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Net Zero Transformation of Buildings with Gamification and Sustainability Performance Monitoring System

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Abstract

Today's digitally hyperconnected world, inching closer to mid-century climate-concern goals, is engaged in accomplishing sustainability targets. Industry and infrastructure have become as central to climate action as they have traditionally been to economic growth and social development. Commercial and public buildings in Smart cities contribute significantly to such progress. However, buildings also carry a negative impact on the environment and society, contributing through pollution, depletion of resources, carbon emissions, and high energy consumption. This paper describes the criticality of a sustainability performance information platform that brings together all the aspects of a sustainable building's social, economic, and environmental qualities through intelligent management and operations. The author extends his belief in multi-dimensional sustainability by emphasizing the importance of people-participation through behavioral change and persuasive design in clean building technology to bring about a change for good. This paper is an attempt at a framework that will lead to greater collaborative efforts towards more intelligent, sustainable cities with interoperable green buildings.

Keywords

Net zero buildings; Sustainable green buildings; Gamification for sustainability; Sustainability performance platform; Interoperability; Internet of Things

1. Introduction

Worldwide, environmental concerns have emerged to be among the most challenging issues of our times. The past decade has heard a clear global call for sustainability practices and climate change mitigation measures. Large cities have shifted towards creating greener and healthier spaces for their citizens. Businesses across various industries, housed in gigantic urban structures, have acknowledged the fact that they are prime influential agents of environmental, social, and economic change in the world. Investors, and even governments, have realized the urgency of expanding the spotlight from mere monetary profits to greater environmental and community impact. Business responsibility towards the environment, building a green image (Alam & Islam, 2021), and net zero transitions have become major subjects of study among business scholars across the world.

1.1. Net zero and sustainability

The dire state of global warming, compounded by net zero transitions and the 2015 Paris Climate Accords, have prodded industries worldwide towards greater climate-conscious behavior. Global energy consumption and carbon emissions being at their highest in history, the built environment that industries and organizations operate from constitutes a large slice of the perilous pie.

In the United States alone, 73 percent of the national energy consumption is attributed to buildings (Giva Inc., 2016). 37 percent of the global carbon emissions come from the built environment (UNEP, 2021). In fact, commercial and public built spaces consume between ten and 12 times more energy than residential structures (Saidur, 2009). Studies indicate that energy usage by buildings is set to rise a worrying 32 percent in the next 15 years (US EIA, 2017), if the current global consumption trends are any indication. The upending statistics have led to a frantic race to net zero.

In the context of buildings, net zero is achieved when a building produces enough renewable energy by itself from its own building footprint and matches its consumption of heat, power, water, and other utility resources. This equalizes the total energy load consumed by the structure (Chong & Yeoh, 2021). A fifth of businesses across the world have already committed to net zero targets (Martella, 2022) to reduce carbon emissions and dependence on fossil fuels.

Part led by a sense of responsibility to the planet and part encouraged by building energy certification programs, more and more commercial and public building owners are making sustainability an indispensable part of their built environment and operations. While energy certifications such as the Leadership in Energy and Environmental Design (LEED) and Building Research Establishment Environmental Assessment Method (BREAM) encourage greener new buildings and retrofits, the need to tip efforts towards operational net zero in buildings is crucial. In other words, while green fit-outs to conserve energy could well lay the foundation for sustainability initiatives, a thriving transformation comes from motivating behavioral change. Figure 1 lists the contributors to net zero sustainable buildings.

1.2. Gamification and sustainability performance monitoring

The United Nations' Sustainable Development Goals (SDGs) and the World Green Building Council provide guidelines to make informed choices with sustainability practices in buildings. Organizations are also recognizing the multi-fold benefits of integrating green concerns with their corporate social responsibility (Alam & Islam, 2021), which include a positive brand image (Fraj-Andrés et al., 2008) and an enhanced green competitive capacity (Ambec & Lanoie, 2008). But reversing climate change is as much an individual responsibility as it is of corporations and governments. Along with sustainability measures initiated by larger governing bodies, the green culture needs to be fostered at an individual level. Collectively classified as the attitudinal aspects, norms, and values related to the environment (Ogiemwonyi et al., 2020), a marked improvement in sustainability-driven inventiveness comes from the shared responsibility demonstrated by individual building occupants.

