Improving climate change resilience knowledge through a gaming approach: Application to marine submersion in the city of Punaauia, Tahiti

Charlotte Heinzlef, Yoann Lamaury, Damien Serre

Environmental Advances 15 (2024) 100467

Contents lists available at ScienceDirect

Environmental Advances

journal homepage: www.sciencedirect.com/journal/environmental-advances

Improving climate change resilience knowledge through a gaming approach: Application to marine submersion in the city of Punaauia, Tahiti

Charlotte Heinzlef [a,*], Yoann Lamaury [b], Damien Serre [a,c]

[a] CEARC, Université Paris Saclay, UVSQ, 11 boulevard d'Alembert, 78280 Guyancourt, France
[b] Faculté des Sciences et Ingénierie, Sorbonne Université, 4 place Jussieu, 75005 Paris
[c] Rescuesolutions, 91 route de chartres, 91940 Gometz-le-châtel

ARTICLE INFO

Keywords:
Resilience knowledge
Risk knowledge
Knowledge co-production
Decision support tool
Serious game
Resilience observatory

ABSTRACT

French Polynesia is a French overseas territory extremely vulnerable to climate risks. However, local risk management strategies focus on crisis management to the detriment of long-term resilience strategies, without integrating the pre-crisis, crisis and post-crisis periods. Through a decision support process, a serious game, intended for local residents, has been developed within a risk and resilience observatory. The objectives of this serious game are multiple: to increase knowledge of risks and resilience in local communities; to develop an understanding of the systemic complexity of resilient risk management; to develop an entertaining and educational tool. This prototype has been developed and tested in French Polynesia. This prototype allowed the players to create links between their sensitive experiences and their theoretical knowledge, allowing them to associate these two dimensions for a better understanding, acceptance and adoption of complex notions, concepts and processes.

1. Introduction

In a context of climate change, island territories are increasingly vulnerable to the increase in frequency and intensity of risks (Heinzlef and Serre, 2019). French Polynesia is an atypical territory. A French overseas territory approximately 16,000 km from Paris, it benefits from an internal autonomy within the framework of the Republic (Fig. 1).

Located in an inter-tropical zone, French Polynesia is extremely vulnerable to risks, including cyclones, floods, tsunamis (Serre and Heinzlef, 2022), sea level rise and landslides (Dominey-Howes and Goff, 2013; Giardino et al., 2018; Jessin et al., 2022; Nunn, 2009; Oppenheimer et al., 2019). In order to prepare French Polynesia for the increase of risks, their intensity, their recurrence and the uncertainties related to them, it is necessary to implement resilience strategies. The concept of resilience is defined as "*the abilities and capacities of a territory and its population to put in place before, during and after a disruptive event in order to limit its negative impacts and to relaunch a dynamic afterwards*" (Heinzlef, 2019; Serre and Heinzlef, 2018). This concept no longer views a shock as a negative element but rather as an opportunity for social, economic, architectural and political innovation (Heinzlef, 2020, 2019; Heinzlef et al., 2019; Serre and Heinzlef, 2018). This concept allows for the construction of a systemic risk management approach that can be adapted to territories that are part of a globalization dynamic. Although this concept is extremely relevant to accompany today's modern and over-connected territories, the concept of resilience still faces limitations (Alexander, 2013; Balsells et al., 2015; Meerow et al., 2016; Reghezza-Zitt et al., 2012). Among these limits, we can name the difficulties of operationalizing the concept (Bahadur et al., 2015; Scherzer et al., 2019; Schipper and Langston, 2015; Sharifi, 2016). Often qualified as a "buzzword" (Davoudi et al., 2012; Heinzlef et al., 2020, 2019; Shaw et al., 2014; Weichselgartner and Kelman, 2015), resilience remains far too often at the level of general discourse and objectives of local managers and decision-makers, which limits its transcription into adapted, informed and localized strategies and actions. Since the concept of resilience is a complex topic for local actors to deal with and operationalize, many tools have been created to simplify, define, measure and attempt to operationalize this concept. The need to create decision support systems makes sense in light of the abstraction of the concept (Aubert et al., 2018; Castellnou et al., 2019; Fox-Lent et al., 2015; Garcia-Aristizabal et al., 2015; Terti et al., 2019). Decision-making consists of distinguishing several potential alternatives in a defined set of options, according to three types of problems (Roy, 1985): i) choosing the best alternative, ii) sorting the alternatives, iii) ranking the alternatives according to an order of preference. In risk

* Corresponding author.
E-mail address: charlotte.heinzlef@uvsq.fr (C. Heinzlef).

https://doi.org/10.1016/j.envadv.2023.100467
Received 10 October 2023; Received in revised form 13 December 2023; Accepted 13 December 2023
Available online 17 December 2023

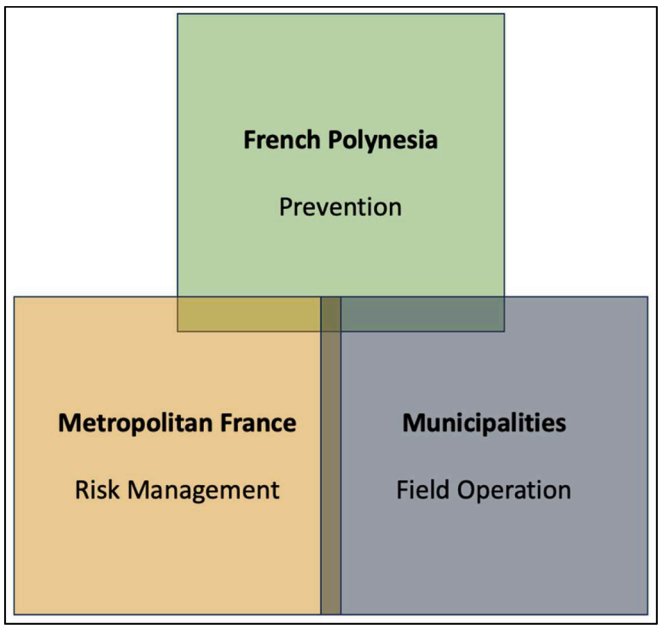

Fig. 1. Identified distribution of risk management skills in Polynesia, adapted from (Bourlier, 2023).

management, decision making is a complex combination of knowledge management and reasoning processes (Heinzlef, 2019). Decision support systems are defined as integrated computer systems designed "specifically for decision making" (Heinzlef, 2019). When territorial issues are addressed, they are referred to as spatial decision support systems (SDSS). They combine spatial and non-spatial data, the analysis and visualization functions of geographic information systems (GIS), and decision models to build, evaluate, and produce solutions (Jankowski et al., 1997; Jankowski and Nyerges, 2001). These spatial decision support systems were developed to address the limitations of GIS, such as the lack of modeling capabilities and the lack of flexibility of GIS to adapt to variations in the context or spatial decision making process (Heinzlef, 2019).

