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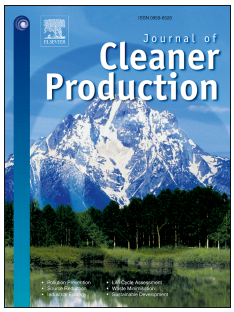

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Facilitating sustainability transition through serious games: A systematic literature review

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Abstract: Exploring aspects of how innovative methods can truly attain a sustainable society is necessary for the future of our planet. This study focuses on serious games, and how users can increase their understanding of sustainability issues and their familiarity with sustainable development strategies. "Users" of serious games consist of all possible target groups that are interested in attaining knowledge of sustainability through the use of games that are designed for a purpose beyond entertainment, in this case for sustainability education. This paper follows the systematic literature review method to deliver a study of serious games featuring sustainable development practices and policies. In order to provide a thorough analysis of their dynamic features, 77 games were explored in this study. The findings show the growing number of serious games that seek to educate in sustainability and the categorization of these games according to the triple-bottom line of sustainability, giving clarification hints to users wishing to select the relevant tool that offers an understanding of specific sustainability issues. The purpose of such research is to reveal the contribution of serious games as effective tools in facilitating sustainability education and to group them according to their nature and direction in relation to sustainability. Limitations in their effectiveness are also identified and a research agenda for new, relevant serious games is proposed that will enhance holistic knowledge and make it easier to clarify their pedagogical basis. The recipients of the findings will be all those future users and trainers who are interested in accessing sustainability education patterns through the use of serious games. This study will enable them to select the serious game that best serves their needs.

KEYWORDS: *Sustainability, Sustainable Development, Serious Games, Game-Based Learning, Education*

1. Introduction & Background

An undisputed feature of modern societies is the rapid change they are undergoing. Major social changes affect or characterize every aspect of society, and influence our ways of life, causing increasing confusion in people's daily lives (Van Opstal and Hugé, 2013, Ferguson, 2016). Scientific techniques need to be called upon in order to provide viable solutions for perpetual sustainability concepts (Nawaz and Koç, 2018, Mihelcic et al., 2003, Kivilä et al., 2017, González et al., 2011). The target scenario needs to include environmental issues such as climate change, social issues such as poverty and happiness, and economical aspects such as profitable investments (Lee, 2012, Komurlu et al., 2015a). Plenty of definitions of the vast field of sustainability exist. However, it is commonly accepted that all definitions should include biophysical, human and economic aspects. As Dick et al. (2018) and Ramcilovic-Suominen and Pülzl (2018) indicated in their work, sustainability can be understood as the interaction of humans with the environment and with other human beings in order to achieve environmental, social and economic advantages. The World Commission on Environment and Development, also known as the Brundtland Report, shaped a definition that has been widely accepted by the scientific community (Renoldner, 2013, Schubert and Láng, 2005, Vasconcellos Oliveira, 2018). According to this report: "Sustainable development is a development that meets the needs of the present without jeopardizing the ability of future generations to meet their own needs" (WCED, 1987). Supplementary to this philosophy are the Sustainable Development Goals (SDG) that the United Nations (UN) have set, the basis of which are the essentials of energy utilization, water and nourishment (United Nations, 2015). As literature suggests, sustainable technologies have come a long way, driven by environmental awareness and the rising costs of fossil fuels (Maroušek, 2013, Mardoyan and Braun, 2015, Bieber et al., 2018, Fazey et al., 2018). The most promising achievements concern renewable energy, sustainable living, organic agriculture, environmental economics and environmental technologies. Within these general categories, technologies like CO2 capture, water cleaning, soil improvement, sustainable design (construction) and

cogeneration all add to the repository of sustainability achievements (Maroušek, 2014a, Koytsoumpa et al., 2018, Maroušek, 2014b, Pérez-Lombard et al., 2008, Gurgun et al., 2015, Robichaud Lauren and Anantatmula Vittal, 2011). The focus seems to be on long-term issues that have environmental, social, and economic implications (Komurlu et al., 2015b). Prevention of physical waste, increase in energy efficiency and improvement of resource productivity, all help to expand profitability and enhance competitiveness in the long run. In fact, due to years of neglect, these are often high-return investment fields (Van Opstal and Hugé, 2013, Hák et al., 2018, Kakoty, 2018).

Nonetheless, as the need for sustainability can no longer be overlooked, there is general agreement that the educational tools used to transmit knowledge of Sustainable Development (SD) and promote new methods to teach it need to be renovated (Dagiliūtė et al., 2018, Jaca et al., 2018, Thürer et al., 2018, Saunila et al., 2018, Beumer et al., 2018, Anand and Sen, 2000). Various attempts have been made to move in this direction. A growing number of Higher Educational Institutes (HEI) are adopting and integrating SD policies and sustainable-oriented communication patterns in their educational research (Tejedor et al., 2018). This study lists the attainment of learning outcomes as tangible and readily definable information in line with sustainable development requirements, or best practices as defined by professional bodies. It promotes Education for Sustainable Development (ESD) as vocationally vital (meeting sustainability requirements), making it worth of investigation. Serious games are a means to encourage sustainability concepts in societies. Education is a crucial element but it does not ensure a change of philosophy towards SD patterns (Brundiers and Wiek, 2013). Analysis of general SD competences in several HEIs has shown that engineering students do not possess the proper skills of systemic thinking and holistic knowledge upon graduating (Fumiyo, 2007, Major et al., 2017). It is crucial to achieve this element if a change of mentality is desired. (Karel et al., 2012, Fazey et al., 2018).

During the last decades, HEIs have been conducting research on how to integrate sustainability into their educational methods (Ragazzi and Ghidini, 2017, Tejedor et al., 2018, Holdsworth and Thomas, 2016). A growing number of HEIs have created educational tools for SD, research on sustainability integration, social outreach, procedures, assessment and statements, university partnerships, institutional schemes, conventional educative programs for educators and green campus projects (Annan-Diab and Molinari, 2017). Universities, and especially engineering-related HEIs, are taking fundamental and essential steps to follow the modern-era trend of SD reformulating their educational strategies (Beynaghi et al., 2016, Luederitz et al., 2017). This long and difficult path involves the crucial step of incorporating Sustainability Assessment Tools (SATs). SATs play an important role in HEIs, favoring the genesis of SD policies and the development of SD practices. They are implementers of innovation (Dlouhá et al., 2018). Nevertheless, as Berzosa et al. (2017) indicate, researchers have shied away from using such tools. Even though the value of sustainability is commonly recognized by academics, SD projects tend to be perceived as trivial tasks, mainly due to the difficulty of specifying clear objectives (the topic of sustainability is too broad) (de Lange, 2017, Ludwig, 1993, Silvius, 2017, Sierra et al., 2018). This lack of engagement gives potency to the demand for innovative educational approaches that facilitate authentic educational content and thinking in the field of SD (Blanco-Portela et al., 2017, Ceulemans et al., 2015, Kevin, 2003). In other words, integration of SD requires demanding perception of the key factors, purviews, limitations and independence of different SD projects in order to obtain a beneficial outcome (Cairns and Martinet, 2014). Such awareness can be established within a united, interdisciplinary framework that requires the learner to dig into compositional thinking in various stages. Such a framework constitutes deep and meaningful learning (Major et al., 2017, Kalsoom and Khanam, 2017).

Figure 1 provides an overview of the matters that need to be considered from the educator's perspective when seeking to instill SD practices through educational methods. It is based on the UNESCO report combined with the sustainable development goals that the UN set in 2015.

