



## An overview of serious games for disaster risk management – Prospects and limitations for informing actions to arrest increasing risk



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### ARTICLE INFO

#### Keywords:

Disaster risk management (DRM)  
Disaster risk communication  
Natural hazards  
Serious games  
Simulations

### ABSTRACT

This paper reviews serious games/simulations addressing issues related to disaster risk management (DRM) and serving as educational and engagement tools for affected communities, policy-makers, and other stakeholders. Building on earlier research in collecting and classifying serious games, we provide an objective and thorough overview of 45 non-commercial digital and analog gaming activities related to DRM, analyzing their characteristics, target groups, portrayed hazards, and possible DRM skills development. Moreover, realizing the need for a more reliable and scientific approach to testing serious games' effectiveness in contributing to DRM, we explore the categories of objectives of existing activities, and collect qualitative and quantitative evidence (players' feedback, quantitative surveys, scientific articles on the analyzed games etc.) supporting their assessment. Further, we identify the prospects and limitations of gaming in the broader context of DRM, and diagnose existing niches that could be exploited by game producers and researchers to develop more user-tailored game design and reliable evaluation methodology. The research reveals that DRM-related serious games/simulations offer a rich social experience with players collaboratively solving a problem. With a capacity of reaching diverse audiences (embracing adults, children, experts and communities) and of realistically simulating disaster reality, serious games/simulations may assist DRM, especially in the realm of disaster risk awareness raising, identifying hazards, undertaking preventive actions, empathy triggering and perspective-taking. At the same time, the research displays the scarcity of quantitative and qualitative research into the games' effectiveness. Therefore more detailed and structured study is called for in assessing these outcomes.

## 1. Introduction

### 1.1. Need for a new approach to information flow

Recent scientific and technological advances have made it possible to better anticipate disaster risks, enabling governments, civil society organizations, international non-government organizations (NGOs) and communities to prepare for these eventualities and take early action. However, devastating impacts of recent disasters in developing countries suggest that the development of improved scientific and technological approaches to disaster risk management (DRM) do not necessarily go hand-in-hand with an improved implementation of DRM,

and despite warnings people continue to locate their homes and assets in exposed areas. Let us take for example the 2016 earthquake in Ecuador that caused a death toll of at least 660 people and injured thousands, severely disrupting the country's economic activity. Similarly, the 2015 super typhoon Haiyan was the deadliest disaster ever recorded in the Philippines; the lack of effective dissemination and communication of early warnings was a notable weakness in the run-up to the typhoon. Research claims that: "If the scale of the impending danger had been communicated properly, and coastal residents had been evacuated to safer ground, fewer lives would have been lost" [1]. Indeed, despite great advances in early action, and self-reporting as required by the Hyogo and Sendai Frameworks for Action, there is a

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<https://doi.org/10.1016/j.ijdr.2018.09.001>

Received 29 December 2017; Received in revised form 9 August 2018; Accepted 3 September 2018

Available online 07 September 2018

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relentless increase in exposure of assets to earthquakes, floods, droughts, landslides, tsunamis, and other hazards [2]. This reveals a serious gap between science-based assessments, practice and implementation; while there are many factors driving this, bridging the communication gap is a critical step [3,4].

Delivering relief to affected communities in the wake of disasters is also very complex, especially as “unnatural disasters,” that is, catastrophic events resulting from human acts of omission and commission in relation to natural hazards [5], are shaped by cultural diversity, disabilities, gender issues, poverty, and governance challenges. The traditional approach to DRM involves top-down, centralized processes in which the decision-making and strategy development is the forte of governments, researchers and disaster managers [6]. Such “forced” or “command and control” methods minimize the participation of and partnership with affected communities and are often implemented without sensitivity to local cultural norms or economic and social needs. Although potentially useful for “simple” decisions, such as determining the height of dikes against flooding, for more complex issues (such as using floodplains instead of physical protection), such processes may be perceived as inappropriate and potentially not useful by disaster-stricken and risk exposed communities, inhibiting both risk communication and mutual trust building [7].

The range of difficulties experienced by DRM practitioners becomes even more evident if we take into account the current inequities in the flow and use of information. In the case of climate change, for instance, it is well known that those people who contributed least to it are paradoxically the ones who are most affected by their negative effects [8]. While developed countries are responsible for 79% of historical carbon emission [9], they are ensured easier access to information and mitigation measures. Meanwhile, limited and uneven access to education, technology and communication tools in many developing countries makes it more difficult for governments and other DRM practitioners to support the most vulnerable populations in these settings.

In the context of such limitations to effective risk communication and relief provision, there have been increasing calls in the last decade to move away from top-down, structural and purely scientific approaches to more participatory and community-based DRM strategies [6,8,10–12,4]. The main advantage of such approaches is the fact that “...the end users of information [are treated] not merely as a target audience but as partners in co-learning through processes and products that reflect their own contributions” [13]. From such a standpoint, the society is not perceived as “...a world where a single ‘correct’ solution is specified by privileged persons, such as a scientist, an influential politician, or a talented administrative government officer (...), but as a debatable, conflicting, and dilemmatic world (...) where multiple ‘viable solutions’ can coexist” [4].

Furthermore, the role of mutual learning has been highlighted as recognition has risen that traditional DRM actions, typically working within an incremental adjustment learning loop process (e.g. raising dikes to protect against floods) need to be complemented by fundamental (e.g. floodplains instead of a dikes) and transformative risk management options [14]. Among others, Lavell *et al.* [15] have suggested a mutual learning loop framework that integrates different learning theories, such as experiential learning, adaptive management or transformative learning.

Following this shift in DRM discourse, decision-making and practice, there is increased recognition that serious games (that is, games developed not only for entertainment) may serve as such participatory tools, and support understanding of essential issues, such as sustainable development, climate-change mitigation and DRM activities [16–27,4]. Consequently, a growing number of such games and simulations have been and continue to be developed to support more traditional top-down approaches to information transmission and awareness-raising activities in the field. In this paper we introduce and examine a variety of serious games/simulations designed to foster public awareness of and engagement in DRM activities and other risk-related issues.

This paper is divided into four main sections: 1) *Introduction* where we outline the main subject matter of the work, 2) *Methods, definitions and selection criteria* in which we describe our approach to this comparative research, 3) *Results* where we provide information on each activity's type, areas of application, and target audiences, and we present the outcomes of a cluster analysis of games/simulations' objectives and try to verify whether they are actually met, 4) *Conclusions and discussion* where we present deeper insights into the most interesting and/or surprising findings, suggest recommendations for DRM-related serious game designers, evaluate the whole study and propose questions for further study. The Appendices to the paper provide detailed information on the analyzed activities as well as links to further materials and literature.

### 1.2. Serious games/simulations as tools for learning and change

The growing popularity of hands-on or *experiential learning* where knowledge is believed to be “created through the transformation of experience” [28] has introduced a shift from authority- and lecturer-based teaching and learning to more engaging approaches in which a strong emphasis is put on emotional aspects, peer-to-peer relationships, horizontal communication and active cooperation. This participatory style of education has laid the groundwork for using games/simulations as an alternative or complementary teaching tool for enhancing skills useful for a collaborative and adaptive response to social-ecological challenges.

The field of *gaming/simulation* is not easily definable, with no clear division between a simulation and a game. As Crookall notes ([29], p. 899), the discipline “...encompasses an array of methods, knowledge, practices, and theories, such as simulation, gaming, serious game, computer simulation, computerized simulation, modelling, agent-based modelling, virtual reality, virtual world, experiential learning, game theory, role-play, case study, and debriefing.” *Simulations* are commonly understood as the imitation of the key characteristics, behaviors and functions of the selected physical or abstract system or process. *Simulation games*, on the other hand, are activities that combine game elements with systems analysis and simulation techniques. It is not our intention to draw a clear line between such fuzzy categorizations, but instead to highlight the very context in which both types of activities may overlap or complement each other to assist experiential learning and skills development via engaging people in a simulated, game-like experience. For the purpose of this paper, the terms: *serious game*, *simulation game* and *simulation* will be used interchangeably to refer to gaming activities that, in contrast to games designed predominantly as activities undertaken for enjoyment or competition, offer their users possibilities to learn actively. These activities act as metaphors reflecting specific systems “in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome” [30].

It is critical to note that although used for serious goals, serious games and simulations do not reject the element of fun. In fact, the emotional aspect of gaming makes it an even more powerful educational tool. In her comment on “Manifesto for a Lucid Century,” Chaplin [31] highlights that games and play constitute the core of how mammals interact with the environment: “Babies and children play as a way of developing their understanding of the world.” In this sense, play makes use of the most natural capacity of the human brain to acquire knowledge effortlessly, somewhat “accidentally.” Indeed, as highly interactive and social activities, games and simulations may trigger a positive emotional response in players that can make them a compelling, challenging, memorable and fun learning experience [16]. In this way, serious games and simulations have a potential to enhance the process of remembering information, as recent studies have found connections between the excitement we feel entering a new social situation and the cognitive process of memory foundation. According to the study led at the University of Haifa, strong positive emotions experienced during the first encounter with previously unfamiliar people

cause the brain to work differently and on distinct frequencies. The findings explain why people tend to remember impressions and information felt and experienced during such “first” meetings better [32].

Moreover, active learning methods have much bigger retention potential than traditional classroom exercises, as studies show that only about 5% of information heard during a lecture is remembered, whereas practical training results in a 75% retention rate [33]. This is because the uninterrupted attention span for adult learners is estimated to be around 20 min, with learning impact being the greatest during the first 5-min portion of the presentation. After that time a lapse comes where students inevitably zone out [34]. Traditional approaches to education also often see learning as synonymous with remembering, thus promoting “shallow” memorization of facts rather than “deep” processing and constructive application of information in order to solve a problem [78]. Meanwhile, game-based approaches offer more meaningful experiential environments, similar to problem-solving learning where students in small groups are presented with a problem that they must try to solve. They are assisted by a “facilitator”, whose function is to guide and advise the group and keep them on the right track, but not to supply information” ([78], p.2). In such an environment participants, by collecting different parts of information and applying critical thinking, are able to obtain what is often referred to as the *big picture*, a holistic perception of a given issue, and thus gain a better understanding of complex systems [35].

In order to accomplish deep learning and holistic perception, modern serious games are much more complex than simple educational games based on *Trivial Pursuit's* quiz concept or rolling a die and moving along a board. Most of them encourage players to immerse in a fully operational and complex in-game “reality” that simulates the key aspects of a given process or problem. Such a setting often entails role-taking and interacting with other players. As a result, participants have to make strategic decisions, deal with the outcomes, and think deeply about the concepts the game is centered on [36]. Within the game setting, they can explore different kinds of behaviors and will likely receive immediate feedback. Whether or not the decision was a good one is of no relevance, since there are no real life consequences. What is important though is that players can explore multiple cause-effect relations in the in-game reality, which can then be extrapolated to the real world system.

