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Review article

Internet-of-things-enabled serious games: A comprehensive survey

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ABSTRACT

Internet of things has been one of the predominant research areas for the past two decades. Many application domains have embraced it to solve challenges that have long been considered hurdles. A recent trend in information communication technologies is integrating miniature sensing devices to elevate the experience in serious games. Serious games are games whose sole aim is not entertainment but rather to serve as a source of information and learning in a playful manner. Serious games are becoming one of the sizzling literature topics and are applied to every part of human lives, such as education, healthcare, and physical training, to name a few. Internet of Things, the biggest provider of modern-day games via personal mobiles, can be utilized to design serious games. However, deploying serious games in the Internet of Things environment engenders new challenges. This paper aims to provide a comprehensive survey on Internet of things-enabled serious games and investigate the challenges towards their realization. First, we highlight serious game domains and spot the evolution and motivation that lead to Internet-of-Things-enabled Serious Games. Later, we classify the state-of-the-art by devising a comprehensive taxonomy. In the end, we present numerous unaddressed open challenges in the current form of the state-of-the-art and identify future directions.

Contents

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1. Introduction

We live in a COVID era in which all the normal operations have been disrupted. From offline to online classes in education, emergency situation in hospitals, and the persistent restriction affecting people's mental health are some of the worst effects of this era. Serious games have been effective in education and healthcare. Still, its true potential has yet to be unearthed, which can play a pivotal role in remedying mental health and maintaining quality education considering online mode. Serious games in which the focus is tilted towards a serious job rather than entertainment [1] is termed as serious games. Serious games have proven to be remarkably productive not only as a learning tool in many domains such as engineering, healthcare, physics, and history [2] but also in playfully achieving a particular job.

Artificial intelligence (AI) technologies have moved games to the next level. The gameplay in earlier serious games was based on experience and prior knowledge and sometimes secured from humans in the form of surveys and questionnaires [3]. Nevertheless, these experts-based data get outdated with the passage of time since the nature of the data is static and is not updated with the newer strategies of the players. [4,5] is the realization of a vision where everything in the real world would interconnect and make smart decisions [6]. The plethora of miniaturized sensing devices generates real-time contextual information that can be exploited to make informed decisions [6]. Over the past few years, many application domains have embraced IoT to provide smart services and add more value to human lives [7].

Consequently, IoT has a huge potential to become a key enabler of modern-day gaming; a traditional game with a dedicated terminal's support can be converted into a smart game while played with remote mobile devices acting as IoT node [8]. There are challenges for IoT connectivity of game agents, which are not yet among the standard approaches, and very few studies have indicated the potential use [9,10]. Nevertheless, serious games' effectiveness has considerably increased with IoT nodes' proliferation, sensing ambient scenarios, and providing real-time contextual information rather than human-based static data from questionnaires. Combining serious games with the IoT ecosystem's interconnected physical hardware develops more data-driven games, and a better-informing games agent when the game progresses [9]. Consequently, there is a considerable rise in the use of IoT-enabled Serious Games (IoTeSG). In some studies, such games are referred to as Smart Serious Games (SSG) [8,11].

One of the challenges in IoTeSG is the management of enormous volumes of real-time context data generated from sensing nodes. The introduction of AI has revolutionized games and equipped them with powerful tools and procedures to make smart agents taking informed decisions. Modern-day games have become intelligent due to AI and machine learning advancements. It is envisioned that Deep Reinforcement Learning (DRL) is poised to revolutionize games with a high level of visual understanding [12]. The success of DRL can be witnessed by AlphaGo, which is the first computer game to beat a three-year human champion. DRL received particular attention in gaming and redefined a new way to approach the game with intelligent background processes.

IoTeSGs are pervasive in nature, and thus, it demands an environment where users can play anywhere and anytime without the need to be on a certain premise. Ensuring fairness of play and synchronization of time and location is another challenge worth considering for successfully integrating serious games with the IoT. Similarly, IoTeSGs can also pose security threats due to data transport and data persistence using public networks and clouds. Although edge and fog computing can overcome some of the limitations in using public platforms, it has limited processing capabilities and is yet to be investigated for computational intensive games.

Some studies [10,11] briefly consider integrating serious games with IoT and answering primitive questions such as the architecture change, game design change, and the communication protocol. Nonetheless, there is not a single comprehensive survey on IoTeSG based on an extensive literature study to present all the possible aspects of IoTeSG. Considering its rising need in the current situation, this article is the first attempt, to the best of our knowledge, to present a comprehensive survey on IoTeSG. We cover the background of serious games and overview some of the common application domains, their evolution in the context of IoT, and the integration of IoT with other contemporary technologies in relation to the games. Furthermore, we present the taxonomy of IoTeSG based on IoT and serious games' requirements using a thorough search of different databases. As mentioned above, IoTeSG presents different challenges, so part of the survey is dedicated to summarizing these challenges and unaddressed open issues that we perceive to be crucial research directions in the future.

1.1. Contribution and scope

This survey outlines current state-of-the-art methods relevant to integrating IoT and serious games. While we also highlight the work done in IoT for games primarily focused on entertainment purposes, the motive is to provide background knowledge and cover the challenges common to all games. We also highlight the introduction of IoT-enabled games for a serious purposes such as strategy planning, understanding, and education. Notice that a serious game can be played with powerful PlayStations or a simple IoT node such as a mobile phone. This survey aims to highlight such differences and parameters that can be considered for new state-of-the-art methods. Many useful surveys exist in each respective field of IoT and serious games. Still, there is no good source of information in which these technologies work together to form a new array of state-of-the-art methods, and this paper aims to fill this gap.

1.2. Data collection

This survey investigates the chronological progress of state-of-the-art different serious games and IoT in parallel. We narrowed down the domain of this study to focus only on serious games

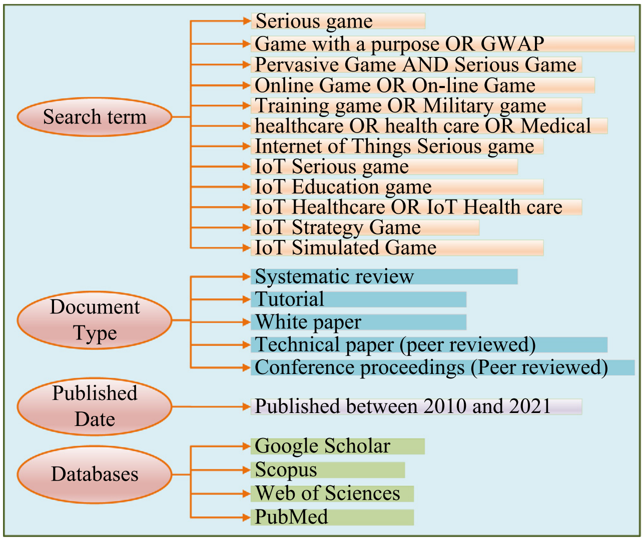

Fig. 1. Data collection criteria.

and in the context of solving a specific set of problems in the IoT environment. The search queries are performed on various types of games and numerous combinations of IoT keywords with each game category. There are different terms for serious games, such as Game With a Purpose (GWAP), educational games, and exergame, to name a few. In the data collection process, we query all possible combinations with IoT. We consider systematic reviews, tutorials, white papers, technical papers, and peer-reviewed conference papers published in the last decade across most different databases. Fig. 1 shows the query structure executed on four databases; Scopus, Web of Sciences and Google Scholar, and PubMed.

1.3. Organization

The survey is organized as follows; Section 2 provides an overview of serious games and IoT. It covers the common requirements of games and IoT and integration scenarios of IoT with different technologies. Section 3 classifies the state-of-the-art and presents a comprehensive taxonomy of IoTeSG. Section 4 illustrates challenges and unaddressed open opportunities. Section 5 concludes the survey with the significance and future directions.

2. Background and foundations

This section presents the background and state-of-the-art methods applied to modern-day serious games. Serious games are thought of as a virtual environment provided to the user to solve different problems. The environment can be immersive in which the user physically interacted with the environment, such as immersive virtual reality (VR) and augmented reality (AR) games. This virtualization encourages games nodes to get connected to the internet in either case. The connectivity of each game node can provide massive insight into the agent mode of playing and their expertise. In the following subsection, we critically analyze the architecture and characteristics of IoT and serious games based on popular literature studies to help understand the core of this survey.

2.1. Overview of serious games

Games are considered an integral part of communities. Games are entertainment and learning sources and have constantly been evolving since the ancient past. Computer-enabled games are ubiquitous and can be utilized for serious purposes such as healthcare, education, and strategic planning, to name a few. The first reference to the word "Serious game" was made way back in 1970 [13] in the context of a board game primarily designed for educational purposes rather than entertainment. The term serious game was still rarely used until 2002 when a first-of-its-kind Serious Game Initiative (SGI) was formed. One of the central goals of the SGI was to harness the capabilities of video games for serious jobs [14]. Afterwards, many literature studies [15–17] analyzed the concept of serious games.

A relevant term Gamification is used in a scenario in which game elements are used in an environment outside games [18], while a serious game provides a game environment to do a serious job. Twitter, LinkedIn, and other popular ventures utilize game elements such as Badges, Leaderboards, and other elements to make it feel like a game and engage visitors effectively. Although it can be considered a serious game, we aim to consider pure serious games in this survey. The timeline of important milestones from 1970 till 2020 has been elucidated in Fig. 2. First book on Serious game was published in 1970 [13] and in the same decade popular games such as Magnavox Odyssey [19] and The Oregon trail [20,21] have also been designed. Both these games are designed for educational purposes.

In the next decade, games such as Battlezone, Bradley trainer [22] and pole position were designed to unearth that serious games are not just for education but can also be exploited in other domains such as training and military deployment. One of the massive breakthroughs came in the form of the Microsoft flight simulator, which was the first of its kind real simulator of flight and, to date, has been widely used in aviation. In the next decade, another domain for which serious games could be designed was revealed in the form of the Marine Doom [23] game which provided a great deal of facilitation to the United States marine corps devising strategies against enemies and other threats. In the 21st century, an initiative was formed that formally recognized Serious game as a distinct research area, and afterwards, systematic literature was started.

In the first decade of 21st century, strategy games such as VBS1, America Army, and Darwars were developed. Similarly, there were also instances of serious games for training in which BiLAT was among the notables [24]. In the past decade, serious games were even more rectified with the advancements in supporting technologies such as VR and the IoT. In 2013, Minecraft [25] game was developed as a link between gaming and education. In a study in 2016 [26], it was revealed that frequent user of Minecraft game has stronger brain cells and have the chance to excel more among the age group in computer programming. Minecraft game design pattern is applied in other application areas such as personal learning and digital citizenship [27]. Nevertheless, kids exposed to social games such as Minecraft are more susceptible to social evils such as bullying and resource theft. Moreover, the addictive nature of the game can cease the opportunity to take part in healthy physical activities [28].

2.1.1. Serious games domains

Some of the most commonly used application domains in which serious games are used are mentioned in the following paragraphs. The games' visual interfaces from the past decade are exhibited in Fig. 4.

