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Review

Gamification Approaches and Assessment Methodologies for Occupants' Energy Behavior Change in Buildings: A Systematic Review

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Abstract: With the trend of achieving both energy efficiency in buildings and occupants' comfort, gamification strategies have started to be developed and applied as incentive mechanisms to increase social interaction and facilitate human energy behavior transformation. In this article, 306 published papers are reviewed, and 21 studies are identified to determine the challenges and potential for the development of gamification strategies to improve building energy efficiency. Specifically, this work reviews the implementation techniques of gamification and methods to assess the impact of gamification mechanisms on human energy behavior changes. This analysis demonstrates that, firstly, the choice of an optimal gamification implementation method should be inherently attuned to the distinct characteristics of the building type and its occupants. Secondly, it is imperative to strike a judicious balance between extrinsic and intrinsic motivations, in which customization of gamification design elements are based on users' unique personality traits and preferences, to properly tailor gamification mechanisms. Thirdly, integrating a fusion of quantification of energy savings and qualitative interpretation of user behaviors to improve the energy efficiency in buildings is essential for a more holistic understanding of the impact of gamification on users' energy-related behavior change. The findings indicate that gamification techniques can enable the effective reduction of energy consumption in buildings.

Keywords: incentive mechanism; performance assessment method; building energy efficiency; energy consumption; user engagement; building information

Citation: Li, W.-T.; Iuorio, O.; Fang, H.; Mak, M.W.T. Gamification Approaches and Assessment Methodologies for Occupants' Energy Behavior Change in Buildings: A Systematic Review. *Buildings* **2024**, *14*, 1497. https://doi.org/10.3390/buildings14061497

Academic Editor: Paulo Santos

Received: 27 March 2024
Revised: 14 May 2024
Accepted: 15 May 2024
Published: 22 May 2024

1. Introduction

The cumulative energy consumption within the buildings sector has demonstrated an average annual increase of 1% over the preceding decade. As of 2022, the energy demand in the buildings sector constitutes approximately 30% of the global final energy consumption, with residential buildings accounting for 22% of this total [1]. The residential sector, serving as the primary energy consumer, allocates approximately 60% of the total final energy consumption for space heating, 25% for residential hot water and 11% for electricity across Europe and the United Kingdom [1,2].

1.1. Building Energy Solution and Human Disruption

Efforts toward improving energy efficiency extend beyond technical interventions aimed at minimizing energy requirements and optimizing buildings' energy-related performance. Buildings have the potential to act as smart systems that facilitate the transition towards a more sustainable energy use paradigm, in terms of heating, cooling, appliances and lighting. In the pursuit of sustainable-energy buildings, from an energy-efficient perspective, significant investments have already been made in the improvement of building envelope elements [3–5], automation and control [6–8], sensing infrastructures [9,10] for relevant data provision and total or partial exchange of energy sources [11–14]. However, human involvement has emerged as a significant factor contributing to energy overconsumption [15–17]. Overconsumption is often associated with unnecessary adjustments to temperature settings, inefficient use of lighting, or other energy-consuming behaviors, which underscore the development of sustainable building practices and are often ignored or not taken properly into account by stakeholders when designing high-performance energy efficient buildings.

Accordingly, human factors in buildings are considered the "dark side" of energy use. Instead, occupant energy-conservation behavior can play a pivotal role in achieving the required and foreseen building efficiency objectives. Therefore, it is imperative to redirect attention towards human-centric considerations. It is also essential to develop strategies that can ensure energy information is not only available to occupants, but also presented in a manner that encourages informed and energy-conscious decision-making among building users. At present, strategies designed to motivate occupants to actively engage in building energy-saving activities encompass eco-feedback, social interaction and gamification [18].

1.2. Gamification and Serious Games in Behavioral Transformation

In the domain of incentivizing occupants' behavior, gamification emerges as a considerable strategy. It involves the application of game-design elements into non-game environments to augment user engagement, motivation and behavioral transformation outcomes [19]. As gamification is a relatively new concept, which has started gaining more attention in the last decade for connecting, collaborating and interacting with consumers, educators and medical partners in areas of business market development [20], online learning [21,22] and medical treatment [23], but key theoretical understandings are still emerging.

Game thinking has been an ongoing trend within society and has gained attention from researchers developing "game-inspired design", "serious games" and "games". Comello et al. [24], for example, conducted a game-inspired infographic test in two formats (scorecard and progress bar), to demonstrate the effectiveness of game-inspired design to convey a behavioral goal against traditional displays (text-only and column bar). However, the game-inspired design lacked a serious purpose and failed to incorporate game elements that reward users and encourage sustained participation in the gamified process. Similarly, within the traditional gaming sphere, while game elements are present, the considerable absence of a serious purpose underscores a focus on entertainment, rather than meaningful objectives that facilitate the realization of the target outcomes.

Serious game instead leverages structured design mechanisms, including gamifying elements and gamifying principles, which constitute a pivotal requisite in motivating and engaging users towards achieving behavioral transformation. Marczewski [25] conceptualized the serious game as a system that has been developed with the purpose of training or conveying a message to a specific group of users; they are ideal for positive reinforcement and just-in-time learning, within a full-game environment. Nevertheless, serious games could be resource-intensive expensive, time-consuming and partially accessible to certain users and can be complex since they necessitate a complete gaming environment, which is not a prerequisite in the context of gamification.

As opposed to environments characterized by high demand and sophisticated system configurations, gamification exhibits a significant ability to be implemented across various platforms and devices, affording more flexibility in terms of different objectives, audiences and the context of the applications. This is attributable to its provision of streamlined and expeditious feedback mechanisms. The design of gamified systems, serving as catalysts for occupants' energy-related behavioral changes and intelligent building operation, represents a valuable potential addition to the building sector's pursuit toward sustainable energy utilization. Gamification offers several benefits, including promoted user engagement, facilitation of behavioral change, improved data communication, information visualization and motivation for energy saving, particularly in the context of energy-related high-performance buildings [26,27]. A limited body of research indicates that the integration of gamification into building automation equipped components, supported by accurate sensing and actuators, has the potential to reduce approximately 50% of the multiple energy consumption in public buildings caused by automated control system disruptions [28]. However, these efforts, grounded in theoretical constructs, deliver varying levels of success.

1.3. Previous Literature Studies

Most of the existing studies have established gamification as a promising tool for incentivizing pro-environmental behaviors and enhancing energy efficiency, predominantly focusing on two key areas: firstly, assessing the effectiveness of applied gamification strategies in influencing users' energy conservation behaviors [22,29,30], and secondly, categorizing various intervention strategies, including gamification, for their impact on users' energy behavior [18,31].

Concurrently, a growing body of literature supporting the gamification framework delves into the intricate dynamics between users and buildings, with the objective of predicting the energy behavior of users to facilitate optimized decision-making with the analysis of collected research data. Konstantakopoulos et al. [32] introduced a gamification framework for smart infrastructure, with the objective of motivating occupants to conscientiously consider personal energy usage, thereby fostering positive impacts on their environment. Furthermore, Franco [33] attempted to add a gamification strategy to formulate a multi-objective control strategy within Information and Communication Technologies (ICT) systems and valuable insights were gained regarding the delicate equilibrium between user comfort and energy efficiency in public buildings. Outside the development of smart building technologies, gamification has also recently gained significant attention as a method of producing attitude and behavior change. Within this context, Iria et al. [26] attempted to implement a gamification platform in an office building environment, however, the automation integration was not fully achieved, since the building energy management system (BEMS) deployed in the building did not have any control over the building's loads. Furthermore, Soares et al. [27] conducted a study that upgraded the BEMS to automatically control loads, independent of office users' actions. They introduced a feedback mechanism equipped with an ICT platform that seamlessly integrates building management and automation systems, resulting in a noteworthy 15.4% improvement in energy conservation contributions. Moreover, this platform efficiently optimizes energy generation and storage processes. These research studies show that the incorporation of gamification principles plays a pivotal role in enhancing user awareness and engagement, facilitated through automated and behavioral change actions.

Nonetheless, existing research exhibits a dearth of comprehensive understanding and analysis regarding methodologies for evaluating changes in human energy behaviors induced by gamification, whether at the individual or group level, spanning real-time, short-term and long-term scenarios. Furthermore, Wu et al. [34] acknowledged the prevailing trends, categories and techniques pertaining to the application of serious games within the context of energy consumption in building systems. This acknowledgment was made within the confines of a constrained literature review framework, adhering to predetermined criteria centered around the educational level of serious games concerning energy-related topics. Remarkably, no extant literature study or systematic review has approached this subject from a gamification perspective [32,35,36]. Thus, it becomes imperative to elucidate its current status and future developmental trends regarding gamification approaches and their impacts on the energy use and users' energy-related behaviors in buildings.