To achieve lasting behavioral change among building occupants requires a strong drive. It is essential that occupants understand the significance of sustainability goals and their impact on the larger environment (Krath, 2021). Game mechanics and game-based initiatives coupled with incentivization play a dominant motivational role (Donato & Link, 2013) in an organization's sustainability strategies. Additionally, measuring the impact occupants have on the built environment and their contribution in overall energy savings, using an intelligent energy management and performance measurement platform, creates a more energy-sustainable building (Ferreira et al., 2018).

Fig 1. Main contributors to net zero sustainable buildings. Image by author.

The present paper endeavors to focus on the importance of persuasive communication through gamification in steering the behavioral patterns of building occupants towards sustainability practices for greater green responsibility. Section 2 analyzes various studies in the past that have focused on gamification in the built environment towards achieving sustainability goals. Sections 3 and 4 spotlight the significance of measuring the impact from gamification practices via a centralized sustainability performance measurement system. Harnessing data collected from various sensors and the Internet of Things (IoT) devices, the interoperable framework brings together energy usage information from building operations and individual consumption to offer relevant insights. While the crux of the net zero transformation in Smart sustainable buildings lies with advanced intelligent technologies and renewable resources, a large part of the onus rests with individuals and their intransigent habits. Section 5 discusses how a change in consumer behavior, along with informed choices and greater engagement, metamorphoses into long-term energy savings and net zero buildings. Section 6 summarizes the proposition of this paper.

2. Background and Literature Analysis

Commercial buildings and office spaces are among the top three consumers of energy (DBEIS, 2021) in the world. Scholars (Cheema et al., 2019; Joyce & Paquin, 2016) aptly note that it is no longer an option for businesses and large corporations to bring together the aspects of environment, society and economy, but a necessity. However, research (CCC, 2020) based on decades of carbon data shows that conserving energy and cutting carbon emissions in commercial and public built environments can be challenging, and organizations worldwide are trying hard to improve their sustainability performance (Williams et al., 2019; Aguilera et al., 2021).

The net zero realization and surge in climate concerns have driven a steep growth in clean technology and sustainability market trends. Valued at USD 10.32b in 2020, the market size is projected to reach USD 74.64b (Khan et al., 2021) in the next eight years. The interaction between businesses and their operating environments contributes significantly to this rising trend. Still, energy consumption and carbon reduction are not just about efficient and intelligent building design and structure. Energy-efficient structures that are rated high for sustainability at construction often lead to large scale energy and resource wastage (Bruno, 2022) during operations, if energy is not consumed responsibly. Integrating user involvement in the overall sustainability plan in a commercial building is be a long-term, reliable solution for sustainable growth and resilience (Alam & Islam, 2021), while also triggering a radical change in the management philosophy of businesses operating from the green structures.

Occupant engagement, in the form of persuasive communication and gamification, holds promise in influencing behavior towards sustainability (Pasini et al., 2017). Gamification involves the application of game mechanics to engage participants in an otherwise non-game context (Zichermann, 2011). In the context of sustainability, its strategies enable occupants to modify their social and consumption patterns through cooperation, competitive spirit, rewards, and awareness about the environment and climate concerns (Avila et al., 2021). Extant research (Wanick & Bui, 2019; Celestine & Yeo, 2020) has examined the positive effect of gamification on increasing employee engagement and motivation at work. With regard to gamification and sustainability, scholars have variously studied its effect on conserving energy in residential premises (Fraternali & Gonzalez, 2019; Launonen et al., 2019) as well as within office spaces (Fraternali et al., 2018; Iria et al., 2020). However, most research has been limited in scope, in that it has not considered the combined aspects of net zero transformations, occupant engagement, clean technology, and sustainability.

A positive step in the direction of examining the subject holistically are studies that attempt to ascertain the influences and best practices of gamification for sustainability. Such research stems from findings that green building design alone does not address sustainability concerns (Patlakas et al., 2015), and that inadequate building performance, unrealistic assumptions of user behavior, and a dearth of incentives and motivation to conform to design assumptions could lead to a mismatch in the intended use and real use of the sustainable building (Gill et al, 2010; Silva & Ghisi, 2014). More often than not, the mismatch renders the efforts of building design redundant. This highlights the need for continual monitoring of sustainable energy performance in buildings to validate the predicted energy performance (Patlakas et al.).