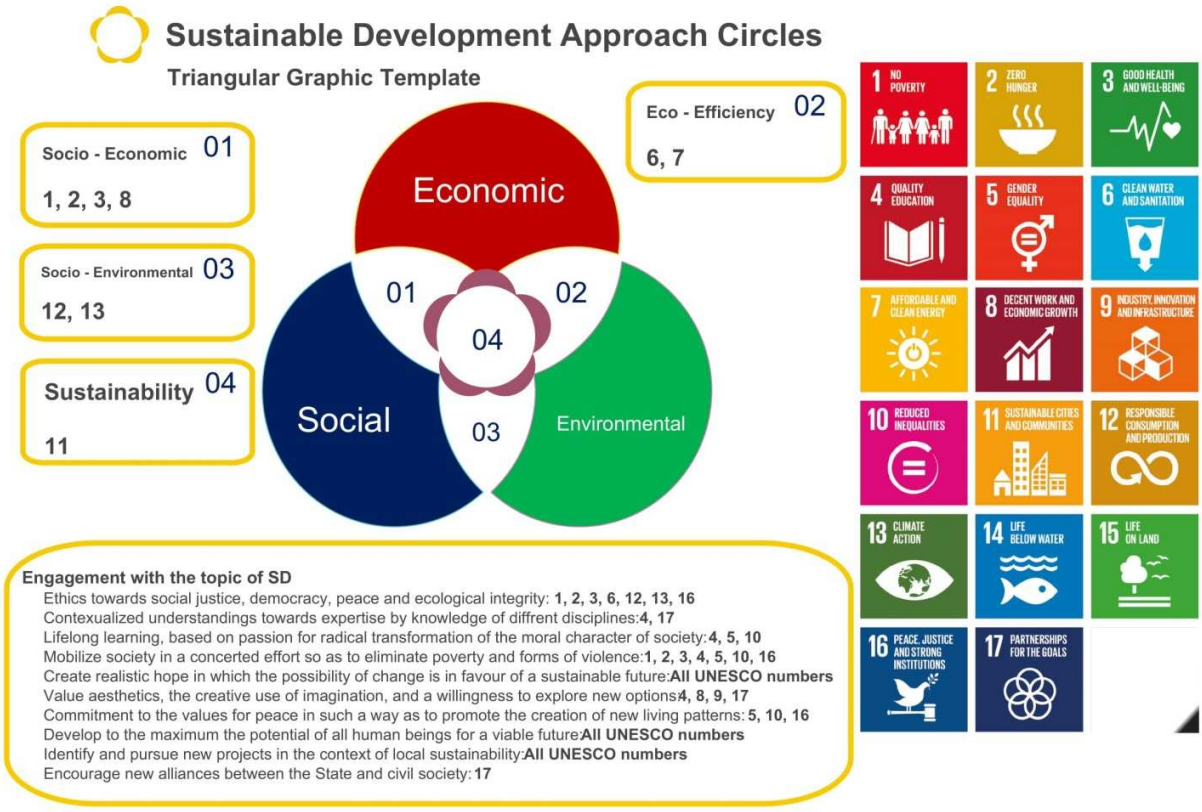

Fig. 1: Engagement with SD practices and policies based on UNESCO and UN reports for sustainable development (United Nations, 2015, UNESCO, 2005).

Goni et al. (2017), developing the proposal made by Stephens et al. (2008), outlined four points that need to be addressed for HEIs to reach the goal of a sustainable-oriented culture, through the implementation of adequate holistic educational SD tools. These points are listed as follows:

i. HEIs can become the means to integrate sustainability thinking in modern societies. This comes as a continuation of the philosophy that each one of us should practice sustainability actions individually to achieve sustainable philosophy thinking.
ii. HEIs teach students the basic principles of design, project management and problem solving for them to be able to confront the need for sustainability.
iii. HEIs can apply project-based learning methods, which will properly guide students through the SD path.
iv. HEIs can be involved in SD practices to create curiosity amongst individuals and collaborate with other institutions or sustainability related centers.

Jickling and Wals (2008) pointed out that by implementing education for SD in HEIs, a whole range of other activities are involved, such as carrying out literature review analysis, tutoring and numerous projects that concern the structure of society. Melkonyan et al. (2017) acknowledged that the implementation of sustainability is a complicated philosophical pattern that leads to long processes, various challenges and risks.

It is generally accepted that Serious Games (SGs) offer great potential in the education sector, mainly due to the positive effects they have on learning outcomes (Rossano et al., 2018). Focusing on sustainability concepts, the use of SGs can deliver a major increase of interest in training, project understanding and evaluation amongst users. The advantages of SGs come from the fact that they receive gameplay characteristics from common entertainment games and focus on learning or training, with concepts of applying theoretical instructions in real-life environments (Wattanasoontorn et al., 2013, Lamb et al., 2018a, Botella et al., 2011). SD games are the main focus of this study. SGs tap into the effects of Game - Based Learning (GBL), especially those that provide directional lines towards multi-meaning concepts like sustainability. Some reviews of SGs on SD have been conducted which analyzed the way these games help to develop the sustainable philosophy. These reviews are those of Katsaliaki and Mustafee (2015) and two years later, Madani et al. (2017). Despite the fact that these two studies were published recently, their data stop at 2013. Since then, an enormous expansion of SGs on SD has been observed. Some of these newer games can be found in this study. Taking the research one step further, their categorization according to the most widely-accepted diagram of sustainability (triple-bottom line scenario of economic, social and environmental attributes) has not been attempted before and appears for the first time in this study. Adding to the same concept, the mapping of the engagement with SD practices and policies based on UNESCO and UN reports for SD has also been achieved. This study is based on the scientific hypothesis which claims that *any SG on SD fully contributes to all educational attributes of sustainability's triple-bottom line (economic, social and environmental dimension).* The aim of this research is to provide an overview and classification of SGs on SD and to explore their potential as educational tools. The implications of the research are two-fold. The practical implication is that practitioners and educators gain an in depth understanding of the existing serious games in relation to sustainability. Furthermore, the grouping of serious games according to the triple bottom line of sustainability and their in-depth analysis provides academics with a basis for further analysis and research into new serious games related to sustainability.

The paper unfolds as follows: A method review of SGs on SD is reported in section 2, analyzing their underlying characteristics (77 SGs are included). In section 3, the results of the study are presented, along with an extended discussion. Finally, section 4 includes the conclusions and the promising prospects for future research.

2. Research method

To meet the aim of the paper, a systematic literature review (SLR) was conducted. The SLR method is considered particularly useful when publishing the crucial conclusions of a large and complex body of research literature (Sengers et al., 2016). It remains a method which is widely used by researchers who wish to produce eye-catching conclusions in their review papers (Velásquez et al., 2018, Fischer et al., 2017, Guitart et al., 2012, Rodrigues and Mendes, 2018). Other studies in SGs have shown the path towards the application of this method, making it easier to select the proper SGs that fit the main purpose of this paper (Katsaliaki and Mustafee, 2015, Goni et al., 2017, Chappin et al., 2017, Dlouhá et al., 2018, Madani et al., 2017). The cases studied in this review concern the use of SGs in SD as a means to incorporate holistic knowledge about sustainability issues in HEIs. In line with the suggestions of Thürer et al. (2018) and Boyle et al. (2016), a systematic formula for retrieving and selecting the academic publications was used. The schema followed is presented in steps in fig. 3. Paragraphs 2.1 to 2.3 shape the research design followed for tracing, filtering, and evaluating the documents, in that order.