Spatial decision support is therefore a computerized aid which assists the development, evaluation and selection of appropriate scenarios, strategies and interventions in the face of a spatial problem. The objective can be both to confront decision making on the long term (development strategies, risk management strategies, etc.) or on the short term (emergency situations for example).

Despite the undeniable advantages of these decision support tools, their increasing multitude contributes to a new conceptual and operational confusion (Heinzlef et al., 2022). This is why a toolbox of spatial decision support systems in the form of a risk and resilience observatory has been developed in French Polynesia (Heinzlef et al., 2022; Jessin et al., 2022; Serre and Heinzlef, 2022). The objectives of this tool are multiple: "*increasing knowledge of territorial risks, the acquisition, storage and enhancement of data related to risks and resilience and finally the integration of stakeholders in the process of reflection and implementation of resilience strategies*" (Heinzlef et al., 2022).

Among these objectives, the integration of local actors is essential. Many decision support tools have been developed upstream, before being presented and confronted with the experiences, needs and perceptions of local stakeholders (Heinzlef et al., 2022, 2020; Heinzlef and Serre, 2020). In order to get out of a top-down relationship, participative and collaborative methods are progressively implemented in order to co-develop common knowledge (Clerveaux et al., 2010, 2008; Solinska-Nowak et al., 2018), an equity of knowledge in order to favor the "*acceptance and appropriation of solutions*" (Toubin et al., 2015). This co-construction of knowledge allows to create bridges between experimental, theoretical, scientific and transformational knowledge. This transition has led to the importance of soft skills and the interest of developing serious games to develop and test them. Developing this serious game as part of a spatial decision support system meets several objectives: to develop a game dedicated to local residents and to help them understand and grasp the systemic dimension of the concept of resilience and the complexity of territorial management.

In the first part of this article, we analyze the contribution of serious games to the operationalization of the concept of resilience. In the second part, we describe a prototype of serious game developed, tested and implemented in the observatory of risks and resilience in French Polynesia.

2. The use of serious games in risk management

The advantages of using serious games in reflective processes have been proven on many occasions (Bellotti et al., 2010; Dörner et al., 2018; Yamori, 2007). Serious game can be defined as games "in which education (in its various forms) is the primary goal, rather than entertainment" (Michael, 2006). In this context, education is understood on a board dimension. Serious games, whether they are board games, digital games, simulation games, modelling games, etc., are now identified as tools that support the processes of education, learning, communication, awareness raising, knowledge sharing, invention, and collective and/or individual involvement (Aubert et al., 2018; Boyle et al., 2014; Khoury et al., 2018; Mossoux et al., 2016; Teague et al., 2021). The active dimension of the learning process of serious games also increases their effectiveness. In the Montessori principles of experimentation (Mossoux et al., 2016), it was determined that in a traditional group, about 5 % of the information was retained during a classical reading, and 75 % of the information was retained during practical activities (Solinska-Nowak et al., 2018). In a game context, players are engaged, challenged, innovative and, thanks to the secure environment of the game, can leave their comfort zone, make decisions, build strategies, interact, assume or deconstruct their beliefs, etc. In collective games, this allows for conflicts of interest to be overcome and to progressively build a consensus, a common vision and a collective investment (Bellamy et al., 2018; Hamari and Keronen, 2017; Mossoux et al., 2016, 2016; Teague et al., 2021; Tsai et al., 2020; Turkay and Adinolf, 2012).

All these advantages of the use of serious games have gradually allowed for their integration in the field of risk management. Indeed, the game environment allows players to be situated in a safe and reassuring framework while allowing them to explore the diversity and complexity of risk management, as well as the different temporalities associated with it (Solinska-Nowak et al., 2018)- before the crisis (preparation), during the crisis (crisis management), after the crisis (recovery, relaunching of activity, learning, resilience). Placing players in an uncertain, stressful, urgent situation, while creating a playful environment, encourages risk-taking, innovation, experimentation, competition or sharing, testing and experimenting with theoretical and scientific knowledge, but also emotional and sensory experiences. This process allows to come out of the game experience grown up and mature. These skills - soft skills - developed will serve as a useful common reference in a real situation.

In the panel of serious games associated with risk management, not all risks and audiences are investigated, and some are prioritized (Fig. 2) (de Ruiter et al., 2021).

Moreover, if the general consensus is to produce risk awareness (Cremers et al., 2015; de Ruiter et al., 2021; Gampell et al., 2020; Mani et al., 2016; Mossoux et al., 2016; Rumore et al., 2016; Taillandier and Adam, 2018; Terti et al., 2019), the objectives are primarily : education in general, being prepared, participation, team-building and communication (Solinska-Nowak et al., 2018).