Specifically, commercial and public buildings offer more challenges in aligning energy consumption per predicted design, mainly due to the lack of occupant motivation and individual accountability (Papaioannou et al., 2017). Specific research on gamification techniques employed to conserve energy in office buildings (Simon et al., 2012; García et al., 2017) have demonstrated the effectiveness of the game-based approach. In fact, the American Council for an Energy Efficient Economy (ACEEE), through its research on more than 50 gamification programs and over 20 case studies meant to influence behavior around energy-efficiency reported three to six percent energy savings in large participant settings and well over 10 percent savings in narrow targeted gamified sustainability programs (Grossberg et al., 2015).

Additionally, research has proved that continual real time monitoring and correlational measurement of energy usage by both occupants and building operations help with operational cost savings while benefitting the environment (Wilson, 2016). With this objective, easy-to-access, user-friendly, and innovative gamified IoT applications that motivate occupants (Fraternali et al., 2018), either individually or collaboratively, are required to make energy saving a habit. Studies have demonstrated that the adoption of occupant-centric building operations and services lead to operational efficacy of the "cyber-physical systems" (Konstantakopoulos et al., 2019) that are specifically aimed at conserving building energy. Together with a sustainability performance measurement platform, the system will support occupant-based energy data visualization along with operational energy consumption data from the building to offer context-specific adaptive suggestions for sustainability aimed at a net zero transformation.

3. Sustainability Performance in the Built Environment

With evolving climate change, there is a parallel evolution in the field of sustainable building design, with scholars in the field (Todd & Fowler, 2016) thinking about the actual performance of buildings that are considered green and sustainable. Sustainable green building projects, the world over, are in the quest to clearly define the right kind of data required to make an effective assessment.

The Whole Building Design Guide puts forth building operations and maintenance practices (WBDG, 2021) for a sustainable building including testing sensor control points for efficacy, using automated monitoring and operational controls wherever possible, performing energy wastage audits, and updating IoT systems for better data inputs and higher efficiency. Global developmental agencies (World Bank, 2021) even propose that the commercial built environment be governed by a regulatory compliance framework that increases sustainability performance through socio-economic, environmental, and management standards, providing benchmarks and best practices for data availability and technological maturity.

However, mere compliance will not sustain green efforts towards net zero. As several studies summarize, the most effective way to realize net zero targets is to build upon innovations and behavioral changes (Petit et al., 2021). What has been termed the 'Fourth Wave of Environmentalism' (EDF, 2019) includes technological innovations, such as Artificial Intelligence (AI), IoT, interoperability, sensor technology, and data analytics, which empower organizations to lower their energy consumption, reduce carbon emissions and waste, and increase resilient sustainability. Described as the "potential for technological innovation to supercharge and scale companies' sustainability efforts," the Fourth Wave provides a boost to the economy and the net zero journey.

3.1. Data and Enterprise Energy Management System

Studies have widely acknowledged that immediate access to real-time data significantly helps understand and improve operational energy efficiency in the built environment (Motegi et al., 2020), optimizing its sustainability performance throughout its lifecycle. Research findings recognize data analytics as having the highest potential impact on sustainability performance at 35 percent (EDF, 2019), compared to other clean technology. The Enterprise Energy Management System (EEMS) within a Smart built environment helps with securing data for predictive and preventive analytics, as it goes through continual data monitoring and measuring cycles.

The EEMS in commercial building uses data from IoT-based sensors and devices to gain deeper insights into the energy consumption pattern of the building and its occupants. An EEMS is a combination of data-gathering devices and an AI-based communication system that collects, analyzes, and displays building energy consumption information (Motegi et al., 2020) on a dashboard. It is intended to identify opportunities to increase the energy efficiency of a commercial building and take action to reduce operational costs. Integrated with the Building Management System (BMS) that monitors and controls the building's energy needs, the interoperability of the EEMS enables energy benchmarking within an enterprise or commercial building, optimizing consumption by harnessing dynamic data, and managing the overall costs.