1.4. Scope, Research Questions and Novelty of This Systematic Review

Given the identified research gaps, this literature review endeavors to address two critical dimensions that pertain to the multifaceted intersection of gamification, building systems, and user energy-conservation behavior, thereby extending the scope of preceding literature reviews to address the following questions: 1. What efficacious implementation methods exist for the seamless integration of gamification into building systems to enhance operational efficiency and elevate user engagement? 2. What assessment methodologies can be deployed to measure the impact of gamification on users' energy behavior change?

The main objective of this study is to investigate the efficacious implementation of gamification and its associated assessment methods, in the context of promoting energy efficiency. This study focuses on various facets of gamification implementation, including exploring the foundational design elements and principles that contribute to its efficacy. It elucidates how tailored gamified strategies can address specific building types and accommodate personal user traits, considering the distinct challenges and opportunities presented in each context. Furthermore, this review systematically addresses the second research question, delving into both experimental and non-experimental perspectives on the assessment methodologies essential for quantitative and qualitative evaluation of gamification's impact on users' energy behavior change. The following four sections constitute the remaining part of the article: Section 2 gives an overview of gamification utilization in achieving energy efficiency in buildings and outlines the systematic review methodology; Section 3 presents the results and analysis of the review, along with the research question responses; a discussion of the study findings is set out in Section 4, and finally, Section 5 furnishes an overview summary of this article as a conclusion and offers insights into future research directions.

2. Materials and Methods

This study adopts a systematic review methodology, an approach for systematically identifying and synthesizing extant literature pertaining to a defined research topic. This method facilitates a rigorous analysis and evaluation of research findings by employing a predetermined search strategy with explicitly stated objectives and minimized bias [37]. By following Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), this review implemented a comprehensive and transparent search strategy, which involved identifying databases, screening records and applying clearly defined criteria for inclusion and exclusion. Each step was meticulously documented, especially bibliometric mapping and publication visualization, which were employed to identify weaknesses and trends in the literature and justify the need for stringent screening criteria to focus on the specific objectives of this review.

2.1. Searching Strategy

This study adhered to the systematic methodology delineated in the PRISMA statement [38]. A review protocol was devised, delineating criteria for article selection, search strategy, metadata extraction and data analysis procedures. Figure 1 presents an overview of the systematic literature review process followed in this study.

2.2. Data Collection

For the current study, the research articles were selected from the main databases, Web of Science, Scopus, ScienceDirect, SpringerLink and IEEE. The following keywords: "Gamification", "Users", "Energy Efficiency" and "Buildings" were used, and the following Boolean sentence was applied in databases to conduct a search for mapping an overview of gamification application in the building energy efficiency field (("gamification" OR "gamified") AND ("occupants" OR "users") AND ("energy saving" OR "energy efficiency") AND ("buildings")). A total of 1645 research articles were initially identified for bibliometric visualization. These studies were further limited to journal articles and review articles and further refined based on the inclusion of all keywords. Among the pool of

1603 refined research studies, 306 studies were selected as specifically relevant for this review's objectives.

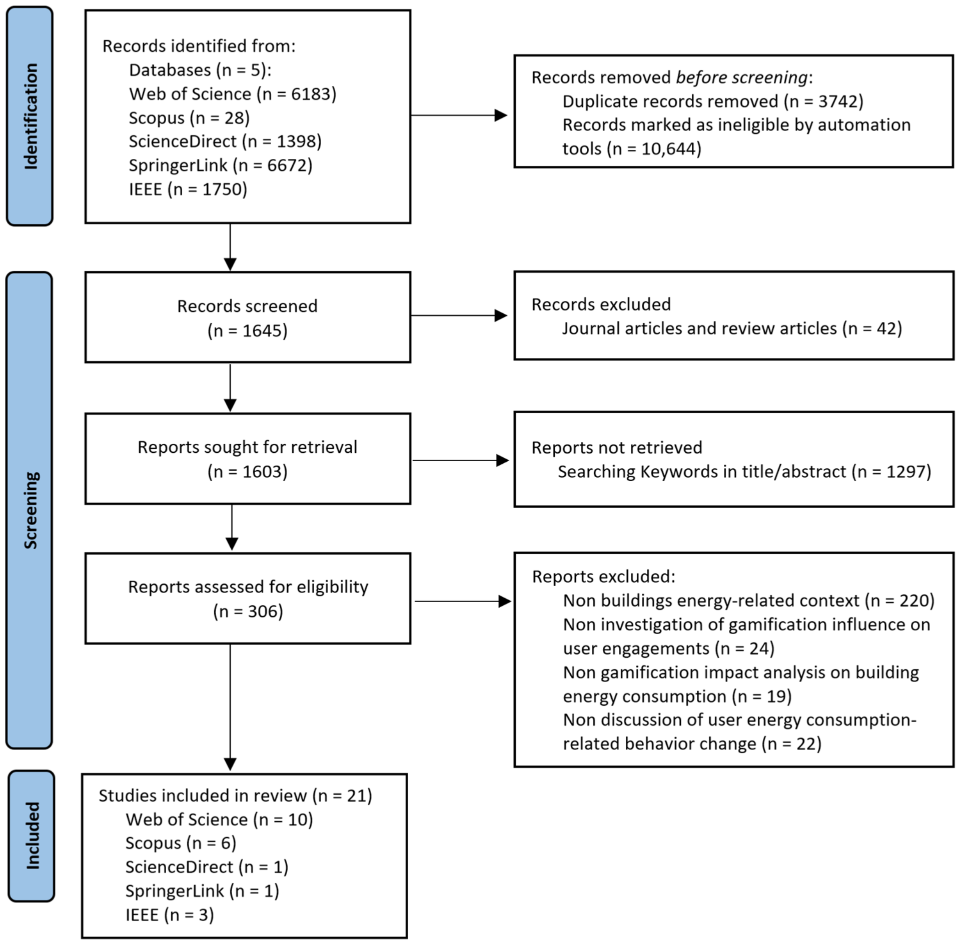

Figure 1. Systematic review literature selection process, PRISMA flow diagram.

2.3. Data Analysis

The research studies selected for the review were obtained based on the inclusion criteria, encompassing four facets: (1) studies containing gamification solutions to engage users into specific energy saving activities; (2) studies utilizing gamification strategies to support user experience or occupant comfort; (3) analyses addressing gamified systems motivating users toward energy consumption-related behavior change; (4) studies employing a gamification approach to building systems or components to facilitate interactions with users and collect user preference data. Excluded from this review analysis were research works that: (1) do not use gamification in building's context; (2) investigations on gamification in building systems solely presenting results, without analyzing user engagement; (3) studies that do not mention any effect of gamification strategy on energy consumption; (4) studies omitting the discussion of user energy consumption-related behavioral change processes; (5) studies that are not published in journals.

Prior to delving into the domain of gamification literature, bibliometric mapping was employed to facilitate the identification of prevalent themes, research trajectories and research gaps within the field of gamification, users and building systems, specifically from the standpoint of energy conservation. Initially, 1645 selected studies were characterized by commonalities in keyword co-occurrence and subsequently clustered into 4 thematic subjects: student (yellow), reality (green), app (red) and relationship (blue), these clusters enhanced the comprehension of the underlying research landscape. The 4 clusters displayed the density, pattern and connection of the network among the 826 detected keywords from selected research articles, as presented in Figure 2. This figure provides insights into the structure and dynamics of scholarly literature within gamification, building energy efficiency and occupant behavior domains.