In this panel of saerious games that are part of the risk management field, the majority of games focus on vulnerable populations, in regards to the risk of flooding and in a general educational purpose

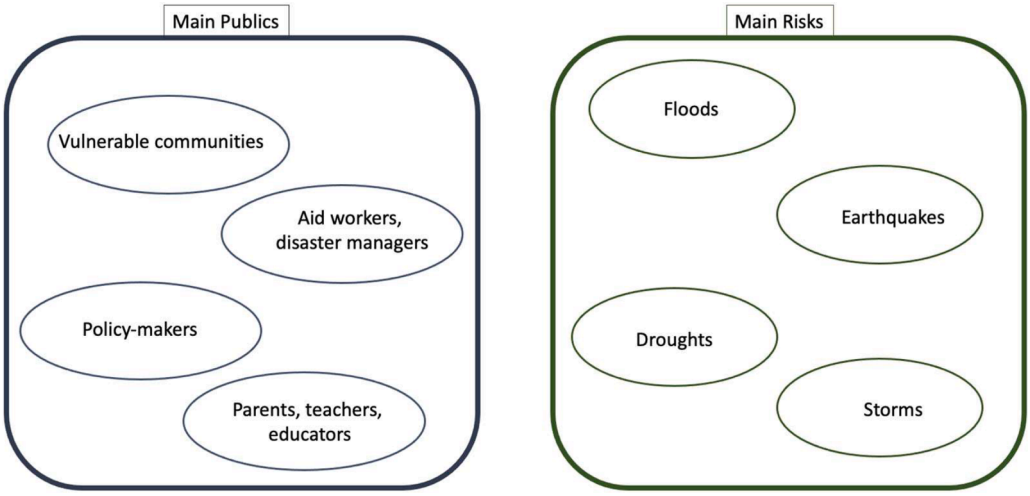

Fig. 2. Main publics and risks included into serious game, adapted from (Solinska-Nowak et al., 2018).

(Solinska-Nowak et al., 2018). Serious games rarely involve the concept of resilience (Marome et al., 2021; Olivares-Rodríguez et al., 2022; Villagra et al., 2023). The few methodologies that have approached the concept of resilience through the prism of serious games have focused on the risk of earthquakes, fires and landslides (Olivares-Rodríguez et al., 2022; Villagra et al., 2023), water resources (Teague et al., 2021) and agriculture in a context of climate change (Neset et al., 2020). These serious games have a desire to translate the concept and integrate it into a game from a perspective of decision support, awareness, understanding and adoption. It is in this perspective that we place our research. Our aim is to develop a serious game applied to a Tahitian commune, to develop knowledge and understanding of the concept of resilience in its systemic dimension, but also to understand the complexity of a local actor in its territorial management purposes and needs.

3. Methodology

3.1. Tahiti case study

French Polynesia is confronted with many risks, primarily marine submersions (Carson et al., 2016; Cazenave et al., 2018; Horton et al., 2018; Nurse et al., 2014; Serre and Heinzlef, 2022), tsunamis (Schindelé et al., 2006; Shao et al., 2019; Sladen et al., 2007) and cyclones (Canavesio et al., 2014; Larrue and Chiron, 2011). Marine submersion refers to the temporary or long-term invasion of coastal areas by the sea, resulting in flooding and possible changes to coastal morphology, due to the dynamic action of waves. This risk can be caused by floods, storms, tsunamis and cyclones. It's a very common risk, and one that occurs regularly. The latest available data on sea level rise show that this rise, which varies widely between regions, has been occurring at a rate of 1.2 cm per year over the last 20 years in the eastern Pacific region. By 2100, it could be 50 cm to 1 m, increasing the risk of marine submersion. (Service public de polynésie française, 2019). To prepare for this growing risk in Polynesia, since January 1, 2023, all new buildings have been required to be elevated: 50 cm in green zones, and one meter in blue zones. For this reason, our prototype focuses on this particular risk.

However, risk management in French Polynesia is mainly focused on crisis management and very little on the construction and implementation of resilience strategies (Bourlier, 2023). Indeed, the management is punctual, at the moment of the crisis, but provides little adaptation on the long term. For example, in all of French Polynesia there are only two Flood Risk Prevention Plans, one of which is in Tahiti and is constantly being questioned. Furthermore, the prospective aspect is absent in PPRs, even in regions where climate change action seems to be a priority. Last but not least, the Polynesian government, despite its competence in this domain, does not have an insurance scheme put in place in the event of a crisis (Bourlier, 2023). This lack of administrative tools leads to an exponential urbanization, without integrating the principles of precaution, adaptation and resilience. Therefore, there is no systemic vision, no decision-making coordination and no long-term projection of risk management. This limited approach is also explained by the two-headed system between the French and Polynesian States (Bourlier, 2023), resulting in a difficult balance between dependence and autonomy. As a result, the concept of resilience is not well known and not integrated in risk management strategies, neither at the level of decision makers nor at the level of the inhabitants.

This is why the objective of this study is to develop a serious game, with a marine flooding risk scenario, aiming to increase the knowledge on risks, resilience and illustrate the systemic dimension of a resilient and long-term risk management strategy.

3.2. Limitations and practical choices

Even before the game was designed, the goal was to select the specificity of the game. Serious games are divided into several large families, including board games and digital games. In French Polynesia, the digital coverage and access to computer tools is not identical in all the archipelagos. 34 % of individuals have a fixed computer in the society archipelago (including the island of Tahiti), and only 8 % in the most remote archipelagos. Concerning access to fiber internet, 13 % have access in the society archipelago and 3 % in the most remote archipelagos (Direction Générale de l'économie numérique, 2019). Therefore, to develop a game prototype adapted to the reality of the Polynesian terrain, the choice was made to first develop a board game. Furthermore, the game is designed as a one to one, the player facing the facilitator. The objective is to create a space of confidence for serene exchanges.

The game prototype was developed and tested during the COVID19 health crisis. Because the population was extremely vulnerable, testing the game with residents proved to be very complicated. In order to disseminate the knowledge of the game to as many people as possible, the choice was made to first test the game with Master's students from the University of French Polynesia. The game was tested with 18 students, thus we accomplished 18 sessions. The facilitator did not know the students personally. They came from different backgrounds: ecology, geography, hard sciences and law at the master level. Testing this game prototype on a university campus proved beneficial for several reasons: the students were in a learning environment, the diversity of profiles could illustrate the diversity of knowledge present in a population, their ability to share their learning within their home allowed for

the gradual distillation of desired information.

3.3. Serious game design

3.3.1. Objectives and scenario

The objective of the development of the game was to increase the knowledge of the participants in regards to risks, the concept of resilience and to allow them to experiment with the systemic complexity of the resilient management of a territory. To do this, the players had to take on the role of a mayor of a Tahitian commune. The aim of this role-playing is to help residents understand the systemic complexity of risk management. In this way, they will be able to apprehend the complexity of the issue and become more involved in their territory. Thus, the notion of individual and collective responsibility required for resilient and sustainable risk management can be initiated. The commune in question was the commune of Punaauia (Fig. 3), part of the agglomeration of Papeete (main city of French Polynesia). It concentrates urban, socio-economic, technical, ecological and political issues.

