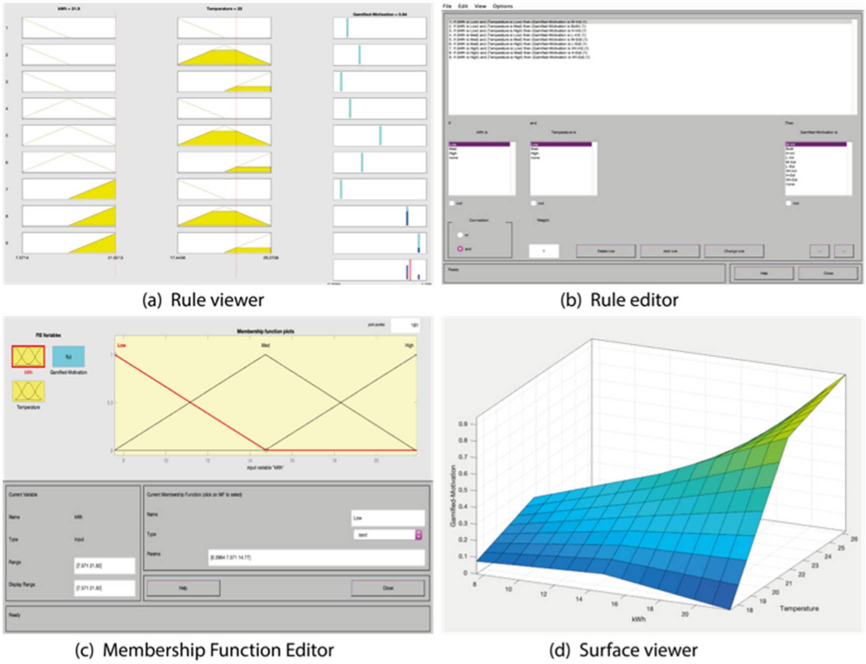

Fig. 4. ANFIS results. (a) Rule viewer, (b) Rule editor, (c) Membership Function Editor, and (d) Surface viewer.

Table 5. Fuzzy logic inference rules.

IF		Then
kWh	Temperature	Gamified motivation
Low	Low	Medium Intrinsic
Low	Med	Both
Low	High	High Intrinsic
Med	Low	Low Intrinsic
Med	Med	Medium Extrinsic
Med	High	Low Extrinsic
High	Low	Very High Intrinsic
High	Med	High Extrinsic
High	High	Very High Extrinsic

5 Discussion

The SRLS has limitations in terms of simulating monthly energy consumption; this is probably because this energy management system is designed to be analyzed daily. Moreover, it is impossible to modify the Peak time hour, affecting the total energy consumption in terms of their electricity cost. However, this simulation gives a comprehensive insight into the home and the behavior patterns of the home.

Using this ANFIS system, it is possible to provide the characteristics required to propose a gamified application in terms of motivation. Moreover, ANFIS considers the UTCI values to provide thermal comfort.

(a) Version for mobile phones.

(b) Version for tablets.

Fig. 5. Smart Home interface for a type of home with High energy consumption and Med indoor temperature setpoint.

As the proposal is based on the home, this preliminary analysis shows how it turns into a social product. With this system, it is possible to register and analyze the home's behavior.

The RECS survey demonstrated that the IECC Climate Zone 3C is the zone with low electricity usage compared to the other 10 zones. This low energy demand is due to California, since 1978, proposing the Title 24 to promote efficient buildings and energy codes that reduce consumption in the household. Another fact is that California is one of the states where electricity costs more than the average of the U.S. Besides, that region has a mild climate, and it is not as humid compared to other regions in the country.

Although Fig. 5 displays a mock-up of a gamified application for smart homes and provides tips and messages about increasing the degrees of setpoints, the analysis of thermal comfort must be performed. Further, this interface can be personalized by analyzing the type of user. In previous research, [8], an adaptation for the Octalysis framework was proposed. This adaptation includes the game design elements in [34], the Hexad gamified user, role player, energy end-user segment, and target group.

6 Conclusion

This paper proposed a three-step framework that integrates an energy management simulator, ANFIS, and gamification structure to propose an interface designed to reduce energy consumption without losing thermal comfort.

This knowledge base step analyzes the RECS database to determine the type of home, Climate Zone, energy consumption, and most common household appliances. Based on that, a one-day simulation was performed with the SRLS toolbox. Three cases were analyzed to determine the reduction of energy by adopting renewable sources. 87.6% of the energy consumption in the case belonged to the stove, lights, and air conditioner; by adopting renewable sources such as photovoltaics, a 14.68% energy reduction was achieved. The ANFIS step provides insight into the gamified motivation and the game elements for the interface that the end-user requires to reduce energy consumption. The last step displays the proposed interface based on the ANFIS suggestions, receive feedback from the users and, if it is required, the interface is adjusted to display other intrinsic or extrinsic gamification elements.

Table 5 and Fig. 3 give outcomes regarding which type of gamification structure to use depending on the level of energy consumption and setpoint. However, to improve this gamification structure, it is relevant to monthly simulate the energy consumption so accurate gamified motivations can be tackled. For instance, the end-user may be motivated more by intrinsic elements and other days more in an extrinsic manner.

This framework helps the designer propose interfaces based on data analysis from the thermostat, climate, and electrical consumption. Another relevant aspect of the ANFIS is that depending on the level of consumption and setpoint, it gives insights regarding which type of motivation is needed to propose accurate interfaces that pro-mote energy reduction or energy awareness.

With this proposal, it is intended to profile and know the type of home better to propose an accurate application that promotes energy reduction and improves quality of life without affecting how residents interact in the home. This HMI provides the opportunity to create an atmosphere where end-users can interact with their smart homes in productive and empowering ways.

7 Future Work

We plan to conduct an online survey in Mexico to review any association between a gamified interface and its personality traits. We also plan to consider augmented AI to better understand users to fully leverage them instead of relying on conventional AI that only automates processes.

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