Many games or simulations employ rule-binding, limiting gameplay by clearly defined rules (e.g. the time allotted or a set of moves players are allowed to take) that make them possible to play. Consequently, at every point of a activity participants explore possibility space created by the limitations, testing available moves and strategies in order to formulate “what if” questions and consider alternative scenarios [35]. This aspect of gaming activities, often referred to as *procedurality*, allows game designers to reflect processes occurring in the real world with greater realism [37]. As a result, players are able to observe the linkages between the components of the game's environment and the mechanisms ruling the real world. In this way games may serve as a useful starting point for game-based learning about many aspects of real life, including natural hazards, climate mitigation or DRM. The safe yet challenging game setting gives space for practicing trial and error strategies, observing others, and thorough processing of different pieces of information at once.

### 1.3. Serious games/simulations for disaster risk management

The dramatic nature of disasters has always captured humans' imagination; since time immemorial, catastrophes have been depicted in paintings, music, novels and recently also in films and games. “Disaster popular culture” (DPC) captures the struggle of humans against the forces of nature, simultaneously documenting the preservation of life and establishment of social organization in the face of danger ([38], pp. 284 after [79,80]). Serious games, being a significant part of this culture, have the potential to reach a wide audience and

convey reliable and consistent information regarding DRM, installing disaster awareness, portraying hazards and vulnerabilities, and modelling useful skills across all stages of the DRM cycle. To reach this aim, serious games' designers must carefully balance the entertainment element with disaster discourse, providing players with an opportunity to explore DRM strategies at both pre-disaster stage (mitigation/prevention and preparedness) and post-disaster stage (response and recovery).

Serious games and simulations may easily simulate the elements of pre- and post-disaster actions, balancing realism with efficiency (e.g. replacing damaged infrastructure with symbolic tokens, adding dramatism with the use of sound effects, augmented or virtual reality, etc.) [24]. In this context, serious games may mirror certain key characteristics of disaster reality, providing players with additional or alternative understanding of risk. While traditional lectures, presentations or community meetings may support dissemination of knowledge and competence required to mitigate or cope with disaster impacts, the question remains how deeply these insights penetrate, and whether they will actually be used to take action on disaster risk. A safe classroom setting in which knowledge is acquired is significantly different from e.g. post-disaster environments, “characterized by high levels of stress, uncertainty, time-pressure, coordination issues and communication difficulties, in addition to disrupted services and damaged infrastructure” [24,81]. Meanwhile, some serious games can resemble emergency drills or field training exercises, requiring participants to build experience required in crisis situations. Other may put players in roles (e.g. a rescue team member, a victim or an aid worker), forcing them to cope with a new and stressful situation and, by triggering empathy, get a better understanding of the circumstances surrounding a disaster reality. Not surprisingly then, international organizations, governments and NGOs as well as researchers promote the use of serious games and simulations as a promising method for raising disaster risk awareness.

With the growing recognition of games and simulations as useful tools for DRM, there is a need to provide a more systematized approach to evaluating the purpose and effectiveness of these increasingly diverse offerings. Although the general notion of a game/simulation designed for a serious goals seems intuitively understandable, boundaries remain fuzzy, with stakeholders not necessarily agreeing on what is and what is not a part of the field [39]. Djaouti et al. [40] provide a brief overview of existing taxonomies of serious games/simulations, and develop an evaluation grid, the so-called G/P/S model (where G stand for gameplay, P for purpose, and S for scope). This grid allows overall classification of gameplay into more free (lacking strictly defined “goals”) and more gain-bound (offering a win/loss option depending on the ability to reach in-game goals). In addition, it helps to assess the serious games' three main objectives (message-broadcasting, training, and data exchange), and to identify targeted games' applications (e.g. healthcare, education, politics, etc.). Based on the G/P/S model, an online collaborative database of serious games/simulations has been developed by Djaouti that includes 3311 (in October 2017) video games designed for a serious purpose [41].

Another effort to provide a systematic overview of serious games/simulations focused on selected fields of interest is Ulrich's [42] survey of games and simulations on environmental and sustainability issues that analyzes the selected games' objectives and underlying models. More recently Di Loreto et al. [43] issued an overview of 10 collaborative serious games for crisis management that analyzed the games' types and scenarios to check their usefulness for increasing participants' management skills. In 2013, Recken and Eisenack [44] provided an overview of 52 climate-change related digital and analog games, analyzing, i.e., their formats and the type and scale of the topics that each game addressed. Additionally, Gampell and Gillard [38] presented a typology of disaster-related serious and entertainment video games, identifying how they instill disaster awareness, portray hazards, vulnerabilities, capacities, disasters and DRR, etc.

These various reviews have proven that although serious games/simulations have the potential to raise awareness and develop various skills, little insight is available via either developers or users regarding their effectiveness. For example, in their analysis of games/simulations for crisis management, Di Loreto et al. [43] were not able to find any long-term evaluation of the activities' impacts. Critically, no coherent and commonly accepted tool for such assessment exists. For example, the G/P/S classification model developed by Djaouti [40] and [41] takes into account only three aspects of gaming activities, providing no qualitative information on their actual application and evaluation against meeting their intended objectives.

The aim of this paper is therefore twofold: 1) Building on earlier research in collecting and classifying serious games/simulations, we provide an objective and thorough overview of 45 non-commercial digital and analog serious games/simulations dealing with issues related to DRM, analyzing their main characteristics and target groups, portrayed hazards, and possible skills development across the DRM cycle. 2) Realizing the need for a more reliable and scientific approach to testing serious games' effectiveness in contributing to DRM, we explore the categories of objectives of existing gaming activities, and collect any qualitative and quantitative evidence (players' feedback, quantitative surveys, scientific articles relating to the analyzed games etc.) supporting their assessment. The findings described in the subsequent sections are further detailed in Appendices A-E.

## 2. Methods, definitions and selection criteria

We undertook several parallel processes to select games and simulations from a wide range of existing digital and analog games. Firstly, to limit the scope of the study, we decided to focus on games available in English only. To do so, we conducted a broad web search utilizing the popular Internet search engines, such as Google, Yahoo, YouTube, Vimeo and the Apple iTunes store, using the keywords (in different combinations): serious game, simulation, simulation game, role-play, disaster risk management, disaster risk reduction, crisis management, emergency, disaster prevention, disaster mitigation, disaster preparedness, disaster response, disaster recovery, disaster resilience, humanitarian help.

In addition, two online databases were especially useful in identifying games/simulations for the analysis, namely the aforementioned collaborative database of serious video games developed by Djaouti [40,41] and a collection of video and analog games' held by the Centre for Systems Solutions [45]. In Djaouti's database the games/simulations are classified according to their gameplay, their purposes, their markets and target audience, alongside with user-contributed keywords. By simply ticking the boxes on this page, it is possible to find any activity together with appropriate links to their homepages. However, the collection embraces only digital games/simulations with no reference to board, dice or other analog gaming activities. The Gamepedia collection developed by the Centre for Systems Solutions, on the other hand, collects both analog and digital games/simulations, and enables advanced search against several criteria (e.g. filtering gaming activities by matching sustainable development goal, time of play, number of players, etc.). In addition to basic information on games/simulations (time, players, plot overview, equipment needed, etc.), the Gamepedia also offers information on prices, which was especially relevant for the purpose of this paper that analyzes only non-commercial serious games/simulations.

The Internet search results were verified against the following four criteria, suitable for the purpose of this paper. Firstly, a game had to fall into the definition of *serious games/simulation*, a term commonly attributed to Abt [46], and originally used to refer to both computer and analog activities that “may be played seriously or casually, [but]... are not intended to be played primarily for amusement” [46]. And although current definitions seem to depart from Abt's proposition, following a trend initialized by Sawyer and Rejeski [47] to use the term *serious*

*game* only in the context of digital games, we opt for a broader scope of the definition that embraces both digital and analog games in which “... players engage in an artificial conflict defined by rules that results in a quantifiable outcome” [30].

Secondly, the game had to deal with the focus of this review—a broadly understood *Disaster Risk Management*, as defined by UNISDR [48]: “The systematic process of using administrative directives, organizations, and operational skills and capacities to implement strategies, policies and improved coping capacities in order to lessen the adverse impacts of hazards and the possibility of disaster.” It is worth noting here that by *disasters* we mean destructive events affecting communities and societies, involving widespread human, material, economic or environmental losses and impacts [48]. They are often caused by environmental/natural or human-made hazards, and affect communities especially exposed to their direct influences. To limit the scope of the study, the analysis embraces only disasters brought about by human interactions with natural hazards (such as earthquakes, floods, tsunamis, droughts, volcanic eruptions, etc.), at the same time excluding those disasters that can be attributed solely to human-driven and technological incidents (such as transport accidents, nuclear radiation, explosions, etc.).

Furthermore, in order to account only for these games and simulations that may reach as wide audience as possible, we decided to analyze only non-commercial games whose content is either available for free (printable, downloadable or accessible<sup>1</sup>), available for rent (like e.g. *Hazagora*) or at least played during public meetings, awareness-raising workshops for communities, etc. We thus consciously avoided including games created for commercial purposes (for example *Triage* by SimpyFun), but we included e.g. *Crossroads: Kobe, Disaster Awareness Game and Disaster in My Backyard*. In the case of *Crossroads*, the game is sold through a shop affiliated with Kyoto University. Yet, it has been designed to be used by relief and governmental organizations, city authorities and civil work services—individuals and institutions whose work is to reach and protect citizens as a principle, and has been used in various settings, from disaster training for government officers to voluntary disaster drills, as well as for disaster education at children's school [12,49]. Such widespread distribution may thus serve as an evidence that the game is publicly available and applied in various environments. As for the *Disaster Awareness Game*, although the game's materials could not be found on the Internet nor could we obtain them directly (we tried, without success, to contact one of the game's facilitators, Dr. Virginia Clerveaux), the game itself seems a promising tool for promoting equitable access to disaster education and information in culturally diverse contexts. It also identifies an overlooked niche in communication strategies, seeking an opportunity in children who may serve as conduits of hazard/disaster information between school and migrant parents. According to related research [6,50,51], the game has the potential to reach a wide audience, including minority groups often neglected in the DRM context, thus we decided to include it in the research. Similarly, *Disaster in my Backyard* is still under development but is being tested with users during public events (such as ISCRAM Summer School in 2012 or Tag der Logistik in 2014) and offers a promising and widely applied awareness-raising tool [23,24].