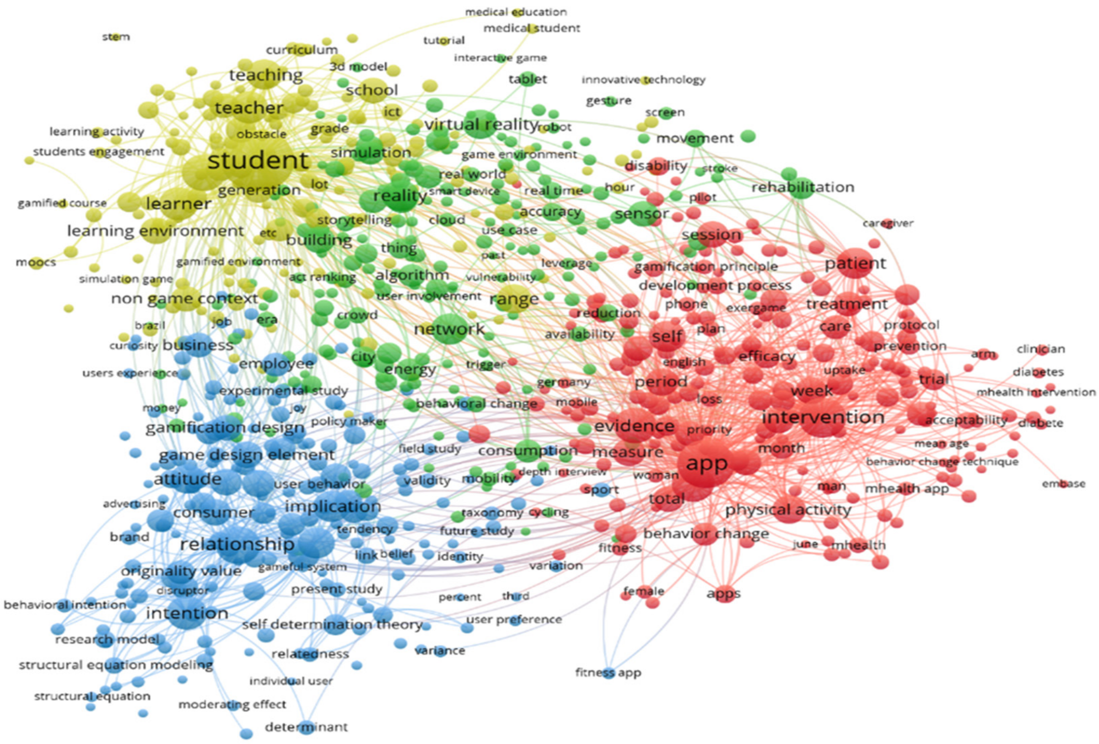

Figure 2. Overview of gamification research network in building energy efficiency.

Figure 2 shows that gamification has exhibited noticeable achievements in design methodologies, techniques and influence, with a limited emphasis on user typology or practical applications. Specially, the impact of gamification remains constrained by its association with a singular user group, primarily in the field of education, as evidenced by the prominence of the keywords related to teachers and students within the yellow cluster. The intersections between user and gamification design techniques require additional refining, from a practical viewpoint.

The search also shows that gamification has attracted increasing attention for research studies as an adaptive incentive mechanism to motivate users to participate in building energy efficiency only recently, with the first research article published in 2012. Figure 3 shows the growing trend since then, with almost 300 research studies focused on gamification and user behavior change in 2023. Among the published literature, 5 are review articles which focus on gamification applications and their impacts on human behaviors from 2016 to 2021 [18,22,29–31].

This overall selection process yielded a final set of 21 principal articles. The chosen studies, meeting all predefined inclusion and exclusion criteria, were found to address various perspectives outlined within the criteria, which have been classified into four categories: (1) gamification integration with different building platforms [26,27,37–42]; (2) gamified design elements [43–46]; (3) gamification solutions with different gamified mechanisms [32,47–50] and (4) various gamification techniques [33,51–53].

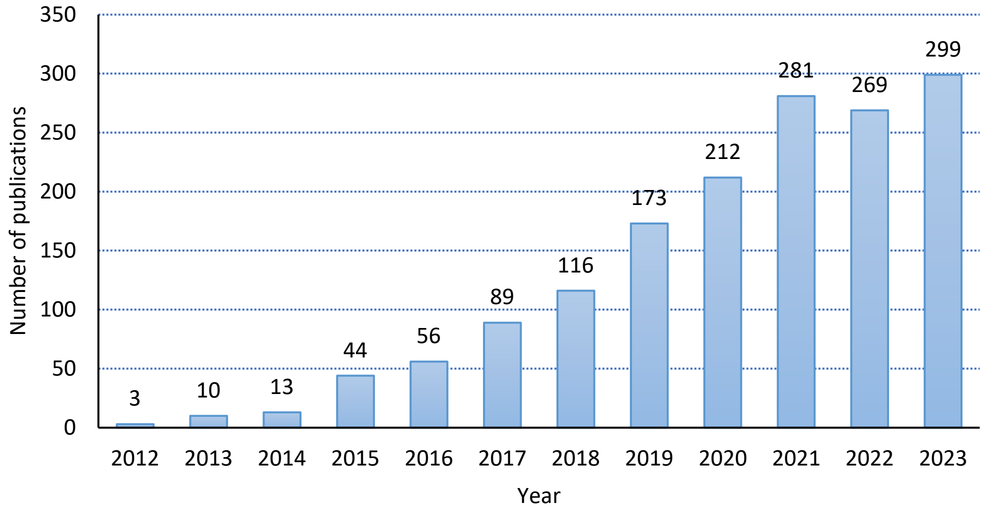

Figure 3. Publication volume over time on gamification and its effects on building energy efficiency.

3. Results

The selected articles were subjected to an extraction and analysis method that included 14 distinct data aspects that were systematically organized into tables (Figure A1). Particularly, data aspects related to building typology, gamification implementation methods and gamification design elements were explicitly used to answer the first research question. Meanwhile, data on the nature of the study (i.e., experimental, or non-experimental), the duration of the experiment, number of participants involved in the experiment, observed behavioral changes, and evaluation methodology used were employed to respond to the second research question.

3.1. Gamification Integration into Building Systems

The first research question seeks to identify effective methods for implementing gamification within building systems, with a specific focus on the energy efficiency of system operation and user satisfaction concerning their gamified experience and comfort aspects. Examination of this research question entails investigations into the independent factors of building features, gamified techniques, and implementation interfaces with suitable gamifying elements. Concurrently, consideration is given to dependent variables, notably gamification integration levels and pertinent human factors, inclusive of user identity and personal traits. With the building system serving as the object of implementation, the discourse is compartmentalized into three distinct perspectives: (1) variability across building types; (2) nuances in implementation techniques and operational features, and (3) insights into user engagement and experience design. This systematic approach aims to holistically address the multifaceted dimensions of gamification within building systems.

3.1.1. Gamification in Different Building Types

While gamification holds promise for promoting energy efficiency across various building sectors, its application needs to be tailored to the specific characteristics and challenges of each building category. In the selected studies, each type of building's shared proportion is shown in Figure 4. It can be observed that residential and higher education buildings show a substantial proportion of gamification utilization, whereas its adoption in offices and other public buildings, including healthcare centers, remains comparatively limited. Paone and Bacher [18] indicated that significant savings in energy usage have been found in residential and office buildings where gamification is primarily employed, accounting for 80% and 60% of savings, respectively. The variance in energy-saving actions between residential and office buildings may be attributed primarily to factors such as utility costs [54]. Specifically, when end-users are financially responsible for their personal electricity usage in residential buildings [55], this factor assumes a crucial role in incentivizing users to engage in more energy-efficient behaviors within gamified frameworks. Due to the varying end-user responsibilities for utility costs across different building categories [55], gamification tends to be easier to adopt and execute in residential buildings (33%) than in public buildings (19%) and office buildings (20%), according to proportion of residential, public buildings and office buildings in Figure 4. In the context of the implementation of gamification in higher education buildings, a discrepancy is observed, with a prevalence 9% higher than in public buildings, despite the fact that the majority of higher education buildings are classified as public buildings (refer to Figure 4). Beyond the physical construction, the importance of users of the buildings should not be overlooked. Given that higher education institutions primarily serve students, this group of users appears to be particularly predisposed to adopting gamified techniques and practicing energy saving [50], due to the pedagogical innovation and technological integration [56].

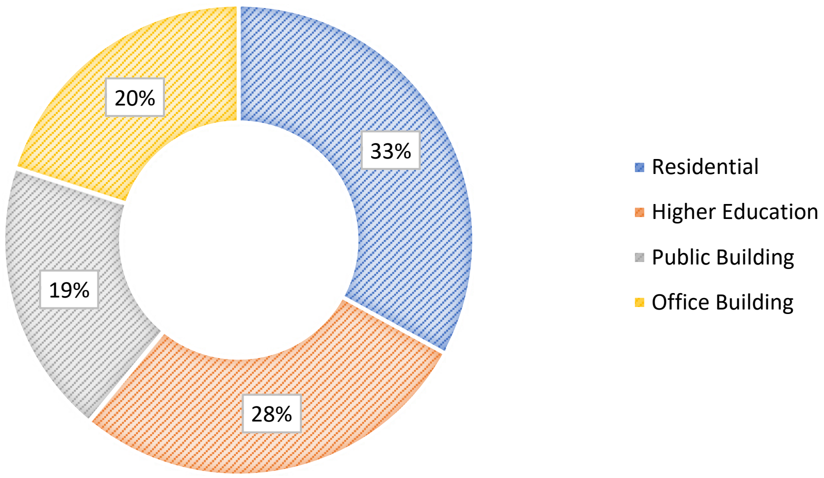

Figure 4. Share of various building types in the selected research studies.