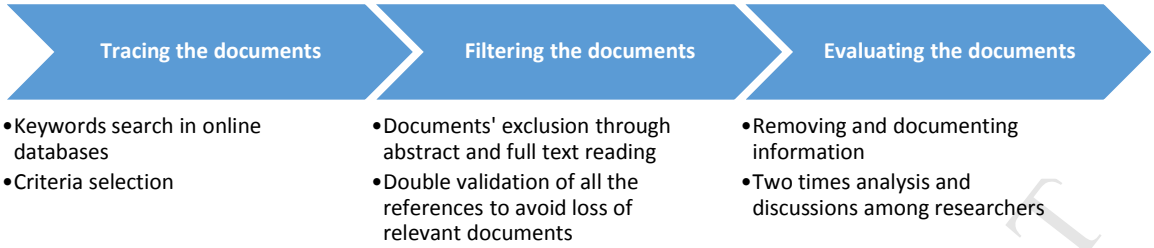

Fig. 3: Research method (SLR) presented in steps

2.1. Tracing the documents

Tracing the documents (documentation) of the related SGs on SD that could be used as educational tools was conducted in the form of a literature review (conference papers, journal articles, book chapters, reports from international organizations, online databases) that provides online links to accessible SGs. In this research, the subject to be analyzed is SGs on SD and their use as effective educational tools. These are thus the three main keywords of the research (refer to table 1).

Table 1: Keywords of research

Serious Games (SGs)	Sustainable Development (SD)	Educational Tools
Gamification	Sustainability	Educational technology
Game based learning (GBL)	Triple bottom line (TBL)	Holistic understanding
Green games	Education for sustainability	Effective learning
SD games	Sustainable management	Motivation
Environmental games	SD issues	Educational process

Relevant documents were identified from six online databases: Scopus, Science Direct, Web of Science, Google Scholar, Springerlink and Emeraldinsight. The selection of these specific online databases was made due to their large coverage of documents. As Table 2 suggests, so as to keep the number of documents manageable and to ensure the significance of the sources, the search was further limited to certain criteria (time period, subject area, etc.). Among 5092 results in total, using different keywords and combinations each time (refer to table 1), 81 journal articles, 10 conference papers, 5 books, 4 reports from international organizations and 1 online database[1] (plus the ones in the Appendix section) were finally included in this study. This determined the first stage of the selection method.

The study of online databases (referring to the one included in the total documentation and the rest in the Appendix section) involved reading the description of each SG as a first step, and then actually playing the game. Following this process, the opportunity to determine the classification, the relevance and the context of the games was provided. Thus, the categorization was achieved relatively easily.

[1] The 1 online database was included in the final documentation sample because of the website's layout which resembles an analytical review of SGs. Other online databases (Appendix) are more like online platforms where users can play the game and read a brief description.

The search relations also resulted from the first review and addressed the diversity of games (video games, sandbox games, etc.) that were played as well as standings for the possible outcomes of playing (assessment effects, learning, educational tools, skills, motivation).

Table 2: Selection criteria of the SLR

Criterion	Inclusion Criteria	Exclusion Criteria
Time period	1990 - February 2018	Older studies
Subject Area	• Computer Science • Engineering • Social Sciences • Environmental Science • Energy • Decision Sciences	All other subject areas
Research Discipline	• Engineering • Sustainable Development • Energy • Ecology • Technology • Business Management/Accounting	All other research disciplines
Document Type	• Conference paper • Journal article • Book chapter • Reports from international organisms • Online databases	All other document types
Scientific Content	• Documents that present a model, technique or literature review to explore and describe SGs on SD • Documents that describe the assessment of a SG • Documents that show cases of study of SD practices and policies • Documents that analyze the educational contribution of SGs • Documents that review existing SGs on SD	• Documents whose main aim is not an assessment of SGs • Documents that do not describe any specs of a SG (just names) • Documents that do not analyze the educational outcomes of a SG • Documents that do not discuss evaluation models of the SGs prism
Language	English	All other languages
Availability	Available in online academic search databases	Not available online

2.2. Filtering the documents

The initial sample of 5092 documents was further reduced to 444 by reading the title and abstract. This was further reduced to 101 documents (plus the online databases provided in the Appendix section) by excluding unrelated documents after reading the full text. The vast number of unrelated documents is acceptable, as restrictions were made on the subject area (computer science, engineering, social sciences, environmental science, energy, decision sciences). This tactic was chosen mainly due to its objectivity and flexibility in the field of sustainability and educational tools like SGs.

To safeguard against relevant documents being lost, all the references were validated twice. Following this process, 4 supplementary documents were discovered and added to the total documentation sample. The final sample was 101 documents from which 31 were reviews on sustainability issues and the rest referred to SGs (on SD and as educational tools). The systematic literature investigation (filtering), including the documents' source is diagrammed in fig. 4.

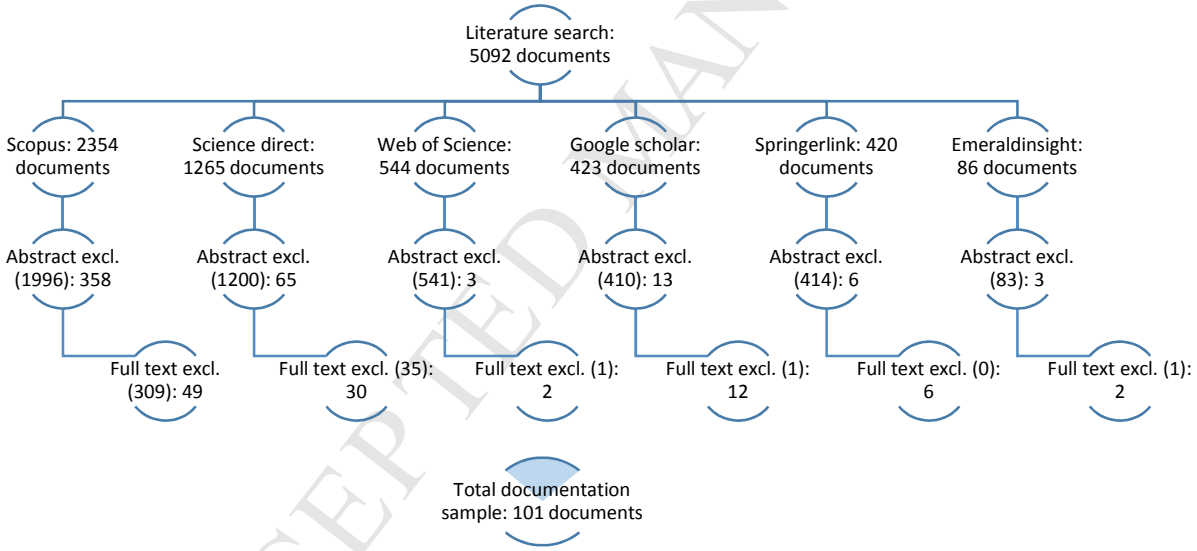

Fig. 4: Diagramming the systematic literature investigation. Adapted from Caiado et al. (2017)

The progression of documents retrieved in scientific databases mentioned in paragraph 3.1. is shown in fig. 5. As expected, Scopus and Science Direct were the electronic platforms that provided the most primary documents to our SLR. The platform with the highest contribution in searches was Scopus, with 2354 documents and the one that engendered the lowest contribution was Emeraldinsight, with 86 documents.