Finally, to exclude unreliable or amateur products, we decided that all the analyzed games had to be created and developed either by researchers/universities, scientists dealing with the DRM issues or humanitarian, non-governmental or any other organizations with practical and credible experience in DRM.

As a result of the processes described above, we arrived at the final list of 45 serious games/simulations that are collected in the [Appendix A](#). In order to assess their relation to DRM activities, we have decided to

<sup>1</sup> The Inside the Haiti Earthquake simulation that is currently available upon subscription, has been available for free upon editing the first draft of the article in October 2017.

partially follow Gampell and Gaillard [38] and identify what type of hazard they address and to analyze them against the DRM framework, outlining the main disaster management strategies and their related actions at all four stages of the *DRM cycle* (prevention/mitigation, preparedness, response or recovery), as defined by UNISDR [3,48]. This information is summarized in the columns “Type of hazard” and “Stage of DRM cycle” in the Appendix A. Moreover, to quantitatively assess what type of gaming experience prevails in the field of DRM-related serious games, we have conducted a content analysis of the collected games’ characteristics; whether it is a face-to-face or computer game, what type of interactions and techniques (e.g. role-taking, storytelling, quiz) it applies, whether it is followed by debriefing or not, etc. This data is collected in Appendix B and summarized in Appendix A, in the column “Game’s characteristics”.

Further, taking into account that the collected games were designed with the primary intention of providing specific DRM-related content to be trained or learned, we have collected objectives/aims that were explicitly declared by the games’ authors or producers on the games’ websites, in the rulebooks and/or any other relevant material (such as, e.g. a scientific article about a given game) and presented them in Appendix C against any observed or evaluated outcomes. The declared objectives were further divided into conceptually meaningful segments that were subsequently grouped by shared common characteristics into clusters in the process of a non-exclusive cluster analysis<sup>2</sup> [52]. In most cases, the “common characteristics” were identified by linguistic analysis, e.g. by grouping objectives that shared certain semantically similar segments, e.g. “to raise awareness of,” “to train decision-making,” “to improve collaboration.” However some segments that shared no semantic resemblance to any emerged category, were classified on the more intuitive, common-sense basis (e.g. the declared objective “to encourage positive behavior among vulnerable people at all stages of the disaster management cycle” was assigned to the category focused on *disaster resilience* even though the word “resilience” was not used. The described practice was, however, assessed by the authors as one that leads to more resilient community, and thus closer in meaning to any other category that emerged during the cluster analysis. The process of grouping the declared aims helped us organize the collected data and identify the most commonly declared games’ objectives that are addressed by DRM-related serious games/simulations. The results of the analysis are presented in Appendix D.

Lastly, while collecting data for the research, we aimed at finding matching scientific publications on the games included in the analysis. We were especially interested in identifying any relevant research into the serious games’ effectiveness in meeting their declared objectives. Using a number of academic databases and search engines, such as BASE, Google Scholar, SafetyLit, Science.gov and WorldWideScience, we have collected nearly 30 articles, reports, and other written publications on the selected games’ effectiveness, which are described in details in Appendix C and summarized in Appendix E. In each case, we also tried to contact the games’ developers and designers to verify if the information collected in the appendices is current and reliable. The response rate, however, was not high with only four developers contacting us back (namely the Red Cross Red Crescent Climate Centre’s representative and the developers of *Hazagora*, *Extreme Event Game* and *Stop Disasters*). The results of the analysis, as well as the content of the appendices are described in the subsequent section.

<sup>2</sup> Non-exclusive or overlapping clustering allows one cluster/segment to be assigned to more than one category (e.g. the cluster “to measure levels of disaster awareness among children in multicultural environments as a means of determining and prioritizing interventions for disaster education” was assigned both to the category 1., focused on *education* and category 11., focused on *multicultural aspects*. As a result, the number of clusters identified in the analysis, outnumbers the number of games collected for the analysis.

### 3. Results

#### 3.1. DRM-related serious games offer space for social interaction

As Fig. 1. shows, the majority (26) of the serious games/simulations on DRM issues collected in this paper provides a face-to-face multi-player experience, characterized by lively direct interactions between the participants. Most of these activities fall into the broad category of *role-play* games/simulations. In such type of serious games, participants gather in one room or open space to assume fake roles and engage in a simulated environment that realistically mirrors certain aspects of the process or problem. In this way, players directly experience the uncertainty, chaos and stress connected with, in our case, disaster management, and enter into what Duke [35] calls a *multilogue*, that is, a communication form that allows many people with different perspectives to parallelly negotiate, persuade, ally, brainstorm or exchange information in order to take a collective decision, adapt a coherent strategy or cooperate for the common good. The reality in role-play games is simulated both by direct interaction among role players and the use of game elements: boards, problem cards, dices and other realia or symbolic tokens (such as pebbles, beans, strings, etc.).

In the analyzed DRM-related face-to-face role-play simulations, players often take on the roles either of disaster managers and NGOs planning for and managing disasters or the roles of vulnerable communities. For example, in *Disaster Imagination Game* players are “appointed” members of the virtual commanding post of disaster relief activities. By recording various details on maps, they have to identify vulnerable areas, and discuss how to command relief activities [53]. In the *Evacuation Challenge Game*, on the other hand, participants take on the roles of evacuation team members and the residents of the affected area that need to be evacuated. They have to process information, assist people with limited mobility or other health or culture-specific limitations, and collaborate on their way to safety. Other examples of roles include e.g. communities vulnerable to mosquito-borne diseases (*Buzz about Dengue*), citizens of a metropolis that experienced a severe disaster almost a century ago (*Cultural Memory Game*) or subsistence farmers trying to develop a more disaster-resilient community (*Dissolving Disasters*).

The most important aspect of role-taking is the fact that it has the potential to push participants to walk in someone else’s shoes and to make them explore the perspectives they would otherwise not consider [26]. Sheltered from anxiety, intimidation or “the stifling effects of etiquette and protocol found in real-life situations,” role-players are able to distance from their personal beliefs and to “defend a perspective, not their own position” ([82], p. 549). Role-playing serves thus as a reminder that this is a “game,” that they are “playing” ([82], p. 538). Consequently, temporarily free from everyday limitations, players become more open and creative, often entering into meaningful discussions and coming up with innovative solutions to the in-game problems.

For example, in the *Upstream/Downstream* board game about collaborative resilience-building, players are put in the shoes of farmers living in the upstream or downstream area. The individual goal of each farmer is to accumulate wealth by investing wisely in one’s farm (each farmer can plant crop and new trees, or cut and sell trees). However, as the upstream area is steeper and lacks fertile soil, upstream farmers soon start to overexploit the forest, leading to deforestation and increasing flood risk downstream. If no interaction is established between upstream and downstream farmers, no exploration of how this risk could be managed emerges. However, recorded gameplay sessions [25] revealed that e.g. in the Nicaraguan village of Moropoto, players overcame this impasse and jointly came up with the strategy to address this risk: the downstream farmers decided to support their neighbors with loans after disasters and with subsidies to plant new trees in order to reduce risk of flood induced by deforestation. Therefore a potential conflict-generator actually evolved into the paradigm of “game as open culture,” in which players jointly created an innovative solution to their

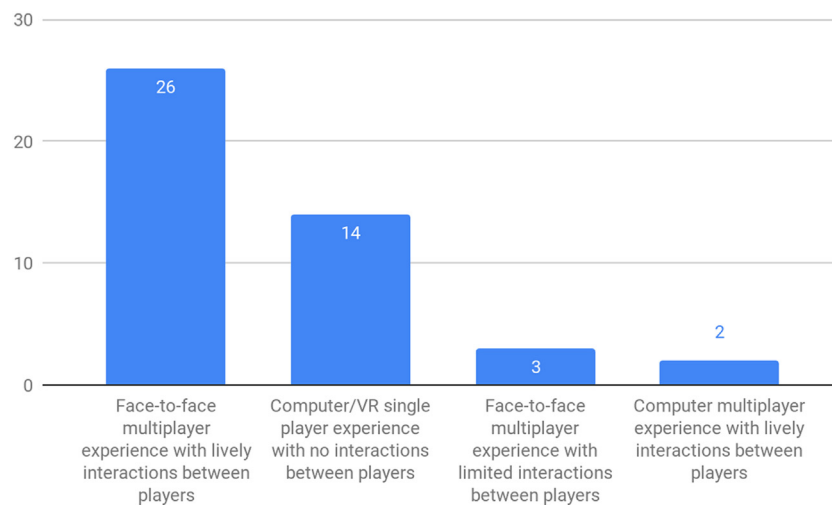


Fig. 1. Characteristics of the experience provided by DRM-related games.

common problem [25].

Another example of such an evolution from an individualistic pattern to a more empathetic, and thus collaborative, strategy has been observed e.g. in case of the *Gifts of Culture* game, where players embody the members of the Citizenship Board in a flood-prone valley inhabited by local and immigrant farmers. As observed during gameplays, initially players usually focus on policies and measures that bring benefit only to the group they represent. These solutions are not inclusive, as e.g. refugees and immigrants are denied access to some of the safety mechanisms. The need for more inclusive, long-term solutions appears only after the first shock that comes with the recognition that a community resilience is the result of individual and collective strengths and vulnerabilities.

The use of various devices—boards, cards, dices, stylized or factual data-based maps, applications or elements of augmented reality—spurs the dynamics of the face-to-face simulations and adds the sense of realism, urgency and fun. In some types of the face-to-face simulations, supportive elements create a very immersive experience of a disaster setting. This applies e.g. to the *Disaster in My Backyard* game in which players use a mobile application that stimulates the field operations. The application is connected to the central database from which the exercise is controlled. Throughout the game, teams use the application to scan QR codes scattered around the area to interact with certain game elements, by e.g. examining the profile of a disaster victim or determining the content of a med-kit [6,50]. Similarly, real objects, such as high-visibility jackets (to mark rescue team members), blindfolds and earplugs (to be used by participants playing people with sight or hearing impairments) are used in the *Evacuation Challenge Game*, whereas realistic sound effects introduce the onset of a disaster in the *Extreme Event Game*. Some activities of this type approach disaster drills or field training exercises, and—like in case of *Disaster Imagination Game*—may make use of real maps on which participants mark roads, important facilities, potential risk zones and evacuation routes [53].

Other role-play activities may apply more symbolic game elements. In many role-plays, real maps are replaced by stylized boards that mirror the key elements of a simulated environment. For example, in *Hazagora* the board displays a volcanic island divided into different, in terms of land use type and disaster exposure, areas. Throughout the game players develop their family settlements, road networks and implement various protective measures [54]. In the *Evacuation Board Game*, on the other hand, the board represents the traffic system that has to be managed by the players evacuating from the flood affected city.

