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Review

Serious Games as an Engaging Medium on Building Energy Consumption: A Review of Trends, Categories and Approaches

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Abstract: Serious games, as an engaging medium on energy consumption, have recently become more popular, as they present an educational mechanism to engage end-users. A novel application of serious games in engaging and educating end-users has been validated during the last years. However, there is little research focusing on the review of its development trends, categories and approaches. The proposed paper reviews serious games as an engaging medium for building energy consumption. The research focuses on the role of energy-consumption awareness-related education in motivating end-users to save energy and make informed decisions to change energy-related behaviours. This research stresses the approaches to underlining the issue as ascertained from a number of efficiency-related serious games. The investigation suggests the potential impact that serious games can have on changing the domestic practices of householders, in a safe, fun and interactive environment. This would enable householders to investigate alternative ways of meeting energy-consumption targets and realise the limits to their energy-saving potential. It concludes that at present, serious games do not take advantage of the opportunities available in energy monitoring and sub-metering, or real-life energy behaviours. Meanwhile, the existing evaluation framework for the effectiveness of an energy serious game still needs to be further developed. However, active engagement in energy monitoring has contributed to numerous past successes in energy use reduction, and gamification and serious games show great potential for building upon these achievements.

Keywords: serious games; building energy consumption; energy-related behaviour; energy-consumption patterns; engagement degree

1. Introduction

Serious games are simulations of real-world events or processes designed for the purpose of solving a problem and can be used to respond to and capture the complex energy-using behaviour of end-user customers [1]. It has been applied to a broad spectrum of application areas (see Figure 1), e.g., public policy, defence, corporate management, healthcare, training and education, for over 40 years [2]. Serious games present a valuable effect on energy consumption, conservation and efficiency. Especially, quite a few research results indicate its positive influence on behaviour, cognition and the user experience [3]. Within the serious game framework, parameters such as those related with the end-user—widely accepted as the most unstable factor of all within the boundaries of the energy consumption cycle—can be categorised and addressed. The advantages of the serious games can be that they are entertaining as well as training and educating users using direct feedback and interaction to convey insights into the energy use outcomes of ordinary domestic behaviour [1].

The catalytic parameter making this possible comes from the fact that the end-user interacts with the game and gains feedback directly, almost in real time, as output after a thorough analysis of the energy consumption-related elements has taken place. The use of serious games can reveal the previously overlooked energy consumption implications of end-user habits, their use of energy-consuming devices, and their use patterns.

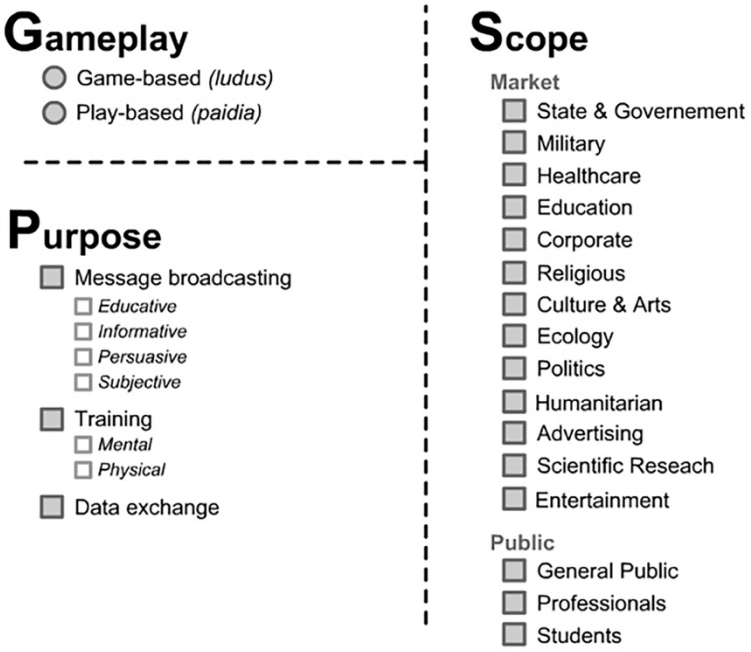

Figure 1. Classifying serious games [4].

Buildings represent a large portion of the world's energy consumption and associated CO_2 emissions. For example, the building sector represents 40% of energy consumption and 36% of the CO_2 emissions in Europe [5]. Beyond a technical issue of energy consumption and conservation, it is also a significant social issue in relation to every person on the Earth. Research results from the International Energy Agency show that building energy consumption is increasing day by day on account of the population blooming and the improvement of building comfort levels [6,7]. A number of targeted surveys and robust investigations have shown the technological challenges in terms of energy consumption and conservation. These challenges include if the energy systems support the affordability of the energy services, the security of energy supplies and the reduction of the greenhouse gas emissions from energy conversions [8]. Proper technical intervention is necessary, but changes in human behaviour to avoid catastrophic climate change are imperative. One of the most cost-effective ways to reduce energy consumption is to increase the awareness of energy saving at home [9]. However, it is seen as a challenge to change human behaviours in relation to building energy consumption [10]. It is not easy to intervene in the communication and social routines of people by simply involving traditional education programmes. No such media can rapidly and increasingly spread and be widely used by today's young people, but only social network sites such as TikTok, which presents visual information over textual, can. A cross-media-oriented and multiplayer-involved role-playing game, a serious game, is one of the main approaches to meeting this challenge in recent decades [11].