The player (the mayor) is confronted with the risk of marine submersion. He is faced with choices representing the pre-crisis, crisis and post-crisis periods. The mayor's goal is to increase the resilience of his or her community by balancing and harmonizing choices while managing the budget. Resilience is divided into 6 categories: social, urban, economic, technical, ecological and governance dimensions (Cutter et al., 2014, 2010; Heinzlef et al., 2019; Jessin et al., 2022; Lamaury et al., 2021; Serre and Heinzlef, 2018). These resiliencies are divided into sub-categories, aiding in the comprehension of the concept of resilience by integrating the temporal notions of risk management: before (preparation), during (reaction) and after (adaptation).

3.3.2. Materials

The game is composed of several elements. Action cards are a center point of the game (Fig. 4). These action cards propose two situations to the players. Each choice is linked to a resilience or resiliencies, impacting them positively and/or negatively. The players however, only know at the end of the game the impact of their choice on the different resiliencies, through the use of "consequences cards" (Fig. 5). These cards are divided into three groups covering the three temporalities of risk management: "pro-active" action cards, "post-active" action cards and "reactive" action cards. In the reactive cards, "bonus" cards are also integrated. They make the link between the choices of the pro-active and post-active phase and to illustrate the consequences of certain choices on the long term.

Associated with these "action" cards, a group of "luck" and "bad luck" cards are integrated (Fig. 6). These cards are supposed to represent the uncertainties and unpredictability of crisis situations. The aim is to position the player in a process of rebound, learning, creativity and innovation, in order to overcome an unpredictable and uncertain situation. Both types of cards are located in the same deck and integrated within the "action" cards. These disruptive events are inspired by real events: power outages on the island, the COVID period, past events such as hurricane OLI or heavy rains, etc. Drawing them is therefore a random way of illustrating the impossibility of preparing for everything, and the need for adaptation and over-adaptation. The aim is also to represent the unexpected risks that can arise at any moment and take managers by surprise.

In order to illustrate the decrease and increase in resilience as a function of choices, "tokens" have been developed to visually represent the impact of choices. These tokens represent increases or decreases of 0.5, 1 or 2 %. This also allows the player to readjust his decisions as needed (Fig. 7).

Along with these cards, a general information document was distributed. The objective is to explain the concept of resilience through the explanation of 6 categories, the major risks in French Polynesia, and key references for the general public. The facilitator explains the document and its purpose, but leaves it to the player to read it before the game begins.

Finally, two questionnaires were constructed thanks to a google

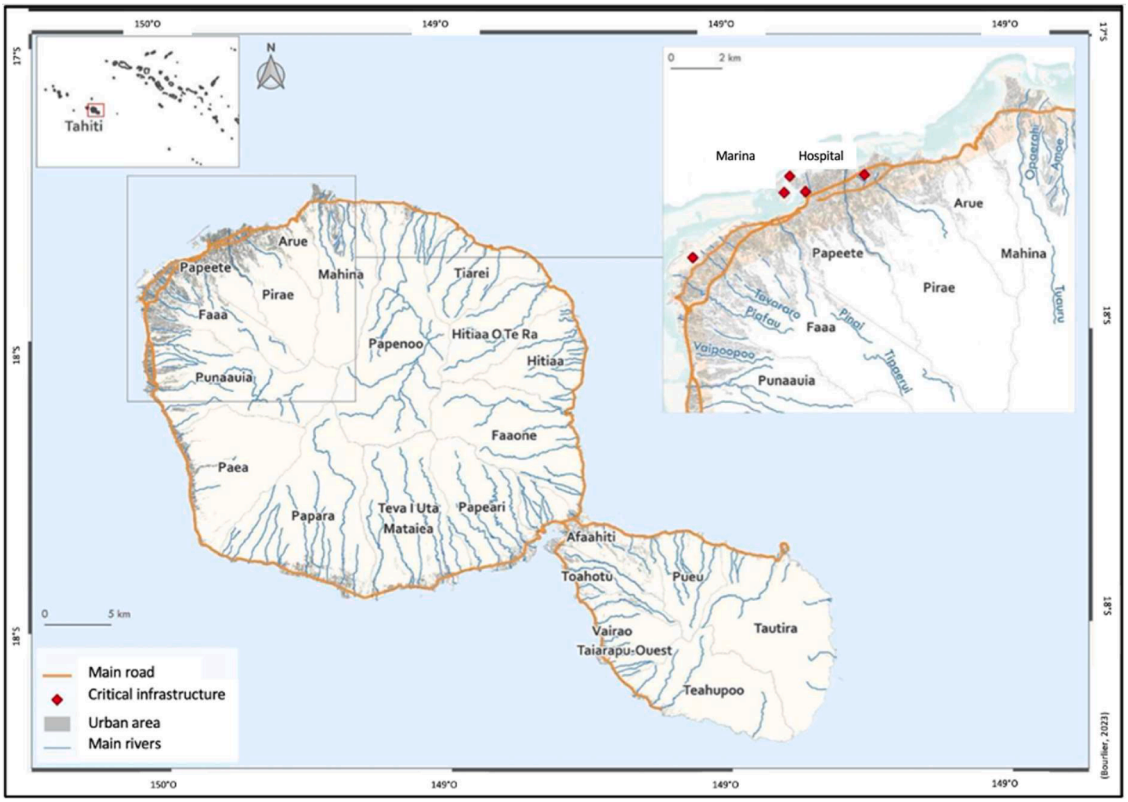

Fig. 3. The case study territory. Adapted from (Bourlier, 2023).