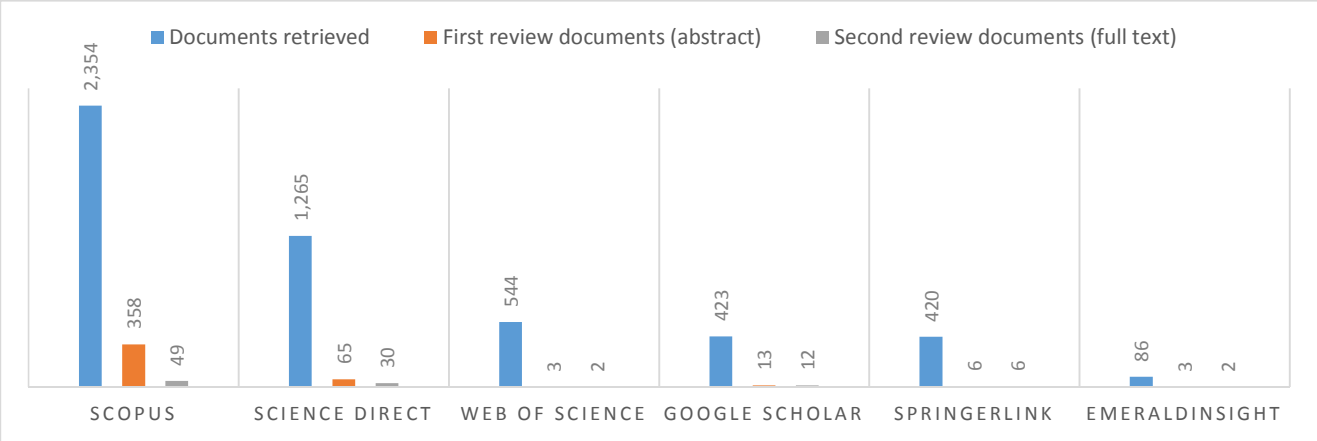

Fig. 5: Progression of documents retrieved in scientific databases

2.3. Evaluating the documents

This phase involved removing and documenting information from each of the 101 final documents (plus the online databases provided in the Appendix section). To ensure objectivity, two-time analysis and extra discussion among researchers were conducted in order to determine any possible illogicality in review results. The suggested path was inspired by Boyle et al. (2016) and Thürer et al. (2018), who developed literature reviews on sustainability and SG practices accordingly.

The difficulty of evaluating the final selection of documents lies in deciding which SGs may foster education in SD issues and how they can be related to educational approaches. The integration of sustainability and SD philosophy in SGs can be understood as the outcome of specific concepts in which numerous characteristics are united. The important part of the evaluation process lies in the concept of how practices are hypothesized by the writers and how they are applied in the curricula in education. Taking these principles into consideration, the final type of document was determined (fig.6). The SGs identified in this study, present an educational character in sustainability topics in line with TBL philosophy. Most reviews were found in journal articles, conference papers and online databases, dependent mainly on the nature of the paper (SGs, SD).

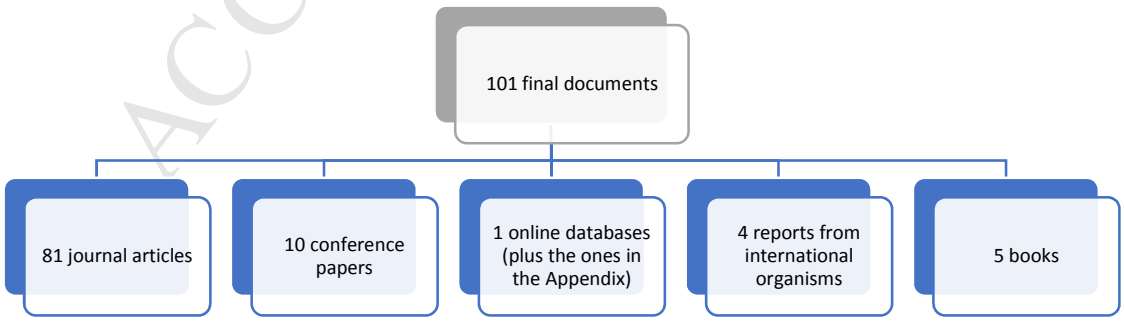

Fig. 6: Final document types

2.4. Synthesis

Each paper individually was a source of general data on the scientific content of the paper, as presented above in table 2. Furthermore, additional specific data required to meet the aim of the paper was collected (SGs, SD, etc.). To reach the desired outcome, an extensive review was performed (fig.4), to ensure that the obtained data were appropriate. This also permitted the straightforward comparison and analysis of the extracted data during the evaluation process.

The scientific database of documents was scrutinized to distinguish patterns in the literature. Three main characteristics were recognized in the results: the nature of the research and the writer, the SGs and the sustainability issues described, and the researchers involved in these practices.

3. Results and discussion

This section presents a research of serious games related to SD and their added value in the educational sector. The SGs were identified through web sources; the main one was CRS (2017), while others are presented in the Appendix and related paper reviews (Katsaliaki and Mustafee, 2015, Madani et al., 2017). All 101 final documents contributed in showing the "path" towards this identification. Besides the name of the SG, the year it first became available, the type, the audience it addresses, the teaching exclusivity the study of each game initially identified and the sustainable technology/SD strategy are described. The findings indicate that the increasing number of SGs featuring SD reveals a preference of the academic community for their use as educational tools to incorporate SD ideals.

3.1. Results

Serious Games (SGs) with SD themes have developed steadily in the academic world over approximately the last fifteen years (fig. 7) and gamification has become progressively widespread since it first appeared (Dias et al., 2018). The most in-depth analysis of SGs on SD was conducted by Katsaliaki and Mustafee (2015) and Madani et al. (2017), where the authors noted the need for further research. However, while the effectiveness and the educational value of the games analyzed is not in doubt, the empirical evidence regarding their holistic contribution to sustainability values is still emerging. After reviewing a large number of SGs on SD (as well as actually playing them to define the possible educational outcomes), it was found that SGs are one of the best means to engage in learning on sustainability. Although this is the case, findings indicate that education of this kind (theoretical background through SGs) is not enough to engage students in a holistic approach to the philosophy of sustainability. A tangible, practical solution has to be applied towards this kind of educational method as well. This is the missing part and the "Achilles' heel" of modern education systems with regard to SD.

The studies of Katsaliaki and Mustafee (2015) and Madani et al. (2017) constitute one of the main sources of this paper for the identification of SGs on SD. Table 3 presents the list of these SGs, along with other useful characteristics. Column 1 states the year that the SG became available. The name of the SG is presented in column 2, the type in column 3, the participants in column 4, whether the SG described was created specifically for teaching purposes (HEIs and other institutions) in column 5, while column 6 shows whether the SG was first documented by Katsaliaki and Mustafee (2015) (with the indication **1**) or Madani et al. (2017) (with the indication

2). Finally column 7 describes the sustainable technology/SD strategy according to each game's educational content. The reference for each SG is provided in the Appendix section.