Dice are also often used to practice decision-making under uncertainty, especially on the basis of probabilistic forecast information.

For example, in many Red Cross Red Crescent Climate Centre's games (including *Decisions for the Decade*, *Dissolving Disasters* or *Paying for Predictions*) the dice represents probability of rainfall, where a 1 represents little rainfall, and a 6 a lot. Without looking at the result (players roll the dice and place it in the cup), participants have to make individual and collective decisions on what (if any) flood preparedness measures to bid on. Complex ideas, such as climate change are represented in the simplified manner of changing probabilities of severe weather events, for example by using different dice. Other “probability-counters” entail i.e. cones, cards or special probability trees.

Although the majority of the face-to-face multiplayer simulations apply role-taking as the main trigger for discussion and reflection, other techniques are also present. *Crossroads: Kobe* and *Story Go Round* make use of narration-building or story-telling techniques. The participants of *Crossroads: Kobe* have to make difficult yes/no decisions in response to a short narration (based on real stories of the Great Hanshin-Awaji Earthquake's survivors), such as e.g. whether to provide food that is close to its expiration date to earthquake victims or not. Players discuss each episode after taking the decision and examine supporting materials, i.e. video clips, expert opinions and statistics (see: [55,56,10,11,12,4,49]). In the *Story Go Round*, on the other hand, players react to a disaster forecast by collaboratively creating a story of how they would manage the disaster (what measures would prove useful to mitigate its impacts or what valuables they would chose to protect). Although the participants of such narration-based activities are not directly asked to assume fake roles, the empathy, and thus perspective-taking, is triggered by the creative process of considering what they would do if they were put in a given situation.

In addition to a number of face-to face multiplayer games that apply direct interactions among players, there is a smaller group of 3 games that do not encourage lively discussions or exchange of thought among their users. This group consists of analog card-driven board games, such as *Save Natalie! The Preparedness Game*, *Riskland* and *Disaster Awareness Game*. These activities, directed mostly to children and pre-teens, rely on a simple race and/or quiz mechanism in which players advance along a board and answer disaster-related questions upon landing on “special” fields. Although such quizzes may be fairly useful in the context of disaster awareness evaluation, as they enable pre- and post-game disaster knowledge analysis (for example, the *Disaster Awareness Game* kit includes a board game with related question cards and a sheet that is used by the facilitator to evaluate levels of awareness prior to and after the exposure to the game; see: [6,50,51]), their immersive or engaging potential seems rather limited, leaving little room for communication or building emotional relationship among participants.

No interaction is provided also by the games categorized as single-

player digital games (14 games). The majority of these games rely on simple quiz-like mechanism in which players have to e.g. click on items that would prove useful in case of emergency (*Build a Kit*), select a proper way of protecting items before the earthquake from three different options (*Beat the Quake*), answer disaster-related questions (e.g. *Disaster Master*, *Hurricane Strike* or *SerGIS: Malmö Flood Scenario*). In contrast to face-to-face analog games in which the competitive or “winning” element is usually less important than collaboration and communication among players, this type of quiz-like games is usually goal-oriented, requiring a player to perform a certain action to get a “reward” (such as scores for answering a disaster-related question properly in e.g. *SerGIS: Malmö Flood Scenario* or *Beat the Quake*) or moving to the next level in e.g. *Disaster Master* or *Earth Girl. The Natural Disaster Fighter*. Players may either send their scores to friends, inviting them to beat their record or compare their results against other players whose scores have been archived. Several games offer more complicated decision-making processes by putting players in control of e.g. flood policy (*FloodSim*), city management (*Stop Disasters!*) or emergency response planning (*Supervolcano*). In these types of games, players are able to select from more than just two or three options and may observe the consequences of their decisions when the disaster finally develops.

Some more realistic, immersive experience may be provided by *Inside the Haiti Earthquake* that falls into the emerging genre of what is referred to as *docugame* or *documentary digital game*, a hybrid of documentary techniques with dramatic reconstruction and computer generated imagery inspired by games [57]. The simulation, rooted in real events and using documentary footage from Haiti, offers a player a first-person experience of disaster reality from a perspective of a journalist, disaster survivor or an aid worker. Although the plot of the simulation is still relatively simple (players walk through the devastated Port au Prince as one of the three roles and are presented with choices that dictate the course of the storyline), its interactive character turns a player from a passive spectator to “an immersive reader” who is “connecting knots and nexus, in a multi-linear, multi-sequential and labyrinth script, which he himself helped to build” ([58], p. 65). Via such *transmedia storytelling*, players do not only have a sense of control of what is happening on the screen but they may also more easily identify with the heroes of the story, which in turn would positively contribute to empathy with the victims and interest in learning more about earthquakes [59]. Similar, immersive experience may also be provided by the DRM-related virtual reality game, *VR for a New Climate* that enables players to manage flood operations by physically operating different virtual devices (shaking an alarm bell, stamping the emergency funding request or picking up the virtual boxes with relief items and loading them on the truck see: [60]).

Only two digital games included in the analysis offered a multiplayer, social experience for the people engaged. *Forest@Risk* and *Lords of the Valley*, although both Internet-based, may be played during face-to-face workshops or online. In the latter case, players are encouraged by the moderator to use chat to communicate, build allies and strategies.

An important part of gaming experience (be it face-to-face or digital) is *debriefing*, that is, a summary discussion after the game that “allows the individuals who were in the experience to share, cross-fertilize, and to generalize their learnings from and between all who participated in the same experience” ([29], p. 907). 27 out of 45 games collected for the analysis include debriefing as part of the whole learning experience. Not surprisingly, most of them are face-to-face multiplayer games with lively interactions between players (24 games out 26 include debriefing, no information about such a discussion was found only in case of *Evacuation Board Game* and *Game of Floods*). Also digital multiplayer games (*Forest@Risk* and *Lords of the Valley*) incorporate debriefing as an essential part of the game workshop. Meanwhile, games lacking a significant social element (all single-player digital games and 2 face-to-face games with limited interactions) do not apply debriefing after the game.

To summarize, the majority of the collected games constitute face-to-face multiplayer experience with direct interactions that is followed by debriefing. Only a couple of face-to-face games (exactly 2) lack both a significant social element and a summary discussion. As far as digital games are considered, we collected 16 examples, out of which 14 offers single-player experience with no social element. The potential of peer-to-peer learning, free communication among players and debriefing is exploited only by two digital games. These results suggest that the strongest rationale behind using games as training or learning tool is their social dimension—collective playing offers more space for building relationships, practicing negotiations and conflict resolution, and exchanging information or sharing experience—all of which may prove useful while planning for disasters. Single-player games, although often informative and offering an immersive environment, may not necessarily mirror many subtle but complex relations between diversified agents involved in DRM activities. Moreover, games lacking a social element often lack also debriefing, which seems a serious oversight, as Crookall notices that—in order to fully benefit from training or learning potential of serious games—it has to be followed by reflection and conclusion: “Some learning often occurs while a game is being played, but deeper lessons are drawn out in a debriefing session ([29], p. 908).

### 3.2. DRM-related serious games reach diverse audiences

The analysis of the 45 DRM-related serious games and simulations reveals two major types of participants; namely youth and children (31 games are designed for this group as its main audience or among other participants, including 16 for young children, 18 games for teenagers, and 13 for college and university students) and adults (39 games designed for adults alone or within a broader range of participants).

The games focused on adults are further diversified, as in many cases they are targeted at a specific group, with an emphasis put on members of disaster-affected or disaster-exposed communities (28 games) or people somehow engaged in DRM activities; relief workers, disaster managers, donors, NGO staff and volunteers (25 games), policy-makers (23 games); and educators and school children's parents (17 games). In some cases, the “vulnerable communities” mentioned among target groups included migrants (*Disaster Awareness Game* or *Gifts of Culture*), culturally and linguistically diverse groups (*Gifts of Culture* or *Evacuation Challenge Game*), less privileged groups (e.g. women in *Gender and Climate Game* or *Gender Walk*) as well as people who are illiterate (many Red Cross Red Crescent Climate Centre's games).

Such diversification of target audiences makes DRM-related serious games and simulations a powerful communication medium, accounting for those people who would otherwise have no or very limited access to disaster information (Figs. 2–4).

### 3.3. DRM-related serious games address a variety of natural hazards

To limit the scope of the analysis, the games chosen for the review exclusively address the environmental/natural hazards classified after the Emergency Events Database (EM-DAT) [83] developed by the Centre for Research on the Epidemiology of Disasters (CRED) (See: Table 1).

The 45 collected games embrace almost all types of hazards identified by EM-DAT, excluding extra-terrestrial ones.<sup>3</sup> Weather-related types of hazards are by far the most frequently addressed by the DRM-related games, with flooding dominating the selection (27 games

<sup>3</sup> Natural hazards and potential disasters connected to them are the main foci of this serious games' review thus they are here emphasized. It has to be noted, however, that some games include also other crises (e.g. interpersonal conflicts or workplace dilemmas in later versions of *Crossroads: Kobe*) [6,50,51].

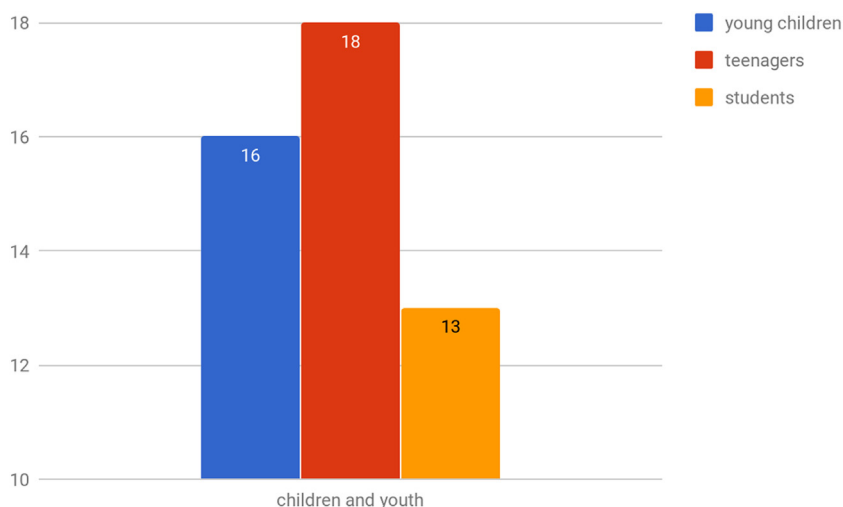


Fig. 2. Children and youth: as target group of DRM-related serious games.

mention this hydrological hazard standalone or among other identified risks). Interestingly, flooding’s “counterpart,” drought, although relatively frequently touched upon by serious games (7 occurrences), is never portrayed alone, but always presented as intertwined with wet seasons. Also storms (including snow—and thunderstorms, hurricanes, tornadoes and cyclones) are hardly ever the main topic of the games (except for the *Hurricane Strike!* this type of hazard always appears among many other topics), and little attention is given to wildfires or extreme weather conditions such as heatwaves and severe cold. Geophysical hazards are mostly represented by earthquakes (10 games), although there are several games focused on volcanic activities (5) and tsunamis (5). Biological hazards, on the other hand, are almost non-existent with only one game addressing an insect-borne epidemic (*Buzz about Dengue*).