A series of empirical research projects in relation to serious games on energy consumption have been developed in recent years. However, only two such reviews of the state of the energy-serious-game field are currently available [3,12]. They focused on either identifying the value of the serious games on energy consumption or improving the design of the serious games, and more case studies and the quality of empirical evidence are required to be reviewed. Furthermore, the current situation and further development trends for the serious games on energy consumption are necessary to emphasise.

Therefore, the aim in this paper is, by reviewing existing energy-consumption-related serious games in recent decades, to formulate a solid theoretical foundation on which future serious games designers can base, create and publish highly immersive simulations with similar directives. Expanding this foundation is an ongoing process lying within the boundaries of the current research activities, and some initial results are presented as part of the following sections, as well as to provide an outline of an educational methodology for energy-consumption awareness. To serve this purpose, representative serious games are presented in some level of detail regarding the methodology employed, targeting group, gameplay approach and so on.

This paper firstly reviews twenty-one serious game projects in relation to the area of energy consumption. By analysing the project findings, addressing the uniqueness of the serious games approach and listing the similarities and differences between the serious game projects, the serious game development trend is elucidated. Secondly, the category of serious games applied for buildings is critically analysed and discussed based on reorganising the characteristics of these projects and the end-user engagement degree. Thirdly, this paper discusses methodologies for serious games in the area of energy consumption by reviewing approaches to the problem as established from a total of fourteen energy-efficiency-related serious games. Moreover, the design stratagem and technique map for energy-consumption-related serious games are presented. Furthermore, the paper discusses opportunities and future directions. Through this structure, we identify progress in and further opportunities for engaging people with their energy consumption through serious games and gamification.

2. Overview of Serious Games Used for Energy Consumption

As the research results for a range of smart energy monitor trials in US indicated, if proper feedback is provided, the savings can reach, on average, 7% [13,14]. The feedback includes but is not limited to the data of frequency, duration, content, and action in conjunction with other interventions. However, the *"double invisibility"* of energy consumption (the fact that it cannot be seen as well as connected to everyday actions) [15] is impacting the effectiveness of feedback in relation to energy consumption. With the purpose of gaining a better understanding of energy usage patterns and how users' habits affect those patterns, a number of approaches and methods have been proposed. Models and general frameworks (mainly employing user behaviour change and automated and/or semi-automated control systems), put forward as outcomes of various research projects in the area of energy consumption, try to open avenues for the average end-user to reduce their energy consumption. Supplementary to these models and frameworks is the deployment of monitoring devices to the appliances that consume energy. The area of energy efficiency and monitoring has spawned many projects, producing various levels of impact on the development of enabling technologies.

In order to engage end-users in energy-related behaviours and evoke their awareness of energy consumption and conservation, the serious game approach, a way of actively engaging energy users in energy saving reaching beyond the traditional approaches (i.e., more informative bills, the face-to-face provision of advice etc.), is being used for energy consumption [16,17]. Compared with entertainment games, serious games have a serious purpose. A well-designed serious game can effectively address all these parameters and can even provide solid ground for the exploration of the effectiveness of more parameters when used as an experimental medium. A serious game incorporating agent-based system methods can, in principle, provide the level of abstraction required by employing an easy-to-use and flexible interface to experiment on, which, at the same time, can be open to dynamic additions or modifications, so as to allow extensibility and evolution.

2.1. The Serious Game-Related Project Findings

By analysing their key results in serious game-related projects, someone, at a later stage, could take advantage of their findings and developments as well as learning from their failures, which could form solid ground for further investigating possibilities and opportunities. Combined with years,

participant ages and groups, countries and building types, this paper reviews the twenty-one serious game-related projects between 2009 and 2018 from scholarly sources, which are listed in Table 1.

Table 1. Serious games listed by age, group, country and building type.