The BMS is the intelligent, automated control hub of the built space. The BMS encompasses the ability to monitor and control a building's operational components. Being extremely adaptable with a wide-ranging implementation stack, it manages and regulates power, lights, water supply, solar thermal units, heating, ventilation, and air-conditioning (HVAC), and all other building operations. The EEMS, on the other hand, provides a holistic view of the data from all the systems, integrating them onto a single platform or dashboard for quicker diagnostics through both data integration as well as disaggregation. Figure 2 depicts the sustainability platform in an intelligent, interoperable building.

IoT forms the primary energy-tracker, leveraging low-cost devices such as Near-field Communication (NFC), Bluetooth Low Energy (BLE), indoor sensors, Intelligent Video Analytics (IVA) cameras, and other Smart technologies installed in a sustainable building. While employees or occupants are connected to each other and to the IoT gateway through sensors and mobile devices, including Smart phones or wearables, their actions are either auto- recorded or tracked through employee inputs, adding to valuable data. The wireless sensors and network-connected devices gather data from the environment to gauge the lighting, water usage, temperature, humidity, and ventilation conditions, sending it to the BMS. Data from wearables and mobile devices, collected in the form of game actions or recorded through other energy-saving apps, are collated by the backend engines, such as the games analyzer, occupancy calculator, or the energy calculator, to be shared and displayed via the EEMS dashboard.

The EEMS data is an amalgamation of employee inputs and sensor data picked from various installations across the built environment via the IoT gateway and the BMS. It is a centralized tool that merges and displays information on energy consumption, electricity supply and demand, indoor ventilation and thermal comfort, outdoor conditions, as well as occupant preferences and consumption patterns for optimal decision-making on energy conservation (Elmouatamid et al., 2020). It also forms the output for game mechanics when gamification is integrated into the building's sustainability strategy.

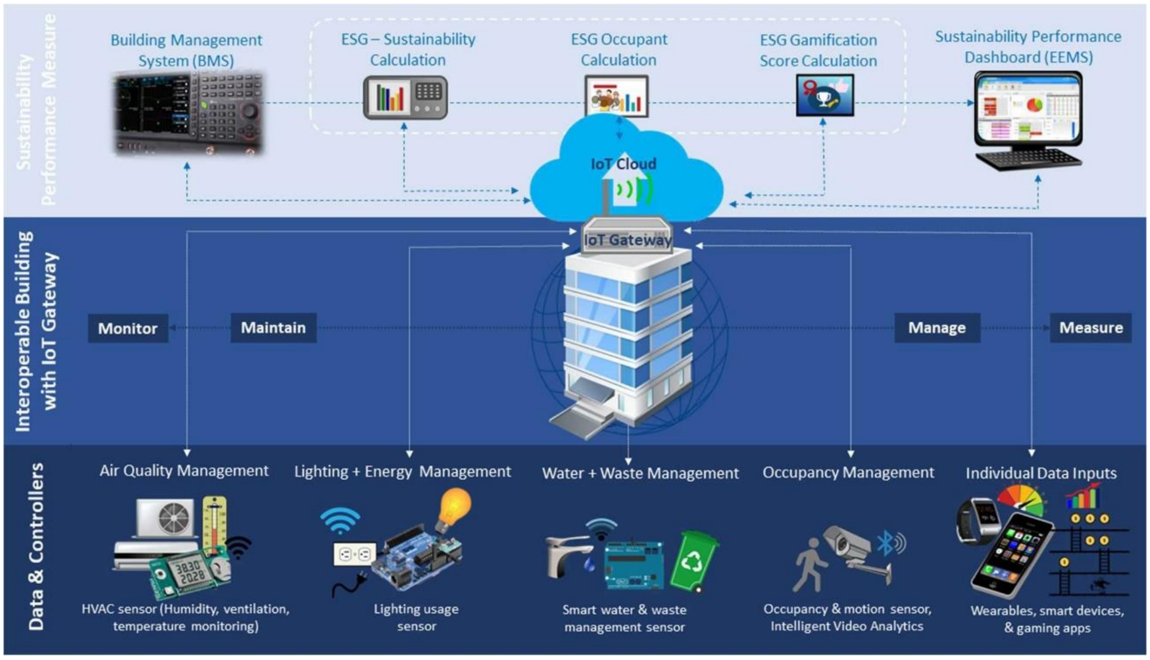

Fig 2. The main components of the sustainability platform in an intelligent, commercial building. Image by author.