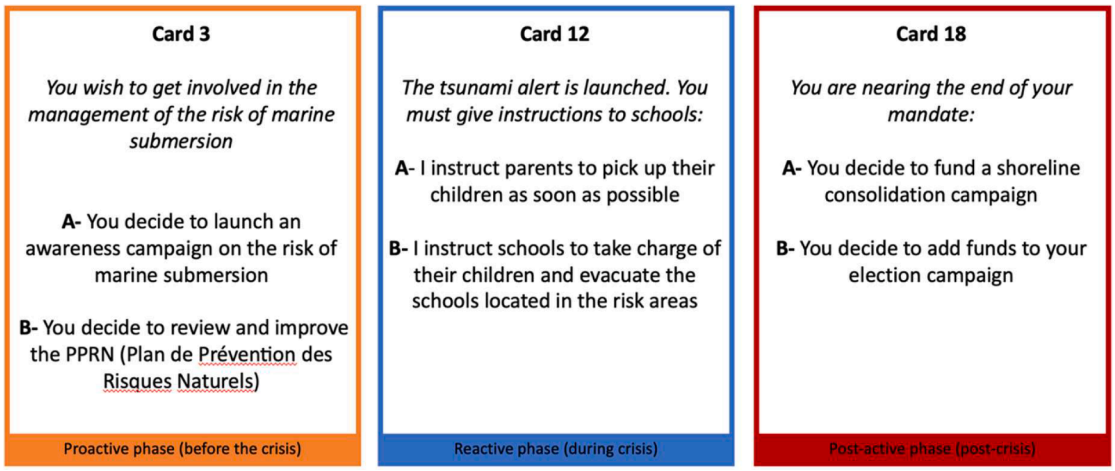

Fig. 4. Examples of "actions cards".

Fig. 5. Examples of consequences cards.

form, one to acquire data on:

- Age,
- Gender,
- Socioeconomic background,
- Place of residence,
- Time spent in French Polynesia,
- Risk and resilience culture.

The second is composed of the same questions, combined with a "perception and experience of the game" category, to acquire feedback from players:

Examples of Questions:

- Questionnaire 1: Before the Game
  - How old are you?
  - What is your level of education?
  - How long have you lived in French Polynesia?
  - In which commune?
  - In your opinion, what are the two major risks in Tahiti?
  - How do you feel about the risk of flooding?
  - What information and forecasts are there concerning marine submersion in Tahiti?
  - What measures should be taken in the event of a marine submersion warning?
  - What is the tsunami warning signal?
  - What structures and developments can amplify the phenomenon of marine submersions in Tahiti?

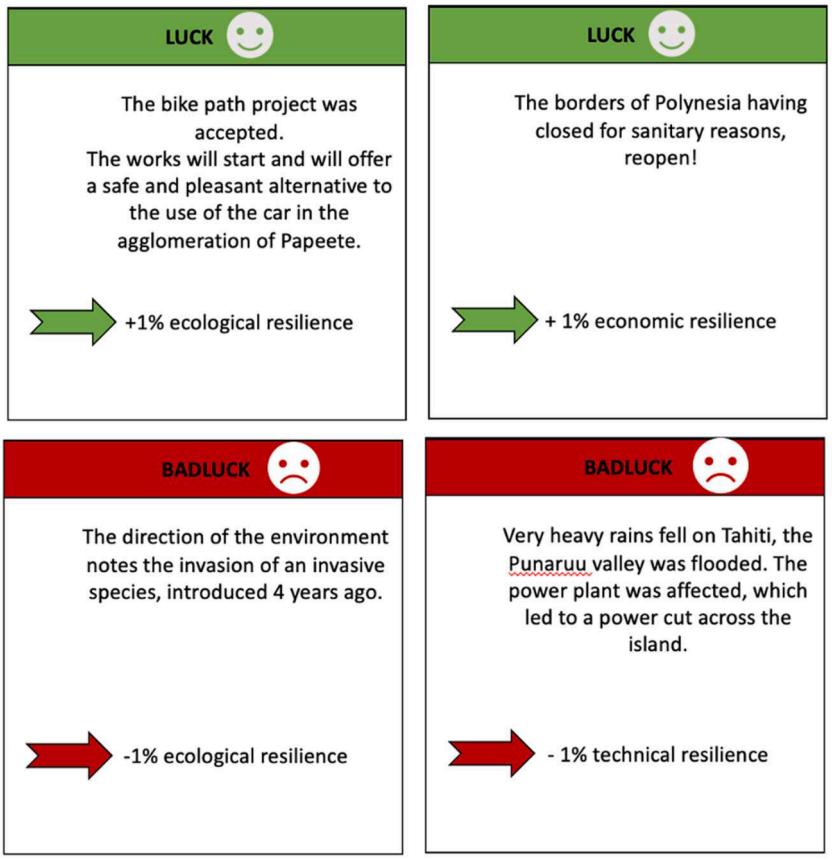

Fig. 6. Examples of "Luck" and "Bad luck" cards.