Project	*Year*	*Age and Participant Group*	*Country*	*Building*
Power Agent [18]	2009	Two teams of teenagers (3 people in each team) cooperate with family members and combine forces with other peer agents in a team	Sweden	Real house
Power Explorer [19]	2009	15 teenagers and families playing games for one week	Sweden	Real house
EcoIsland * [20]	2010	6 families (20 persons, 12 male and 8 female) Parents (47–58 years) with 1–2 children (15–24 years)	Japan	N/A
EnerCities [21]	2011	Over 5000 students in a school setting	Europe, six different languages	Virtual cities
EnergyLife [22]	2012	4 households, 4 female and 6 male, aged 38 on average; at least two participants belonged to each different household.	Catania, Italy	Real house
Energy Battle [23]	2012	17 student households (2–5 people in each household)	Rotterdam, Netherlands	Dormitory
Super Delivery [24]		Sixth-grade students (4 male and 4 female)	Taiwan, China	Virtual cities
Greenify * [25]	2013	26 adult students, 8 males and 18 females	New York, USA	N/A
Ghost Hunter [26]	2014	7 families (13 adults, 2 girls, and 7 boys); the average age for the children was 6.78 years.	Chicago, USA	Real house
eViz [27]	2014	40 participants from Plymouth University, 18 males and 22 females	Plymouth, UK	Virtual apartment
Do It In The Dark [28]	2014	201 students from the University of British Columbia	Canada	Dormitory
Energy Chicken [29]	2014	61 participants	USA	Real office
Residence Energy Saving (RES)-battle [30]	2015	68 secondary school students	Bhutan	Virtual house and virtual commercial
Power House [31]	2015	40 people: 51 adults aged from 18 to 55, 21 males and 30 females	USA	Virtual house
Social Power [32]	2016	108 household members	Switzerland	Virtual house
Greenplay [33]	2016	200 households	France and Spain	Real house
Ringorang [34]	2017	522 single-family residences	USA	Real house
Energy Cat [35]	2017	More than 40 households; five of them were randomly chosen	Plymouth, UK	Real house
Energy Piggy Bank [36]	2017	39 engineering students including 21 men and 18 women between the ages of 20 and 27	Sweden	N/A
Serena Game * [37]	2018	50 girls between the ages of 12 and 16	Germany	Virtual house
Smarter households [38]	2018	Participants in 19 houses	West Midlands area, UK	Real house

* means that the project focused on the design and improvement of Serious Games (SGs).

As shown in Table 2, there are mainly two key aspects to classifying serious game-related project findings. The first key aspect is in relation to the design and improvement of the serious games regarding the identification of key factors that impact the willingness of users to engage in and explore the design strategies employed in persuasive applications. The second key aspect is to explore how serious games change human behaviours in relation to energy consumption. Typical projects mainly focus on family members' behaviours at home but also extend to the city scale, dormitories, offices and commercial buildings.

Table 2. Serious game project findings.

Findings	Categories	Example Projects	Number of Projects
How to design and improve SGs	Explore design strategies applied in persuasive applications	EcoIsland [20]; Greenify [25]; Serena Game [37]	3
SGs change human behaviours	Family members' behaviours at home	Power Agent [18]; Power Explorer [19]; EnergyLife [22]; Ghost Hunter [26]; eViz [27]; Power House [31]; GreenPlay [33]; Energy Cat [35]; Smarter Households [38]	9
	Education-oriented SGs—increase awareness of energy consumption	EnerCities [21]; Super Delivery [24]; Social Power [32]; Ringorang [34]; Energy Piggy Bank [36]	5
	Students' behaviours in dormitories	Energy Battle [23]; Do It In The Dark [28]	2
	Participants' behaviours in offices and commercial buildings	Energy Chicken [29]; Residence Energy Saving (RES) – Battle [30]	2

2.2. *Advantage of Employing Serious Games for Energy Consumption*

There are distinct advantages to employing serious games for energy consumption.

The first advantage of serious games is the visualisation of energy consumption. A serious game can mainly be visualised as a simulation with the look and feel of a game, at the same time, corresponding to non-game events or processes, including a diverse set of operations, applications and behaviours. Every attempt to visualise energy-consumption-related data, for monitoring and controlling energy usage by small or large-scale energy consumers, involves the modelling of a daily load curve. Within the context of a serious game, novel approaches can firstly be explored with the aim of providing output against a set of pre-calculated parameters provided at the input (such functionality can be employed particularly for demand-response modelling). The data collected could be analysed by comparing daily energy consumption to end-user behaviours for a better energy consumption strategy.

Secondly, it is proved that the persuading technology could improve the end-user's engagement [39–41]. Gamification is a definition of a method that engages users in real-world activities by using game-like elements and principles [42]. Gamification provides a significant possibility for motivating and intervening in an end-user's energy-related behaviours in everyday life. Consequently, the main aim of a serious game is to provide an engaging (either virtual or real) environment in which to motivate and educate the end-user. By taking advantage of the fact that a serious game can provide a Web-enabled development platform, consumers can be encouraged into forming "Customer Coalitions" (CCs), to effectively increase their response capabilities through competition and/or collaboration. They can also encourage their families and friends to engage in the serious games for raising wider public concern in relation to energy consumption.

Thirdly, the feedback of the end-users can be collected by the serious games directly. Because serious games require the end-user to use skills, initiative and strategy (unlike games of chance), the direct end-user feedback can be combined in the background with any type of specialised algorithm/machine-learning

technique (neural networks, genetic algorithms, support vector machines, data mining etc.) to solve problems and provide advice in relation to load prediction, energy-consumption reduction opportunities, and/or decision support.

Aside from the end-user's direct feedback, Consumer Preference Modelling (CPM) can be incorporated within the gameplay of a serious game: an invaluable component in every attempt for the development of Dynamic Consumer Models (DCM), as well as guiding choices and decisions. From all the above-mentioned possibilities, the most directly implementable within the framework of a serious game is Preference Aggregation (PA), mainly because of the nature of the input expected from the end-user's side. This is a very important feature since it allows for the direct implementation of more complex consumer structures.