Table 3: List of SGs on SD identified in this study

Year	Names of SGs on SD		Type of SG	Participants	Teaching exclusivity	Initially identified by	Sustainable technology - SD strategy
1990	1.	Simearth	Sandbox video game	General public	Yes	1	Air cleaning
1994	2.	Irrigation Management Game	Hybrid simulation game	Students, SD prof.	Yes	2	Management of landfill
1998	3.	Geology Explorer	Online game	Students	Yes	2	Earth resources exploitation
1999	4.	Build a Prairie	Computer quiz game	Students	Yes	1	Soil improving
2000	5.	Learning SD (LSD)	Card game	Students	Yes	1	Env. conservation & urban development
	6.	The Great Green Web	Computer quiz game	Students, stakeholders	Yes	1	Sustainable consumer behavior
	7.	Samba Role Play	Board game	Stakeholders	No	2	Natural resource management
2003	8.	Industrial Chlorine Transport Metagame	Card game	Students, SD prof.	Yes	2	Social technology as a SD public policy
	9.	Slyvopast	Hybrid simulation game	Students	Yes	2	Effective strategy for SD
2004	10.	Balance of the Planet	Online game	SD prof.	No	1	CO2 capture through managerial choices
	11.	Keep Cool	Board game	General public	No	1	Sustainable process negotiation
	12.	River Basin Game	Board game	Students, SD prof.	Yes	2	Water cleaning
	13.	Industrial Waste Game	Card game	Students	Yes	2	Industrial waste management
2005	14.	Atollgame	Role-playing videogame (RPG)	Stakeholders	No	1	Groundwater cleaning
	15.	MHP	RPG	Stakeholders	No	1	Strategies for SD technologies
	16.	Better Business Dilemmas	Computer quiz game	Students, SD prof.	Yes	1	Decision making for SD technologies
2006	17.	Shrub Battle	Board game	Students	Yes	1	Sustainable landscape design
	18.	3rd World Farmer	Online sandbox game	General public	No	1	Sustainability of agricultural land use
	19.	Climate Challenge	Online sandbox game	General public	No	1	Renewable energy sources & politics
2007	20.	Stop Disasters!	Online sandbox game	Students	Yes	1	Natural disasters prevention
	21.	Energyville	Online sandbox game	General public	No	1	Sustainable energy supply
	22.	Encon City	Online sandbox game	Stakeholders	Yes	1	Energy conservation
	23.	Butorstar	Hybrid simulation game	Students	Yes	2	Biodiversity & agricultural conservation
	24.	Food Import Folly	Online sandbox game	Students	Yes	-	Sustainable resource use
2008	25.	World Without Oil	Online alternate reality game	Stakeholders	No	1	Renewable energy sources (RES)
	26.	Environment Game	Computer quiz game	Stakeholders	Yes	1	Sustainable building design
	27.	Building Game	Computer quiz game	Students	Yes	1	Sustainable building design
	28.	Electrocity	Online sandbox game	Students	Yes	1	Environmental management
	29.	Catchment Detox	Online sandbox game	General public	No	1	Sustainable development (TBL)
2009	30.	The Sims Adapted	Sandbox video game	General public	No	1	Energy conservation
	31.	Shortfall	Online game	General public	No	1	Sustainable engineering
	32.	Green City	Computer simulation game	Students	Yes	1	Green urban development
	33.	MIT CleanStart	Online sandbox game	General public	Yes	-	Sustainable decision-making
	34.	Tragedy of the Tuna	Computer simulation game	General public, students	Yes	1	Water resources management
2010	35.	Enercities	Online sandbox game	Students, SD prof.	Yes	1	RES & urban development
	36.	Fate of the World	Online sandbox game	General public, students	Yes	1	Global warming solutions
	37.	Cityone	Online sandbox game	Students, SD prof.	Yes	1	Sustainable city development
	38.	Oceanopolis	Online sandbox game	Stakeholders	No	1	Water management
	39.	The UVA Bay Game	Computer simulation game	Stakeholders	Yes	1	Sustainable products & services
	40.	Sustainable Delta Game	Hybrid simulation game	General public	No	2	Water cleaning
2011	41.	SOS 21	Online sandbox game	Stakeholders	No	1	Sustainable living
	42.	River Basin Game	Computer assisted game	Students	Yes	2	Reclaimed water management
	43.	Fate of the World: Tipping Point	Video game	General public	No	2	Global warming solutions
	44.	Spent	Online sandbox game	General public	No	-	Sustainable economics
2012	45.	Irrigania	Online game	Students	Yes	2	Sustainable agriculture
	46.	Aqua Republica	Online game	Students	Yes	2	Water resources management
	47.	Citizen Science	Online game	Students	Yes	2	Water cleaning
	48.	Earthopoly	Board game	Students, stakeholders	Yes	-	Resources management
2013	49.	World Climate	Computer simulation game	General public	No	1	Global warming decision-making
	50.	Climate Change Survivor	Board game	General public	No	2	Eco-innovation
	51.	Papers please	Video game	General public	Yes	-	Sustainable immigration & cultural integration
2014	52.	Paying for Predictions	Dice game	Stakeholders	No	-	Climate-based disaster risk reduction
	53.	About That Forest	Video game	General public	No	-	Sustainable forest management
2015	54.	Earth: A Primer	Mobile app	General public	No	-	Geoengineering & environmental SD
	55.	Polar Eclipse	Board game	General public	Yes	-	Earth resources management
	56.	EcoChains	Card game	General public	No	-	Sustainable food chains
	57.	Cities: Skylines	Video game	General public	No	-	Sustainable urban design
	58.	Evacuation Challenge Game	RPG	Stakeholders	Yes	-	Natural disaster & emergency planning
	59.	PeaceMaker	Video game	General public	No	-	Government's role in social sustainability
	60.	The Arcade Wire: Oil God	RPG	General public	No	-	Food sustainability & geopolitics
	61.	Extreme Event: Coastal City	RPG	Stakeholders	No	-	Sustainability of natural hazard risk

2016	62.	Laudato Si	Board game	General public	Yes	-	Biodiversity & economic inequalities
	63.	UrbanClimateArchitect	Online game	General public	Yes	-	Sustainable urbanism
	64.	Flood Resilience Game	Board game	General public	Yes	-	Flood resilience
	65.	Never Alone	Video game	General public	No	-	Resilience & sustainability
	66.	Lie, Cheat & Steal	Board game	General public	No	-	Politics of sustainability
2017	67.	The Catan: Oil Springs Scenario	Board game	General public	No	-	Resource management
	68.	Energy Safari	Board game	Students	Yes	-	Energy conservation
	69.	New Shores: A Game for Democracy	Computer simulation game	General public	Yes	-	Green project management
	70.	The world's future	Board game	Students, stakeholders	Yes	-	Resource management
	71.	Nexus	Board game	Stakeholders	Yes	-	Water management for SD
	72.	Gifts of Culture	Board game	General public	No	-	Cultural sustainability
	73.	Lords of the Valley: board game	Board game	Students, stakeholders	Yes	-	Biodiversity & water management
	74.	Flood Control Game	Board game	General public	Yes	-	Flood disaster management
	75.	Energy Transition Game	RPG	Stakeholders	Yes	-	Energy saving
	76.	Lords of the Valley	Video game	Stakeholders	Yes	-	Sustainable leadership
2018	77.	ECO	Video game	Students	Yes	-	Sustainable civilization

Among the 77 games analyzed, the seven categories of SG orientation (TBL) included sandbox video games, hybrid simulation games, online games, computer quiz games, computer simulation games, computer assisted games, card games, dice games, mobile apps, board games, RPGs, online sandbox games, online alternative reality games and video games. Table 3 displays the thematic breakdown of each SG, while fig. 10 shows the type of SGs released over the period examined. An additional feature of these SGs is that many of them, even the single-player games, could be modified for use by teams of players instead of individuals. The majority of the games have been designed to educate students, SD professionals (SD prof.) and stakeholders. Some of them can be used by the general public in order to increase awareness of sustainability issues. Stakeholders are typically motivation groups of entities that need to be clearly aware of sustainability topics for their own reasons. The general public, on the other hand, are players who have no direct interest in engaging with the SD world, including all other subcategories as well. The reasons for playing and educating themselves in this direction are totally different. The virtual environment of the majority of the SGs is two dimensional.

The 77 SGs that were identified in Table 3 reveal that, although the first game featuring sustainable criteria was created in 1990, the majority of the games were developed between 2010 and 2018. However, the research concerned SGs developed before February 2018, and the next five years are expected to see the release of more SGs on SD. Figure 7 summarizes the above-mentioned information, displaying the release of all the SGs (a total of 77) over time.