The dominance of floods, earthquakes and droughts over other natural hazards portrayed in the selected serious games does not seem surprising in the face of statistics. As the joint CRED and UNISDR’s report shows, flooding has been the most common natural disaster in the last 20 years, accounting for 43% of all recorded events. The second most frequently occurring disaster was storms, at 28%, while earthquakes was third (8% of all natural disasters) [61]. Floods, droughts and earthquakes are also listed among the most deadliest events, causing more than 57,000; 20,200 and 357,000 deaths respectively in

the period of 2009–2015 [84]. The attempt to portray the most prevalent and deadliest hazards seems logical. Another hypothesis could be that it is easier to convey a sense of urgency in a game setting with a rapid onset event. This would explain why the slow onset drought is always intertwined with wet seasons. Nevertheless, the paucity of games on disasters like wildfires or disease epidemics may be taken into account while setting priorities for future DRM-related serious games design.

3.4. DRM-related games focus on pre-disaster phase activities in DRM cycle

The ongoing process by which governments, relief organizations and civil services prepare for and reduce the impact of disasters, react during and immediately after a disaster, and take steps to recover from the impacts is often illustrated through the so-called DRM cycle [48]. This cycle accounts for both ex-ante actions to reduce risk and prepare for disasters, and ex-post actions to respond to and recover from events: 1) prevention/ mitigation, 2) preparedness prior to disaster, 3) response and 4) recovery in the post-disaster stage. The stages of the DRM cycle that the selected games address, are illustrated by Fig. 5.

The vast majority of games are focused on pre-disaster phases of disaster management, including the prevention/ mitigation phase (25 games) where effort is made to avoid or lessen the impacts of hazards

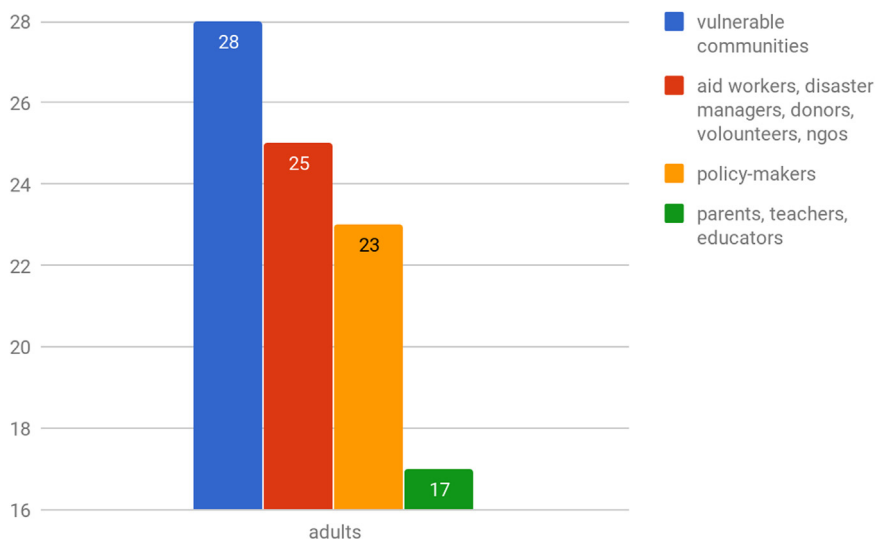


Fig. 3. Adults: as main target group of DRM-related serious games.



**Table 1**  
Classifying natural hazards by disaster type (adapted after [61], p. 11).

Geophysical	Weather-related			Biological	Extra-terrestrial
	Hydrological	Meteorological	Climatological		
Earthquake Mass movement Volcanic activity	Flood Landslide	Storm Extreme temperature Fog	Drought Glacial lake outburst Wildfire	Animal accident Epidemic Insect infestation	Impact Space weather

and related disasters through longer-term action taken in advance, and the disaster preparedness phase (39 games), in which the activities and measures taken aim at preparing people and assets for hazard events or conditions.

The prevention/mitigation activities presented, modelled or trained via DRM-related games include for example investing in earthquake/seismic observation systems (e.g. *Stop Disasters!* or *Supervolcano*) or crowdsourcing river level data to help calibrate science-based hydrological models for more reliable flood predictions (e.g. *UpRiver*), adopting hazard-reducing building codes (e.g. in *Extreme Event Game*, *FloodSim*, *Stop Disasters!*) and retrofitting vulnerable houses and public buildings (e.g. *Cultural Memory Game*, *Flood Resilience Game* or *Hazagora*), investing in man-made protection (such as dams, embankments, water retention areas, channels or seawalls—in e.g. *Florima*, *Game of Floods*, *Gifts of Culture*), forestation and green infrastructure (e.g. *FloodSim*, *Game of Floods*, *Forest@Risk*, *Flood Resilience Game*), conservation and maintenance of drainage systems (e.g. *Extreme Event Game*, *FloodSim*, or *Lords of the Valley*), reducing vulnerability and exposure of communities by land-use regulations, zoning and other long-term policies and public awareness-raising campaigns (e.g. *Stop Disasters!* or *FloodSim*). Most of the games that present or model some aspects of the prevention/mitigation phase, also include elements of preparedness. Only a couple of games, including e.g. *Game of Floods* and *FloodSim*, are predominantly focused on long-term planning for risk reduction.

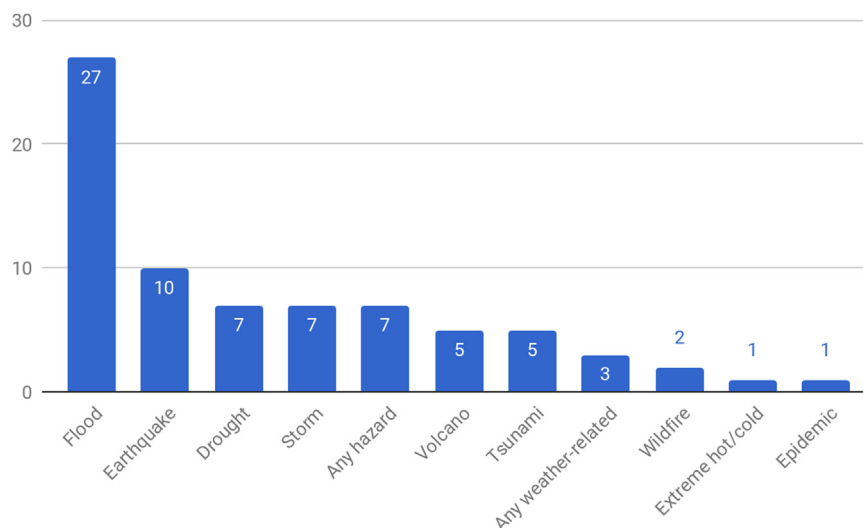
The *Game of Floods* is a clear example of a prevention/mitigation-focused game. It is a face-to-face participatory activity in which participants are tasked with developing a long-term vision for *Marin Island 2050*—a hypothetical landscape that highlights the conditions that will be experienced in Marin in coming years with sea level rise and increased storm impacts causing the loss or deterioration of homes, community facilities, roads, agricultural land, beaches, wetlands, lagoons, and other resources. Integral to the activity is the introduction and consideration of green infrastructure approach as an alternative to



**Fig. 5.** Stages of DRM cycle accounted for in DRM-related games.

traditional flood protection measures [62]. In the online policy simulation *FloodSim*, on the other hand, players are allowed to experience the challenges and complexity of flood policy in the UK for the three upcoming years. Equipped with some basic knowledge about the population density, economic output and flood risks of the specific regions, a player has to decide how much money to spend on flood defenses, where to build houses and how to keep the public informed. But as in real life, money is limited.

The vast majority of the analyzed games (39) depict and educate on preparedness, that is, the knowledge of what to do, where to go, or who to call for help before a potential disaster happens. These skills vary from elementary knowledge, such as how to recognize the first signs of disasters (e.g. in *Disaster Master*), when and how to shelter during a disaster (*Hurricane Strike!*, *Disaster Master* or *Save Natalie! The*



**Fig. 4.** Types of hazards addressed by the selected DRM-related serious games.

*Preparedness Game*) what to include in an emergency kit (e.g. *Build a Kit, Hurricane Strike!* or *Riskland*), the importance of monitoring weather and alarm systems (e.g. *Before the Storm, Weather or Not* or *Young Meteorologist Program. Severe Weather Preparedness Adventure*), the necessity of stockpiling of water and food (e.g. *Act to Adapt, Crossroads: Kobe* or *Hazagora*) and securing furniture and household objects before disaster (e.g. *Beat the Quake, Cultural Memory Game* or *Young Meteorologist Program. Severe Weather Preparedness Adventure*) to more complicated, collective and coordinated actions, such as executing trainings and field exercises (*Act to Adapt* or *Extreme Event Game*), preparing contingency plans (*Before the Storm or Ready!*) or developing arrangements for coordination, evacuation and public information (e.g. *Disaster Imagination Game, Extreme Event Game, Evacuation Role Play* or *Supervolcano*).

As discussed above, preparedness skills are usually paired with prevention/mitigation knowledge. There are also many games that combine preparedness skills with response to provide a player with a more lively, fast-paced gameplay, often including physical activity. Such games include e.g. *Evacuation Challenge Game* or *Ready!* However, there are also some interesting examples of serious games focused exclusively on preparedness, such as e.g. *Disaster Imagination Game* or *Evacuation Role Play*. In the first activity, players assume the roles of the members of the disaster relief commanding post and, recording various details on maps, try to anticipate damage, mark risk zones and draw the evacuation plan. Similarly, in the *Evacuation Role Play*, participants gather at the city board meeting to discuss the evacuation plan for the city of Greenwood that has been struck by a flood. As all the roles receive only partial information on the situation, a complex net of interdependent problems and obstacles emerge, enabling players to better understand the coordination and preparation of the evacuation scheme.