Education: The initial thoughts behind serious games were to educate people in a fun way, and thus it was the vital motive behind the invention of serious games. Serious games are one of the most effective means of learning as they influence the mood of the learner [29]. The learner's mood is vital in learning, and one of the advantages of serious games is to model a positive

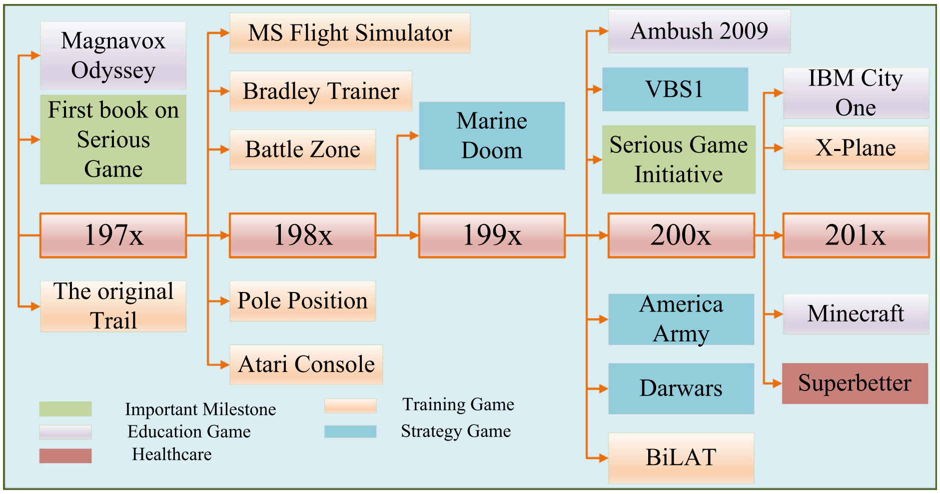

Fig. 2. Serious games evolution and historical milestones.

mood to encourage the continuation of play for a long time. There are quite a few subcategories for which different serious games are designed. A majority of the work is dedicated towards science education [30], medical education [31] and pharmacy education, to name a few.

Nevertheless, serious games bring a significant improvement over traditional pedagogy. For instance, Zhonggen et al. [29] in his survey highlighted that serious games facilitate learners' perception of scientific concepts [32], helps in nurturing learners' cognitive abilities, provide flexible learning [33], enhance the outcome of learning [34]. Moreover, it can increase the positive effect of learning and develop teaching science as a subject [35]. Some educational games, such as Skill Arena, are aimed at a conventional classroom facilitation [36]. These games address the challenges identified by Cheng et al. [30] relevant to pedagogy dimensions such as a subject domain, educational theoretical foundation, instructional strategy, and pedagogical role, to mention a few.

Healthcare: Healthcare is another primary application domain of serious games. Healthcare industries are always looking for innovative methods and strategies to enhance human beings' health. Serious games are well poised to play their role in healthcare. Over the past few years, various serious games have been developed to improve the general practices in healthcare industries and help the learners understand complex yet vital concepts. Some games are deployed as a quiz, some of them are mere simulations, some are board games, and some are well-rounded adventure games. They aim to understand and nurture the masses' interactive understanding of the domain knowledge. eMedOffice, GeriatriC, and InsuOnline are some of the serious games widely used in healthcare.

Exergames: Exergames [37] are serious games designed to assist users in performing exercises in a game. Games such as Dance–Dance revolution and Wii Sports are a class of exergames often known as active video games [38]. Exergames targets audience who may be reluctant to other forms of traditional exercises and prefers a sedentary lifestyle or people who have some diseases, such as diabetes, which require exercise but due to weakness do not have the motivation to do conventional exercises [39]. Exergames have particularly attracted older adults' attention due to their life stage and problems with going to offline training facilities. There are numerous incentives for exergames. Whitehead et al. [40], for instance, highlighted some of the advantages exergames offer to motivate users who do not usually prefer going out and carrying out physical activities. Similarly, it can also offer a customized experience that varies from user to user depending on the preference, job nature, age, and medical history. In addition to diabetic patients and older people, exergames are also proving to be significantly effective among obese people. Höchsmann et al. [41] in a survey elaborated on the effectiveness of exergames on obese people by extensive survey over the literature spanning across previous ten years. The authors selected different parameters: oxygen uptake, energy expenditure, and heart rate, to assess the exergame's effectiveness on the player. It was concluded that there are evidences that the game trials resulted in improvement of metabolism [42,43], heart rate [44,45] of the player. Similarly, it was also identified that the mean oxygen consumption was increased during exergame play by 316% [43], minimum 78% to maximum 200% [42].

Training Games: Serious games have been widely designed for training purposes due to their effectiveness in training. The game's addictivity makes the trainees motivated and engaged in contrast to the otherwise conventional method that can be boring at times. Scenario-based simulation games can play a vital role in comprehending verbal and non-verbal behavior to adapt to socially challenging situations from the gamelike experience [46]. Serious games for training can be considered a super-category for other types of games such as education and healthcare due to the same end goal [47]. Some of the significant application areas of the training-based serious games are social skills training [46], corporate training [48], faculty development [49], emergency evacuation training in case of unforeseen situation such as earthquake [50], employee training [48] and healthcare training [51] are among the notables.

Strategy Games: In strategy games [52], the aim is to find optimal strategy based on real conditions or data from the experiment. One of the strategy games' goals is to build the game agent's insight with time for it to make an informed decision in a similar situation. Based on the incentives and penalties given in the past, the strategy can be optimized to correct the behavior, draw incentives, and avoid penalties [53]. Strategic games are aimed at small goals such as nurturing arithmetic concepts of children [52] to the real-time mission such as flying jet simulation. Strategy games are good candidates for areas where there is no single solution, and a better solution should be selected among the possibilities. For instance, dynamic table assignment [54] to customers in a restaurant and revenue management policy development are some examples evident in the literature to search for optimal strategy in a gamelike environment. Real-time strategy (RTS) games, which are a subcategory of serious strategy game, has gained wide popularity [55]. RTS's key aspect is to create human-like game agents that are context-aware and can adapt

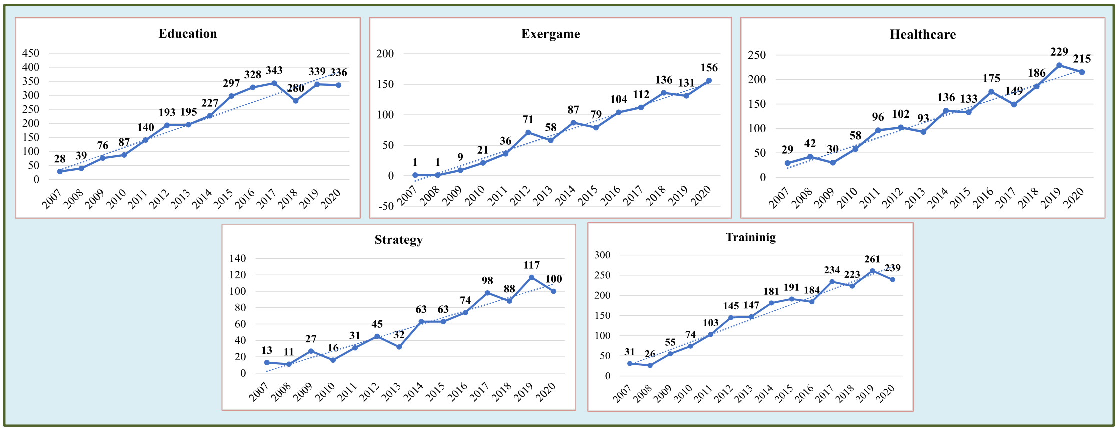

Fig. 3. Serious games trend and publication statistics in different applications domains.

Fig. 4. Examples of serious games in education and training from the past decade.

themselves with varying contexts [56]. RTS games are a more recent form of serious strategy game and demand the integration of new techniques such as sensor networks, VR, IoT, and AI.

2.1.2. Research trend in serious game

Research on serious games has significantly increased over the past decades. Before 2002, there were occasional references to the term Serious game. Since the SGI, the term got wide acceptance, and different researchers across the globe have found it an exciting research area. In order to investigate the research trend in different categories of games, the Scopus database is searched for the appropriate term, and the results are gathered from 2007 to 2020. Fig. 3 portrays the number of research articles each year for each serious game application domain. Overall, the trend-line for all the domains has a positive slope, which signifies considerable growth. Some games such as education, training, and exergame have a very steep slope, which indicates the impact of serious games on education. Thus, more and more research articles are contributed over time.

2.2. Overview of IoT

Ashton Kiven first coined the term IoT in 1999, and it gained significant attention in the following years. IoT is a crucial enabler of transforming common technologies and application areas to the next level. Smart cities, smart health, smart grids, the industrial revolution, and autonomous cars are some of the notables. Serious games have also embraced IoT, and different studies have been carried out as a step forward towards its realization. The term "IoT" is one of the widely used terms, yet it has no standard definition [57]. However, different authors have subjectively defined the term, yet the goal of the IoT is common among all of them [58]. In this paper, we define IoT as a network of addressable and uniquely identifiable physical objects, "Things" which enable the creation of massive contextual data in real-time to support data analytics for the future.

IoT-enabled technologies have two distinct sets of requirements; IoT general requirements and integrating technology domain-specific requirements. Following are the general attributes of IoT applications.

Resource Management and Control: One of the fundamental characteristics of IoT applications is the ability to manage and control resources. Every registered resource must be uniquely represented and persisted. In case the persistence is distributed, the server(s) in which the resources are hosted must be tracked, and the consistency of the instances of the same device must be insured. Moreover, they can be controlled from anywhere [59,60].

Power Management: IoT involves the interconnection of a massive number of sensors and actuators over a wireless sensors network. One of the crucial requirements for IoT is the design of low-power sensors that do not require battery replacement over their lifetimes. This introduces a challenge for energy-efficient design, and low-power communication [61]. Therefore, for the integration of IoT and serious games, a wide range of energy-efficient and power-efficient solutions need to be considered [62,63].

Interoperability: The resources must be pervasive and ubiquitous, i.e., even though the devices can be from different vendors, they can be seamlessly accessed [64].

Security: IoT devices have constrained capabilities and thus have no intelligence to detect the access to be authorized or not. It is a severe security concern, and part of IoT is to instate a lightweight security protocol to avoid such malicious attacks without draining much of its power [65].

Scalability: The IoT application must be scalable if more devices are registered. Supporting scalability up to millions of devices can have incumbent costs. Still, considering the vision that every object will be connected to another in the future, scalability is of paramount importance [66].

Analytics Support: IoT devices generate massive sets of data. Modern IoT applications must have the ability to stage the data and carry out insight on the data to make better and informed decisions in the future [6].

Communication: IoT devices should be addressable and controllable (resource control). Thus, the devices must be connected and have the means to communicate within a network or outside a network. Inter-network communication is preferably performed via the HTTP protocol. In contrast, intra-network communication, i.e., device-to-device communication, can be made with specialized lightweight protocols such as CoAP, MQTT, and LoRAWan, to mention a few. However, the latter can also be performed with HTTP to avoid any middle-layer translation [59,67].

Architectural Patterns: IoT has a set of different requirements, while serious games have a completely different set of requirements. Therefore, prior to integrating IoT and serious games, the architecture aspect of IoT should be introduced. There are so many studies aimed to standardize the architecture of IoT, yet the technical specifications and reference architecture are not standard; however, there are various architectures proposed for different areas of applications [68]. The common layers are the application, network, and physical layers. These layers have expanded into multiple sub-layers depending on the application category. Delay-sensitive applications require the bypassing of certain layers such as middleware to boost the performance [69,70]. Similarly, enterprise-level applications demand a more stable architecture [61]. Though the main layers are more or less similar, the underlying sub-layer changes as per application nature and requirement. A variety of open-source platforms are developed to provide services for the users. Some platforms are based on service-level orchestration [71] while some recent platforms have encouraged the use of task-level orchestration. Task-level orchestration [61,69,72] is considered a more scalable and flexible approach and is well-suited for real-time IoT applications. In addition to orchestration, virtualization also plays a pivotal role in IoT architecture.

Nevertheless, some popular architectures are considered the basis for modern IoT architecture. One of the notable architectures of earlier IoT is a three-layer architecture proposed as a European research project [73]. MediaSense is another notable effort by Swedish researchers. In modern IoT, the cloud of things (CoT) and the web of objects (WoO) are among the contemporary architectures that utilize virtualization to store sensors and actuators' virtual representation in the cloud. There are some service-oriented architecture [71] which has been used as a connection of functional unit (services). The do-it-yourself (DIY) paradigm uses a service composition plane to allow non-technical users to constitute their services without any coding skills [74].