3.1.2. Gamification Techniques Utilization and Their Performance

The investigation was extended to the examination of various gamification methods employed in different building types. The literature reveals seven implementation techniques, namely Human–Machine Interface (HMI) [38], Apps [26], Internet of Things (IoT) based [50], web-based gamified systems [43], software [44], ICT platforms [27,33] and Graphical User Interface (GUI) [56], as identified by the principal studies selected for this review. The radar chart below (Figure 5) gathers data from the chosen relevant literature on various gamification techniques, based on the building type. The numerical values associated with each technique denote the cumulative frequency of its application across the selected studies, despite instances where multiple techniques were employed within an individual study. In terms of total usage, Apps and HMI stand out in residential and higher education buildings, occupying first and second position, respectively, while software and GUI are barely utilized.

Given the findings on the various gamification implementation techniques across multiple building types, providing a controllable data visualization monitoring function interface for users to interact with was found to be critical for implementing gamification in residential buildings [6,42,57,58]. In relation to Figure 5, individuals who occupy office spaces for prolonged periods, particularly in a shared workplace, require the utilization of ICT and IoT intelligent approaches. These approaches facilitate real-time data collection and exchange, thereby optimizing smart automation systems and enabling users to exercise real-time control [26,28,52,59]. Conversely, for higher education buildings and other public buildings, Apps are necessary for gamification to allow the users to engage without a specific fixed location. This interface accommodates users [60], primarily students and commuters, who frequently transition between locations, necessitating a flexible and accessible tool for interaction with the gamified system. To further improve the understanding of the subsequent integration of various gamification technologies with the targeted platform inside buildings, an in-depth analysis of their performance was also conducted, as described.

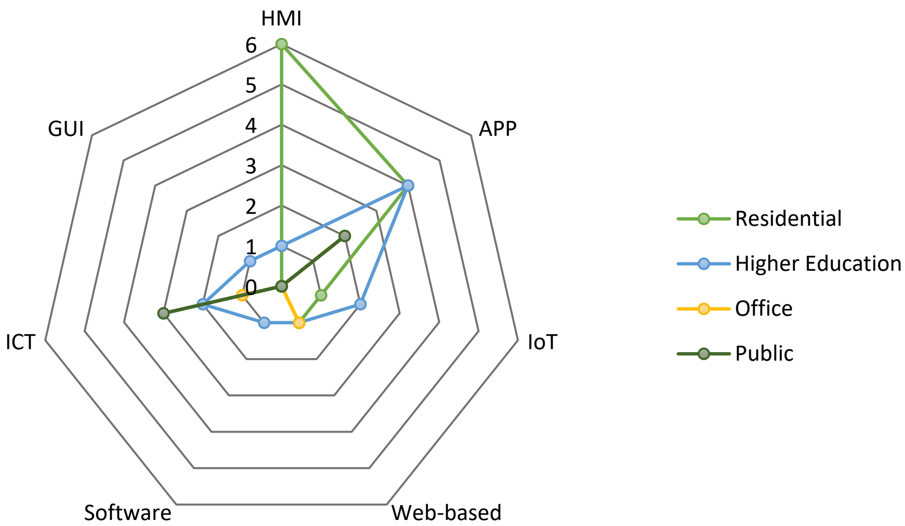

Figure 5. The distribution of gamification techniques in various building types.

A decision matrix was used to show the characteristics of pros and cons among seven implementation techniques, in terms of human-centric [45,48], data-driven [57], and convergence perspectives [37,42] (see Table 1), based on the selected studies. Specifically, among the seven evaluated aspects, 'User-friendliness' and 'Customization' emerged as recurring themes in the literature, mainly emphasizing the improvement of user engagement and behavior change [32,43–50]. Hence, these aspects were assigned to the 'human-centric' perspective for the discussion of different gamification techniques in Table 1. Similarly, the data-driven perspective often includes automated control systems in studies on gamification and flatform [26,28,48,50,52,61], focusing on technology-based methods for energy consumption management, such as smart sensors, meters, monitoring and device usage. 'Data collection', 'data analysis' and 'real-time control' are prominent components in discussions of automation systems. In addition, 'User accessibility' and 'System integration' were categorized under the 'convergence' perspective, as these aspects are often discussed in the context of the full implementation of gamification [27,37,40–42]. The assignment of weight to each criterion in the table reflects its relative significance in the decision-making process (where 1 denotes low, 2 signifies medium and 3 conveys high importance). Each technique was evaluated on the basis of its relevant characteristics, as discussed in the selected literature.

Table 1. Decision matrix for seven gamification implementation techniques based on indicative scoring mechanism.

	App [32,37,48]	**HMI** [38,45,53]	**IoT** [39,48,50]	**Web-Based** [43,52]	**ICT** [27,46,53]	**Software** [44]	**GUI** [32,41]
User-friendliness	3	3	1	2	1	2	2
Customization	3	3	2	3	2	3	3
Data collection	3	2	3	2	3	2	2
Data analysis	2	2	3	3	2	2	1
Real-time control	2	3	3	2	3	3	2
User accessibility	3	2	2	1	3	1	2
System integration	3	3	2	3	2	2	3
Total score	19	18	16	16	16	15	15

Notably, the weighted decision matrix is utilized to show quantifying differences, however, it is pertinent to note that the scoring mechanism is indicative, thereby bearing the inherent risk of biases, which requires verification through future research beyond the scope of this review study.

As can be seen in Table 1, among the seven different gamification implementation techniques, the App achieved the greatest score, while the GUI and software had the lowest and most limited utilization in the existing research. For a diverse user base, Apps provide mobility and portability, as they are easily accessible on mobile devices such as smart phones, tablets and smartwatches, facilitating engagement through various gamification components [32,48]. Significantly, Apps can be developed across diverse construction contexts. In environments including both public and mixed-use structures (e.g., commercial and residential), HMI provides real-time control and is favorable for monitoring and operating machines and systems [38]. GUI enhances user-friendliness and accessibility, thereby supporting user engagement through the interface design, particularly suited for deployment in offices, higher education and public buildings [32]. IoT contributes to automation and energy management by supplying data for gamified systems. ICT facilitates data sharing and collaboration, supporting the integration of gamification features. Both IoT and ICT are applicable to various building types, especially smart buildings. However, the utilization of software is primarily constrained by the considerable time and cost requirements associated with development and maintenance. Web-based gamified systems, while offering cross-device compatibility, garner comparatively less attention than Apps or other intelligent screens or touchable interfaces [43].

3.1.3. Gamification Interface Integration and Design of Gamifying Elements

In addition to assessing the performance attributes of various gamification techniques, the integration of gamifying elements within building systems necessitates careful consideration of the target platform. The selection of relevant gamification elements holds paramount importance in meeting project objectives and satisfying end-users. Reward serves as a fundamental element in gamification initiation, irrespective of the utilized implementation method. Typical rewards include points, badges, coupons and discounts, as they offer tangible benefits to users [25]. In terms of popularity, these elements are followed by feedback [34,42,46], dashboard [26,27] and social message [61–64]. Table 2 presents the characteristics and evaluations of different integration platforms shown in the selected literature among the seven gamification techniques. The platforms used to integrate with gamified systems within building contexts are classified into three directions. These directions include groups related to energy acquisition and dissipation, such as thermostats [38], photovoltaics (PV) [51], heating, ventilation and air conditioning (HVAC) systems [45]; the energy monitoring group [46], including smart meters, sensors and plugs [47]; and notably, the least prevalent application platform identified in this synthesis is the computer [44]. Furthermore, the effectiveness of different gamification design elements in optimizing resource utilization and energy consumption was also investigated across various implementation techniques, with the results detailed in Table 2.