4. Gamification for Sustainability-Led Occupant Behavior

Characteristically motivating and engaging, gamification captures participant attention and keeps interest levels high, mainly because there is a reward at the end. Gamification prompts occupants to use game-like techniques in the real world, pushing them beyond their routine activities or work scope, while also educating them with relevant information and improving their skills (Albertarelli et al., 2018). Extended to energy conservation in commercial buildings, gamification will encourage employees to compete and cultivate new energy-saving habits while positively influencing their outlook on carbon control.

Challenges, social sharing of progress and results, vying to achieve individual and shared goals, rewards and incentives, tips and knowledge sharing, scores and ranks, avatars and badges, all reflected on leaderboards, add to the excitement of gamification. In the context of commercial sustainable buildings, game mechanics promote environmental awareness, and occupant engagement (AlSkaif et al., 2018). Leveraging these elements of engagement, time, and enjoyment to drive human behavioral response to stimulus, gamification in built spaces could be one of the main solutions to sustainability concerns. The game mechanics considerations in a sustainability setting aimed at behavioral change are listed in Figure 3.

4.1. IoT-enabled gamification

The convergence of IoT with gamification elicits greater interactive participation and engagement. IoT provides wider scope of data collection from not only occupant inputs but also sensory inputs from across the building, making for richer data, immersive experiences, and enhanced context awareness (Xiao et al., 2021). Participants demonstrate longer commitment-to-cause, motivated by multisensory feedback and game-related enjoyment.

IoT-enabled gamification affords effective reward for energy-saving action, being characterized by social collaboration, novelty, peer comparisons, and feedback. Its incorporation at various levels—individual occupants, teams, floors, or entire buildings—curbs demand while exercising greater energy control through comparison and competition.

Gamification in the built environment need not be complex. Simple mobile applications also translate into perceptible returns when the set targets are converted into measurable outcomes. Recent research (Oppong-Tawiah et al., 2020) shows that simple IoT-based apps engage employees while tracking their electricity usage from computer-related equipment at their workplace.

Fig 3. Considerations of sustainability game mechanics for behavioral change. Image by author.

The author conceptualizes IoT-enabled energy-efficiency gamification in a commercial building to comprise an Environmental-Social-Governance (ESG) super-app ecosystem. Within the gamut of the umbrella app will be embedded a complex blend of several standalone micro-apps that seamlessly integrate themselves into a single interface for an efficient user experience. The micro-apps help monitor and record each sustainability aspect in the built environment, from electricity usage to water and waste management.

Micro-apps will also be extended to include external influences, including the occupants' preferred mode of commute to work. The game logic behind each micro-app could be hosted by the ESG super-app. Each micro-app has its own interface, tasks to be accomplished, and score design. They could be in the form of physical accomplishment of real-world tasks, virtual earnings from learnings and knowledge sharing, or, in more advanced applications, lifelogging via the metaverse (Park & Kim, 2022) because studies have shown immersive experiences to have better behavioral outcomes in sustainability-driven experiments. Simply put, each micro-app encourages achieving a particular target. It also provides participants with the route to achieving the target set in the app, while triggering alerts related to it. When the target set against a specific micro-app is achieved, it leads to individual scores, badges, and incentives.

While constantly communicating with the micro-apps via API (Pereira, 2019), the super-app provides a consolidated leaderboard with overall winning trends, using target achievement data from each micro-app. It is important that the intelligence behind the game mechanics and score design be explainable and interpretable. With gamification involving human behavior evaluation at scale, explainable AI (Fulton et al., 2020) in the super-app ecosystem plays a critical role in not only ensuring fairness in score design but also in the evolution of the dynamics of game mechanics.

The micro-apps integrated into the super-app network bring together data from individuals' devices as well as sensors, IoT controllers, and sustainability performance engines to build a 360°view of sustainability practices via the EEMS. This intelligent ecosystem assists in energy disaggregation, providing data on energy consumption and wastage at equipment/device, floor, department, and individual levels. This is particularly significant in measuring sustainability performance in the building as well as in calculating game scores based on individual performance. Figure 4 is a representative depiction of a possible super-app with sample micro-apps within its network.

Fig 4. Representative depiction of an ESG super-app with its micro-apps in a gamified network. Image by author.