Finally, service-oriented architecture (SOA) is yet another powerful solution for integrating heterogeneous devices to realize interoperability among them, irrespective of their diverse nature. SOA refers to a programming model that may aid in integrating serious games; through supporting interoperability and information exchange among heterogeneous devices [75]. SOA is a middleware solution that hides different device vendors' technical complexity and provides a uniform front for consumers, thus making the access transparent. The use of SOA is favored in many recent studies when it comes to the integration of IoT with different domains such as industry 4.0 [76].

2.3. IoT meets modern technologies

IoT has evolved over the past few years and embraced existing technologies to enable smart systems. The advancements in healthcare, waste management, recommendation systems, education, and smart grids would not be possible without IoT. In the following section, IoT areas are discussed briefly as part of the foundation of IoTeSG.

Artificial Intelligence: AI and IoT are the backbones of smart cities' transformation. The integration of AI made the applications intelligent to predict future decisions. Conventional IoT systems deal with mere communication with devices via the Internet. The use of AI technologies such as deep learning, recurrent neural networks, and decision trees has significantly impacted smart cities' transformation. For instance, AI platforms such as Bonseyes acting as a data marketplace and learning toolbox can be integrated into pure IoT platforms such as FIWARE to different smart systems. According to the current state-of-the-art methods, the data generated by IoT devices are staged in the cloud. AI algorithms are applied to the data, and the trained model is hosted on the IoT gateway. However, the recent trend is to make lightweight machine learning techniques to move these processes closer to the devices and enable time-sensitive applications.

Blockchain: Blockchain technology has initially found a way in the financial and banking sectors; however, it did not take long to use blockchain in other domains. In recent years, blockchain has been used in healthcare, greenhouse, smart grids, etc. The robust consensus protocol in blockchain and the data's distributed persistence make the application robust and secure. IoT application security has always been a massive hurdle, and with blockchain, IoT applications have become more robust and secure.

Cloud Computing: Cloud computing offers many advantages, such as the on-demand use of resources. IoT applications started to utilize cloud applications' capabilities for staging the context data generated from sensors. However, clouds in modern IoT applications are beyond mere data staging. Most IoT applications use clouds to host massive data sets, perform predictive analysis and provide useful insights to the application users for a more personalized experience. Nonetheless, the cloud also has several challenges, particularly for time-sensitive and real-time applications in terms of performance and latency.

Edge Computing: Edge computing moves the computation closer to IoT devices to improve the latency of IoT applications significantly. Edge computing is not a contradictory technology to cloud computing. The current form of state-of-the-art suggests that most IoT applications use the strong points of cloud computing and edge computing. Edge computing has overcome some of the challenges for IoT, such as real-time compliance of the applications; however, it is still far from realizing a hard real-time IoT system. It is envisioned that Edge computing coupled with 5G technology can guarantee a task deadline at some point and thus can realize a true hard real-time system.

IoT Domains: Apart from the core technologies mentioned above, IoT embraced various application fields to transform them into the next level. Industry 4.0, smart healthcare, autonomous vehicles, smart games, VR/AR, smart cities, smart waste management systems, smart grids, digital twins, etc., are the witness that IoT shaped them autonomous and optimal.

IoT has also integrated with games in mobile node agents and immersive VR games. However, the true potential of IoT in serious games is not yet revealed, and very few studies are carried out on how IoT can play its role in improving the experience of the game with remote IoT nodes.

Advantages and Limitations: IoT combines ICT with traditional industries and application domains to accelerate the development, digitization, and intelligence crucial for the next-generation evolution of industries. On the one hand, the integration of IoT in different domains offers a plethora of advantages but, on the other hand, poses some limitations due to the involvement of low-powered embedded resources. For instance, the streaming context data from IoT nodes can evolve different sectors towards making positive changes.

1. Smart Transportation: With the use of real-time context data received from different sensors deployed in smart cities can play a vital role in traffic analysis, reduction of traffic, and optimal routes for fuel reduction, to mention a few
2. Smart Healthcare: Numerous sensors deployed in the smart home through a wireless body area network can help remotely monitor patients' vital signs and thus provide timely healthcare services when and if required.
3. Predictive Maintenance: Monitoring sensors linked with massive machinery and equipment detect the possibility of failure and thus can be replaced or repaired pro-actively.
4. Smart Grid: The live data from weather stations improves the reliability and helps in predicting the accurate balance of renewable energy consumption and conventional non-renewable energy resources.
5. Other Domains: The sensors equipped with posts keep track of the status of the post and provide a better experience to users. Similarly, the sensors in the building can monitor the vibration and identify the abnormal vibrations and thus identifies the possible fall down. Moreover, the sensors in the home, airports, and even the shoes can periodically send signals to enhance safety and other crucial jobs.
6. Proposed Domain: The sensors deployed on the terminal on which the games are played, or the tracking sensors such as navigation sensor, body sensors can record the impact of the player on its health and also the game data can make informed decisions in future similar episodes.

Nonetheless, the IoT comprises a low-powered physical device, gateways, fog, and edge nodes, a centralized server or cloud, and data communication via the Internet. Even though it provides an unprecedented benefit, the involvement of constrained devices over the Internet exposes them to security threats. Thus, IoTeSG has to address and add security algorithms that might not be needed if played in a conventional environment. One possible research could be introducing Blockchain technology to persist the data uses players for the consensus protocol. This way, the scores, and history can be made more transparent and robust.

Another possible limitation that arises due to IoT integration with other technology is the diverse nature of IoT nodes. The manufacturing model of the node, the data format, communication mechanism and protocol can all differ. Consequently, it brings additional challenges such as privacy and interoperability. To remedy this, a middleware broker is commonly deployed in the cloud to translate all the data into a uniform manner and solve privacy and security issues.

Finally, constrained resources, immutable records on IoT networks, server failure, and mobility are some limitations that can give the integration architects a significant focus.

2.4. Lesson learned

Serious games have the potential to emerge as one of the popular technologies applied to different applications. Serious games induce a fun element in a serious job, which could otherwise drive the user exhausted and less benefited. IoT has evolved to embrace different technologies, such as Blockchain, Edge computing, and AI, to unleash their potential and overcome its limitations. There are successful case studies in different domains such as healthcare, smart grids, and smart cities, in which the integration of IoT with these technologies can make a more improved and optimal system. Consequently, serious games coupled with IoT can make the game pervasive and add a whole new perspective towards learning and strategy adaptation. However, the integration of IoT can engender limitations such as security, heterogeneity, and resource management, to name a few, which have to be taken into consideration while designing IoTeSG. In the subsequent section, detailed taxonomies of IoTeSG are discussed about the current state-of-the-art. The benefits of smart, serious games implemented in IoT-enabled smart spaces and the challenges are also highlighted.

3. IoT-enabled serious games taxonomy

IoTeSGs are conventional games played in the IoT space with some additional requirements. According to the extensive literature review for taxonomies on IoT and serious games, some parameters are considered highly relevant for these games. These are architecture, security, data management, hardware, and connectivity. For instance, the following questions arise when IoT meets a different technology.

Q1. What change to the architecture of IoT and the integrating technologies is anticipated?

Q2. How crucial is the security after integration, and what additional security aspects should be addressed?

Q3. How data coming from sensors are managed to make informed decisions?

Q4. What underlying hardware can be used, and how can different vendors be made interoperable?

Q5. How the devices or the game agents are connected, and which protocols are used?

Based on the above questions, five parameters are considered vital for IoTeSG: *P*1. Architecture, *P*2. Security, *P*3. Data Management, *P*4. Hardware, *P*5. Connectivity. Table 1 summarizes the existing taxonomies concerning the parameters mentioned above and illustrates instances from serious games literature and IoT literature pertaining to these parameters. We put ✓where the study addresses a particular question and ✗otherwise.

The taxonomy of IoTeSGs is defined in terms of architecture, topology, security, environment, hardware, controller, connectivity and data management which is portrayed in Fig. 5.

3.1. Design architecture

In a truly interconnected IoT smart space, serious games not only could harvest the data coming from the surrounding physical worlds of game players but also perform insight on it to help them generate a meaningful gameplay [11]. IoTeSG reflects both game and IoT characteristics, and thus the architecture is made to follow their requirement. A study on architecture for serious games reveals that modern serious games' architectures, in many cases, follow a service-oriented approach. By definition, a serious game must have a goal, and the gameplay must be converged towards its achievement. Similarly, by definition of IoT, the game must be ubiquitous. It can be played anywhere, anytime, and have a mechanism to optimize its decisions based on the generated

Table 1
Overview of various state-of-the-art IoT architectures.

Domain	Survey	Purpose	Survey taxonomy				
			P1	P2	P3	P4	P5
IoT	Atzori et al. [77]	Comprehensively illustrate the vision, characteristics and challenges of IoT. It also covers the enabling technologies and the industry standards.	✓	✓	✓	✗	✓
	Yaqoob et al. [78]	Investigate forensic technique of IoT against various cyberattacks and to investigate the daunting challenges and the mechanism to cope them	✗	✓	✓	✓	✓
	Yaqoob et al. [79]	Explore IoT architecture in terms of scalability, security and interoperability with respect to the increasing number of devices	✓	✓	✗	✗	✓
	Mukrimah et al. [80]	Study the security challenges in IoT arises due to the increasing devices and the generated data which are transmitted on the Internet	✗	✓	✗	✓	✗
	Bruno et al. [81]	Propose a taxonomy model for object connectivity and its related impacts in different sectors such as healthcare and asset tracking.	✓	✓	✗	✓	✓
Serious games	De Lope et al. [82]	Summarize the Serious games taxonomy from various aspects including Gameplay, hardware, architecture and scope.	✓	✗	✗	✓	✓
	Fedwa et al. [24]	Conduct an overview on serious games from a general aspect and covers a comprehensive guidelines on the design and architecture of serious games.	✓	✗	✗	✓	✓
	Djaouti et al. [2]	Presents serious games classification with respect to gameplay purpose and scope	✓	✗	✗	✓	✗
	Sara Cravero [83]	Investigates the impact of serious games on sustainable cities and societies and presents insights on the development of serious games for smart cities.	✗	✗	✓	✓	✗
	Barca et al. [84]	Presents a generic classification of serious games and suggest a topological importance and human approach in them.	✓	✗	✗	✓	✗

P1. Architecture, P2. Security, P3. Data Management, P4. Hardware, P5. Connectivity.

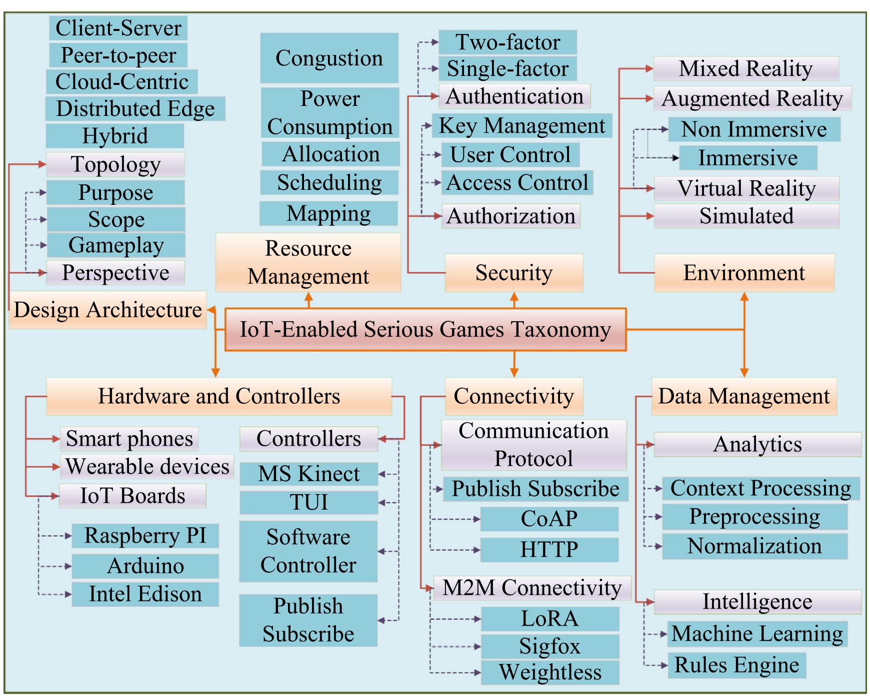

Fig. 5. Taxonomy.

contextual data. The architecture of the IoTeSGs thus considers these guidelines. For instance, a game with definite requirements of gameplay, scope, and purpose as defined by Zyda and others [2, 15] has to be implemented on the service description level and can be added by game designers in contrast to game users. One approach for this is using natural language processing techniques to consume service requirements and autonomously generate tasks and micro-services for the gameplay [61,67].