2.3. The Level of the Education of the Energy-Related Serious Games

Even though the advantages of the serious games on energy consumption are obvious, the existing energy-related serious games are not exhibiting all of them. The gap can be filled by setting a criterion based on the usage of energy technology (or the advantages mentioned in the above section) to evaluate the projects. Consequently, the levels of the education of serious games can be classified into four levels (see Table 3) to better achieve the ultimate goal—end-user behaviour change. The levels are summarised based on the outcomes of the serious games. Level 1 for the serious games indicates that the projects aim to visualise the energy consumption for enhancing the end-user's energy usage; Level 2 indicates that the projects aim to deliver energy-related knowledge to the end-users; Level 3 indicates that the projects deliver energy-related knowledge to the end-users as well as providing a direct feedback mechanism in due course, which is used to change their energy-related actions in the games; however, Level 4 gives a further indication compared to Level 3, enhancing the capability of serious games to improve the end-user's engagement and energy-related behaviour change. More specifically, Level 4 involves multiplayers doing in-game interactions with others [21] or encouraging the end-user's family and friends to get involved in the game through social media [21,28].

Table 3. The evaluation criterion for energy-related serious games.

The Level of Education
Level 1 (L1): Energy knowledge presenting
Level 2 (L2): Knowledge transfer
Level 3 (L3): Knowledge transfer and feedback
Level 4 (L4): Knowledge transfer and feedback and engagement

2.4. The Development Trend of Serious Games on Energy Consumption

Serious games have been adopted widely, and energy consumption is a significant and critical social issue. The serious game, as an engaging medium for building energy-consumption knowledge, has emerged in recent decades. Through the serious game line chart (see Figure 2), it can be seen that Europe is a pioneer of developing serious games in energy consumption and they are still leading the research to date. However, the projects on energy-related serious games in Asia and North American emerged after 2010 and present an increasing trend. All in all, it can be seen that the number of serious game projects on energy consumption is increasing.

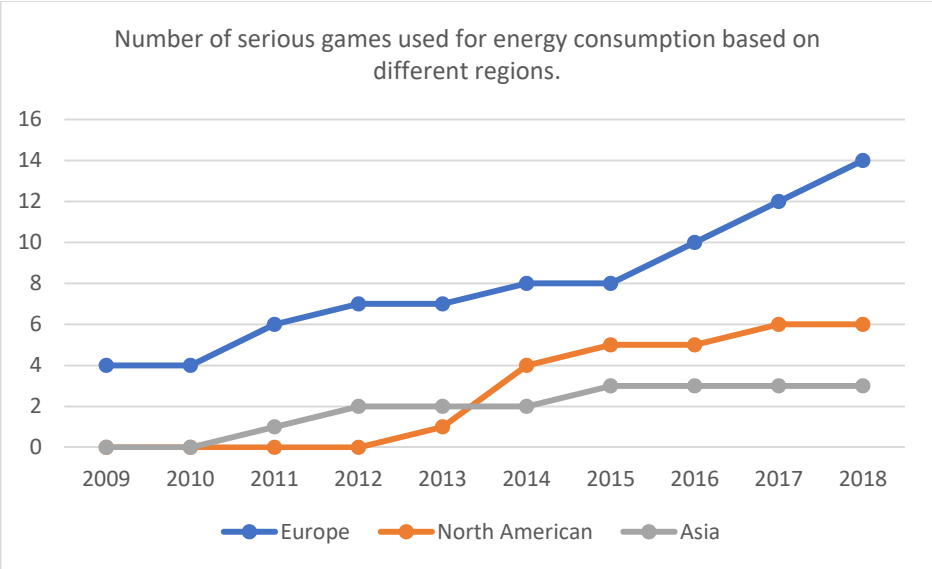

Figure 2. The number of serious games used for energy consumption based on different regions.

The second trend of the development of serious games on energy consumption is that the means of applying the serious games on energy consumption have shifted from educating end-users in the virtual world to employing real-time data in the real world. As Figure 3 presents, there were five projects that employed virtual data and only three projects that employed real-time data in the real world in the first half of the decade. However, the situation changed in the second. More specifically, the total number of energy-related serious games increased by five, including five games in the virtual world and eight games employing real data or real-time data in the real world. Serious games are often more effective if they more closely simulate the lived experience of the participants [43]. That is to say, the transfer from the virtual world to the real world emphasises the practical meaning and achievements of applying serious games on energy consumption. It also represents the success of employing serious games on building energy consumption.