4.2. IoT and data disaggregation

Smart sustainable buildings are fitted with power meters on circuits whose data needs to be captured. These could be circuits of devices that control lighting, HVAC, computers, and other equipment used for employee utility and comfort within workspaces. They could also be water meters, automated waste disposal systems, or utility devices such as printers and even elevators. The readings from these meters are sent to the central database backed by cloud services. Similarly, BLE technology is used to detect occupants in an area, their proximity to each other as well as to other connected devices (Papaioannou et al., 2018). NFC with Radio

Frequency Identification (RFID) is used to label and identify switches, electric points, and other device controllers. Occupants will then use their personal devices to swipe the NFC tags to record who is using which equipment, and for how long. All the data from various sources are recorded through the micro-apps and centrally integrated within the ESG super-app to be disaggregated. This disaggregation helps understand exact energy usage at both the individual level as well as equipment level. It could be applied to departmental, team, or floor levels as well. Data disaggregation not only helps understand which equipment is in highest use and grosses the steepest energy costs but also which individuals are motivated to engage in more sustainable practices.

The disaggregated data is then used with the super-app platform that sends notifications to occupants about their energy consumption behaviors. The notifications could be in the form of alerts when individual consumption is high or comparative insights about the energy-saving behaviors of other employees, teams, departments, or floors. It could also be nudges or reminders about actions to be taken, such as turning off a power control, or energy-saving tips to get ahead of competition while also gradually helping to steer towards healthy energy habits. All these shared best practices from the super-app will contribute to a positive change in behavior around occupants' sustainability-led habits through competitive motivation. Figure 5 uses an example to illustrate the role of IoT in gamification and sustainability performance measurement in sustainable buildings.

4.3. Gamification score design in sustainable buildings

Score design is the analysis, distribution and management of game data to measure the target outcome. A robust score design directs occupants through the most logical next steps in the energy game, and influence the desired behavioral change.

Broadly, all data is classified as either interaction data, recorded through interaction between the various components on the IoT and AI network, and sensory data, recorded from activities of the occupants in the real world (Albertarelli et al., 2018). The comprehensive IoT-enabled gamification framework is a consolidation of technical data and behavioral data. Data from the BMS is technical, captured by sensors and controllers, and includes components such as the smart metering system, the web or mobile applications, network and software that monitor and control both energy usage as well as occupant intervention. Data from the other engines are largely environmental and behavioral, and could be from the ESG games analyzer, the ESG occupancy calculator and the ESG – sustainability calculator, and include behavioral inputs, occupant connections, performance status, rewards, progress, and points.

Fig 5. An example of IoT in gamification for sustainability performance measurement. Image by author.

The consolidated data is analyzed to create profiles at various levels: individual occupants, team or department, floor, or the entire building. Scores are generated based on these profiles, using both IoT data as well as individual behavioral inputs. The scores based on behavioral data are verified against the IoT data, and weightage is assigned to individual, zonal, floor-wise, and occupancy-level energy savings. The game scores act as a feedback mechanism, with score-related trigger tips, to both alleviate the lack of knowledge on energy saving and share information on its impact. Such feedback, along with incentives (Papaioannou et al., 2018), offers the much-needed drive to save more.

The criteria for score design include deciding the activity and its corresponding target that needs to be scored (Simon et al., 2015). For example, turning off the lights after a meeting will help achieve the carbon-control and energy- saving targets. Some activities may require self-rating or occupant inputs while others depend completely on sensor and system data. In any case, it is important that participant targets coincide with targets set by the business to internalize and facilitate externally-promoted behavioral change (Nicholson, 2012).

Various criteria combined into a single consolidated score determines ranking and badges. Using weighted sum strategies to integrate different criteria, data from the micro-apps is combined with that from the BMS by embedding the goals of the building into the individual's context (Simon et al., 2015). The scores will have different scale levels, such as nominal, ordinal, interval or ratios (Michell, 2002) and will help build on badges earned in earlier micro-apps. For instance, a reward or badge earned for using an energy-efficient mode of commute to work will be turned into a nominal scale for reducing carbon emissions as well. Paying careful attention to score design is important to draw meaningful insights from the data and determine whether the desired behavioral change has been achieved.