In addition to the top-level design architecture, one of the crucial characteristics of IoTeSGs is the arrangement of elements that can be accessed over the Internet, commonly referred to as network topology. IoTeSG is currently undergoing a shift from virtual gaming experience to physical gaming experience [8]. Such kinds of games are often referred to as pervasive games in many literature studies [85]. There are some requirements such as scalability, security, and quality of service (QoS) on which topologies are based [8]. There is evidence of using certain topologies that are frequently utilized in IoTeSGs. Though deemed as conventional topology, client–server topology and peer-to-peer topology are effectively used in modern IoTeSGs. Nevertheless, these topologies have the same shortcomings. For instance, if the server fails, the whole system falls apart. On the other hand, peer-to-peer topology offloads the server and thus can act as a potential candidate for a massively multiplayer online game, as highlighted by Yahyavi et al. [86]. When it comes to IoT, scalability plays a pivotal role due to the exponential rise in the development of sensing devices; therefore, peer-to-peer topology is favored over client–server topology and could harness scalability.

Another topology is cloud-centric topology, in which the cloud acts as a core of IoT applications and sensors, middleware, and private clouds. IoTeSGs using the cloud can offer the benefits of scalability, and data insight [77,87]. However, there are issues such as security and theft. The use of a localized server confined to a small network of sensors and actuators and open-source data can be a good choice for IoTeSGs. The localized server can act as a private cloud while the public cloud can act as a data host to perform analytics [8,11].

Edge-based distributed topology encourages edge nodes, acting as access points to sensors and actuators, another alternative to the cloud-centric topology. It is considered well-suited for modern multiplayer serious games and immersive VR games due to sensor clustering's involvement based on dispersed users and their respective locations, such as Father.io game [88]. Finally, hybrid topology can also be used to combine client–server, peer-to-peer, cloud-centric, and edge-based topology, combing the benefits from all to ensure scalability and quality of experience.

3.2. Resource management

In IoT, the key resources are the enormous number of IoT nodes, smart devices, and IoT servers. Therefore, to enable serious games in the IoT environment, it is paramount to manage these resources. Resource discovery, provisioning, management tools, scheduling, and fair allocation algorithms are some of the pressing research questions. In recent literature studies, IoT resource management is considered fair allocation, quality of service, throughput, and power/energy consumption. Moreover, optimization-based algorithms, game-theoretic approaches, and graph theory are some of the notable approaches used for resource management in the different application domains of IoT. As mentioned earlier, in IoTeSGs, the respective player's physical worlds play a massive role in gameplay. Thus, the physical objects and the players can be registered and addressed. Many architectures use the concept of a virtual representation of physical objects to interact with them from cyberspace [67,89]. Similarly, a definite mechanism must enable communication among objects and monitor them during gameplay. Based on the approaches mentioned above, to enable optimal resource management in IoTeSG, we derive the following conceptual flow for resource management.

Game Description: A conceptual flow for resource management in serious games with defining tasks which have to be allocated. Tasks can be manually generated or can auto-generated using the game description. Therefore, there should be a module that autonomously handles the game description and generates tasks for the later case. The gameplay can be described as a service or a problem with a definite goal and target audience (scope). There must be a mechanism to process the description and generates game activity in the form of tasks.

Game Activity Management: The next crucial element to enable resource management for IoTeSGs can be managing game activities. Another role of this component is mapping game activity on physical objects. It can also have the ability to ensure fair play with appropriate activity scheduling among players.

Predictive Analytics: Resource management tools have to have an inherent capability to know past allocation footprints and make informed resource allocation decisions based on the AI and ML algorithms. Specifically, it must have a module for handling the data generated from game players and their respective physical worlds. The data can be consumed to make smart decisions using prediction algorithms.

Virtualization: This component acts as a bridge between the physical and cyber worlds. It deals with the virtualization of physical resources and representing them within the cyber world to manage them transparently irrespective of the device's nature.

3.3. Security

The ubiquitous nature of IoTeSGs allows various game activities at any time at any location with heterogeneous devices and sensor networks [90]. Some of the fundamental issues to consider in ubiquitous computing are trust, privacy, and security [91,92]. The outsourcing of context data from sensors and mobile devices to the cloud leads to a growing concert of security. There are instances in which the sensitive data were accessed by unauthorized means or breached cloud service providers [93]. Two main factors are worth considering in modeling the game's security: authentication and authorization. Authentication makes sure that the user has the permission to access the game component, whereas authorization requires the right user must access the right information [94]. In homogeneous games where the data are exchanged on a localized server [11], security issues are not of much concern. Thus, one of the early methods to secure the game is private clouds and localized servers. However, this solution does not align with IoTeSGs' scalability requirement. Some of the fundamental schemes relevant to authentication are single-factor authentication and two-factor authentication. Single-factor authentication confirms user identity by matching the password in a single place, whereas two-factor authentication confirms the identity in two places.

The authorization module has a more complex job in securing the game than authentication. Identity management, access control, user control, and key management are fundamental responsibilities. Authorization also has a massive impact on context-awareness (another vital attribute of IoTeSGs). Since the absence of an appropriate authorization function makes the game exposed to malicious attacks, it also has no means to identify the change of the context [95,96]. Therefore, it is of paramount importance to have access control algorithms that are adaptive and context-aware, such as the one presented in [96]. There are popular industry-standard open-source modules, such as Simple Auth and OAuth2 [89] to define authorization rules and guard against unauthorized access. An IoTeSG can use a 3rd party module or its proprietary solutions to ensure security requirements. Similarly, identity management is handled with autonomous device registry or virtualization of devices to persist them the moment they join the network [61].

In addition to authorization and authentication, smart devices are exposed to a wide array of security threats due to their constrained capabilities. We, therefore, derive that one of the fundamental goals of security is to protect all the devices from malicious attacks using state-of-the-art security protocols. For IoTeSG, the game's fairness can be affected with denial-of-service, man-in-the-middle, privacy leakage, and authentication and authorization. Furthermore, the implementation criteria should also address the lightweight encryption and decryption schemes not to overload the constrained resources.

3.4. Environment

The majority of earlier serious games were played in a true simulated environment. In fact, the simulation was fundamental to the realization of serious games' vision in the last century, and different studies were contributed to propose a learning environment [97,98] Simulated serious games attempt to copy various activities from the real world and imitate them into the cyber world to achieve a specific purpose such as training and predictions. However, quite a few projects recently contributed to the simulated environment of games. For instance, Heri et al. [99] emphasized simulator games' role for the improvement of analysis ability, and decision making in enterprises. Similarly, a serious simulated game can also prove beneficial in health teaching and learning [100].

Although serious simulated games are still heavily used, the advancements in VR/AR shifted game designers' focus from a mere visual simulation to VR games. There is some players' immersion in the physical world [15]. One of the early immersive VR games is America's Army, which is still the most widely used serious game. VR games can be played in a non-immersive environment using a mouse and keyboard to control a simulated virtual world; however, the recent trend is partial immersion or full immersion to make the game a more fun experience. Although VR equipment, at times, is more expensive, they fascinate young people and thus serve the purpose of the serious game more than simulated games [101]. The combination of IoT and VR environment for the design of serious games makes it a fascinating choice among users and promises a ubiquitous experience. The users do not have to be on a particular premise to play the game. Pokémon GO's popularity, a combination of AR and IoT, has already attracted millions of worldwide users. Moreover, various exergames are played with a serious health improvement job, which utilizes the IoT for connectivity and remote multiplayer experience, and VR for immersion into the physical world [40,102]. A recent study indicates that such games attracted many more individuals than physical gym facilities and considerably improved the health of sedentary people [41,103, 104]. To summarize it, IoTeSG environment can be classified into two broad category; simulated and augmented. We also envision that the combination of augmented and simulated environments can also elevate the true potential of serious games. For instance, performing a physical activity while wearing VR goggles can lead to improved results.

3.5. Hardware

The most popular games are aimed to be played with dedicated consoles such as PlayStation, Xbox, and Nintendo, to name a few. Mobile phones are a widespread gaming platform and the fundamental enablers of IoTeSGs by acting as major hardware of multiplayer online games. Apart from mobile phones, microcontrollers such as Arduino and Raspberry PI are also used as main hardware components [105]. For instance, in a serious game related to healthcare, Arduino is used as a microcontroller and IoT server to collect data from sensor devices, namely pulse oximeter, electroencephalogram (EEG), electrocardiogram (ECG), and other health sensors during gameplay. The data from Arduino is sent to the cloud with a particular method, such as the publish–subscribe MQTT protocol.

Another approach is the use of Raspberry PI, acting as edge nodes and a host for health sensors to get the data and push it to the cloud server or private cloudlets to collect health data and perform some analysis [106]. For instance, in exergames, the data analysis can score the health reading and motivate the game player to meet a particular health goal. Apart from Raspberry PI and Arduino, various dedicated sensing devices and gateway nodes allow tangibly controlling the game. Tangible user interface (TUI) [107] is a very popular approach in gaming, and with the use of IoT, players can interact with the physical world, which has been considered a dream for so many years. Another major hardware that has revolutionized serious games is wearable devices. Gaming sensors costumes are examples of wearable devices being used extensively in modern-day games [108]. Wearable smart identification sensors such as gyroscope to track the physical activity of the data and assess the subject behavior when it participates in a serious game and estimate the depression level across various gaming activities [109].

Another crucial hardware component related to IoTeSGs is the controller. A controller is a hardware or a software program to interact with the game. In conventional games, dedicated hardware Kinect is used to control the game world. In mobile games, Emotiv Epoc and Mindwave Neurosky attracted particularly in IoTeSG [10]. In a recent-day popular PUBG game, PC emulators such as Tencent Gaming buddy and Blustacks act as a controlling programs to interact with the world using a software program. Moreover, a monitoring program can also act as a controller by subscribing to a particular event, and when that event occurs, it publishes a specific action as a consequence. TUI is another form of controller that controls physical object contrary to virtual interaction and is among the most popular interface in exergaming.

3.6. Connectivity

The IoT revolution is significantly attributed to the significant advancements in networks and connectivity. The connectivity in a conventional IoT paradigm involves communication over different layers. The sensors and actuators, often known as IoT devices, communicate on device layers with different requirements. The data going from one service to another service have a different set of requirements [61]. Services can generally be placed in a centralized way, such as the cloud, and can be placed in a distributed way, such as edge and devices. Both approaches have pros and cons. For instance, hosting a monolithic service on constrained IoT nodes makes them overloaded, and thus intermediate solutions such as ''Edge orchestrator'' are needed [110]. On the other hand, the central hosting of services on cloud makes them easy to provision, but its response time is not up to the standard of modern high-speed requirements. A possible alternate solution proposed in [61] decomposes services into small micro-services and hosts them on end devices. The later approaches There are popular wide-range communication protocols such as LoRa, Sigfox, and Weightless to enable low power, long-range wireless communication among IoT devices [61,111]. These protocols are used to ensure IoT's availability requirement at the cost of very little power. In serious games, game mechanics and controllers such as TUI are designed based on one of these protocols. While Sigfox and Weightless have their advantages, LoRa is the preferred option due to the use of a very cheap transceiver [112]. For instance, Radeta et al. [113] have emphasized the use of LoRa protocol in designing the TUI and its impact on the usability of the serious game with a purpose (GWAP).