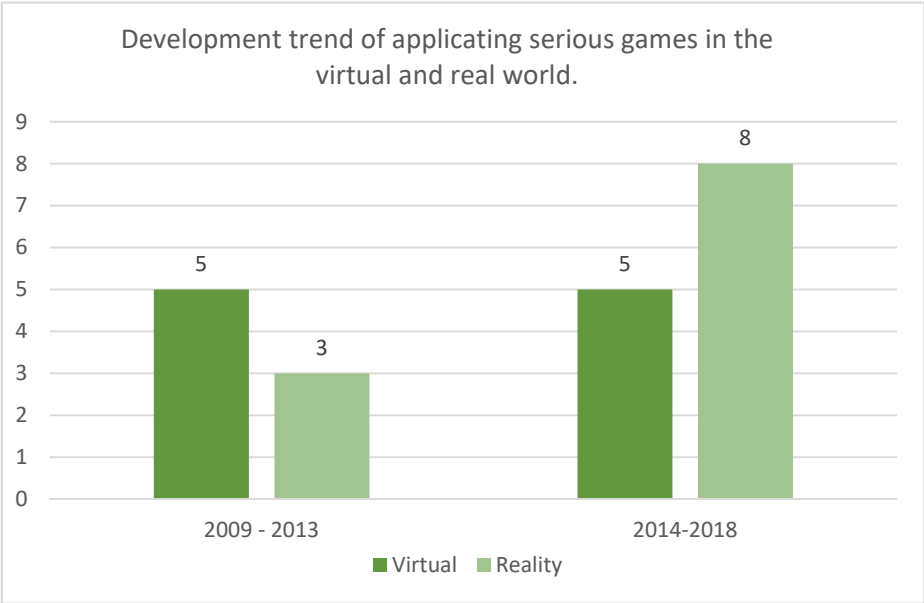

Figure 3. Development trend of employing serious games in virtual and real world.

The third trend of serious games on energy consumption is the development of the level of education. As the previous section presents (see Table 3), half of the energy-related serious games are classified into Level 3, which occupies 50%. The significant social impact of the energy-related serious games is imperative for changing the end-user's behaviour. However, the serious games that are classified into Level 4 account for 38.9% (see Figure 4). This means that the next phase of developing energy-related serious games is focusing on the end-user's engagement and behaviour change, which will help to reduce energy consumption and enhance the impact of the serious game strategy on the end-user's energy use in the real world.

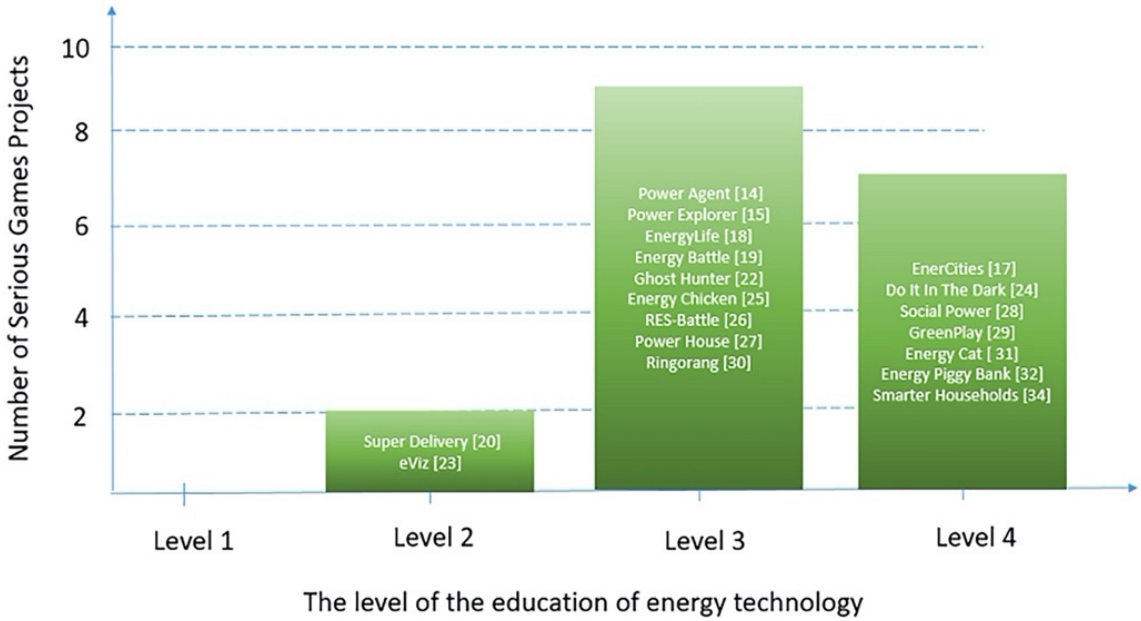

Figure 4. The social impact of the level of education of energy technology.

3. Categorisation of Serious Game Applied for Buildings

A clear categorisation of serious games applied for buildings can help further research in this area. The existing classification of the serious games related to eliciting pro-environmental behaviours for energy efficiency is based on different areas—*environmental education*, *consumption awareness*, and *energy efficiency behaviours* [44]. This section emphases three types of classification for buildings, based on the applications for the building types and energy types, data resources, and end-user engagement degree.

3.1. Categorisation Based on the Applications for the Building Types and Energy Types

The category of serious games based on the applications for the building types and energy types can be seen in Table 4. It can be seen that serious games on energy consumption are mainly employed in the house, which is the case for over half of all the serious game projects. Meanwhile, they are also widely applied to different building types, including the dormitory, shopping mall, office building and urban area. Furthermore, electricity is used as the main energy type to examine the application of the serious games on energy consumption. There are also a series of projects using other energy types, such as the eViz [27] and Smarter Households projects [38].

Table 4. Categorisation, based on the building types and energy types, of serious games.