Connected to the framework of measuring sustainability performance in buildings, gamification will, therefore, be used to control and channel behavior towards energy-efficiency. Data analytics from the performance framework helps identify which components of the framework need a greater impetus. Mapping each gamification component to a specific target (Avila et al., 2021) will contribute to better environmental and operational performance in buildings.

Figure 6 summarizes examples of gamification techniques employed in sustainable buildings.

Fig 6. Examples of real world IoT-enabled gamification models. Sources: Iria et al. (2020); Dankov (2021); García et al. 2017); Papaioannou et al. (2017). Image by author.

5. Discussion and Future Research

The element of chunking sustainability objectives into smaller games or tasks help make gamification an effective tool in individual or team settings. Additionally, the advantages provided by sensors to monitor performance, analyze the data collected, and determine the level of participant engagement (Méndez et al., 2021) make it the ideal fit for sustainability performance measurement.

A stable sustainability performance measurement framework will result in reducing environmental footprint, endorsing cost-effective gains, promoting occupant collaboration, and enabling resilience while increasing competitiveness (World Bank, 2021) through gamification. Measuring sustainability performance and presenting data analytics and insights in an impactful way will enhance the significance of gamification, with game scores, badges, and rewards acting as the driving force.

This paper emphasized that gamification, when suitably designed, will decrease energy consumption and increase motivation to positively change occupant attitudes towards sustainable habits. The BMS and EEMS, connected to a heterogenous set of IoT devices and sensors, accomplishes the main objectives of energy efficiency and occupant participation and comfort (Paris et al., 2019). Given the dynamic nature and complexity of the data collected from the sensors, and the game design based on the sustainability goals, the system requirements constantly evolve at runtime to ensure both energy efficiency in the building and continued occupant engagement in green behavior.

However, limitations cannot be dismissed. Gamification and sustainability performance measurement do not auto-render themselves into any standard or regulatory scheme. One of the main reasons is that designing gamification for sustainability in commercial and public buildings largely overlooks the personal and contextual characteristics of the occupants. While some studies show that gamification helps support achieving sustainability goals at large, they do not quite integrate seamlessly with daily work routines (Krath, 2021).

Future game and persuasive design would do well to infer from focus groups, surveys, and gathered data the exact nature of behavioral psychology to be applied to achieve desired targets. Examples of implementing gamification for sustainability at an individual level maybe measuring existing environmental knowledge of occupants to determine the level of engagement and acceptance of proposed game objectives. At an organizational level, it is critical that a clear, data-driven view of the pain-points and requirements with regard to energy savings and sustainable resource usage (Ferreira et al., 2018) be outlined. For impactful changes to effect, formal labeling and certifications, national and local regulations on sustainability and policy changes in environmental standards are in order.

Along with these changes, it is essential that studies over extended periods of time be conducted to determine whether the proposed gamified systems along with constant performance measurement modify behavior and drive expected results. Such research is required to also better understand the engagement stimuli and application scenarios that proffer the best outcome. The findings can be implemented in reaching out the gamification strategies from within commercial buildings to eco-industrial parks and to the community at large. Newer gamified applications should be experimented (Albertarelli et al., 2018) to keep the ball rolling towards net zero targets.

6. Conclusion

Initiatives that unburden the load of carbon footprint and transform buildings into green structures are not only about sustainability but also about resilience to adapt to the rapidly evolving climatic conditions. While renewable resources and clean technology in buildings will boost energy function and efficiency, building occupants play an oft- discounted, but crucial, role in lowering energy usage and carbon emissions within their built environment.

This paper highlighted the importance of gamification along with the need for sustainability performance measurement to transform energy-consumption behavior and reduce environmental footprint. Employing IoT-based sensors and low-cost devices to disaggregate data and determine energy consumption at individual, device, and organizational levels, gamification of behavioral change will target energy wastage and offer real-time feedback in the form of game scores, reminders, or notifications, prodding occupants to do better in comparison with their competing and motivated peers.

Along with IoT-enabled devices, there have been several solutions in new building design as well as in retrofits, to meet the carbon neutral and net zero commitments. But net zero is not just about big climate battles to be fought and won. While building design, management, and operations can do only so much as technology can afford, the onus to better energy management is also on occupants. It can start at an elementary level, with individual behavioral change, leading to an increased uptake at the organizational level and beyond. After all, "buildings don't use energy; people do" (Janda, 2011).

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