In accordance with the illustrated details in Table 2, points represent a crucial element of gamification, serving as a direct motivational tool to engage users and stimulate their involvement in energy-related behaviors. Within the platforms of thermostats, HVAC systems and PV, the incorporation of gamification design elements assumes paramount significance, enabling users to dynamically manipulate and monitor energy dynamics in real-time. Gamification elements such as energy data feedback, competitive mechanisms, and dashboards are employed to incentivize users to actively engage in planning and regulating energy consumption in response to varying indoor environmental conditions and weather fluctuations. Méndez et al. [38,45] designed a gamified thermostat interface which depends on the users' personality traits. In this study, fuzzy logic was employed to engage the users with the thermostat to teach, engage, and motivate end users to become energy aware. The gamified thermostat interface allowed around a 15% energy saving, compared with the original thermostat system without gamification. Specifically, in this project, the gamifying elements of feedback and dashboard were directed towards enhancing the functionality of automated control and system monitoring within thermostats associated with energy consumption. Instead, Konstantakopoulos et al. [32] utilized the gamifying elements of reward and dashboard in GUI techniques as a key element to support the visualization of energy-related information for enhanced end-user understanding, obtaining an energy use reduction of about 40%. Therefore, it is important to acknowledge that the visual representation of energy information on dashboard elements directly influences the awareness of users for energy-saving practices.

Table 2. Characteristics and evaluation of each platform of gamified system within buildings.

Techniques	Target Interface	Gamification Elements	Resource Utilization	Energy Consumption Savings
HMI	Thermostat, PV, HVAC	Points, feedback, competition, dashboard, statistics	Control, monitoring	15% [38,40]
App	Thermostat, PV, smart meters, smart plugs, sensors, HVAC	Feedback, points, challenges, dashboard, statistics, leaderboard	Get user engage in resource interaction	20% [26]
IoT	Smart meters, plugs, sensors	Competition, points	Enable real-time automation and data-driven decisions	40% [50]
Web-based	Computer	Points, competition, feedback, leaderboard, cooperation	Media and social network to support user engagement	10% [43]
Software	Computer	Points	Customization with optimize resource utilization	8% [44]
ICT	Lighting, HVAC, meters, plugs	Points, dashboard, feedback, competition, social	Data exchange, communication and collaboration	15–30% [46]
GUI	Sensors, meters	Points, dashboard	Visualization, easy to understand	40% [32]

Similarly, a 40% reduction of energy consumption has been achieved with the integration of smart meters, plugs and sensors within gamification strategy in the IoT gamified technique [39,50,65]. These strategies allow collection of data in real-time and transfer to the back-end component of the game application, to aggregate energy and sensor data. Smart meters, plugs and sensors are more focused on real-time data collection and analysis to put them into the functionality of an automation system, where the gamifying element of competition for community engagement and personalized social challenges can be provided. Paris et al. [48] applied a simulation gamifying element in a social setting of a building's automation system, where the sensor's server platform is responsible for storing data in the database and changing the settings of the environment to enable the system to run on its own, without supervised control.

As for HVAC systems, ICT demonstrates enhanced energy savings, specifically at a rate of 30% [33,46]. This improvement is attributed to the incorporation of a social element, which serves to augment participant empathy during gamification interactions, a feeling of belonging can be provided to the end-users during the behavior and awareness shifting periods. The social element also sustains ongoing participant interest and facilitates the gathering and exchange of information regarding user preferences within the interactive user interface. Compared with the social element, the game element of cooperation can also give users a sense of belonging, especially when they are making some changes based on old habits to get out of their comfort zone. Web-based techniques can build a social community for the users to share their experiences and achievements. A card game was developed by Albertarelli et al. [43] to engage people when using a gamified website platform which offered a wide set of activities, aimed at triggering water saving actions. In that work, the portal allowed users to team up to work on the same energy-saving task and implemented an awards system that combined points and badges to reward water-saving behaviors.

In conclusion, the aspects of gamification implementation techniques and operating platform characteristics discussed in the previous Sections 3.1.2 and 3.1.3 underscore the importance of the dynamic tracking of user activities and progress as another crucial aspect of the interaction platform. This necessitates the inclusion of a dashboard and statistical features. Within the gamified framework, the game design element of competition in IoT and ICT can leverage real-time data to exchange for greater information. In other words, the gamifying element of competition within various users' environments may not only enhance user engagement, but also contribute to the optimization of energy distribution in building automation systems. Web-based techniques require feedback mechanisms and social interaction to foster community networking, thereby promoting sustained user engagement. Given the comparison between characteristics of different gamification elements and their energy saving efficiency among different techniques, it is evident that less commonly utilized elements, such as simulation and dashboard visualization, offer significant energy savings. In contrast, extensively used elements like points and feedback show comparatively lower effectiveness. This suggests that the strategic integration of gamification elements, specifically simulation, dashboard visualization, points and feedback, is crucial for optimizing user engagement and maintaining long-term user interest.

3.1.4. Gamification Mechanism and User Engagement

Effective motivations target inactive individuals, according to their varied personalities and preferences, enabling the selection of pertinent gamifying elements to construct incentive mechanisms. This strategy stimulates consumers to participate in programs that they would otherwise be hesitant to engage with. Motivation can possibly be divided into two parts: intrinsic and extrinsic mechanisms, namely psychological autonomy and material benefits, respectively. A good gamification principle can provide a game's theoretical basis for mapping relevant mechanisms for short-term behavior change to behavior transformation.

The Octalysis framework for gamification and behavior design, created by Chou [66], is centered around human motivations, a framework that emphasized "human-focused design" instead of "function-focused design". Eight drivers of human motivation were identified in the framework (Figure 6), namely, epic meaning, accomplishment, empowerment, ownership, social influence, scarcity, unpredictability and avoidance. In Figure 6, the left red tangle deals with extrinsic motivations and the right green tangle fosters intrinsic motivations. The gamification mechanisms described in current relevant literature utilize the first seven core human motivation drivers.

The first core driver of human motivation, shown in Figure 6, is "Epic Meaning", which can be achieved by creating a story or narrative with a clearly defined end goal. The epic meaning can maximize the user's engagement by immersing them in a world where the meaning is infused into users' actions. In the project of the EnerGAware energy game, Gangolells et al. [46] applied the main character and narrative context to create the background, information, and game rules for players to prioritize different energy-saving investments, promoting the player's awareness of energy efficiency in social housing communities by putting them into immersive realities to make decisions on balancing the cost, energy saving and indoor comfort.

Analogous to the concept of "epic meaning", the psychological motivator of "accomplishment" engenders a sense of pride and confidence through the realization of personal achievements. The development of skills, surmounting challenges, and making discernible progress are essential components in preventing any given task from feeling devoid of purpose. In gamification contexts, the introductions of points, badges and leaderboards serve as tangible, albeit transient, metrics of developmental milestones and accomplishments [26,27,40,45,47,49].

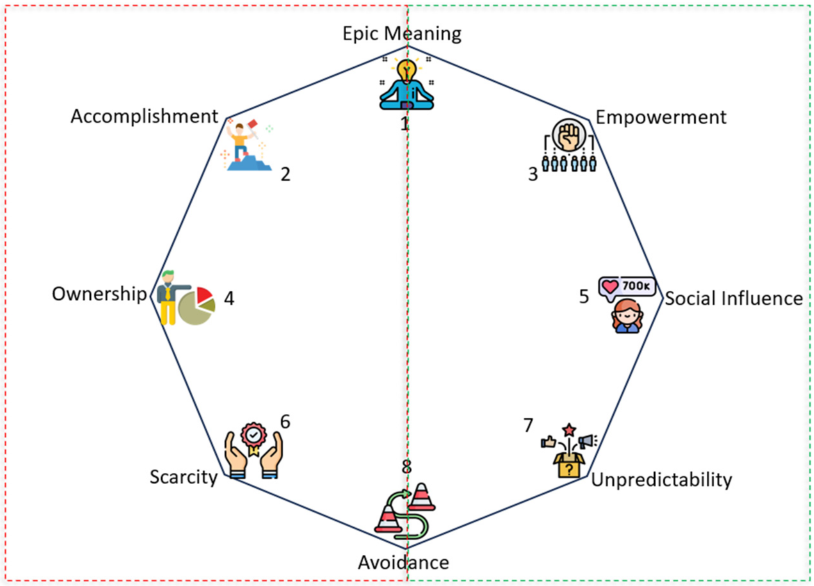

Figure 6. Eight core drivers of human motivation in the Octalysis Framework, adapted from Chou [66].

The concept of "empowerment," characterized by the facilitation of creativity and feedback, is critical to instilling a sense of responsibility in individuals' lives. In the study by Mendez et al. [51], modifications to the classroom's air conditioning setpoint are contingent upon majority agreement from students. These students possess the requisite credentials to monitor real-time changes and offer input, while rankings and energy usage are displayed through an interface. The collaborative and competitive dynamics within and between classes motivate students and teachers alike to fulfil their responsibilities and enjoy corresponding incentives.