Building Types	Project Numbers	Energy Types	Project Examples
Dormitory	2	Electricity Electricity	Energy Battle [23]; Do It In The Dark [28]
House	12	Elect., remote heating Electricity, CO_2 Electricity Electricity Temp., ventilation and heating Electricity Electricity Electricity Electricity Elect. and gas Electricity Elect., gas, CO_2, temp. and humidity	Power Agent [18]; Power Explorer [19]; EnergyLife [22]; Ghost Hunter [26]; eViz [27]; Power House [31]; Social Power [32]; GreenPlay [33] Ringorang [34] Energy Cat [35] Energy Piggy Bank [36] Smarter Households [38]
Shopping mall	1	Electricity	RES–Battle [30]
City	2	Electricity and CO_2 Electricity	EneCities [21]; Super Delivery [24]
Office building	1	Electricity	Energy Chicken [29]

3.2. Categorisation Based on the Data Resources

The categorisation of serious games based on the applications for the building types and energy types can be seen in Table 5. Over half of the serious game projects have started to adopt real data as a resource into the game. There is only one serious game using real-time data.

Table 5. Categorisation, based on the building types and energy types, of serious games.

Data Resources	Types of End-User Engagement	Serious Game Project Examples
Virtual data	Education-oriented serious games	Power Explorer [19]; EnerCities [21]; Super Delivery [24]; eViz [27]; Energy Cat [35]
Real data	Simulation-oriented serious games	Power Agent [18]; Energy Battle [23]; Ghost Hunter [26]; Do It In The Dark [28]; Energy Chicken [29]; RES-Battle [30]; Power house [31]; Ringorang [34]
Real-time data	Application-oriented serious games	EnergyLife [22]; Social Power [32]; GreenPlay [33]; Energy Piggy Bank [36]; Smarter Households [38]

3.3. Categorisation Based on End-User Engagement Degree

Serious games present a significant advancement in how to interpret an end-user's energy-related behaviour and further correlate with behaviours in the real world [45]. One of the best ways to encourage an end-user's energy-related behavioural change may be to increase empathy. The research found out that people were more likely to adjust their behaviours when they perceived the consequences for other people of their behaviour—even when virtual [46]. It could be an effective way to increase empathy

and further behaviour by providing stories, images, and simply a good example. Human–computer interaction has been widely seen as a useful tool for evaluating subjective factors such as motivation and behaviours [47]. Quite a few studies on building energy consumption focus on the effect of serious games, a human–computer interaction tool, to stress effective learning transfer as well as engage end-users [18,48,49]. It is not possible to evaluate learning outcomes through the application of serious games if they are simply not attractive games [50]. This section, therefore, attempts to classify serious games through the different degrees of end-user engagement. Three types of serious games are education-oriented, simulation-oriented and application-oriented.

3.3.1. Education-Oriented Serious Games

This type of project exploits game technology and game design principles in an attempt to rise above pure entertainment through the addition of layers of simulation, learning and decision-making approaches to evoke an end-user's awareness of energy consumption in real life. Through employing virtual data relating to energy consumption and conservation in the virtual environment, this type of serious games seeks mainly to shape the player's behaviour regarding energy-saving issues. The mechanism for achieving this is associating the player's performance and score with sustainable decisions and actual energy savings. Education-oriented serious games offer clear ways of influencing specific behaviours, such as switching off appliances or using more efficient equipment. They are normally targeting specific groups, such as children, students and adult households. The advantages of the education-oriented serious games simplify the complexity of real life into a virtual environment. Inspired mainly by active learning, this serious game proposes an immersive learning mode to develop critical thinking and motivation. The interactive environment provided to the player is a virtual environment that recreates daily situations of energy consumption relating to the real living environment.

However, even though education-oriented serious games can allow players to deploy several scenarios and experiment in different ways, to let them experiment and experience the potential effects that individual actions can have on the planet before it is too late, as well as investigate the long-term consequences of their actions, the transfer of this learning to real life may not be straightforward.

3.3.2. Simulation-Oriented Serious Games

This type of serious game aims to guide end-users to reduce daily energy consumption, increase energy efficiency and seek the best renewable energies. With proper advice in relation to economy, the environment and society, a set of real energy-consumption-related data, collected from end-users in real life, is monitored to seek potential strategies for reducing energy consumption. It is up to the end-user to make the appropriate decisions to lead to an improved future. To some extent, simulation-oriented serious games require end-users to play an engaging role, with a strong incentive to output private energy-related data and make appropriate decisions. Their main characteristic is that while holding a comprehensive selection of information, they do not attempt to replace a course in the field. The game succeeds in illustrating the key concepts linked to sustainable development and stresses energy-related debates in society.

A weakness of the game is that one game can only be used in specific building types. The control of the engineering parameters is representative but not concrete in detail. Furthermore, the database collected can only be used as the condensed output information rather than detailed hourly or monthly values. The calculations are not automatically calibrated to measured consumption. However, the simulation-oriented serious game offers a benefit over the other education-oriented serious games considered here in that it is much easier for the player to connect gameplay to their everyday behaviours. By suggesting efficiency products and improvements specific to the player's own home, the gap between the virtual world and real life is reduced.