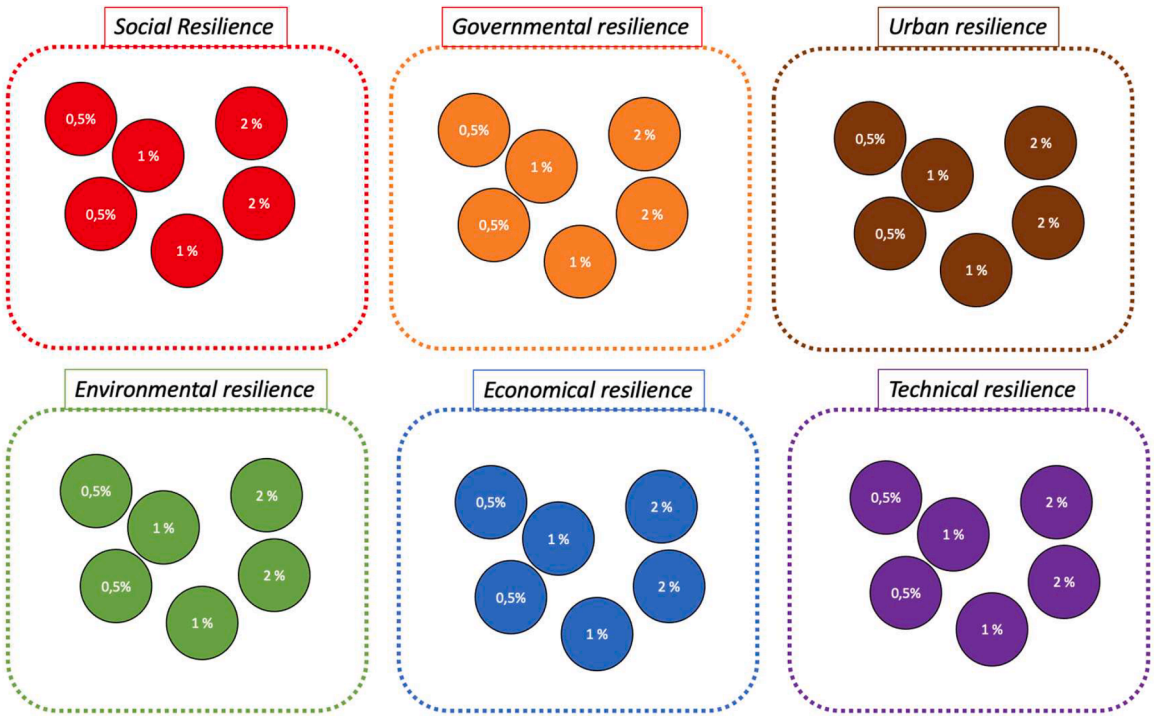

Fig. 7. Examples of tokens.

- What temporality(ies) are involved in the concept of resilience?
- Tick the 4 criteria you consider most important for a territory to be resilient in the face of natural hazards.
- Which actor(s) or service(s) should be integrated into a resilient territorial management of the risk of marine submersion?

- Questionnaire 2: After the Game

- Same questions than questionnaire 1
- Define territorial resilience as you understood it at the end of the game.
- What would you change to be better prepared for a sea flood?
- Did the workshop help you understand the concept of territorial resilience?
- Did the workshop give you a better understanding of how a commune is managed?
- Did you find the workshop entertaining?

3.4. Rules

The rules of the game are read to the players by the facilitator before the experiment begins (Fig. 8)

3.5. Flow of the game

The game is played face-to-face between the facilitator and the player. The facilitator is part of the game development team, but is not responsible for methodological and development choices, types of resilience, card impacts, etc. They are therefore relatively neutral and non-judgmental. The idea is to create a relaxed and trusting atmosphere. The fact of not having to express oneself in front of others can make one feel more at ease, freer to ask questions and express doubts or misunderstandings. The game is organized in several phases.

- Phase 1: Consists of the first questionnaire. The objective is to acquire data on the players' profile in order to build player typologies and identify potential gaps that could be linked to identified profiles.
- Phase 2: The second phase consists of reading the information document. The facilitator remains a resource for the player, but does not try to complicate the information given by the document.
- Phase 3: The game phase (Fig. 9). The player rolls the dice. The number on the dice indicates the number of the card. Depending on the choices, the player increases or decreases certain resiliencies as he goes along. The facilitator is seen as a resource, to answer questions if necessary. The facilitator observes, and notes the choices as they are made by distributing the resilience tokens. During the game, the facilitator repeatedly questions the player's perception of the consequence of the choice. This allows the facilitator to note the type of resiliency the person was hoping/thinking would increase with these questions. In this way, a sample of the players' real preferences is collected. This can be compared with the scores to assess the representativeness of the players' thinking through the game. A maximum of notes are also taken during the workshop: the players' reactions to the roll of the dice, the comments made during the interactions, the time taken to think about the choices, the questions asked, the interest shown in the concept, etc. The game ends with the resilience scores being reported on a "rubric". The total duration of the game is 30min.
- Phase 4: The last phase consists of the second questionnaire to illustrate the learning dimension of the game, the perception, the experience and the usefulness of the game experience. This is the debriefing phase. The facilitator launches an informal discussion of the game experience, learning processes and feelings. Topics such as the attractiveness of the game, the perception of game duration, the game experience, the learning dimension, etc., are addressed. The second questionnaire is used to guide the questions and provide statistical data on the individual experience of the game. This phase lasts around ten minutes, depending on the player's needs.

4. Results

The results are acquired both by observation, by the answers to the questions and by data from the questionnaires. These results are based on 18 players.

4.1. Resilience priorities

Regarding the prioritization of the different categories of resilience, the priorities made during the discussions and the priorities actually made during the game are extremely diverse. The choices made during the game are globally balanced. The players managed to balance the different resiliencies and did not prioritize one or the other. Nevertheless, we observe a prioritization of the governance dimension and choices at the expense of economic resilience (Fig. 10).

In contrast, the results from the discussions with the facilitator illustrate a clear prioritization of the ecological dimension of resilience

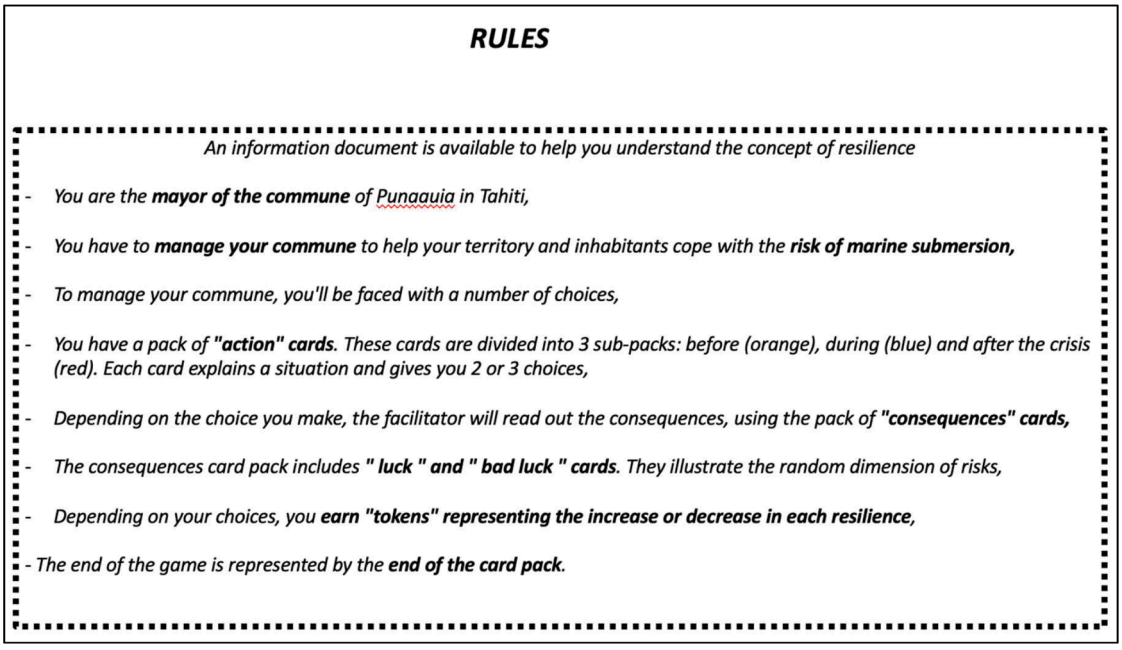

Fig. 8. Rules of the Game.