"Ownership" confers upon users a perception of control, wherein the act of "owning" something instigates an inherent inclination to safeguard, enhance, or augment that entity [66]. In a comparable vein, Soares et al. [27] introduced account creation into the gamified system, wherein users' activities, rewards and achievements are systematically recorded within a personalized system. This approach offers users a tailored experience, allowing them to monitor and manage their energy consumption patterns.

"Social influence" represents extensively researched aspects of behavioral science [67]. The expansion of user engagement is challenging without a social context, as the establishment of the preceding three core drivers (1, 2 and 3) relies heavily on relational elements. Gangolells et al. and Morton et al. [41,46] implemented gamified platforms for sharing achievements, fostering competition and providing energy advice. The study by Franco [33] witnessed the formation of a gamified social community among building occupants. Interactions within this community contribute various occupant preferences to the control system, facilitating the implementation of strategies aimed at regulating indoor air quality, reducing energy consumption and enhancing occupant satisfaction. Leveraging technology facilitates the integration of this core driver into gamification approaches, evidenced by the utilization of leaderboards, competition boards and social gamifying elements, although the efficacy of many of these designs remains suboptimal.

Regarding "scarcity" as an extrinsic mechanism of gamification, it is associated with motivations driven by the desire to possess something due to its limited availability [68]. For instance, the establishment of a rewards system where users surpass a finite number of rewards serves as an effective approach. Konstantakopoulos et al. [32] implemented a lottery mechanism, featuring one gift card distributed as an incentive for building occupants.

The likelihood of winning the lottery is positively correlated with the accumulation of points by occupants, thereby instigating a competitive driver and enhancing engagement in various activities.

The concept of "unpredictability" has been subjected to examination in multiple studies, wherein different rewarding mechanisms have been incorporated into gamified systems [27,45,47,48,51]. Within these studies, users are kept unaware in advance of the rewards they are to receive, rendering the rewards unpredictable and presenting them as surprises. The introduction of unforeseen rewards is more likely to engender heightened user engagement, as individuals, anticipating future rewards, are motivated to uphold positive energy-saving behaviors and subsequently generate desired outcomes.

3.2. Assessment Methodologies of Gamification Performance for Driving Users' Energy Behavior Change

What assessment methodologies can be deployed to measure the impact of gamification on users' energy behavior change? Understanding what methodologies can be deployed to assess the gamification performance in influencing the user behavior, engagement, and outcomes was the intent of the second lens of study for this review paper. Table 3 indicates the 21 selected studies and the assessment methods used in their works. There are 12 studies [26,32,37,39,40,42,44,46,47,49,50,52] based on experiments and nine research studies [27,33,38,41,43,45,48,51,53] based on theoretical frameworks. Due to the absence of information about the experiment duration and participant numbers in the selected nine non-experimental studies and the partial omission of the assessment method, the corresponding fields within Table 3 remain unpopulated. Nine of the studies have been verified by experimental testing that lasted more than a year, with the longest one lasting three years [47] and the shortest lasting two months [39]. The number of participants in each of the selected 12 experiment-based studies was less than 100. Only one study [47] had about 2000 participants and was based on a questionnaire survey.

Table 3. Selected studies and assessment methods.

Reference	Gamification Principles	Experimental	Duration	N. of Participants	Behavior Change Driver	Assessment Method
Soares et al., 2021a [27]	Goals, rewards	No	-	-	Accomplishment	-
Franco 2020 [33]	Goals, social interaction	No	-	-	Social influence	-
Méndez et al., 2021 [38]	Personalization	No	-	-	Unpredictability	-
Morton et al., 2020b [41]	Challenges and competition	No	-	-	Empowerment	Surveys
Albertarelli et al., 2017 [43]	Goals, data analytics	No	-	-	Social influence	User acceptance
Méndez et al., 2020 [45]	Personalization	No	-	-	Unpredictability	User analytics
Paris et al., 2019 [48]	Goals, personalization	No	-	-	Unpredictability	-
Mendez et al., 2021 [51]	Feedback, rewards	No	-	-	Empowerment	-
Sintov et al., 2015 [53]	Choice and autonomy	No	-	-	Empowerment	-
Iria et al., 2020 [26]	Challenges and competition	Yes	2 years	24	Social influence and accomplishment	Energy usage

Table 3. *Cont.*

Reference	Gamification Principles	Experimental	Duration	N. of Participants	Behavior Change Driver	Assessment Method
Konstantakopoulos et al., 2019 [32]	Goals	Yes	7 months	72	Scarcity	Goal achievement
Lu 2018 [37]	Data and analytics	Yes	1 year	22	Social influence	Energy saving
Ferreira et al., 2018 [39]	Goals	Yes	2 months	80	Social influence	Surveys
Avila et al., 2021 [40]	Goals	Yes	6 months	30	Accomplishment	Energy saving
Kim et al., 2022 [42]	Challenges and competition	Yes	2 years	13	Empowerment and accomplishment	Energy saving
Patlakas and Raslan 2017 [44]	Rewards	Yes	2 years	89	Ownership	Surveys
Gangolells et al., 2021 [46]	Goals, feedback	Yes	1 year	137	Epic meaning	Energy saving
Fraternali et al., 2018 [47]	Rewards, achievement	Yes	2 years	2000	Accomplishment	Surveys
Fraternali et al., 2017 [49]	Goals, social interaction	Yes	3 years	120	Accomplishment	Surveys
Papaioannou et al., 2018 [50]	Data and analytics	Yes	1 year	200	Unpredictability	Energy saving
Gandhi and Brager 2016 [52]	Choice and autonomy	Yes	2 years	30	Empowerment	Energy saving

In the non-experimental research studies, the gamification principles of behavior shifts involve material triggers of extrinsic incentives and punishments [27,33,38,41,45,51], which encourage participants to reach expected outcomes swiftly in the short term. Surveys and comparisons of energy use before and after gamification application are applied to assess participants' behavioral changes. Two studies divided participants into five groups, based on different personality traits (openness, conscientiousness, extraversion, agreeableness and neuroticism), and selected appropriate gamification design principles for each group, to encourage them to engage in energy-saving behaviors [38,45]. Personalization was used as a strategy in these two non-experimental studies, tailoring the gamification experience to each user's preferences and behaviors. Personalization enhances the experience by making it more meaningful and enjoyable, resulting in autonomous behavioral changes rather than extrinsic material stimuli. In comparison to the short-term changes, a greater understanding of participants' personality traits can be gained, resulting in a long-term behavior reform process. User analytics and questionnaires were employed in both studies to examine behavioral changes. Both studies employed user analytics and questionnaires to examine behavioral shifts. The appropriateness of gamification design mechanisms and elements for different users can be discerned by tracking and analyzing participant engagement frequency and the extent of behavior change, supplemented by end-user surveys and feedback.

From the 21 selected main studies, approximately 40% of selected experiment-based research involved a comparative analysis of baseline energy consumption data preceding the implementation of gamification [26,37,40,42,46,50,52]. This evaluation assesses the efficacy of gamification design mechanisms and the effectiveness of participant behavioral changes. Additionally, surveys have been employed in 20% of non-experiment-based studies to further gauge the efficiency of gamification interventions on participant behaviors [39,41,47,49]. The remaining nine studies did not assess alterations in energy consumption or changes in user behaviors associated with energy conservation following the implementation of gamification mechanisms [27,32,33,38,43–45,48,51,53].

4. Discussion

4.1. Relationships and Challenges in Gamification Implementation

To derive an effective implementation strategy for gamification mechanisms applied in buildings, three distinct perspectives are considered: building type, end-user type and gamified characteristics, as shown as Figure 7, based on the review of existing studies in the previous sections. These perspectives serve as the frameworks for mapping out gamification mechanisms, including gamifying elements and gamifying principles, to inform the design of a suitable gamification technical platform. Central to this approach is the incorporation of human motivational core drivers, aimed at achieving a balance between intrinsic and extrinsic incentive mechanisms within the gamified system design.