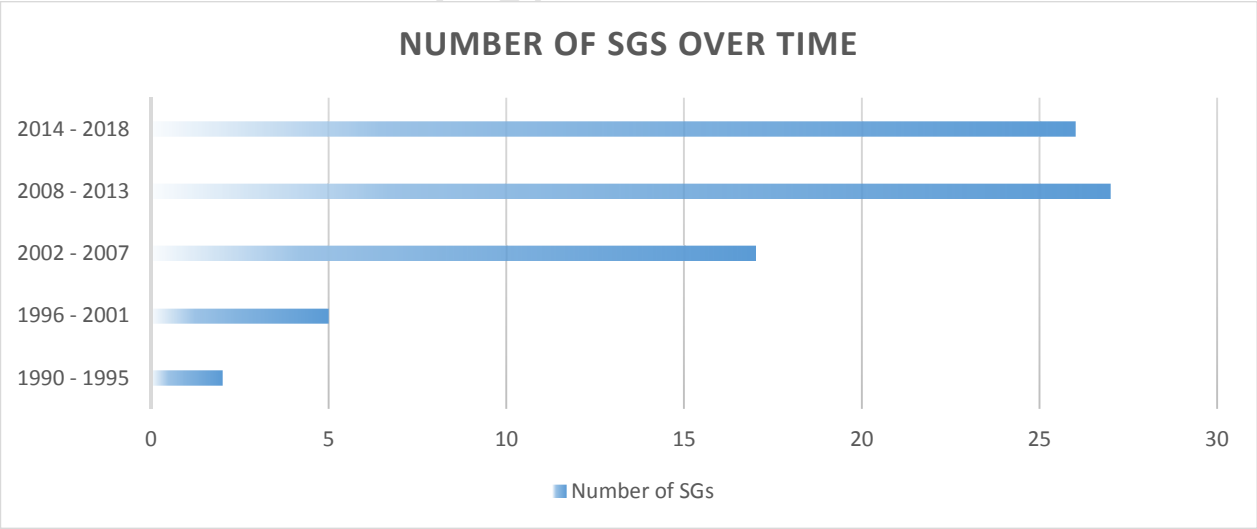

Fig 7: SGs on SD over time (until February 2018)

The findings on game characterization, which is specified according to the TBL of sustainability, show that although the vast majority of SGs are designed to educate users in SD, their field of gravity is sometimes centered on only a part of the dimensional TBL diagram. Figure 8 provides an overview of each game according to its orientation on the TBL. The numbers in the figure indicate that the SGs described in Table 3 follow the same numeration pattern. The majority of the games (total of 25, or 32% according to fig. 9) have achieved the goal of educating players in SD principles by involving all three dimensions of sustainability. The second largest percentage, of 18% with a total of 14 games, belongs to the environmental aspect. Environmental management games tend to be highly popular nowadays, especially due to ecological destruction and the huge increase in the use of the Earth's natural resources (Damania et al., 2018). The Socio-Economic, Socio-Environmental and Eco-Efficiency dimensions are almost equally developed, with 12%, 13% and 8% respectively, which corresponds to 9, 10 and 6 games in each dimension. Adding these percentages (33%), with a total amount of 25 SGs, it is obvious that following two dimensions of the TBL achieves superior results in the educational road towards SD. Covering at least two of the selected dimensions makes it easier for educators to somehow facilitate the third one and attain holistic SD knowledge. The economic dimension is the least popular amongst these kinds of SGs with only 1 game (1%). On the other hand, the social dimension is gaining in popularity, with 12 games (16%).

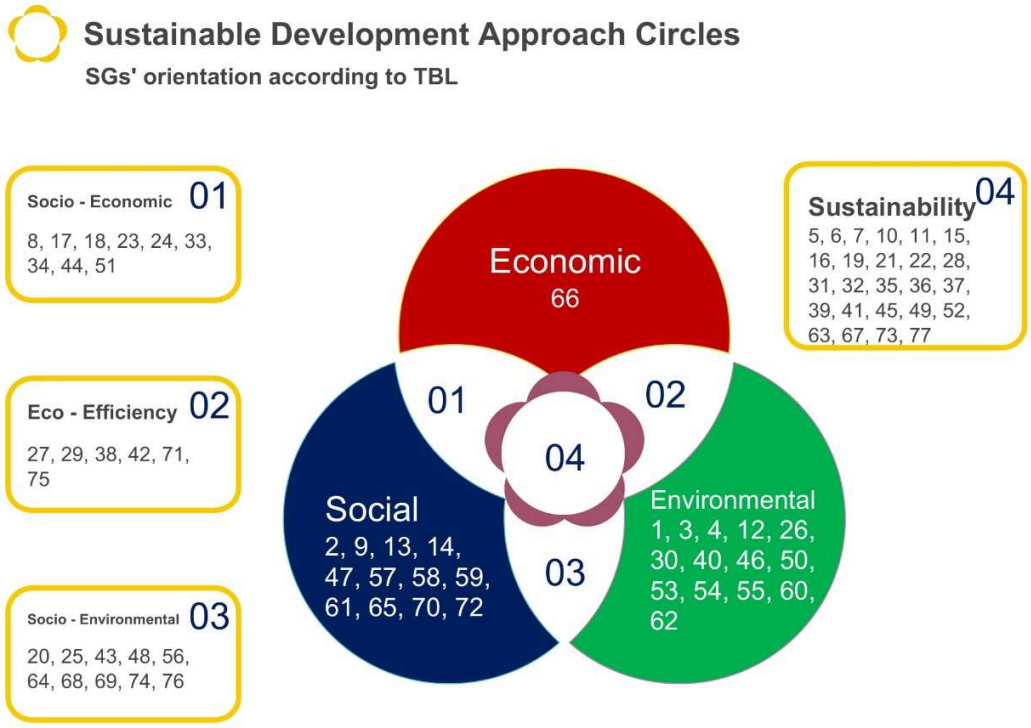

Fig. 8: Orientation of SGs on SD according to TBL (following the numeration of Table 3)

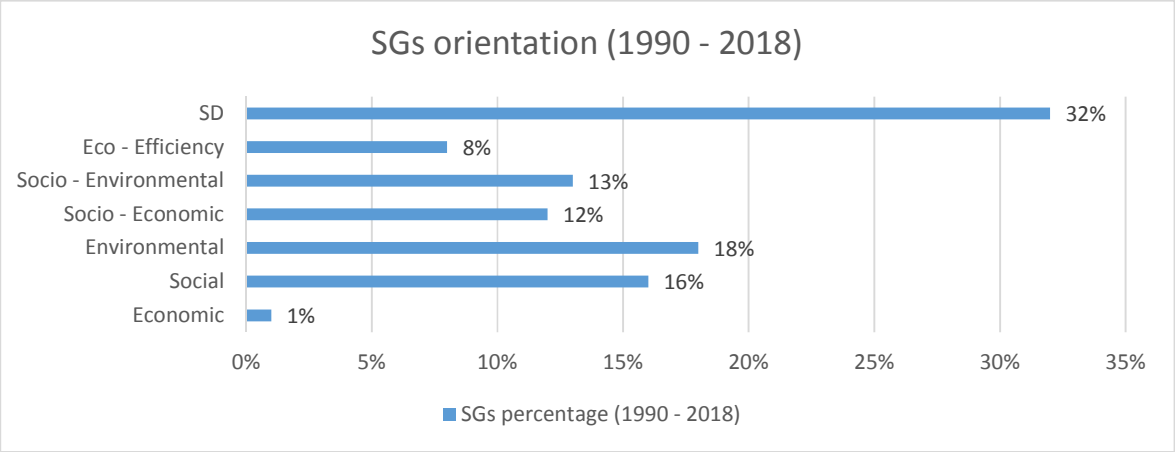

Fig. 9: Percentage of SGs on SD according to their orientation policy (TBL)