In addition to wireless connectivity for modeling game mechanics, application-level connectivity is also important, distinguishing IoT from conventional machine-to-machine (M2M) communication (M2M). There are a wide array of protocols such as publish–subscribe based MQTT [114], CoAP [115] and even some studies recommend the use of standard HTTP to avoid intermediate translations middleware [61,67]. The most common example of connectivity in IoTeSCG is the adoption of publish–subscribe-based protocols. Publish–subscribe is a software design pattern that exchanges information in a publisher–subscriber pair. A publisher provides a piece of data or message that subscribers can access the moment it gets published. MQTT, which implements the publish–subscribe model, has changed the landscape of data sharing in recent years due to its light footprint in terms of energy and computation [116].

Moreover, the inherent support of diverse architecture and cloud in publish–subscribe architecture makes it an ideal candidate for a game that has a massive number of connected IoT devices. The publish–subscribe family of protocol not only allows the exploitation of the gaming controller irrespective of its underlying hardware but also enables the controller to be consumed by multiple systems at a particular instance [10]. In the majority of recent studies on serious game integration, publish–subscribe architecture is among the preferred choices [10]. For instance, a serious game proposed for energy efficiency as part of the EnerGAware project used the publish–subscribe protocol as the core of its middleware [117]. Nevertheless, CoAP also has significant use in serious games where performance is vital. The lightweight nature of CoAP makes the response time of CoAP much less than the other contemporary algorithms [118,119]. Herein, we derived that for IoTeSG, different schemes should be applied at different layers. For instance, on HTTP/CoAP-based connectivity on the application layer, LoRA/Sigfox, and similar low-power, high-range sensor connectivity protocols.

3.7. Data management

Data management is the heart and mind of IoTeSGs due to the provision of controlled environments and simulation of a wide range of AI and ML applications. Data management, at its core, has various responsibilities. The data coming from different game devices are raw data that is unusable for processing. One role of the data management module is to preprocess the data and normalize it to a uniform format. When the data is ready, the next job is to investigate it to make smart decisions. Game AI is a submodule of data management module which has been extensively researched in various domains such as mechanical control, player modeling, procedural content, and assisted gameplay, to mention a few [120]. The European flagship project's report on the serious game has highlighted the importance of AI in serious game modeling. Player modeling is performed with real-time facial expression and difficulty adaptation, while natural language processing (NLP) can help in sentiment analysis and scoring mechanisms. Moreover, open-source AI components can be plugged in generically in different sorts of serious games with little modification [121].

The context-awareness and pervasiveness in IoTeSGs are partly due to data management. The data coming from sensors can also play a role in making future decisions. Such decisions can make the gameplay more adaptive. For instance, matching two human players' abilities after a certain gameplay period can be assessed with the data generated based on the player's history. Thus a minimal AI can help in comparing their skill level. Games such as TrueSkill, Adaptive Practice Game (APG), Hierarchical Task Networks (HTN) are some examples of adaptive gameplay [121]. Similarly, in educational games, NLP can support natural dialogues with educators and robots to help solve a particular problem in an interactive storytelling way [122].

Nonetheless, constrained embedded devices in IoTeSGs demand lightweight AI algorithms. Some machine learning models need to be optimized, while some of the models should be trained in one place and deployed in other places. Similarly, to tackle these issues, different lightweight implementation libraries are already introduced, such as Tensorflow light, to support the constrained requirement of IoT devices. However, the development in optimization of full-fledged AI and ML models is still far-fetched. It is one of the notable areas which can further revolutionize IoT integration with serious games. Based on the above requirements for data management and insights, federated learning and distributed learning on edge nodes and deep reinforcement learning on players' actions are aligned well considering the requirements of IoTeSG.

3.8. Lesson learned and insights

We conclude that it is vital to have a conceptual architecture with definite modules responsible for performing the functionality defined in each subsection in a decoupled way. Moreover, integrating simulated and augmented environments coupled with sophisticated controllers and tangible user interfaces is a way forward towards implementing next-generation serious games. Additionally, security breaches and attacks are easily made to low-powered IoT devices. On the one hand, well-established state-of-the-art schemes are available but need to be optimized. Therefore, these lightweight and optimal solutions are vital for implementing IoTeSG security solutions. Finally, data management and intelligence have different challenges such as the persistence of data in a central or distributed way and the training of model in edge nodes such as federated learning or in a more gamified way such as reinforcement learning.

4. Challenges and future directions

The integration of IoT with serious games is at its infant stages despite a significant amount of work in the recent past. In this section, research challenges in the realization of IoTeSG are elucidated. The overview of possible challenges and their respective future direction is provided in Table 2.

4.1. Conceptual architecture

IoTeSG is a relatively newer technology, and different works have been proposed towards integrating the serious game in the IoT paradigm to further its capabilities. The first and foremost challenge considered the cornerstone is conceptual architecture. Such architecture will highlight the necessary guidelines and design patterns for IoTeSG's new projects. Some studies presented to standardize the integration of serious games with IoT and ubiquitous computing. For instance, in [11], as part of the integration of serious games with IoT, a game framework is presented with five layers: application layer, data processing layer, middleware layer, networking layer, and user interface layer. However, the proposed framework is not reflecting the full potential of IoTeSGs. In another effort [123], the essential components of a serious game for Industry 4.0 have been highlighted. Similarly, the InLife project [124] has also attempted to propose architecture but all of these studies are specific to the domain of the particular paper.

The conceptual architecture of IoTeSG should at most satisfy the requirements of both IoT and serious games by leveraging a bi-directional interaction between real-world smart space and game activities. It should also have a module for carrying out data analytics and AI. Additionally, an automation mechanism

Table 2
Overview of challenges and open issues in the realization of IoTeSG.

Challenges	Relevant approaches	Research questions and guidelines
Conceptual architecture	• InLife Architecture for combining real life with serious games using IoT • Smart serious game architecture for integration of serious games and IoT • Education 4.0 standardized architecture	How to enable the standardization of architecture for business trying to integrate serious games in IoT? • Layered Architecture based on top-down or bottom-up methodology. • Model-driven architecture based on [67] • Game as a Service approach based Service-oriented architecture
Tangible user interface	• Urban decision support system titled CityMatrix [125] • Keppi TUI for self-reporting pain [126]. • Visualization system on a chip-based TUI [127].	How to ensure usability and explainability criteria for tangible user interface considering it to be used by people of diverse age groups? • User-driven TUI for simplified serious games. • Brain-computer interface for cognitive serious games. • ML-based Brain-computer interface for artificial cognition in serious games. • Spatial Learning for early-year education.
Scalability	• Dynamic and on-demand edge node provisioning. • standby edge nodes and data replication.	For a diverse number of players across the globe, how to enable transparent access to devices? YU • Scalable location in case a new player from different location is registered • Scalable node in case a new device is registered. • Cluster reconfiguration in case of overloading • Wireless sensor networks update to accommodate new nodes and locations
Auto-Adaptability	• Optimal recommendation systems [128,129]. • Static adaptation [130]	Considering a scalable and robust architecture, how will the system adapt to the change in the context such as registering new players, leaving players and adding/removing new devices? • Agent learning based on DRL and contemporary algorithms • Reward modeling for game agent. • adaptive recommendation with policy evaluation and iteration.
1-3 Resource management	• Mission-critical application as a case study for resource management based on task orchestration. • Driver assistance system as a case study for two-fold scheduling as a subpart of resource management.	How to fairly allocate resources to game players under dynamic environment where players frequently partake and leave the game? • Gamification approach for resource management. • Task orchestration on game nodes with edge intelligence. • Two-fold Scheduling for control actuating tasks and periodic sensing tasks.
Virtualization	• IoT Device Virtualization • VR Games • AR Games	For full-fledged representation of game agents, virtual representation of every game entity is vital. How to provide virtualization which is generic for players, devices and game environment? • IoT-enabled VR Games • IoT Virtual game objects • Virtual game player

should inherently perform reinforcement learning or other learning algorithms to closely follow and analyze a player's learning progress and behavior adaptation when the game progresses. The conceptual architecture may deal with the heterogeneity of connected devices, so it must have a module for uniform device registry and access irrespective of their vendors, as proposed in some recent IoT frameworks [61,89]. Finally, the conceptual architecture should be as generic as possible and adapt with minimal or no modification for a wide range of games. An architecture with such characteristics is a massive gap in the current state-of-the-art. Therefore, one of the future directions is to investigate the existing architecture in games and IoT and contribute to the standardization of IoTeSG.

4.2. Intelligent tangible user interface

The recent advancement in IoT and tangible computing have garnered increased interest in developing intelligent TUI for IoTeSG. While TUIs have been developed for many education-based serious games [107], there are still many open issues with employing AI techniques to make the TUI more intelligent [125]. Some of the goals of intelligent TUI are to make it intuitive and to have improved accessibility towards the decision-making process. TUI involves human-to-computer interaction, so the new approaches are more tilted towards the concept of user-driven intelligent interfaces based on multimodal AR. Some studies suggest the use of brain-to-computer interaction to make the interaction intuitive and intelligent [127,131]. While brain-to-computer interaction offers new strategies to overcome the limitations of current state-of-the-art TUIs, the combination of brain-to-computer TUI and machine learning-based multimodal interaction can make it to the next level. For instance, Gang et al. investigated the use of brain-to-computer TUIs for people with functional disabilities. They suggested that the combination of machine learning with brain-to-computer interaction will profit from the immediate feedback from the neurophysical reactions classified by machine learning models [131].

TUIs also play a pivotal role in nurturing spatial skills, i.e., early years thinking, which are essential for routine tasks in children's everyday environment. Examples of spatial learning are packaging a toy box and cutting equal slices of cake based on the number of people. The job of TUI in the serious game is to use machine learning algorithms to develop cognition and improve intrinsic spatial skills such as mental rotation. Moreover, TUI can facilitate early spatial learning through embodiment effects of children's physical actions, manipulating and grasping physical objects, and the embedded power about them. In a nutshell, the advantages of TUI so far depict considerable improvements by innovative strategies such as guided instructions, independent learning [132], cognitive minds-on engagement with brain-to-computer interaction [133] and, more importantly, individual experience for children [134]. Nonetheless, more empirical research is required to investigate the impact of intelligent TUIs towards improving the required serious job in IoTeSG.

4.3. Scalability

In IoTeSG, a massive rise in the number of devices and users can be witnessed when a particular game hits users' attraction. How the IoTeSG architecture will react to a sharp spike in connection qualifies scalability. Though scalability is one of the primitive requirements of IoT architecture [61], there is very little work done in gaming to ensure scalability the case the number of connecting nodes increases drastically at a specific interval. As discussed in the topology section of serious games, edge nodes are deployed to provide game intelligence closer to IoT devices; one approach to accommodate an increasing number of nodes is to add new edge nodes. It can increase scalability, but other challenges such as reliability of the newly added edge node can come into question due to the dynamic update in computing infrastructure, software flaws, and network failure [135]. There are potential challenges that were pointed out in [11] that, in addition to the number of nodes, new locations can also be added on-the-fly in case the game is location-aware. It also engenders a new set of questions; for instance, which sensors and actuators will be clustered in the newly added location?, What network application programming interface should be changed to add the new extrinsic sensor networks to reflect the location update.