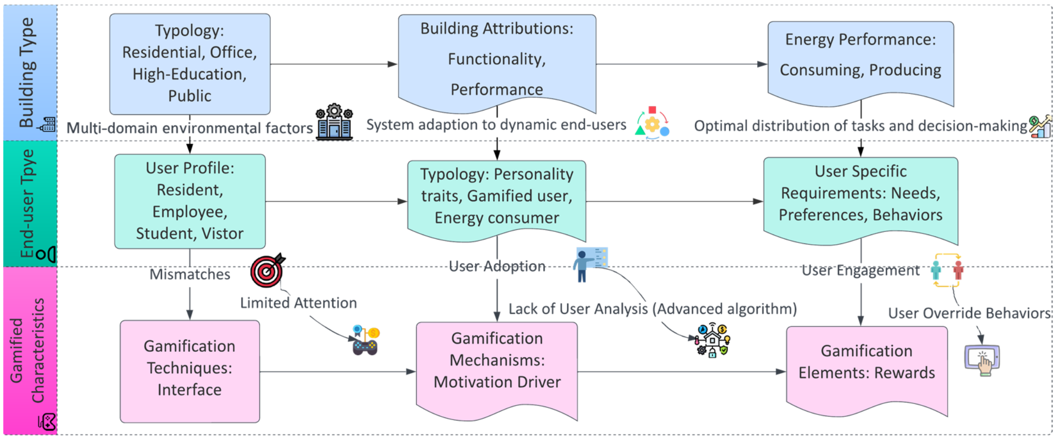

Figure 7. The relationships and challenges between gamification, building energy-related systems and users.

Referring to Figure 7, among the three stated perspectives, to apply gamification techniques concerns the building typology, with a focus on residential structures. Higher education and residential buildings have taken center stage in the adoption of gamification strategies. However, it is noteworthy that existing research has not adequately accounted for the inherent distinctions of residential building settings. Specifically, in rental scenarios, a portion of utility costs is often subsumed within the overall rental fee, which tenants remit on a monthly or fixed-term contractual basis [69]. This circumstance poses a unique challenge to the effective implementation of gamification strategies among occupants in this category. The rationale behind this challenge is rooted in the fact that renters, under such arrangements, may exhibit a diminished incentive to regulate energy consumption. Irrespective of the actual energy usage, these individuals are obligated to remit a predetermined sum for their accommodation. As a result, gamification initiatives targeting energy conservation may not resonate with this subset of occupants. An analogous scenario can be observed in other building typologies, such as hotels, student accommodation and offices.

4.2. Gamification Strategies Tailored Building Types and User Profiles

Drawing from the attributes delineating diverse building types and dynamic occupancies with varied user profiles, this review suggests that a nuanced approach recommends a hybrid amalgamation of disparate gamified implementation techniques. Given these variations, the implementation of gamification techniques should be tailored to suit the specific characteristics of each building type and user profile. For instance, gamified solutions in residential buildings may need to focus on promoting energy-saving behaviors related to household appliances, lighting and thermostat settings, while those in commercial buildings may need to address energy consumption associated with HVAC systems, office equipment and lighting.

Furthermore, the dynamic nature of occupancies within buildings presents additional challenges and considerations for gamification. Occupancy patterns can fluctuate throughout the day and week, affecting energy usage and the effectiveness of gamified interventions. For example, peak occupancy periods in commercial buildings may require different gamification strategies compared to off-peak periods. Moreover, user profiles within buildings can vary widely, leading to differences in energy-related behaviors and motivations.

Gamification methodologies necessitate sensitivity to these diversities and should consider factors such as age, occupation, cultural background and individual preferences. However, it is important to note that this study did not incorporate detailed user information, such as age, occupation and cultural background, due to privacy concerns. Future research endeavors should explore methodologies for responsibly handling and incorporating such sensitive data into gamification strategies, while ensuring compliance with ethical and legal considerations.

In addressing these challenges, gamification techniques can capitalize on the inherent characteristics of diverse building types and occupancies to promote energy efficiency and behavior change. By integrating user-centric design principles, data-driven insights and adaptive strategies, gamified interventions can be optimized to engage users effectively, foster sustainable behaviors, and ultimately contribute to the overarching goal of energy conservation. However, the efficacy of gamification deployment critically relies on the meticulous design of gamification mechanisms.

4.3. Integrating Extrinsic and Intrinsic Motivators in Gamification

The effective utilization of gamification mechanisms to induce changes in users' energy behavior necessitates the harmonious integration of gamification elements and principles, considering variables such as building type, implementation interface, and the characteristics of the target users. Fundamentally, rewards constitute a foundational element, while feedback, dashboard features, and competitive elements prominently feature within the human–computer interaction interface. These elements predominantly appeal to extrinsic incentives, facilitating transient accomplishments without profoundly influencing users' intrinsic motivations. For the cultivation of enduring behavior change, an approach involving the amalgamation of both extrinsic and intrinsic mechanisms becomes imperative. Gamification strategies that incorporate intrinsic elements, including social interaction, simulation, achievement and statistical feedback, empower users to delineate precise goals based on personalized information. Concurrently, these approaches stimulate community collaboration, fostering a sense of belonging and collective advancement. This intrinsic impetus assumes a pivotal role in molding users' subconscious commitment to energy conservation in the long term. Crucially, the gamification mechanism should not be construed as a static entity; instead, it should dynamically adapt to the evolving characteristics of users. This adaptation involves the selective refinement of gamification mechanisms, with a focus on data information displays, user engagement strategies and overall user experience. Striking a balance between extrinsic and intrinsic mechanisms is emerging as a requisite for perpetually influencing users' energy behavior change, thereby facilitating sustained, long-term behavioral transformation.

4.4. Gamification in Building Components

In the context of the operational convenience, afforded by intelligent controls, particularly through the utilization of Apps, HMI and an IoT sensor system, gamification predominantly concentrates its efficacy on key building components, such as HVAC systems, thermostats and lighting. These components are primarily supported by an array of sensors, smart meters and plugs. However, a notable scarcity exists in instances where gamification has been applied to building products, prompting a comprehensive exploration within this review. Specifically, this review seeks to identify antecedent cases wherein gamification strategies have been deployed in conjunction with building façades, given that the façade stands as a pivotal element significantly influencing the overall energy consumption of the building. It is noteworthy that, within the extant literature, only a singular study has endeavored to integrate gamification principles with building lifts. Intriguingly, the current body of research lacks any documented instances of gamification integration specifically within the domain of building façade applications. This observation underscores a notable gap in the literature, prompting further inquiry into the unexplored potential effects of gamification strategies on users' energy behavior, within the realm of building façades.

4.5. Quantitative and Qualitative Assessment Approaches

On the other hand, concerning the effective assessment approach for gauging the impacts of gamification on user energy behavior change, a comprehensive approach is warranted to sustain engagement towards long-term behavioral transformation. This entails the fundamental necessity of incorporating experiment-based quantitative studies alongside qualitative investigations into users' ongoing involvement and their experiences with gamification. Such a multifaceted approach is indispensable for shaping and refining gamification mechanisms, aligning them with user preferences and patterns to optimize responses and operations within building façade systems.

Both experimental and non-experimental studies predominantly employ quantitative assessments to gauge the impact of gamification on user energy behavior and engagement. Since the ultimate objective is energy conservation, it is crucial to note that the direct results of energy savings do not necessarily reflect the behavioral shifts in users. Comparing pre-intervention and post-intervention energy consumption, though a common method, may inadequately capture the nuances of behavior change. To address this limitation, some studies [41,43,47,49] have incorporated questionnaires to assess user behavior changes and energy usage. However, surveys introduce the potential for response bias, as relying solely on baseline data may overlook the external factors influencing energy use. Notably, there is a dearth of studies [26,40,42] that combine quantitative and qualitative assessment approaches, such as merging surveys with energy consumption measurements to comprehensively evaluate users' energy behavior transformations.

5. Conclusions and Future Recommendations

This study addresses the pertinent gaps identified in prior literature reviews, with a specific focus on the effective implementation of gamification techniques in building systems to improve energy efficiency and assess their impact on users' energy behavior changes. A rigorous systematic review methodology was employed, including the selection of relevant studies, data retrieval, rigorous analysis and data visualization. This work highlights the importance of tailored gamification elements based on users' personality traits and preferences, particularly in higher education and residential buildings. Notably, building components, particularly façades, receive limited attention. The integration of quantitative and qualitative evaluation techniques is essential for a holistic understanding of the influence of gamification on user behavior and energy savings.

The evidence synthesized in the current review elucidates the efficacy of implementation strategies that utilize gamification to incentivize individuals towards heightened energy awareness and translate this mindset into the action for energy savings. This positive influence mechanism of gamified systems provides fundamental insights for mitigating potential issues stemming from human factors that are commonly disregarded within building systems. Consequently, these findings contribute to the advancement of long-term energy efficiency goals for buildings.