3.3.3. Application-Oriented Serious Games

The application-oriented serious game is a type of serious game employing real data or even real-time data in the real world to visualise the invisible energy-related data. This type of serious game is tending to be used as a product to guide end-users for better coping with daily energy issues and shaping an end-user's sustainable daily load curve.

Taking the Smarter Households [38] project as an example, the IMSS system, comprising electricity and gas monitoring, along with sensors measuring carbon dioxide, humidity, indoor temperature and outdoor temperature, is installed into 20 households for 18 months to collect their real-time energy and indoor environment data. Meanwhile, the householders are engaged by serious games and a relevant educational package on a low carbon lifestyle. The real-time data can be visualised by end-users, and they can decide further action in relation to reducing energy consumption.

However, becoming proficient in application-oriented serious games and the complexity of the parameter settings necessitate more time to manipulate energy-related data. Furthermore, how the application-oriented serious games could be applied in the wider population to further enhance the engaging function of the serious games in building energy consumption must be well considered.

4. Discussion

4.1. Dimensional Evaluation Frameworks for the Serious Games on Building Energy Consumption

It is not possible to integrate resources and translate the iterative cycle into one sufficiently pragmatic serious game due to resource constraints. Consequently, different serious games on building energy consumption are generated for different programmes. It is not a sustainable route and contributes insufficient research for ensuring valuable feedback into the next cycle. One serious game may not be applicable to another. If the pedagogical elements are involved in serious games and the aims of serious games transfer to training and even persuading people to increase awareness of energy consumption, the challenge may be tackled. Therefore, serious game designers attempt to involve pedagogical elements to tackle the challenge [2]. Documentation plays a significant role for the methodological approach [51], and the existing development of e-learning methodologies is a good example of that. By attracting and retaining learners, serious games can emphasise instructional content with little affordance. Dimensional evaluation frameworks in support of developing and deploying serious games in pedagogical contexts are emerging. The research on the case of ubiquitous games notices the significance of access to data and gamification [52]. Consequently, the fourth-dimensional framework was created in order to support the design and evaluation of educational games.

The four dimensions can broadly be described in the following terms:

(1) *A process of profiling and modelling the learner and their requirements.* This step ensures that the learning activities match the required outcomes. However, profiling itself can be a complex process, particularly in the case of distance-learning scenarios wherein a broad demographic is targeted and may respond differently to game-based learning [53].

(2) *A learning and teaching model to support the learning process.* This step analyses learning activities through the pedagogic perspective. A particular challenge here is merging the need for comprehensive pedagogic support with the need for engaging gameplay dynamics [2].

(3) *A representational dimension.* It includes how interactive the learning experience needs to be, what levels of fidelity are required, and how immersive the experience needs to be, as well as the world of experience and how the levels of engagement and motivation are affected. This is typically a combination of pragmatic and theoretical concerns; higher fidelity is typically accompanied by a higher budget. However, research has also suggested higher fidelity is not necessarily related to more rapid or comprehensive learning transfer and, in some cases, may even be to the detriment of usability and, returning to Davis' model [54], uptake [55,56].

(4) *A simulating context.* It involves the place where learning is undertaken and which subject area is being studied as well as the supporting resources used for learning. Online learning contexts are increasingly gaining relevance, as support for game-based learning is a natural evolution of the technology-enhanced learning environment [42]; however, these also bring particular challenges in eliminating or reducing the role of the facilitator [57].

Fundamentally, any design methodology intended to be applied specifically to serious games often struggles to be generic as a consequence of both sector specificities in expectations and requirements, and differences in fine-grained aspects such as software development. Iterative approaches to game development, for example, development along a spiral model [58], have high costs associated with each iteration, a result of the need for both extensive user testing and the disposal or adaptation of content in response to findings. When such an evaluation must also incorporate an evaluation of the efficacy of pedagogic elements, this cost can easily increase.

4.2. Approach and Design Stratagem for the Serious Games on Building Energy Consumption

A few years ago, in an article remaining as relevant today as it was then, the first conclusions from the Cape Light program pilot test for energy-saving behaviour modification were published. These suggested four major phases: (a) the "get participants to set goals" phase; (b) the "ask for greater commitment as you go" phase; (c) the "use points as rewards" phase, and (d) the "help people teach and encourage one another" phase.

A closer look at these four phases reveals that all four phases are almost naturally following the individual phases of a computer game and could effectively be turned into a serious game scenario. In the first "get participants to set goals" phase, the player is asked by how much they wish to reduce their electricity consumption for the coming estimated duration of play. The average goal is set from this figure. Setting goals is a key step in every behaviour modification procedure because setting goals helps a person move from interest to tangible commitment. In the second "ask for greater commitment as you go" phase, suggested actions help participants meet their goals and actually put the serious game scenario into motion by making suggestions specific to the end-user's situation. Simple tasks are suggested first, to make initial participation easier and get the end-user successfully through the training cycle. After training the end-user on how to collect the relevant pieces of information only for the task at hand, the serious game scenario can turn into getting the end-user to start seriously considering more significant engagement, thus putting them on the path to consistent behaviour change. The "use points as rewards" phase is a very important factor in every computer game scenario and remains so in the serious games field. Doing something deemed as positive within the boundaries of the serious game scenario is rewarded by points, mirrored directly by real-life elements such as committing to an action, reaching a goal on a particular day, et cetera. In the final "help people teach and encourage one another" phase, social-networking features in the serious game scenario encourage learning through questions asked, comments, recommendations and direct energy usage comparison with others.