4.4. Auto-adaptability

When the AlphaGo outplayed the decade-long human champion, no one at the time thought of the enormous potential of AI and reinforcement learning. Machine learning algorithms can outperform human beings, and considering serious games are aimed at humans' well-being, unlike general games. Thus, an autonomous agent's involvement can find optimal policies that a human player may not find. For instance, consider a serious, smart waste management project game in a smart city. The player is scored on the assigned areas' overall cleanliness and the amount of waste collected at minimal fuel cost. To find optimal recommendation systems, it must investigate statistics and involve humans to know the dynamic of the geography [128]. Suppose a self-configurable agent is deployed to adjust its route each time the agent is scored based on the requirements mentioned above. In that case, the optimal policy can find the best score, which a human may not achieve even after many attempts. Thus, adaptability and auto-gaming are not yet investigated despite their enormous potential for serious games. Therefore, a more empirical study is needed to investigate the potential of reinforcement learning adaptation in IoTeSG.

4.5. Resource management

IoT devices have constrained capabilities and, although they enable smart spaces, exhibit massive temporal and traffic variations. This phenomenon leads to congestion on one device while other devices are under-utilized. Consequently, power issues arise due to such imbalanced resource management. Some approaches recommend dynamic and resource-aware scheduling of tasks based on the capabilities of IoT devices [136]. They can solve the congestion issue with a minimal dropping rate; however, within a game environment where there are far more users than in a conventional IoT space, such algorithms need to be investigated for their effectiveness in a more dynamic environment.

IoTeSGs are pervasive in nature, and pervasive applications pose even further challenges due to the miniature and unattended IoT devices. Zahoor et al. [137] presented a comprehensive survey on resource management and narrowed it down to a case where the resources are limited. The potential users can be peaked at times, such as in IoTeSGs. Some of the challenges in resource management of IoTeSGs are power management, adequate scheduling mechanism, and resource allocation to ensure fairness and discourage a job from starving [136]. To this end, conventional scheduling and resource allocation need to be tweaked to align with pervasive IoT and game requirements. There are different studies [138–140] which modify the existing algorithms to make them aligned with IoT applications. For instance, Malik et al. [139] proposed a novel scheduling algorithm named Fair Emergency First, which is based on conventional rate monotonic and earliest deadline first to handle complex tasks in an IoT environment. In another effort, [140], separate resource allocation scheduling algorithms of sensing tasks and actuating tasks are suggested for driving assistance systems. The authors highlighted that actuating devices perform more crucial tasks, so they should be given more priority than periodic sensing tasks to avoid accidents [106].

Some more recent studies introduce the concept of the task orchestration approach as an optimal way for resource management [69,140]. Task orchestration involves mapping tasks on virtual devices, generating a scheduling footprint in virtual space, and finally deploying them in the physical world. Such an approach is deterministic and autonomous [61]. Moreover, task-level orchestration, in contrast to service-level orchestration, makes it more scalable and flexible, which is one of the inherent attributes of IoTeSG [67].

4.6. Virtualization

Virtualization refers to the digital representation of physical entities in the real world. Since IoTeSG, by definition, involves the representation of sensors and actuators nodes in cyberspace. Therefore, virtualization is considered a massive challenge for enabling it. VR/AR games are the results of the optimal use of virtualization. In the pure IoT world, the concept of virtual objects [67,140,141] has been in use to bypass the diversity of different sensors and actuators' vendors and represent them in cyberspace transparently and uniformly. Some of the advantages of virtualization of IoT devices are auto-registration, scalability, and uniform representation [141].

Virtualization also plays a crucial role in resource management. Recently assigning tasks on virtual objects can make them manageable even before actually allocating them to physical IoT nodes [69]. In other words, virtualization is crucial not only for transparent access of diverse physical IoT nodes but can also play a pivotal role in managing them. There are studies in the gaming industry that investigate the use of virtualization techniques in VR and AR games. Still, its use in IoTeSGs is far from realization and, thus, one of the fundamental open issues to be considered in a standardized conceptual architecture.

5. Conclusion

Serious games are a promising way to engage users to perform a serious job in a more fun way. In the last five years, the emerging trend in different domains of serious games paved the way to explore the possibility of integrating them with IoT to reach its true potential. Conventionally, serious games are played with a dedicated terminal, which was limited in scope and did not offer a scalable and ubiquitous aspect. The IoT's inherent ubiquitous and pervasive characteristics have paved the way for a more pervasive experience in serious games. While the adoption of IoT in serious games makes them more scalable and smart, its implementation engenders significant challenges in play on-demand and on-premise.

In this survey, the integration of IoT with serious games is studied comprehensively. To this end, we first described the history and background of serious games and identified the core application areas. Additionally, we also demonstrated the never-fading research trend since the last century and emphasized game evolution in this period. The need to evolve serious games forms a basis for IoT discussion. Thus, the core architecture of IoT and the adoption of IoT with complementary technologies have been elucidated in terms of distinguished attributes of serious games. Furthermore, we have classified the IoTeSG based on existing state-of-the-art and presented a comprehensive taxonomy. Finally, numerous challenges and open issues are identified in the light of the current state-of-the-art.

We anticipate IoTeSG is the next big thing in learning and development. The countries with exemplary education standards, such as Norway and Sweden, have already started the initiative of learning by doing. The advancement in IoTeSG will be a step towards learning-by-doing. However, in the realization of pervasive serious games, standardization must be taken as a priority job that will allow people to design their games with ease.

CRediT authorship contribution statement

Shabir Ahmad: Conceptualization, Methodology, Writing – original draft. **Sabina Umirzakova:** Data curation, Writing – review & editing, Resources. **Faisal Jamil:** Methodology, Visualization, Investigation. **Taeg Keun Whangbo:** Supervision, Conceptualization, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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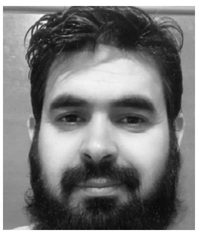
References

[1] B.M. Iglesias, C. Fernández-Vara, B. Fernández-Manjón, E-learning takes the stage: From la dama boba to a serious game, IEEE Rev. Iberoam. Tecnol. Aprendiz. 8 (4) (2013) 197–204.
[2] D. Djaouti, J. Alvarez, J.-P. Jessel, Classifying serious games: the g/p/s model, in: Handbook of Research on Improving Learning and Motivation Through Educational Games: Multidisciplinary Approaches, IGI Global, 2011, pp. 118–136.
[3] A. Calderón, M. Ruiz, A systematic literature review on serious games evaluation: An application to software project management, Comput. Educ. 87 (2015) 396–422.
[4] P. Friess, Internet of Things-Global Technological and Societal Trends from Smart Environments and Spaces to Green ICT, River Publishers, 2011.
[5] F. Xia, L.T. Yang, L. Wang, A. Vinel, Internet of things, Int. J. Commun. Syst. 25 (9) (2012) 1101.
[6] M.S. Mahdavinejad, M. Rezvan, M. Barekatain, P. Adibi, P. Barnaghi, A.P. Sheth, Machine learning for internet of things data analysis: A survey, Digit. Commun. Netw. 4 (3) (2018) 161–175.
[7] F. Cirillo, F.-J. Wu, G. Solmaz, E. Kovacs, Embracing the future internet of things, Sensors 19 (2) (2019) 351.
[8] J. Melthis, S. Tang, P. Yang, M. Hanneghan, C. Carter, Topologies for combining the internet of things and serious games, J. Intell. Fuzzy Systems 31 (5) (2016) 2685–2696.
[9] J. Henry, S. Tang, S. Mukhopadhyay, M.H. Yap, A randomised control trial for measuring student engagement through the internet of things and serious games, Internet of Things (2020) 100332.
[10] E.I. Konstantinidis, A.S. Billis, I.T. Paraskevopoulos, P.D. Bamidis, The interplay between iot and serious games towards personalised healthcare, in: 2017 9th International Conference on Virtual Worlds and Games for Serious Applications (VS-Games), IEEE, 2017, pp. 249–252.
[11] J. Henry, S. Tang, M. Hanneghan, C. Carter, A framework for the integration of serious games and the internet of things (iot), in: 2018 IEEE 6th International Conference on Serious Games and Applications for Health (SeGAH), IEEE, 2018, pp. 1–8.
[12] K. Shao, Z. Tang, Y. Zhu, N. Li, D. Zhao, A survey of deep reinforcement learning in video games, arXiv preprint arXiv:1912.10944.
[13] C.C. Apt, Serious Games: The Art and Science of Games that Simulate Life in Industry, Government and Education, Viking, New York.
[14] J. Alvarez, D. Djaouti, et al., An introduction to serious game definitions and concepts, Serious Games Simul. Risks Manage. 11 (1) (2011) 11–15.
[15] M. Zyda, From visual simulation to virtual reality to games, Computer 38 (9) (2005) 25–32.
[16] P. Wouters, C. Van Nimwegen, H. Van Oostendorp, E.D. Van Der Spek, A meta-analysis of the cognitive and motivational effects of serious games, J. Educ. Psychol. 105 (2) (2013) 249.
[17] D.R. Michael, S.L. Chen, Serious Games: Games that Educate, Train, and Inform, Muska & Lipman/Premier-Trade, 2005.
[18] S. Deterding, D. Dixon, R. Khaled, L. Nacke, From game design elements to gamefulness: defining gamification, in: Proceedings of the 15th International Academic MindTrek Conference: Envisioning Future Media Environments, 2011, pp. 9–15.
[19] Magnavox odyssey, 2016, https://en.wikipedia.org/wiki/Magnavox_Odyssey [Online; accessed 25-December-2020].
[20] H. Beaver, Parkman's crack-up: A bostonian on the oregon trail, New England Quart. (1975) 84–103.
[21] The oregon trail, 2016, https://en.wikipedia.org/wiki/The_Oregon_Trail_(series) [Online; accessed 25-December-2020].
[22] Bradley trainer: Atari's top secret military project, 2011, https://arcadeblogger.com/2016/10/28/bradley-trainer-ataris-top-secret-military-project/ [Online; accessed 25-December-2020].
[23] Marine doom, 2012, https://en.wikipedia.org/wiki/Marine_Doom [Online; accessed 25-December-2020].
[24] F. Laamarti, M. Eid, A. El Saddik, An overview of serious games, Int. J. Comput. Games Technol. (2014).
[25] G. Ekaputra, C. Lim, K.I. Eng, Minecraft: A game as an education and scientific learning tool, in: ISICO 2013, 2013.
[26] S. Nebel, S. Schneider, G.D. Rey, Mining learning and crafting scientific experiments: a literature review on the use of minecraft in education and research, J. Educ. Technol. Soc. 19 (2) (2016) 355–366.
[27] D. Melián Díaz, J.L. Saorín, C. Carbonell-Carrera, J. de la Torre Cantero, Minecraft: three-dimensional construction workshop for improvement of creativity, Technol. Pedagog. Educ. (2020) 1–14.
[28] Minecraft features, advantages and disadvantages, 2016, https://www.online-sciences.com/games/minecraft-features-advantages-and-disadvantages/ [Online; accessed 08-May-2022].
[29] Y. Zhonggen, A meta-analysis of use of serious games in education over a decade, Int. J. Comput. Games Technol. (2019).
[30] M.-T. Cheng, J.-H. Chen, S.-J. Chu, S.-Y. Chen, The use of serious games in science education: a review of selected empirical research from 2002 to 2013, J. Comput. Educ. 2 (3) (2015) 353–375.
[31] I. Gorbanev, S. Agudelo-Londoño, R.A. González, A. Cortes, A. Pomares, V. Delgadillo, F.J. Yepes, Ó. Muñoz, A systematic review of serious games in medical education: quality of evidence and pedagogical strategy, Med. Educ. Online 23 (1) (2018) 1438718.
[32] M.-T. Cheng, Y.-W. Lin, H.-C. She, P.-C. Kuo, Is immersion of any value? Whether, and to what extent, game immersion experience during serious gaming affects science learning, Br. J. Educ. Technol. 48 (2) (2017) 246–263.