Nonetheless, a limitation of this review may exist in the assessment of the seven characteristics of gamification techniques, presented in Table 1, which may be subject to potential bias due to the utilization of a decision matrix scoring method for quantifying differences. This method involved weighting various features of gamification techniques based on selected literature, which inherently carries an indicative nature. To mitigate potential bias and validate the findings in Table 1, broader surveys involving users are necessary in future research.

Future research could investigate the integration of gamification with building façades, with a particular emphasis on the symbiosis between gamification and building façades automation systems. This could enhance users' energy intervention behavior and promote heightened energy efficiency and user comfort. Additionally, it is essential to investigate the adaptability of gamified solutions tailored to diverse building typologies, to address the unique challenges and strengths inherent to each environment in a systematic manner. One prospective avenue for exploration entails the examination of gamification mechanisms' influence on the energy behaviors of participants within buildings featuring diverse energy cost structures. This investigation could elucidate the nuances of gamification's impact within contexts where energy expenses differ significantly.

Future advancements in gamification mechanisms could aim to deliver personalized experiences tailored to individual user preferences, demographics and behavior patterns, facilitated by advanced data analytics and machine learning algorithms. This adaptive approach could sustain long-term engagement by incorporating narrative-driven experiences, social dynamics and rewards systems. To effectively measure the impacts of gamification on building energy conservation, comprehensive evaluation metrics and methodologies are crucial, necessitating the identification of key Performance Indicators (KPIs) and outcome measures. Bridging the gap between gamification research and practice requires closer collaboration between researchers and practitioners to develop empirically grounded, user-centered methods. Moreover, cultural and global perspectives should be integrated into gamification design, to ensure inclusivity and cultural sensitivity. As gamification proliferates, ethical considerations regarding privacy, consent and manipulation will become increasingly important, necessitating a focus on user well-being, autonomy, and transparency in gamified system design and deployment.

Finally, mixed-method assessment approaches hold the potential to enrich our understanding of how gamification impacts users' energy behavior. Collaborative interdisciplinary research ventures, with experts in behavioral psychology, hold promise in providing deeper insights into the cognitive processes underlying the behavioral changes facilitated by gamification. This could potentially further advance comprehension of human motivations and behavior which, in turn, could inform the development of more effective gamification strategies for the purpose of energy efficiency in buildings.

Author Contributions: Conceptualization, W.-T.L. and O.I.; methodology, formal analysis, investigation, W.-T.L.; validation, O.I., H.F. and M.W.T.M.; writing—original draft preparation, W.-T.L.; writing—review and editing, O.I., H.F. and M.W.T.M.; supervision and project administration, O.I., H.F. and M.W.T.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The original contributions presented in the study are included in the article and in the Appendix A, further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Figure A1. The selected studies are examined in terms of gamification design principles, gamification design elements, building type, gamification implementation technique, target component, experiment-based, experiment duration, number of participants, behavior change, assessment and façade. These data were collected and analyzed based on the scoping questions of this review article.

Number	TITLE	YEAR	PRINCIPLE	ELEMENT	BUILDING TYPE	IMPLEMENTATION	TARGET COMPONENT	EXPERIMENTAL	DURATION	PARTICIPATION	BEHAVIOUR CHANGE	ASSESSMENT	FACADE
S1	A smooth and accepted transition to the future of cities based on the standard ISO 37120, artificial intelligence, and gamification constructors	2021	Feedback, rewards	rewards; Challenges; levels; Dashboard; Statistics; Degree of Control; leaderboard	Campus	HMI, APP	Thermostat; lighting; PV systems				Empowerment		No
S2	a social-technical system based on gamification towards energy savings	2018	Rewards, achievement	achievements, rewards	Residential, campus, public building	HMI, APP	Meters, smart plugs, and sensor	Yes	2 years	around 2000	Accomplishment	Surveys	No
S3	iot-based adaptive context-aware and playful cyber-physical system for everyday energy savings	2018	Data and analytics	information visualization	Residential	IoT	Cyber Physical System	yes	1 year	22	Social Influence	Energy Saving	No
S4	Commercial office plug load energy consumption trends and the role of occupant behaviour	2016	Choice and autonomy	competition, points, and cooperation	Office buildings	Web-based	Plug	Yes	2 years	30	Empowerment	Energy Saving	No
S5	using gamification to motivate occupants to energy efficiency in a social setting of a building automation system	2019	Goals, personalization	achievement; challenges; rewards; feedback; social forum; levels; leaderboards; competition	Campus	IoT, App, Web-based	Lighting; sockets, air conditioner				Unpredictability		No
S6	personalized energy reduction cyber-physical system (PPERCS): a gamified end-user platform for energy efficiency and demand response	2015	Choice and autonomy	personalized feedback, competition	Residential	HMI and mobile phone platform	Smart meter				Empowerment		No
S7	DROP and Funergy: Two Gamified learning projects for water and energy conservation	2017	Goals, data analytics	feedback tips; leaderboard	Residential	Web-based	Water system				Social Influence	User acceptance	No

Figure A1. *Cont.*

S8	A computer game to help people understand the energy performance of buildings	2017	Rewards	point-based	Campus	Software		Yes	2 years	89	Ownership	Surveys	No
S9	enCOMPASS-an integrative approach to behavioural change for energy saving	2017	Goals, social interaction	rewards	Residential, campus, and office	APP	Smart meters, sensors, HVAC, plugs	Yes	3 years	120	Accomplishment	Surveys	No
S10	A Rapid HMI Prototyping Based on Personality Traits and AI for Social Connected Thermostats	2021	personalization	Rewards	Residential	HMI	Thermostat				Unpredictability		No
S11	S4 Product Design Framework: A Gamification Strategy Based on Type 1 and 2 Fuzzy Logic	2020	personalization	challenges; competition; social comparison; dashboard; monitoring; feedback; progress bar; leaderboard, and rewards	Residential	HMI	Thermostat, HVAC				Unpredictability	User analytics	No
S12	FEEdBACk: An ICT-Based Platform to Increase Energy Efficiency through Buildings' Consumer Engagement	2021	Goals, rewards	competition; Login and Account Creation; Dashboard; Leaderboards; Badges; Comfort Measures and Graphics; Energy Measures and Graphics; Notifications; Prizes	Public buildings, campus	ICT, APP	Meters, sensors				Accomplishment		No
S13	An energy management platform for public buildings	2018	Goals	Rewards	Campus	IoT	Lights	Yes	2 months	80	Social Influence	Surveys	No
S14	Energy management system based on a gamified application for households	2021	Goals	Rewards, levels, dashboard, challenges, statistics, degree of control, leaderboard	Residential	APP, HMI	HVAC	Yes	6 months	30	Accomplishment	Energy Saving	No

Figure A1. *Cont.*

S15	An IoT-Based Gamified Approach for Reducing Occupants' Energy Wastage in Public Buildings	2018	Data and analytics	Rewards	Public buildings	APP, IoT	Heating, HVAC, lifts, lighting, IT infrastructure	Yes	12 months	200	Unpredictability	Energy Saving	No
S16	Exploring the Potential of a Gamified Approach to Reduce Energy Use and Carbon Emissions in the Household Sector	2021	Goals, feedback	Educational objective; main character and narrative context, feedback, and social sharing	Residential	ICT	Meters	Yes	1 year	137	Epic Meaning	Energy Saving	No
S17	Empowering and engaging European building users for energy efficiency	2020	challenges, competition	Competitions; social networks	Residential, office, school, health care centres	ICT	Thermostat, air conditioning, heating, plugs, computer, lights				Empowerment	Surveys	No
S18	Balancing user comfort and energy efficiency in public buildings through social interaction by ICT systems	2020	Goals, social interaction	Rewards	Public buildings	ICT	HVAC system, lighting system, fire alarm, Miscellaneous Electric Loads				Social Influence		No
S19	A gamification platform to foster energy efficiency in office buildings	2020	challenges, competition	Leaderboard, free meal challenge, soccer game, message.	Office buildings	ICT, APP	Lighting	Yes	2 years	24	Social Influence, Accomplishment	Energy usage	No
S20	A deep learning and gamification approach to improve human-building interaction and energy efficiency in smart infrastructure	2019	Goals	Rewards	Campus	UGI	Lighting, HVAC	Yes	7 months	72	Scarcity	Goal achievement	No
S21	MySmartE – An eco-feedback and gaming platform to promote energy conserving thermostat-adjustment behaviours in multi-unit residential buildings	2022	challenges, competition	competition	Residential	APP	Thermostat	Yes	2 years	13	Accomplishment, Empowerment	Energy Saving	No

Figure A1. Selected studies and fetched relevant data in aspects of gamification, building energy and human behaviors.

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