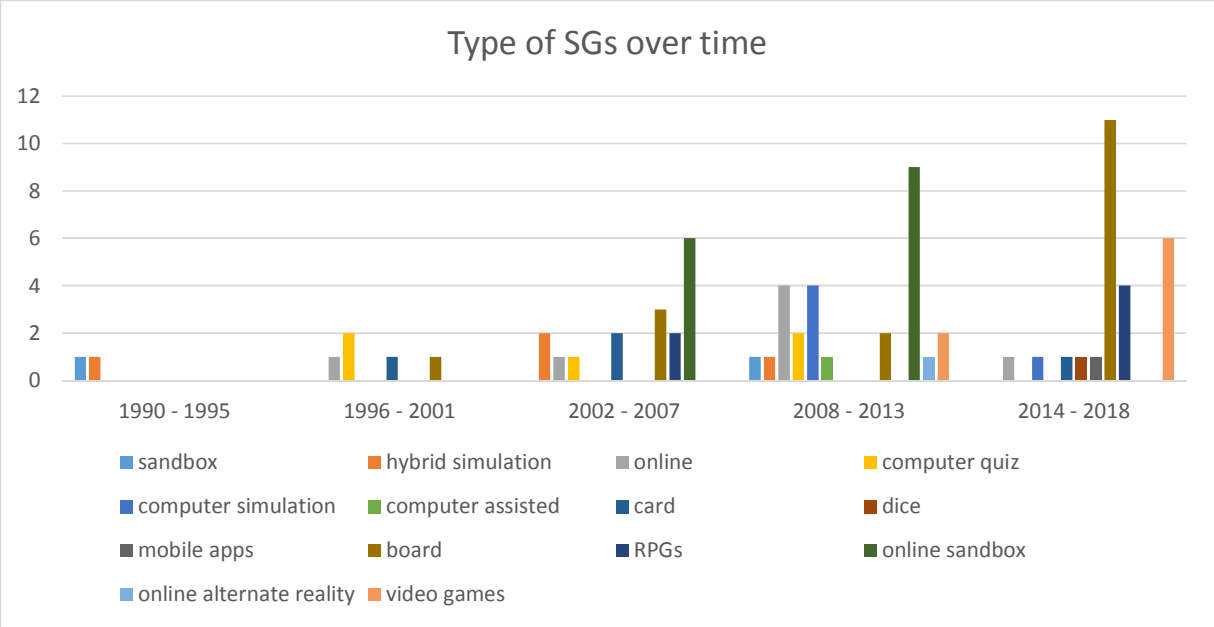

Fig. 10: Type of SGs released from 1990 – February 2018

3.2. Discussion

Having analyzed a large number of papers in the field of SGs on SD, it is clear that GBL in general, and the development of SGs that address sustainability issues in particular, are growing fields, and very promising for the future of sustainability education. In this paper, an analysis of a sample of recent SGs was conducted according to significant parameters like game objective and gaming type. The problems identified during this research concerns the lack of references to new SGs in the sustainability field, their categorization according to the TBL scenario and

their numeration so that they can become easily accessible to users who desire to be educated towards certain aspects of sustainability values.

In order to fill the gap that has existed so far in literature reviews of SGs addressing SD issues, wide-ranging research with all-embracing contributions from various scientific fields needs to be considered, in order to meticulously comprehend all the vital features that SGs on SD have to offer. Features that should be addressed include educational outcomes, ethics, aims, strategies, teaching exclusivity, the audience involved and the learning directions of sustainability issues.

One limitation identified in this study has to do with the fact that not all available SGs on SD could be found in academia or through internet sources. SGs tend to be less popular than entertainment games and thus their discovery presents obstacles.

Following the research method of the paper, a systematic literature review was conducted. Through the SLR, critical conclusions concerning the "nature" of the SGs on SD were drawn, defining their concepts and intentions towards sustainability. The analysis of the 77 SGs on SD principles involved SGs released from 1990 until February 2018. Throughout the years a progressive rise in the number of SGs has been observed (fig. 7). While there are plenty of types of SGs on the market (board, card, online sandbox, etc.), those that have ultimately been the most popular during recent years are board games and computer games (fig. 10). Other types, like dice games or sandbox games present a lower rate of recurrence. The thematic field of these SGs covers a variety of topics (economical aspects, social policies, environmental management) and thus their categorization according to the TBL scenario of sustainability was possible (fig. 8). To fully examine the thematic breakdown of these games, a quick play was performed in order to access the basic features of each game.

When seeking to teach specific sustainability attributes, educators are confronted with difficulties in deciding which SG is the most appropriate to their needs. Through this paper, guidance towards the desired path becomes easier than ever. Users can easily gain access to the SG of their choice by knowing beforehand if it is appropriate for their intentions (including internet links in the Appendix section). Observations through this literature review search revealed that not all SGs on SD are exclusively reserved for teaching. Among the 77 SGs presented in this study, those that seem to contribute exclusivity to teaching appear in table 3.

The high rise in the number of SGs that address SD issues (fig. 7) is an indicator that additional instruction and knowledge methods are expected to be developed in the future. SGs have the potential to be used as a tool for effective educational involvement. In this review, the state of SGs that give guidance in SD principles was analyzed, to provide awareness of their practicality as educational tools.

These SGs (their characteristics) have been briefly described and analyzed. The main objective of carrying out the SLR was to extract beneficial information about SGs that incorporate SD principles. The findings show that a growing number of SGs that seek to educate SD issues are being developed, especially during the last decade. The majority of these games contain major characteristics like the fact that they are available for free, making the task easier for educators and stakeholders. Another important factor is that most of them can be found on the web and are therefore easily accessible to anyone interested. Furthermore, they offer a single player option, which removes the need for team playing.

Apart from assessing the educational outcome of these games, the formation of multiple key factors is examined, including incentive, user experience and user-friendliness. Conclusions drawn from this analysis concern, the effectiveness (through their design and the audience they refer to) of the SGs mentioned in providing a holistic understanding of SD, the lack of quantitative results in some cases, and finally the increase in motivation and engagement that SGs can provide (which has valuable effects on knowledge outcomes). The reviewed SGs address a variety of learning values like motivation, socialization and understanding, as well as learning positionings, like behaviorism and humanism. There is a lack of harmony between the vital examination features of each study. Most assessments of SGs lack scientific accuracy. Based on the current analysis, it can be concluded that scientific

accuracy calls for improvement in the value of SGs for educating in SD principles, in order to attain effective outcomes.

The purpose of this study was to determine the educational contribution of SGs on SD, based on the TBL of sustainability and identify their impact scenario in sustainability teaching. Based on the findings (SGs characteristics) which is consistent to the existing literature, there appears to be a lack of information in the field of GBL on the topic of SGs for sustainability education (Annetta, 2010, Michael and Chen, 2005, Rugelj and Zapušek, 2013, Wattanasoontorn et al., 2013, Young et al., 2012, Cahier et al., 2011, Charsky, 2010, Corti, 2006, Crookall, 2010, Westera et al., 2008, Madani et al., 2017, Argasiński and Węgrzyn, 2018, Lamb et al., 2018b, Moloney et al., 2017, Giessen, 2015, Allal-Chérif and Makhlouf, 2016). Thus, five basic inferences can be drawn: (1) the effectiveness (teaching exclusivity) of SGs in meeting sustainability's educational requirements does not apply to all the games, but depends on the philosophy, the design and the type of each game; (2) a large number of studies of SGs (on SD or not) do not properly define their research method and lack quantitative results. Consequently, the clarity of the findings is hard to evaluate; (3) considering that the fields of SGs and sustainability are relatively new, there is a cleat need to inspect the educational outcomes over time and to clarify the influence and the effectiveness of SGs, if any, on the users; (4) interviews are a significant part of GBL, permitting users to describe their understanding and comprehend the educational link that connects "pure" gaming itself and didactic objectives; and (5) education through SGs (GBL) raises users' incentive and engagement, resulting in advantageous outcomes through fast learning.