Relatively few games focus on the post-disaster phase, with 22 games addressing the response phase and 7 on the recovery phase. The activities embracing the response phase model or train such skills as e.g. providing medical health (e.g. *Buzz about Dengue, Inside the Haiti Earthquake* or *Disaster in My Backyard*), warning and saving people's lives (*Earth Girl. The Natural Disaster Fighter, Sai Fah: The Flood Fighter* or *SerGIS: Malmö Flood Scenario*) or managing evacuation (e.g. *Evacuation Challenge Game* or *SerGIS: Malmö Flood Scenario*). In many cases, these games combine response-related skills with the elements of preparedness. Only a handful of games, including i.e. *Disaster in My Backyard, SerGIS: Malmö Flood Scenario* or *Inside the Haiti Earthquake* are mainly occupied with response (with the last activity touching also on recovery). For example, while *Disaster in My Backyard* is a very lively physical activity in which players have to gather information, make decisions and coordinate search and rescue efforts, *SerGIS* combines a virtual geography-based game with a quiz to provide a player with an exercise on both spatial thinking and decision-making under pressure. A very dramatic image of people struggling to emerge from the aftermath of the earthquake is, on the other hand, offered by the *Inside the Haiti Earthquake* simulation. It allows “players” to observe the impacts of the disaster from one of the three perspectives; a local survivor, an international journalist or an aid worker, and to interact with the storyline by choosing one of the possible narration paths. Moving forward, disruptive footage based on real documentation of the Haitian capital Port au Prince is revealed; while bulldozers and excavators are striving to clear away the rubble, desperate survivors are scrambling around trying to find their relatives or scavenging whatever they can out of the remains of their city. Exhausted aid workers direct people to temporary shelters, assist the wounded and distribute food and water. The simulation illustrates the chaos, desperation and difficulty in maintaining hope and dignity in a crisis situation.

Only a few games (6) account for the recovery phase, in which the restoration and improvement of facilities and living conditions of disaster-affected communities are undertaken. For example, certain elements of recovery activities may be found in *Gifts of Culture Game, Flood Resilience Game, Hazagora* or *Lords of the Valley* where players have to

deal with the consequences of flood and support their families and community members on their way to becoming more disaster-resilient. In all cases the games that include recovery activities in their gameplay, model actually a full DRM cycle. For example in *Hazagora*, players, put in the shoes of the mayor, the fisherman, the lumberjack, the farmer or the tour guide, develop their households and support their families' basic needs. They may also prepare themselves for the emergencies by stockpiling resources, ensuring access to water and securing roads and houses. At variable time intervals geohazards (i.e. earthquake, tsunami, lava or ash flow) occur on “the island.” Whenever they happen, players have to first assess its intensity and impacts and then remove the destroyed elements (e.g. huts, houses, roads) and the killed families, make the contaminated resources inaccessible (e.g. water wells, food markets), and go off without income for some time. In this way, players virtually experience the impacts of the disaster and are confronted with the consequences of their decisions. At the same time, in the “recovery phase,” they may learn how to prevent or mitigate future disaster impacts by investing in mitigation, preparedness or adaptation cards [54].

To sum up, the majority of the games account for pre-disaster phases, modelling possible ways to reduce and mitigate potential destructive impacts or to prepare for a specific potential hazardous event. Such a result is in-line with an observed shift in DRM efforts to more successfully motivate risk reduction. This shift is marked by the integration of mitigation/prevention and crisis preparedness within broader community development pathways, seeking ways to pursue social, ecological and economic goals while at the same time managing potential disaster risks. By situating DRM in this way, games may be useful in promoting disaster resilience (see [2] for a discussion of the relationship between DRM and development); not only in terms of providing relief activities and coping with impacts but also in promoting sustainable development, for example by enhancing protection and regeneration of environmental assets, investing in disaster-resilient constructions, ensuring proper resource management and land-use regulations, raising safety awareness, and helping people understand the human contributions to disasters.

### 3.5. DRM-related serious games aim at disaster awareness raising and training skills

Via the clustering process described in Section 2, 17 categories of objectives addressed by the DRM-related games have emerged (see: Appendix D), ranging from general awareness raising to more specific disaster management skills training.

Fig. 6. reveals that the most frequently declared objective in the DRM-games collected for the analysis is education or awareness raising (general awareness raising appeared in 24 segments, whereas climate change-related awareness in 9). This group of objectives is focused on transmitting educational knowledge, by providing the public with basic concepts, terms and other substantial information on e.g. dengue disease (*Buzz about Dengue*), flood (*Florima, FloodSim, Sai Fah: The Flood Fighter, Upriver*), earthquake (*Inside the Haiti Earthquake*), hurricanes (*Hurricane Strike!*) or volcanic eruptions (*Supervolcano*). Sometimes, the educational focus is more precise and addresses a specific target group. For example, in the *Disaster Awareness Game* the emphasis is put on determining and prioritizing educational activities among children.

A separate subgroup of education-oriented aims addresses climate change (impacts)/ climate-related disasters. Here the emphasis is explicitly put on the relationship between the human-driven climate change and the disasters it may cause (e.g. *Buzz about Dengue* not only provides information on what dengue's consequences are and how to deal with them, but also makes people aware how climate change supports the activity of dengue mosquitoes).

Another common objective of DRM-related games is to support preparedness (24 segments), by e.g. promoting the use of early warning system (e.g. *Before the Storm, Ready!, Weather or Not*) or providing training in preparing emergency kits (e.g. *Build a Kit*). Also important is

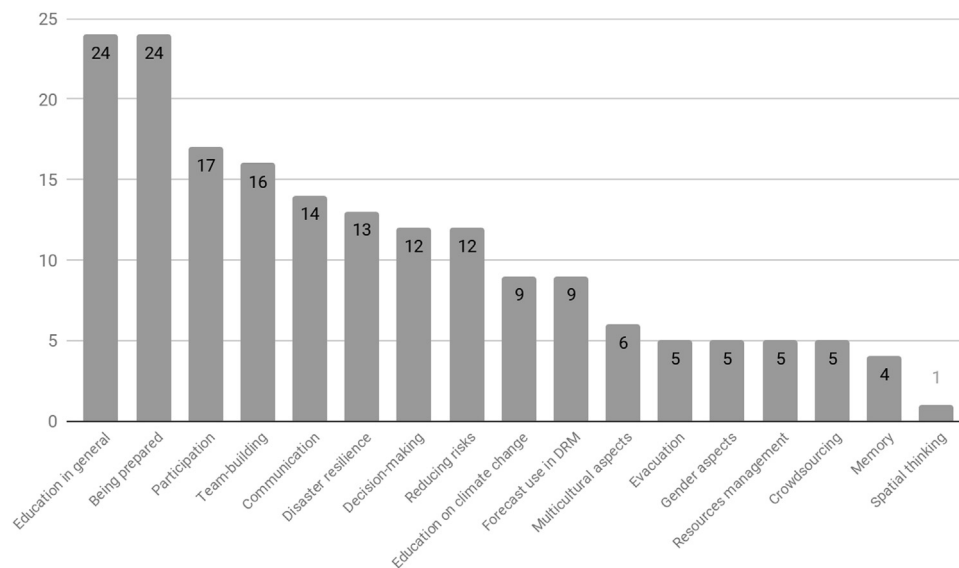


Fig. 6. Declared aims of DRM-related serious games.

the issue of participation and activation of people in the face of crisis (17 segments). The declared aims include e.g. sparking public discussion/dialogue on DRM issues (e.g. *Hazagora*, *Story Go Round*), training participatory decision-making (e.g. *Flood Resilience Game*), decreasing fear of taking measures “in vain” (e.g. *Paying for Predictions*) or drawing people’s attention to the importance of effective city management in the face of disaster (e.g. *Stop Disasters!*).

Team-building and the cultivation of cooperation, sense of community and face-to-face relationships are also frequently mentioned among games’ intended outcomes (16 segments). Some of the segments within this category recognize the importance of collaboration, empathy and sense of community in DRM efforts and are thus focused on simply training or promoting these abilities (e.g. *Before the Storm*, *Evacuation Challenge Game*, *Decisions for the Decade* or *Inside the Haiti Earthquake*), while others stress the need for improving these skills (e.g. *Gifts of Culture* or *Ready!*).

Another important category of aims focuses on resilience, that is, the ability to resist, absorb, accommodate to and recover from the effects of a disaster (14 segments). Training or improving communication is yet another frequently declared objective (14 segments). Games focused on this objective highlight the importance of shifting from top-down to participatory, peer-to-peer exchange of information (*Crossroads: Kobe*), the need to bridge the gap between linguistically and culturally diverse groups (e.g. *Evacuation Challenge Game* or *Gifts of Culture*) or between international and local organizations and communities (e.g. *Story Go Round*), and finally they address the need of enhancing the dissemination of information to the right decision-makers (e.g. *Paying for Predictions*). Also the development of decision-making skills is relatively often listed among intended objectives (12 segments), with emphasis put on making decisions under uncertainty (like in e.g. in *Decisions for the Decade* or *Dissolving Disasters*).

Other frequently recurring intended aims of the analyzed DRM-related games revolve around presenting and equipping players with tools, activities and measures to avoid current and future disaster risks (12 segments). Thus they may be focused on general brainstorming regarding what can be done to reduce or better manage risks (e.g. *Act to Adapt* or *Story Go Round*) or on demonstrating the benefits of prospective risk reduction (e.g. *Flood Resilience Game*).

Less frequently declared objectives include e.g. proper use of forecasts (only 9 segments), bridging gaps between people of different cultural and linguistic backgrounds to better manage risks (6 segments), fostering evacuation (5 segments), fighting gender inequities in vulnerable communities (5 segments), promoting sustainable management

of resources (5 segments), crowdsourcing of data either for the development of scientific models or disaster-awareness education programs (5 segments), and highlighting the importance of past experience of disaster as an asset that enables people to draw conclusions, prepare for and anticipate adverse future risks (4 segments). In one segment skills related to spatial thinking and geographic information systems (GIS) for disaster management activities appeared as the declared objective of the *SerGIS: Malmö Flood Scenario* game.

As it can be seen, the intended purposes are either focused on increasing the level of disaster awareness or on training and developing specific skills that enable effective disaster risk management. In many cases, these aims, in fact overlap or support each other (e.g. team building, better decision-making or spatial thinking abilities presumably support disaster preparedness and resilience, whereas improved communication will likely enhance disaster awareness). Surprisingly enough, little attention is given to issues such as cultural diversity, gender equality or learning from past events, which certainly could also positively affect communication and thus support disaster preparedness and/or resilience. However, it must be remembered that the cluster analysis embraced only the declarations/ descriptions found on the games’ informational materials (websites, rulebooks/ instructions, articles published, etc.). No game’s elements (e.g. information on cards, the content of quizzes, etc.) were taken into account. Thus it may be assumed that some of the games collected for the review do in fact cover some of these less popular topics, without explicitly declaring them as the game’s objectives.