Serious games in the area of energy-consumption and energy-saving behaviour modification mainly employ simulation, and educational and practical methodologies for increasing energy-consumption awareness. Future designers have much to gain from a study of the existing methodologies and features realised in today's state-of-the-art serious games in the field, and in order to provide a solid basis for this direction, here are discussed representative serious games in each area in some level of detail regarding their methodology, targeted group and gameplay approach. The types of real-life energy-using behaviours should be paid more attention because they may be changed through gameplay, where applicable. Where conceivable and for keeping the descriptions of the purposes, design methodologies, etc. as close as possible to those put forward by the game designers themselves, descriptions have been taken from the corresponding serious game official web sites. The interested reader can find all the relevant URLs in the references section.

4.3. Validation, Trial and Results Evaluation of the Serious Games on Building Energy Consumption

As the research results showed, serious games have a significant potential to impact individuals by establishing a reward mechanism. By revealing opportunities for productive change and providing the feedback needed, this tool can generate significant change in energy-related behaviour. Compared with the other energy-conservation and consumption strategies, the results of using serious games have practical implications and contribute a solid database on shaping an end-user's energy-related behaviours. Consequently, it is proved that serious games can be deployed as a workplace energy-management and stimulating tool for energy consumption.

5. Conclusions

The proposed paper presents an extensive review of energy-related serious games based on serious game projects in recent decades. The paper set the evaluation criterion based on the level of the education of the energy-related serious games, discussed the development trend of serious games on energy consumption, and classified serious games applied for buildings based on the building types, energy types, the data resources and end-user engagement, by reviewing serious games' approaches to the problem. The concept of gamification as the application of digital game design techniques to the energy-consumption question has been given special treatment, mainly because the world of possibilities available through gamification is directly applicable to the energy-consumption sector. Energy-consumption monitoring, related data gathering and the provision of feedback to the consumer through a visualisation system are only half the story in what effective energy-consumption management and energy policy involve. The investigation and past experience in the field strongly suggest that the elements of active engagement through "real world" events have been considerably underestimated in past investigations. Without a clear connection between gameplay and real-life behaviours, it is very difficult for the consumer to make optimal decisions in terms of reducing their consumption. A serious game that effectively provides the link between the energy grid and the energy consumer can prove itself as a valuable tool in changing consumers' energy consumption behaviour.

Despite the fact that some serious games addressing energy-consumption-related issues are now commercially available, the significant new opportunities for the development of serious games in the field (real-time monitoring, sub-metered energy usage, the condition monitoring of services and appliances, and consumer coalitions/clusters) have by no means been explored to their full potential. As a result of these factors, a whole new field of serious games looks to be emerging, slowly but steadily, with the capability to become a new hotbed of activity. A serious games environment along with an appropriately designed gameplay concept can introduce revolutionary relationships and methodologies of interaction between Small Scale Consumers such as household owners. This is the most common type of consumer, with every family or single person occupying a house, an apartment, etc. qualifying as an active household consumer. As individuals, they may possess limited energy-consumption understanding or energy-saving capabilities, but when they are grouped in small or large-scale clusters, the more-or-less fluent flow of information considerably increases the possibilities of the correct information and messages being distributed. The central role in this procedure is held by the serious game's real-time feedback (part of the general gameplay concept) provided to the end-user. The coalition of consumers into clusters through gameplay is quite a novel concept that can be possibly more effectively enforced through a serious game than it is through a multiplayer game mode. The promotion of and participation in activities related to energy efficiency are also feasible within this context. In general, the cluster can be visualised as a social structure, consisting of a serious of nodes, which are tied by specific types of interdependency, such as values, friendship, etc. Due to its own inherent complexity, the cluster has a complex graph-based structure, which provides an opportunity for serious games to simplify it through the gameplay structure.

There are three major characteristics a future gameplay design within the framework of the serious game needs to possess in order to provide the player with an engaging and, at the same time, educational environment: (a) a real-time monitoring capability for energy consumption, which can be proved

invaluable for decision making, saving money and carbon credits; (b) monitoring sub-metered energy usage, which can lead to informed recommendations for savings; and (c) the condition monitoring of services and appliances to detect changes in efficiency or performance. The three elements mentioned above are of equal importance and possess the capabilities required to lead to gameplay scenarios that are more relevant to real situations, in collaboration with the deployment of more advanced feedback systems. Meanwhile, based on open energy models and associated data, a reinforced co-evolution of the energy technology and human behaviour realms could potentially stimulate the development of serious games on energy consumption [59]. As a final comment on future serious game designs in the area of energy consumption, there are two major challenges to be tackled: (a) the identification of a range of internet-enabled services to be offered, and (b) the development of an internet-based communication and multi-stream data processing system. In a second stage, and serving as a proof of concept, the establishment of workable and well-tested deployments within occupied buildings is needed.

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