As already mentioned in the introduction sector, the scientific hypothesis of this study claims that *any SG on SD fully contributes to all educational attributes of sustainability's triple-bottom line (economic, social and environmental dimension)*. The Systematic Literature Review (SLR) process is a formal, repeatable, recognized process, which in our case, was used for tracing, filtering and evaluating the literature relevant to SGs, sustainability and SD. By revealing the rate of recurrence of different documents in serious gaming and sustainability concepts, SLR has become a very satisfactory method to examine the original hypothesis (prove or deny) and to thoroughly gather, explore and describe the results. As Imtiaz et al. (2013) mention in their study, after identifying 174 published SLRs between 2005 and 2011, SLR is a valuable tool for researchers seeking wide-ranging knowledge. The fact that SLR offers helpful information concerning the need for further research in older studies, further demonstrates that it is a very promising clarification method (Hassler et al., 2016). Figure 11 examines the research factors and their interconnections allowing deeper examination of the SLR findings.

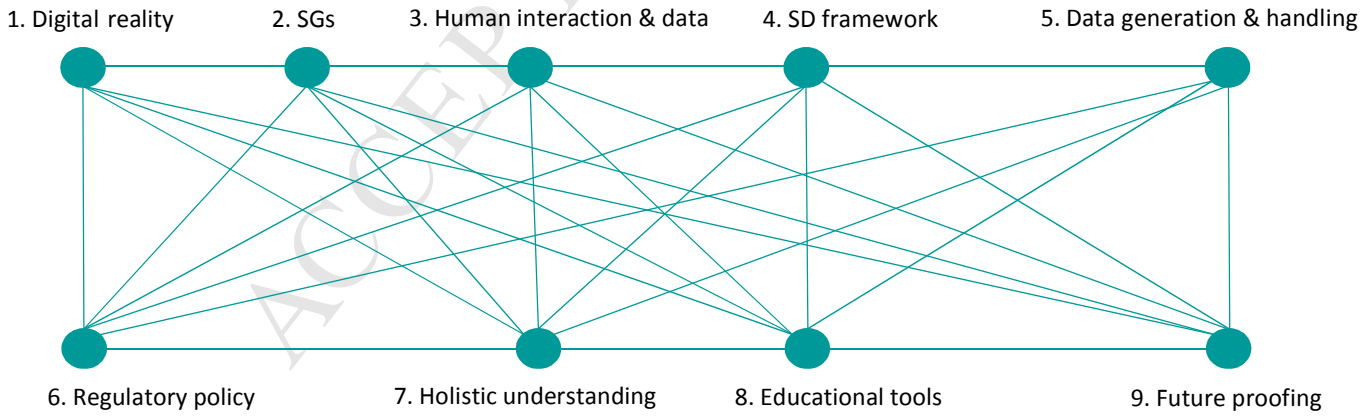

Fig. 11: Research factors and interconnections

1. Digital reality is transforming our society in fundamental ways, becoming increasingly pervasive across all sectors and being integrated in several aspects of our lives. Education, and SGs in particular, are part of

this transformation (Yu, 2017). Thinking ahead, new digital technologies are expected to create massive integration, both in the professions and in educational sectors previously considered unaffected (Frey and Osborne, 2017).

2. SGs, which are the main subject of this review, are an example of a different type of game. They are designed to develop a specific aspect of knowledge or training (sustainability issues in our case) and to be used in education (Dias et al., 2018).

3. Users of digital reality are currently generating data at an unprecedented pace with information coming in many forms and directions. However, there remains a fragmented relation between the data, the environment and the human interaction involved (sustainability and SD issues).

4. Increasing attention is being paid to integration of sustainability into development patterns within a SD framework. The predominant modeling approach under the SD framework is to develop peoples' awareness of sustainability initiatives through effective educational methods (SGs) (Halati and He, 2018).

5. The data generated nowadays usually entails a disparate and broad variety of sources, forms, locations, accuracy and velocity of collection, which results in great complexity in terms of its management and use (Kwon et al., 2018). Thus, appropriate collection and handling procedures are essential, as well as particular trials for its management and application.

6. The response to these pressures has resulted in an increased interest in regulatory policies regarding procedures for the use and control of digital reality tools, like operational SGs (Lemstra, 2018).

7. Holistic understanding of sustainability values is the most important educational outcome of a SG that addresses SD principles. Some games are getting closer to this goal, others not so much.

8. Training shows that in order for users to better acquire knowledge of sustainability issues, there is a need for the implementation of educational tools (SGs) that reinforce inter-disciplinary influences. The key factor for the establishment of such methods is to acquire holistic knowledge through educational methods (Mayorova et al., 2018).

9. Along with these lines of development, there is a need for people (users) to engage in sustainability topics and thus future-proof themselves, so as to prevent long-term economic, social and environmental damage (Rowley et al., 2012).

4. Conclusions

This study offers an understanding of the concept of 77 SGs and their contribution in sustainability matters. The analysis performed in this study shortens the gap between SD practices, policies and education (SGs), creating an extensive mapping (fig. 1). A categorization of 77 SGs was achieved according to the TBL (fig. 8), giving clarification hints to users wishing to select the relevant tool that offers an understanding of specific sustainability issues (TBL). After numerating the reviewed SGs on SD, they are positioned in a three-dimensional diagram of sustainability, to provide easy access to users. The trend of new SGs on SD appearing over time, and the sharp increase in their development over recent years (fig. 7), indicates that sustainability is becoming more and more essential for modern societies, and education in SD issues is seen as crucial for its proper implementation.

Considering all the above-mentioned aspects and the findings of the study, it can be concluded that the original scientific hypothesis, which claims that any SG on SD fully contributes to all educational attributes of

sustainability's TBL, should be rejected. Findings indicate that there are indeed some SGs that fully contribute towards the apprehension of all of sustainability's triple-bottom line (economic, social and environmental dimension) parameters (fig. 8), nonetheless there are plenty that do not. A large number of SGs on SD cover certain educational aspects of the TBL, such as the economic part, or in some cases, a combination of two (economic-social). As previously mentioned, the implications of the research are two-fold. The practical implication contributes towards the understanding of the existing SGs in relation to SD. This enables users to select the SG that complies with their educational needs. Going one step further, the grouping of SGs according to the TBL of sustainability (fig. 8) and their painstaking scrutiny offers prospect for further research on SGs that address SD values.

Despite the considerable interest in SGs as educational tools, it is important to understand that developing SGs for educational purposes can be very complex, and expensive and entail significant challenges. A possible direction for future research could be the development of experimental studies that systematically uncover key features that are useful in promoting holistic learning. Another conceivable track towards improving the layout of these SGs is to integrate realistic 3D graphics that bring users closer to reality. These graphics are impressive and thus help to raise players' motivation (Sweetser and Wyeth, 2005). Additionally, SGs should develop more intense social interaction (providing gains in the social dimension of TBL). Future research might also include a survey of the data on profiles of users and instructors, or a survey of stakeholder aspirations, including HEIs, industry and society.

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