### 3.6. DRM-related serious games are promising tools for learning and change

To verify if the DRM-related games fulfill their declared objectives, we collected and examined scientific publications on the games included in the analysis. Our intent was to match the games’ declared objectives (as categorized in the cluster analysis) with any reliable documentation of them being met and evaluated. However, although we have found nearly 30 articles, reports, and other publications on the selected games’ effectiveness (see: [Appendix E](#)), their value and reliability varied to such extent that no dependable conclusions could be drawn.

As [Fig. 7](#) shows, in many cases (e.g. *Florima*, *Hurricane Strike!* or *Save Natalie! The Preparedness Game*) no information on games’ objectives evaluation was found by the authors (in October 2017). Some games, for example, *Earth Girl*, *The Natural Disaster Fighter*, were tested on players and scientists, but the main focus of the test was put on

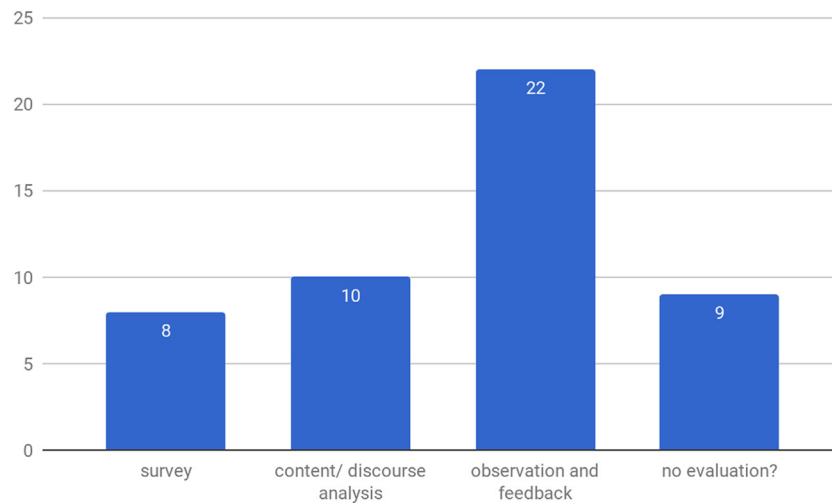


Fig. 7. Evaluation technique.

playability and reliability of disaster-related information rather than on the players' level of disaster awareness (see: [63,64]). In other cases, the evaluation technique was not sufficiently described, leaving room for speculations. For example, a number of games developed and applied especially by humanitarian organizations, such as the Red Cross Red Crescent Climate Centre or UNESCO were described in case studies and projects' reports (e.g. [65–67,25,68,69,8,70,27,71]). They provide a reader with examples of good practices and successful use of serious games to e.g. raise disaster awareness and build the resilience of vulnerable communities in developing countries. However, they do not describe the evaluation method, offering either general statements such as e.g. “The important ‘huh?’ moment usually comes when [players] see other players proposing choices that seem not to make sense given the forecast. The ‘aha!’ moment involves a sudden awareness of the need for communication and mutual understanding between forecasters and users, given the validity of their differences” ([25], pp. 83–86) or quoting players' positive opinion after taking part in the game.

Other game developers (e.g. Centre for System Solutions) have recently began conducting more systematic research to test the potential positive impact on players. Their approach to this matter is not yet grounded, varying from structured/ unstructured games sessions observation and structured/ unstructured feedback sessions (see for example the following publications on game sessions: [18,19,21]). Since the data provided by aforementioned organizations enable no clear division between evaluation methods, they are collectively referred to as “observation and feedback”, and include as many as 22 games.

Only 8 games collected for the analysis were evaluated using (semi-)structured surveys on or interviews with players. In most cases, the method included a pre-game questionnaire, exposure to a game and a post-game questionnaire. In the case of *Ready* [72] and *FloodSim* [73] post-game self-assessment questionnaires and semi-structured post-game telephone interviews were used respectively. In case of *SerGIS* [85], a computer virtual geography-based single-player game, users participated in the think-aloud game sessions. While playing the games, the participants verbally expressed what they were thinking about spatially. Their comments were transcribed and keyword frequency content analysis was performed to find thematic patterns.

Most games (semi-)structurally tested and evaluated by players are predominantly focused on awareness raising (*Disaster Awareness Game* [6,50,51], *FloodSim* [73], *Hazagora* [54], *Inside the Haiti Earthquake* [57,59], and *Stop Disasters!* [74,38,75]), offering limited opportunity to validate other categories of declared goals that were identified in the process of cluster analysis. However, the general educational potential they offer seems to be evaluated positively. For example, in the case of *Disaster Awareness Game* (focused on disaster awareness raising in

children in multicultural settings), the preliminary research results [6,50] showed a notable increase in natural risk perception, as well as significant increase in children's knowledge of preparedness measures (for both Anglophone and non-Anglophone students). Similar positive results were noted by Mossoux et al. [54] in reference to *Hazagora* (focused on promoting knowledge on geohazards). After the exposure to the game, players become more aware of 1) mechanisms of hazards, impacts on infrastructure, natural resources, and livelihood, 2) the elements influencing the vulnerability of a community with respect to hazardous phenomena, and 3) potential strategies that can be applied to make a community more resilient. Also, the analyzes of potential positive impact of *FloodSim* in raising the general public awareness around flooding in the UK suggest that the game increased awareness at a basic level and was perceived as an accurate source of information about flood risk and prevention by players [73]. Positive results were also noted in reference to *Stop Disasters!* Pereira et al. [75] suggest that the game has increased the players' awareness of disaster prevention measures at an overall level and in specific topics, such as e.g. land management or community initiatives.

An interesting insight into the educational (activating) potential of DRM-related serious games is offered by Jenner [57] who studied the relationship between different types of engagement (active, emotional and critical) triggered by docugames (including *Inside the Haiti Earthquake*). Preliminary research suggests that the simulation has a potential to act as a catalyst for carrying out actions beyond the game's environment, i.e. finding out more about the issues dealt with or entering into discussion. It also triggered empathy while “players” claimed that they felt closer to victims and were able to understand their position. Some participants also noted that *Inside the Haiti Earthquake* made the complexities of humanitarian relief “easier” to understand.

Some quantitative research was also done in reference to serious game's effectiveness on players' ability to make decisions. For example, in *Crossroads: Kobe* [55,56,10,11,12,4,53], one of the objectives is to enhance risk communication and to shift from more paradigmatic, scientific and top-down approach to risk reduction to a narrative mode that deals with human-to-human relations (such as conflict resolution, consensus building, etc.). The questionnaire data collected by Kikkawa et al. [55] proves that after being exposed to the game, players adopted more varied opinions rather than polarized “yes” or “no” answers to problems. This suggests that playing *Crossroad: Kobe* could have led the players to become aware of different viewpoints by facing different opinions of other participants. Similarly, in the preparedness-oriented serious game *Ready!*, almost all participants (answering a paper-based self-assessment survey) indicated that the game helped them prioritize early actions and make better decisions [72].

*SerGIS* [85], a computer game targeted at shaping spatial thinking in relation to DRM activities, also undertook impact analysis which rendered positive results. The participants used the computer game environment to answer a series of questions and verbally express what they were thinking about spatially when using the computer game environment. The sessions were transcribed and keyword frequency content analysis was performed to find thematic patterns that matched the National Research Council [76] definition of spatial thinking, understood as an amalgam of three items: concept of space, tools of representation and processes of reasoning, and spatial thinking concepts (such as buffer, location, distance, identity, etc.) based on Lee and Bednarz [77] research to develop a spatial thinking ability test (STAT). As a result of this process, main themes emerged: 1) process of reasoning (the participants were making distance estimations and reasoned about relationship between spatial patterns and potential vulnerable population impacts), 2) tools of representation (the participants were able to use different representation types such as points, lines and polygons to e.g. mark elevations on the map), 3) operations based on spatial thinking concepts (the participants were dealing with overlay and dissolve tasks that demanded advanced operations, such as clip, intersect or union to determine e.g. priority evacuation areas or medical treatment areas). All the above processes revealed areas of learning and knowledge gaps in GIS operations and mapping, as some of the participants were not familiar with certain operations or terms (e.g. “choropleth map”). In addition to these themes, the gaming scores of the participants were also analyzed. The analysis revealed that participants with limited GIS experience, but with spatially-oriented education background, had higher game scores when compared to participants lacking spatially-oriented education background. With these results, it may be stated that the tool fulfills its objective to measure the level of students’ critical spatial thinking, as the aloud session revealed some learning gaps that may be further addressed via education. The game also provides some training of critical elements of spatial thinking, as the participants are actively engaged in using an interactive online map and explore its functions [85].

An important attempt to evaluate disaster-related games’ effectiveness via content and discourse analysis—rather than exploring players’ experience—was offered by Gampell and Gaillard [38]. Their study embraced both entertainment and serious video games, out of which 10 are included also in this paper (namely *Beat the Quake*, *Build a Kit*, *Disaster Master*, *Earth Girl*, *The Natural Disaster Fighter*, *Earthquake Response*, *FloodSim*, *Inside the Haiti Earthquake*, *Sai Fah: The Flood Fighter*, *Stop Disasters!* and *Young Meteorologist Program. Severe Weather Preparedness Adventure*). The authors first conducted content analysis of selected video games (if possible each video game was played) to determine which DRM actions were present within that particular video game. The actions of each category: prevention, mitigation and preparedness, became the criteria for the analysis. Further, the games with the highest scores in terms of DRM content were selected for specific discourse analysis that aimed at uncovering and understanding how disasters and DRM activities are portrayed and communicated to players.

The content analysis demonstrated that all video games described in Gampell and Gaillard’s study may enhance disaster management awareness, as they provide players with some form of DRM content. The intended focus of most serious video games’ content was for players to “learn” a particular strategy, which is achieved via modelling a variety of disaster management actions, such as placement of schools, hospitals and housing, etc. in order to win the game in *Stop Disasters!* or by choosing appropriate equipment for an emergency kit in the *Build a Kit* game. The discourse analysis confirms the hypothesis that games may raise disaster awareness, as all video games selected for further examination tell a story and reflect discourses around disasters, demonstrating and portraying hazards, disasters, vulnerabilities and capacities to face and reduce risks [38].

Although the results of Gampell and Gaillard’s [38] research suggest

video games have the potential to be positive tools to reinforce messages surrounding disaster management, they also revealed a lack of research surrounding the success of these games (whether the declared objectives are rendered into real actions). The authors found only a few studies touching upon these matters, yet they are often focused only on one aspect of video game analysis, namely the content. Also, as highlighted by the authors, the very nature of discourse analysis is somewhat subjective (it requires author’s subjective interpretation of discourses offered by games). Therefore, further research is needed to assess whether players gain some knowledge on and awareness of disasters after playing a game and how game design may influence their motivations to play a game and therefore their potential to learn.