[33] V. Garneli, M. Giannakos, K. Chorianopoulos, Serious games as a malleable learning medium: The effects of narrative, gameplay, and making on students' performance and attitudes, Br. J. Educ. Technol. 48 (3) (2017) 842–859.
[34] M. Bakhuys Roozeboom, G. Visschedijk, E. Oprins, The effectiveness of three serious games measuring generic learning features, Br. J. Educ. Technol. 48 (1) (2017) 83–100.
[35] R.L. Lamb, L. Annetta, J. Firestone, E. Etopio, A meta-analysis with examination of moderators of student cognition, affect, and learning outcomes while using serious educational games, serious games, and simulations, Comput. Hum. Behav. 80 (2018) 158–167.
[36] N. Shin, L.M. Sutherland, C.A. Norris, E. Soloway, Effects of game technology on elementary student learning in mathematics, Br. J. Educ. Technol. 43 (4) (2012) 540–560.
[37] F. Mueller, S. Agamanolis, Sports over a distance, Comput. Entertain. (CIE) 3 (3) (2005) 4.
[38] A. Barnett, E. Cerin, T. Baranowski, Active video games for youth: a systematic review, J. Phys. Activity Health 8 (5) (2011) 724–737.
[39] G. Zhao, E.S. Ford, C. Li, L.S. Balluz, Physical activity in us older adults with diabetes mellitus: prevalence and correlates of meeting physical activity recommendations, J. Amer. Geriatr. Soc. 59 (1) (2011) 132–137.
[40] A. Whitehead, H. Johnston, N. Nixon, J. Welch, Exergame effectiveness: what the numbers can tell us, in: Proceedings of the 5th ACM SIGGRAPH Symposium on Video Games, 2010, pp. 55–62.
[41] C. Höchsmann, M. Schüpbach, A. Schmidt-Trucksäss, Effects of exergaming on physical activity in overweight individuals, Sports Med. 46 (6) (2016) 845–860.
[42] L.E. Graves, N.D. Ridgers, K. Williams, G. Stratton, G. Atkinson, N.T. Cable, The physiological cost and enjoyment of wii fit in adolescents, young adults, and older adults, J. Phys. Activity Health 7 (3) (2010) 393–401.
[43] J.E. Barkley, A. Penko, Physiologic responses, perceived exertion, and hedonics of playing a physical interactive video game relative to a sedentary alternative and treadmill walking in adults, J. Exerc. Physiol. Online 12 (3).
[44] E.J. Lyons, D.F. Tate, S.E. Komoski, P.M. Carr, D.S. Ward, Novel approaches to obesity prevention: effects of game enjoyment and game type on energy expenditure in active video games, 2012.
[45] E.J. Lyons, D.F. Tate, D.S. Ward, K.M. Ribisl, J.M. Bowling, S. Kalyanaraman, Engagement, enjoyment, and energy expenditure during active video game play, Health Psychol. 33 (2) (2014) 174.
[46] P. Gebhard, T. Schneeberger, E. André, T. Baur, I. Damian, G. Mehlmann, C. König, M. Langer, Serious games for training social skills in job interviews, IEEE Trans. Games 11 (4) (2018) 340–351.
[47] K. Sipiyaruk, J. Gallagher, S. Hatzipanagos, P. Reynolds, A rapid review of serious games: From healthcare education to dental education, Eur. J. Dent. Educ. 22 (4) (2018) 243–257.
[48] K. Larson, Serious games and gamification in the corporate training environment: a literature review, TechTrends 64 (2) (2020) 319–328.
[49] K. Boudreaux, Serious games for training and faculty development–a review of the current literature, J. Educ. Online 15 (2) (2018) n2.
[50] Z. Feng, V.A. González, R. Amor, R. Lovreglio, G. Cabrera-Guerrero, Immersive virtual reality serious games for evacuation training and research: A systematic literature review, Comput. Educ. 127 (2018) 252–266.
[51] P. Gamito, J. Oliveira, C. Coelho, D. Morais, P. Lopes, J. Pacheco, R. Brito, F. Soares, N. Santos, A.F. Barata, Cognitive training on stroke patients via virtual reality-based serious games, Disabil. Rehabil. 39 (4) (2017) 385–388.
[52] R. Neira, L. Barba-Guaman, A. González-Eras, Matebrun: serious game as a strategy to teach basic arithmetic operations for six-years-old children, in: Proceedings of the IX Latin American Conference on Human Computer Interaction, 2019, pp. 1–4.
[53] A.K. Adisusilo, M. Hariadi, E.M. Yuniarno, B. Purwantana, Optimizing player engagement in an immersive serious game for soil tillage base on pareto optimal strategies, Heliyon 6 (3) (2020) e03613.
[54] H. Mizuyama, A. Yoshida, T. Nonaka, A serious game for eliciting tacit strategies for dynamic table assignment in a restaurant, in: Intersections in Simulation and Gaming, Springer, 2016, pp. 394–410.
[55] S. Ontanón, G. Synnaeve, A. Uriarte, F. Richoux, D. Churchill, M. Preuss, A survey of real-time strategy game ai research and competition in starcraft, IEEE Trans. Comput. Intell. AI Games 5 (4) (2013) 293–311.
[56] D. Daylamani-Zad, L.B. Graham, I.T. Paraskevopoulos, Swarm intelligence for autonomous cooperative agents in battles for real-time strategy games, in: 2017 9th International Conference on Virtual Worlds and Games for Serious Applications (VS-Games), IEEE, 2017, pp. 39–46.
[57] F. Wortmann, K. Flüchter, Internet of things, Bus. Inform. Syst. Eng. 57 (3) (2015) 221–224.
[58] M. Ben-Daya, E. Hassini, Z. Bahroun, Internet of things and supply chain management: a literature review, Int. J. Prod. Res. 57 (15–16) (2019) 4719–4742.
[59] S. Ahmad, S. Malik, I. Ullah, D.-H. Park, K. Kim, D. Kim, Towards the design of a formal verification and evaluation tool of real-time tasks scheduling of iot applications, Sustainability 11 (1) (2019) 204.
[60] S. Ahmad, S. Malik, D.-H. Kim, Comparative analysis of simulation tools with visualization based on real-time task scheduling algorithms for iot embedded applications, Int. J. Grid Distrib. Comput. 11 (2) (2018) 1–10.
[61] S. Ahmad, D. Kim, A multi-device multi-tasks management and orchestration architecture for the design of enterprise iot applications, Future Gener. Comput. Syst. 106 (2020) 482–500.
[62] Z. Ouyang, X. Sun, J. Chen, D. Yue, T. Zhang, Multi-view stacking ensemble for power consumption anomaly detection in the context of industrial internet of things, IEEE Access 6 (2018) 9623–9631.
[63] A. Abusukhon, B. Hawashin, M. Lafi, An efficient system for reducing the power consumption in offices using the internet of things, Int. J. Adv. Soft Comput. Appl. 13 (1).
[64] A. Iqbal, F. Ullah, H. Anwar, K.S. Kwak, M. Imran, W. Jamal, A. ur Rahman, Interoperable internet-of-things platform for smart home system using web-of-objects and cloud, Sustainable Cities Soc. 38 (2018) 636–646.
[65] X. Huang, P. Craig, H. Lin, Z. Yan, Seciot: a security framework for the internet of things, Secur. Commun. Netw. 9 (16) (2016) 3083–3094.
[66] T. Kanter, S. Forsström, V. Kardeby, J. Walters, U. Jennehag, P. Österberg, Mediasense–an internet of things platform for scalable and decentralized context sharing and control, in: Proceedings of 7th IARIA International Conference on Digital Telecommunications (ICDT), 2012, Citeseer, 2012.
[67] S. Ahmad, F. Mehmood, D.-H. Kim, A diy approach for the design of mission-planning architecture using autonomous task–object mapping and the deployment model in mission-critical iot systems, Sustainability 11 (13) (2019) 3647.
[68] R. Nicolescu, M. Huth, P. Radanliev, D. De Roure, Mapping the values of iot, J. Inform. Technol. 33 (4) (2018) 345–360.
[69] S. Ahmad, A. Khudoyberdiev, D. Kim, Towards the task-level optimal orchestration mechanism in multi-device multi-task architecture for mission-critical iot applications, IEEE Access 7 (2019) 140922–140935.
[70] G. Hassan, H.S. Hassanein, Mot: A deterministic latency mac protocol for mission-critical iot applications, in: 2018 14th International Wireless Communications & Mobile Computing Conference (IWCMC), IEEE, 2018, pp. 588–593.
[71] J.-S. Leu, C.-F. Chen, K.-C. Hsu, Improving heterogeneous soa-based iot message stability by shortest processing time scheduling, IEEE Trans. Serv. Comput. 7 (4) (2014) 575–585.
[72] B. Billet, V. Issarny, From task graphs to concrete actions: a new task mapping algorithm for the future internet of things, in: 2014 IEEE 11th International Conference on Mobile Ad Hoc and Sensor Systems, IEEE, 2014, pp. 470–478.
[73] S. Krčo, B. Pokrić, F. Carrez, Designing iot architecture (s): A european perspective, in: 2014 IEEE World Forum on Internet of Things (WF-IoT), IEEE, 2014, pp. 79–84.
[74] C. Valderrama, J. Vachaudez, F. Bettens, F. Vinci dos Santos, N. Menezes, M. Roelands, Architecting the internet of things: The diy smart experiences project: A European endeavour removing barriers for user-generated internet of things applications, Archit. Internet of Things.
[75] M. Hammoudeh, G. Epiphaniou, S. Belguith, D. Unal, B. Adebisi, T. Baker, A. Kayes, P. Watters, A service-oriented approach for sensing in the internet of things: intelligent transportation systems and privacy use cases, IEEE Sens. J. 21 (14) (2020) 15753–15761.
[76] A.N. Lam, Ø. Haugen, J. Delsing, Interoperability for industrial internet of things based on service-oriented architecture, in: IECON 2021–47th Annual Conference of the IEEE Industrial Electronics Society, IEEE, 2021, pp. 1–6.
[77] L. Atzori, A. Iera, G. Morabito, The internet of things: A survey, Comput. Netw. 54 (15) (2010) 2787–2805.
[78] I. Yaqoob, I.A.T. Hashem, A. Ahmed, S.A. Kazmi, C.S. Hong, Internet of things forensics: Recent advances, taxonomy, requirements, and open challenges, Future Gener. Comput. Syst. 92 (2019) 265–275.
[79] I. Yaqoob, E. Ahmed, I.A.T. Hashem, A.I.A. Ahmed, A. Gani, M. Imran, M. Guizani, Internet of things architecture: Recent advances, taxonomy, requirements, and open challenges, IEEE Wirel. Commun. 24 (3) (2017) 10–16.
[80] M. Nawir, A. Amir, N. Yaakob, O.B. Lynn, Internet of things (iot): Taxonomy of security attacks, in: 2016 3rd International Conference on Electronic Design (ICED), IEEE, 2016, pp. 321–326.
[81] B. Dorsemaine, J.-P. Gaulier, J.-P. Wary, N. Kheir, P. Urien, Internet of things: a definition & taxonomy, in: 2015 9th International Conference on Next Generation Mobile Applications, Services and Technologies, IEEE, 2015, pp. 72–77.
[82] R.P. De Lope, N. Medina-Medina, A comprehensive taxonomy for serious games, J. Educ. Comput. Res. 55 (5) (2017) 629–672.
[83] C. Sara, Methods, strategies and tools to improve citizens' engagement in the smart cities' context: A serious games classification, Valoriz. Valutaz. 24.