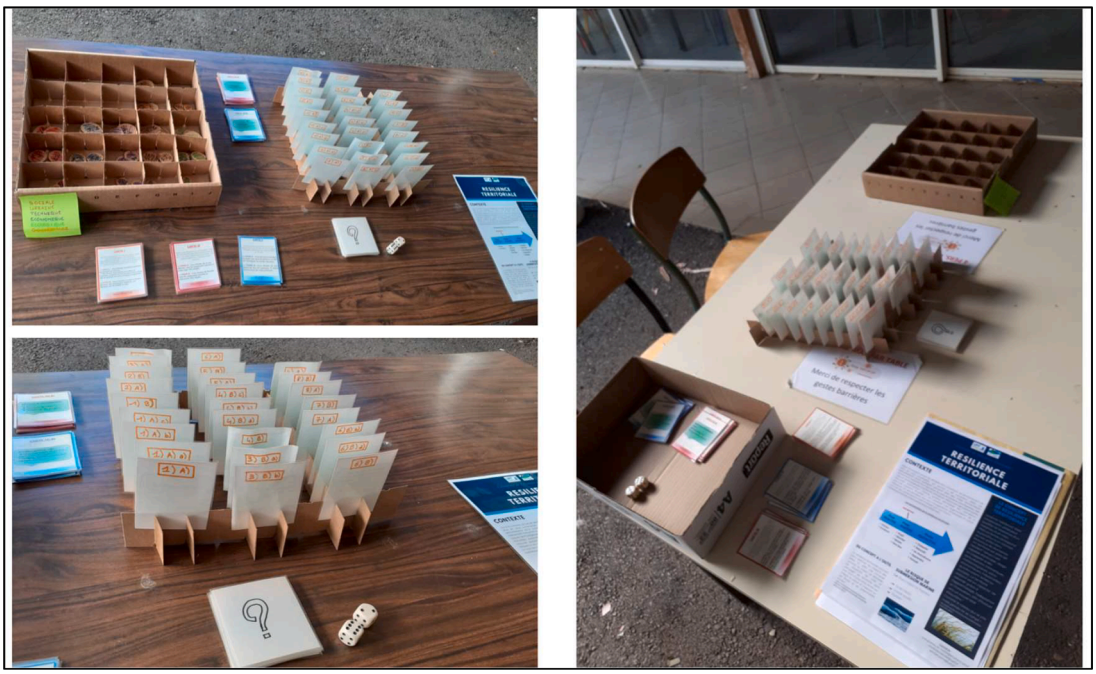

Fig. 9. Pictures of the game.

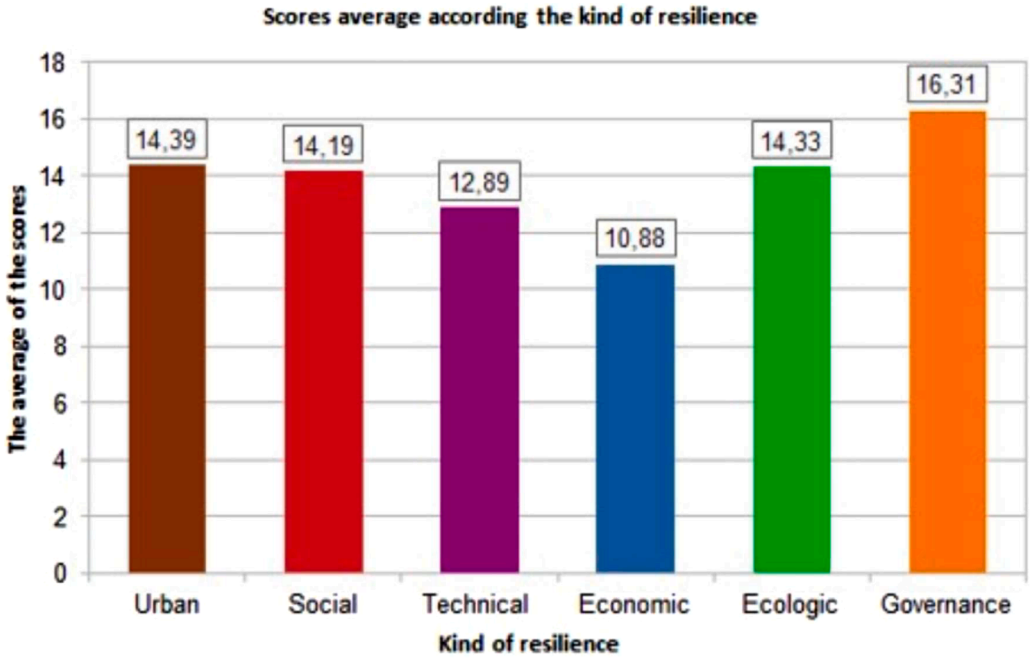

Fig. 10. Priority choices by resilience category - choices made during the game based on the cards.

(Fig. 11).

There are several reasons for this distinction. In the collective mind, resilience is associated with environmental protection. Moreover, the students involved in this iteration of the game are mostly students involved in studies related to "environmental" themes. Regarding the data from the game itself (choices related to the maps), the dominance of "governance" can be explained by the scenario of the maps themselves. Certain card options could lead to a preference for governance. As for the low rate of "economic" resilience, this can be explained by the limited psychological association between resilience and the economy.