The results presented in this section demonstrate that DRM-related serious games have the potential to assist disaster risk management, especially in the realm of disaster risk awareness raising, identifying hazards, undertaking preventive actions, empathy triggering and perspective-taking. At the same time, it displays the scarcity of quantitative and qualitative research into their effectiveness in reaching their declared objectives. More detailed and structured study is called for in assessing these outcomes.

## 4. Conclusions and discussion

### 4.1. Summary and final conclusions

This paper presents and reviews 45 serious games and social simulations that address issues related to disaster risk management (DRM) and serve as educational and engagement tools for affected communities, policy-makers, and other stakeholders. The main aim of this comparison was to identify the prospects and limitations of gaming in the broader context of diverse risk management activities, and to diagnose any existing niches in disaster-related games that could be filled by game developers and transformed into more comprehensive and user-tailored game design in the future. Moreover, given the need for a more reliable and scientific approach to testing serious games’ effectiveness in raising DRM awareness and training skills, we collected and analyzed any qualitative and quantitative proves (players’ feedbacks, quantitative surveys, scientific articles relating to the analyzed games etc.) that could enable their assessment, and thus their usefulness in DRM education and training.

As far as the prospects of gaming in the context of DRM is concerned, the research revealed that social simulations and role-plays are the most common forms of games found, outnumbering other analog and digital games. Such games often gather a bigger number of people in one place to engage them in multi-stakeholder face-to-face negotiation in a setting that resembles real life. As a result, players have the opportunity to face different viewpoints and perspectives, gaining more multidimensional understanding of a given problem. Players also practice many disaster-related strategies without bearing the real costs of their potentially wrong decisions. At the same time, face-to-face simulations entail real interaction with people of different backgrounds who might not have met otherwise. This social aspect of role-playing gaming makes it an ideal tool for an open discussion and peer-to-peer, horizontal learning.

Moreover, serious games reach a wide range of audiences, including NGOs, relief organizations, volunteers and public officers and disaster managers, as well as more vulnerable groups (communities exposed to disasters, children, women, etc.). Furthermore, the vast majority of analyzed games focuses on the pre-disaster phases of the DRM cycle, directing stakeholder’s efforts to take up prevention/mitigation measures and training preparedness skills rather than waiting idly for a disaster to strike. Such a tendency reflects the most general shift observed in DRM efforts, which nowadays integrate crisis situations within larger community development pathways, seeking opportunities to maintain social, ecological and economic growth while at the same time managing potential disaster risks. It is also in line with the cluster

analysis of the declared games' objectives, which revealed that most DRM-related games are developed with the aim of raising disaster awareness, preparing for disasters and training skills necessary for effective disaster management. The selected serious games thus model and offer training in a number of useful activities, including maintaining and monitoring warning systems, retrofitting vulnerable houses and public buildings, stockpiling equipment and supplies, preparing emergency kits, and providing medical health to disaster victims. It may therefore be assumed that serious games offer a very practical approach to knowledge and skill acquisition, enabling players to gain simulated experience of relief activities rather than presenting them with dry facts.

#### 4.2. Games limitations and recommendations for game designers

Although serious games seemingly can reach a wide audience and foster both the exchange of information and less formal learning and training of DRM-related activities, the research revealed a number of limitations that can potentially limit their effectiveness. First of all, although the collected serious games target a wide range of audiences, relatively little attention is given to issues such as cultural diversity or gender equality. According to the cluster analysis of declared games' objectives, the aims of "bridging gaps between people of different cultural and linguistic backgrounds to better manage risks" and "fighting gender inequities in vulnerable communities" were mentioned only 6 and 5 times, respectively. This finding is especially surprising, giving the limited effectiveness of international relief activities delivered without ability to communicate with local communities and with no sensitivity to custom-imposed taboos or local needs.

Secondly, although effective forecasting information communication, dissemination, interpretation and usage is key to addressing and reducing disaster risk among vulnerable communities, few game developers include the aim of promoting forecast usage among their declared objectives. Almost no emphasis is also put on promoting sustainable management of resources or highlighting the importance of past experience of disaster, which seem important (yet neglected by the analyzed serious games) aspects of building resilience among vulnerable communities, and as such should be taken into account by serious game designers in the future.

Thirdly, although the analyzed DRM-related serious games addressed various natural hazards, most of them are focused on floods, earthquakes and drought threats. On the one hand it is not surprising, as they are both most common and deadliest natural disasters. On the other, however, the paucity of games on e.g. wildfires, extreme cold/hot weather conditions or disease epidemics offers another niche for DRM-related serious games design.

The major gap revealed by the research relates to the lack of solid, scientific evidence of the serious games' effectiveness. In many cases, documented evidence (players' feedback, quantitative surveys, scientific articles relating to the analyzed games, etc.) offers little detailed information on the evaluation technique, leaving room for speculations and debate. Only a few games were tested against their declared objectives, using (semi-)structured surveys. Their results seem promising and suggest that serious games may be successfully used to model and train many DRM-related activities, and raise disaster awareness. In the face of scarcity of quantitative and qualitative research, however, we recommend more detailed and structured examination of serious games in the realm of disaster risk reduction.

In relation to the research findings, we suggest a set of potential recommendations for DRM-related serious game designs that would potentially lead to more effective learning outcomes. Firstly, it seems that most successful serious games use real objects, symbolic tokens, rules, instructions, sets of roles, etc. to enable players to learn through processes or problem-solving (often referred to as *procedural* or *simulation rhetoric*) rather than through simply answering quiz questions and memorization of facts. Such problem-solving and creative exploration

of possible strategies, may assist players in discovering the analogies between in-game problems and real world, enabling them to cope with issues outside the game. In the context of game design, procedural rhetoric would entail balancing explicit information (educational input) with free problem solving, self-exploration and peer-to-peer information-sharing.

Secondly, as the study revealed that the majority of DRM-related serious games and simulations constitute an engaging multiplayer experience, it seems reasonable to assume that they may trigger strong emotional reactions, provoke conflicts or misunderstandings. Therefore a qualified facilitator or detailed facilitation instructions should be provided to avoid the risk of players experiencing negative feelings that are not properly addressed. An essential element of the game experience should also be debriefing, which offers space for airing emotions and clarifying any conflicts among participants. Assuming that the game-based learning relies mostly on active engagement of players (doing things rather than just reading or listening about them), social interaction (possibility to observe others, communicate with them, get to know their perspectives, etc.) and incremental, cyclical nature of knowledge and skill acquisition, debriefing seems an important factor determining the game's training or educational potential. It allows players to process the game experience and turn it into learning. An ideal situation is when a game-kit includes debriefing instruction for moderators, like e.g. in case of *Flood Resilience Game*.

Critically, in order to reach the most vulnerable and disadvantaged communities, games and their materials (such as boards, cards, instructions for players and moderators etc.) should be easily accessible, that is, downloadable or available in printable versions. Relatively low costs related to the game preparation (use of printable or downloadable materials and easily accessible and cheap objects) would make such games applicable in contexts where economic factors or low levels of technology would otherwise limit their reach (schools, developing countries).

We argue that a successful game is a game that fulfills its purpose. Each game, be it entertaining or serious one, should always be developed with its specific target group and objective in mind. Users should be made aware of the purpose of the game and an environment it was originally meant for, as the specific solutions in all of DRM cycle steps vary due to e.g. geographical or cultural factors. For example, immediate response to the earthquake or flood should be based on the characteristics of the place that entails type of landforms, architecture, landmarks, roads, etc. Comprehensive research in the pre-production phase, user tests and evaluation are also always recommended. In many cases, although some learning may actually happen, lack of proper tools for measuring the game's impact provide no information on behavioral change. For example, the current paper has revealed that not many games targeted at raising disaster awareness and training life-saving skills were properly tested and evaluated by users. This leaves space for game designers, UX specialists, researchers and other individuals and organizations interested in applying serious games to advance future work in this direction.

Finally, regardless of their many advantages, serious games/simulations cannot be treated as a standalone disaster-awareness raising tool. Nor can they replace more standard approaches to education on DRM. One of the key limitations of games is the inevitable simplification of the circumstances surrounding disasters. Many aspects of disasters, such as e.g. variable impacts or spatial extent dependent on topography or distance of the source, cannot be recreated without sacrificing the playability. Therefore, more detailed information on mechanisms of hazards, exposure and vulnerabilities should be provided to participants in the form of videos, leaflets, educational worksheets, extra readings (such materials accompany e.g. *Hazagora, Disaster Master* or *Hurricane Strike!*) or by standard disaster drills and field exercises.

### 4.3. Future work

Although an essential first step in surveying and assessing DRM-related serious games has been taken, our analysis is by no means comprehensive. First of all, due to the paucity of literature and actual research on potential effectiveness of serious games in meeting their intended objectives, the original concept of the paper had to be modified. Rather than matching the intended objectives identified in the process of cluster analysis with any qualitative and quantitative proof points (players' feedbacks, quantitative surveys, scientific articles relating to the analyzed games etc.,) we delivered a brief overview of existing documentation. Moreover, the large number of games chosen for the analysis prevented us from more detailed content analysis. We were not able to play and test all the games, often relying on information provided by the games' developers, rather than on direct exposure to a game. Although we tried to contact all games' authors in order to gain information on any evaluation of their games' effectiveness, the response rate was low. As a result, we used materials from the Internet and from primary literature as the main source of information on the selected games.

We hope that this extensive review of DRM-related video and analog serious games may serve as a useful starting point for more detailed research in the future. A logical extension would be to advance research towards the development of tools necessary to make game outcomes more measurable. More specifically, reliable and comprehensive evaluation methodology of DRM-related serious games/simulations should be developed, which could serve as metrics for measuring the improvement of risk perception and disaster awareness among players. Furthermore, although we have established a range of opportunities for the use of games for DRM, a note of caution is warranted: it is important that the right tool is used for the right setting. Critically, the skill of the facilitator to guide a learning experience, while fully understanding the system behind the game is very important in many of the mentioned activities. Further potential and limitations of game-based learning should be developed by follow up research.

### Author declaration

This review was funded and developed as part of the Zurich Flood Resilience Alliance in collaboration with the partners of the Alliance (including the International Federation of Red Cross and Red Crescent Societies (IFRC) and the International Institute for Applied Systems Analysis (IIASA)) and the Centre for Systems Solutions.

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

We confirm that the manuscript has not been published and is not under consideration for publication elsewhere.

We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property.

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### Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.ijdr.2018.09.001](https://doi.org/10.1016/j.ijdr.2018.09.001)

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