[84] S. Barca, B. Botte, G. Marinensi, C. Matera, C.M. Medaglia, A taxonomy and a proposal for a classification of serious games, in: Handbook of Research on Serious Games as Educational, Business and Research Tools, IGI Global, 2012, pp. 1064–1079.
[85] T.H. Laine, C.I. Sedano, Distributed pervasive worlds: The case of exergames, J. Educ. Technol. Soc. 18 (1) (2015) 50–66.
[86] A. Yahyavi, B. Kemme, Peer-to-peer architectures for massively multiplayer online games: A survey, ACM Comput. Surv. 46 (1) (2013) 1–51.
[87] D. Mishra, M. El Zarki, A. Erbad, C.-H. Hsu, N. Venkatasubramanian, Clouds+ games: A multifaceted approach, IEEE Internet Comput. 18 (3) (2014) 20–27.
[88] Father.io, 2018, https://www.indiegogo.com/projects/father-io-massive-multiplayer-laser-tag [Online; accessed 12-January-2021].
[89] S. Ahmad, F. Mehmood, A. Mehmood, D. Kim, Design and implementation of decoupled iot application store: A novel prototype for virtual objects sharing and discovery, Electronics 8 (3) (2019) 285.
[90] Z. Yan, P. Wang, W. Feng, A novel scheme of anonymous authentication on trust in pervasive social networking, Inform. Sci. 445 (2018) 79–96.
[91] Z. Yan, V. Niemi, Y. Chen, P. Zhang, R. Kantola, Towards trustworthy mobile social networking, in: Mobile Social Networking, Springer, 2014, pp. 195–235.
[92] Z. Yan, Y. Chen, Y. Shen, A practical reputation system for pervasive social chatting, J. Comput. System Sci. 79 (5) (2013) 556–572.
[93] T. Peng, Y. Lin, X. Yao, W. Zhang, An efficient ranked multi-keyword search for multiple data owners over encrypted cloud data, IEEE Access 6 (2018) 21924–21933.
[94] A.S.V. Koe, Y. Lin, Offline privacy preserving proxy re-encryption in mobile cloud computing, Pervasive Mob. Comput. 59 (2019) 101081.
[95] M.C. Domingo, A context-aware service architecture for the integration of body sensor networks and social networks through the ip multimedia subsystem, IEEE Commun. Mag. 49 (1) (2011) 102–108.
[96] A. Arfaoui, S. Cherkaoui, A. Kribeche, S.M. Senouci, M. Hamdi, Context-aware adaptive authentication and authorization in internet of things, in: ICC 2019-2019 IEEE International Conference on Communications (ICC), IEEE, 2019, pp. 1–6.
[97] S.S. Boocock, J.S. Coleman, Games with simulated environments in learning, Soc. Educ. (1966) 215–236.
[98] S.S. Boocock, E.O. Schild, Simulation games in learning.
[99] H. Pratikto, S.W. Prabowo, A. Murdiono, A. Basuki, The role of business simulator games implementation in improving the ability of analysis and business decision making independently for students (literature research), KnE Soc. Sci. (2019) 1005–1010.
[100] C.A. Santos, V.D. Souza-Junior, F.F. Lanza, A.J. Lacerda, B.M. Jorge, I.A.C. Mendes, Serious games in virtual environments for health teaching and learning.
[101] D. Checa, A. Bustillo, A review of immersive virtual reality serious games to enhance learning and training, Multimedia Tools Appl. 79 (9) (2020) 5501–5527.
[102] S. Göbel, S. Hardy, V. Wendel, F. Mehm, R. Steinmetz, Serious games for health: personalized exergames, in: Proceedings of the 18th ACM International Conference on Multimedia, 2010, pp. 1663–1666.
[103] M. Jordan, B. Donne, D. Fletcher, Only lower limb controlled interactive computer gaming enables an effective increase in energy expenditure, Eur. J. Appl. Physiol. 111 (7) (2011) 1465–1472.
[104] L.M. Taylor, R. Maddison, L.A. Pfaeffli, J.C. Rawstorn, N. Gant, N.M. Kerse, Activity and energy expenditure in older people playing active video games, Arch. Phys. Med. Rehabil. 93 (12) (2012) 2281–2286.
[105] H.-Y. Kim, A design and implementation of a framework for games in iot, J. Supercomput. 74 (12) (2018) 6516–6528.
[106] S. Ahmad, F. Jamil, A. Khudoyberdiev, D. Kim, Accident risk prediction and avoidance in intelligent semi-autonomous vehicles based on road safety data and driver biological behaviours, J. Intell. Fuzzy Syst. 38 (4) (2020) 4591–4601.
[107] A. Sánchez-Morales, J. Durand-Rivera, C. Martínez-González, Usability evaluation of a tangible user interface and serious game for identification of cognitive deficiencies in preschool children, Int. J. Adv. Comput. Sci. Appl. 11 (6) (2020) 486–493.
[108] T. Chittenden, Skin in the game: the use of sensing smart fabrics in tennis costume as a means of analyzing performance, Fash. Text. 4 (1) (2017) 22.
[109] R. Maskeliūnas, T. Blažauskas, R. Damaševičius, Depression behavior detection model based on participation in serious games, in: International Joint Conference on Rough Sets, Springer, 2017, pp. 423–434.
[110] P. Ioan, R. Omar, A. Reza, Edge-cloud orchestration: strategies for service placement and enactment, in: 2019 IEEE International Conference on Cloud Engineering (IC2E), 2019.
[111] A. Augustin, J. Yi, T. Clausen, W.M. Townsley, A study of lora: Long range & low power networks for the internet of things, Sensors 16 (9) (2016) 1466.
[112] M. Bor, J.E. Vidler, U. Roedig, Lora for the internet of things.
[113] M. Radeta, M. Ribeiro, D. Vasconcelos, N.J. Nunes, Lorattle-an exploratory game with a purpose using lora and iot, in: Joint International Conference on Entertainment Computing and Serious Games, Springer, 2019, pp. 263–277.
[114] F. Mehmood, I. Ullah, S. Ahmad, D. Kim, Object detection mechanism based on deep learning algorithm using embedded iot devices for smart home appliances control in cot, J. Ambient Intell. Humaniz. Comput. (2019) 1–17.
[115] S. Ahmad, L. Hang, D.H. Kim, Design and implementation of cloud-centric configuration repository for diy iot applications, Sensors 18 (2) (2018) 474.
[116] L. Malina, G. Srivastava, P. Dzurenda, J. Hajny, R. Fujdiak, A secure publish/subscribe protocol for internet of things, in: Proceedings of the 14th International Conference on Availability, Reliability and Security, 2019, pp. 1–10.
[117] P. Barbosa, A. Barros, L.M. Pinho, Iot for energy-efficiency: connecting a serious game with energy metering in the energaware project, in: INForum Simpósio de Informática 2017 (INForum 2017).
[118] Q. Liu, Integrating Game Engines Into the Mobile Cloud as Micro-Services (Ph.D. thesis), 2018.
[119] S. Stavrev, D. Ginchev, Towards a cost-efficient gunner controller for a modular battle tank simulator, in: 2020 International Conference Automatics and Informatics (ICAI), IEEE, 2020, pp. 1–6.
[120] G.N. Yannakakis, J. Togelius, A panorama of artificial and computational intelligence in games, IEEE Trans. Comput. Intell. AI Games 7 (4) (2014) 317–335.
[121] W. Westera, R. Prada, S. Mascarenhas, P.A. Santos, J. Dias, M. Guimarães, K. Georgiadis, E. Nyamsuren, K. Bahreini, Z. Yumak, et al., Artificial intelligence moving serious gaming: Presenting reusable game ai components, Educ. Inf. Technol. 25 (1) (2020) 351–380.
[122] G.N. Yannakakis, J. Togelius, Artificial Intelligence and Games, Springer, 2018, http://gameaibook.org.
[123] M. Oliveri, J.B. Hauge, F. Bellotti, R. Berta, A. De Gloria, Designing an iot-focused, multiplayer serious game for industry 4.0 innovation, in: 2019 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC), IEEE, 2019, pp. 1–9.
[124] P. Kosmides, K. Demestichas, E. Adamopoulou, N. Koutsouris, Y. Oikonomidis, V. De Luca, Inlife: Combining real life with serious games using iot, in: 2018 IEEE Conference on Computational Intelligence and Games (CIG), IEEE, 2018, pp. 1–7.
[125] Y. Zhang, et al., Citymatrix: An Urban Decision Support System Augmented by Artificial Intelligence (Ph.D. thesis), Massachusetts Institute of Technology, 2017.
[126] A.T. Adams, E.L. Murnane, P. Adams, M. Elfenbein, P.F. Chang, S. Sannon, G. Gay, T. Choudhury, Keppi: A tangible user interface for self-reporting pain, in: Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems, 2018, pp. 1–13.
[127] K. Ryabinin, M. Kolesnik, Scientific visualization system on a chip with tangible user interface.
[128] S. Ahmad, N. Iqbal, F. Jamil, D. Kim, et al., Optimal policy-making for municipal waste management based on predictive model optimization, IEEE Access 8 (2020) 218458–218469.
[129] S. Ahmad, I. Ullah, F. Mehmood, M. Fayaz, D. Kim, A stochastic approach towards travel route optimization and recommendation based on users constraints using markov chain, IEEE Access 7 (2019) 90760–90776.
[130] F. Mehmood, S. Ahmad, D. Kim, Design and development of a real-time optimal route recommendation system using big data for tourists in Jeju island, Electronics 8 (5) (2019) 506.
[131] P. Gang, J. Hui, S. Stirenko, Y. Gordienko, T. Shemsedinov, O. Alienin, Y. Kochura, N. Gordienko, A. Rojbi, J.L. Benito, et al., User-driven intelligent interface on the basis of multimodal augmented reality and brain-computer interaction for people with functional disabilities, in: Future of Information and Communication Conference, Springer, 2018, pp. 612–631.
[132] N. Frey, D. Fisher, A. Gonzalez, Teaching with tablets: How do I integrate tablets with effective instruction? in: ASCD Arias, ASCD, 2013.
[133] K. Hirsh-Pasek, J.M. Zosh, R.M. Golinkoff, J.H. Gray, M.B. Robb, J. Kaufman, Putting education in educational apps: Lessons from the science of learning, Psychol. Sci. Public Interest 16 (1) (2015) 3–34.
[134] B. Sargeant, What is an ebook? What is a book app? And why should we care? An analysis of contemporary digital picture books, Child. Lit. Educ. 46 (4) (2015) 454–466.
[135] L.U. Khan, I. Yaqoob, N.H. Tran, S.A. Kazmi, T.N. Dang, C.S. Hong, Edge computing enabled smart cities: A comprehensive survey, IEEE Internet Things J..
[136] S. Ahmad, S. Malik, I. Ullah, M. Fayaz, D.-H. Park, K. Kim, D. Kim, An adaptive approach based on resource-awareness towards power-efficient real-time periodic task modeling on embedded iot devices, Processes 6 (7) (2018) 90.

[137] S. Zahoor, R.N. Mir, Resource management in pervasive internet of things: A survey, J. King Saud Univ.-Comput. Inform. Sci..
[138] S. Malik, D. Kim, A hybrid scheduling mechanism based on agent cooperation mechanism and fair emergency first in smart factory, IEEE Access 8 (2020) 227064–227075.
[139] S. Malik, S. Ahmad, I. Ullah, D.H. Park, D. Kim, An adaptive emergency first intelligent scheduling algorithm for efficient task management and scheduling in hybrid of hard real-time and soft real-time embedded iot systems, Sustainability 11 (8) (2019) 2192.
[140] S. Ahmad, D. Kim, et al., Design and implementation of thermal comfort system based on tasks allocation mechanism in smart homes, Sustainability 11 (20) (2019) 5849.
[141] I. Ullah, M. Sohail Khan, D. Kim, Iot services and virtual objects management in hyperconnected things network, Mob. Inf. Syst. (2018).



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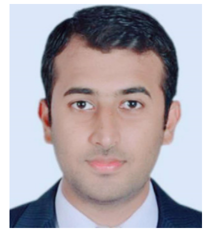

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