4.2. Learning dimension of the game

This learning ability was analyzed following the results of the two questionnaires, to compare pre- and post-game time frames. Regarding the "risk culture" dimension, there is a clear improvement in the correct answers after the game. In response to questions such as "What measures should be taken in the event of a marine submersion warning?", "What structures exist in Tahiti to limit marine submersion?", "What structure (s) or development(s) can amplify the phenomenon of marine submersi in Tahiti?", the answers improved significantly. Globally in the section “risk culture”, the percentage of correct responses increases from 46 % on the first questionnaire to 64 % on the second. This is an increase of 18

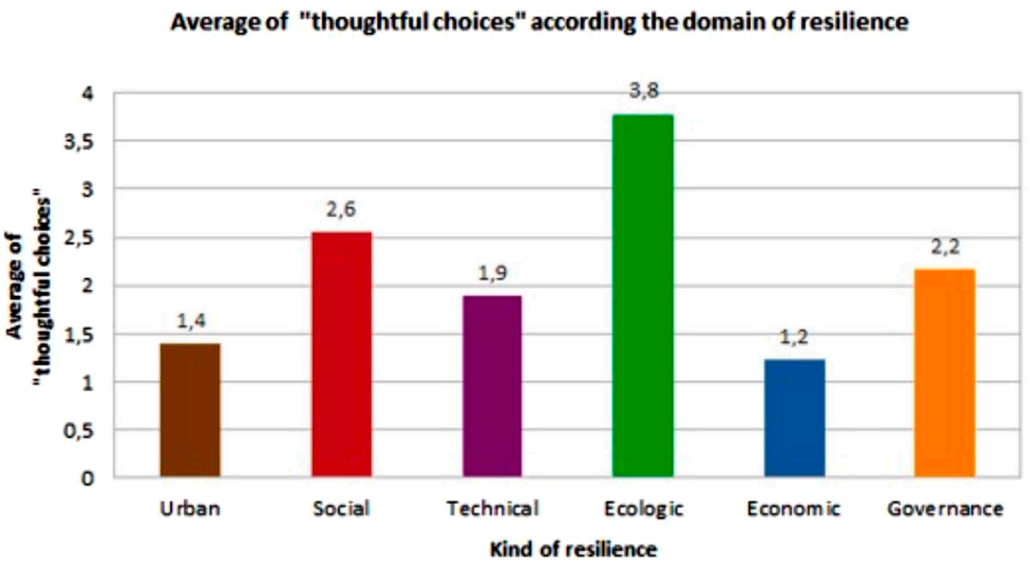

Fig. 11. Priority choices by resilience category - choices made during the game based on the discussions.

% (Fig. 12).

Regarding the understanding of the concept of resilience, the propensity to learn is also high. In response to questions such as: "What timeframe(s) does the concept of resilience incorporate?", "Choose the 4 criteria you feel are most important for a territory to be resilient in the face of natural hazards", "Which actor(s) or service(s) should be integrated into a resilient territorial management of the risk of marine submersion?" the answers improved significantly. Globally in the section "resilience concept", the percentage of correct answers increased by 40 % between the first and the second questionnaire (Fig. 13).

This increase in knowledge is not only factual but is also perceived directly by the players. Players intrinsically perceive the exponential dimension of their knowledge. They also perceived and apprehended the systemic dimension of the management of a commune (Fig. 14).

Regarding the players' perception of the different importance of the resilience categories, this aspect also evolved. In the first questionnaire, the hierarchy between the resilience categories was very disparate (ranging from 3 % to 26 %). In contrast, the importance given to the resilience categories is more balanced, ranging from 8 % to 20 % (Fig. 15).

Finally, concerning the experience of the serious game as such, the players appreciated the playfulness and the temporality of the serious game. Regarding the possibility of reproducing the experience, the players are all inclined to play again (Fig. 16). These results underline

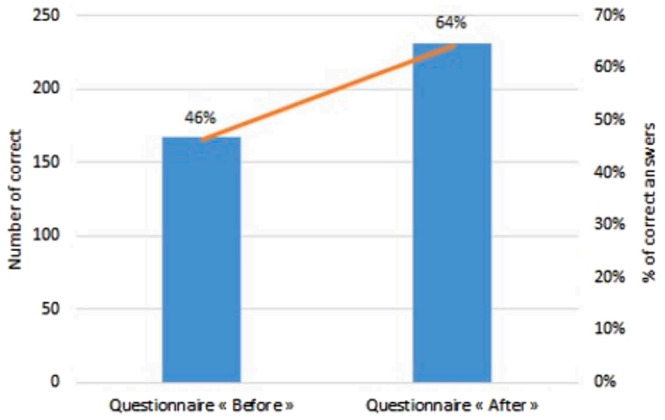

Fig. 12. Percentage of correct answers about risk culture between pre- and post-workshop questionnaires.

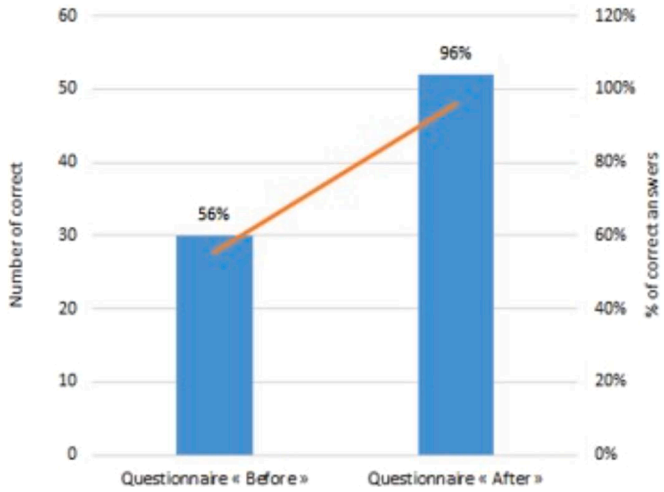

Fig. 13. Percentage of correct answers about resilience concept between pre- and post-workshop questionnaires.

the quality of the experience, the appreciation of the time spent, the knowledge acquired and the desire to continue this learning process via other media or on other occasions.

5. Discussion

The objectives of this serious game prototype were multiple:

- to allow players to discover the concept of resilience, its complexity and its holistic dimension;
- to understand the systemic complexity of a resilient territorial management;
- to develop a playful and educational tool.

From the data acquired through the questionnaires, these three objectives were met. Knowledge about risk management and the concept of resilience increased significantly through the game experience. Whether it was through the information document, or the action cards illustrating the link between understandable actions and resilience categories, the players developed a systemic and sensitive understanding of these issues and concepts. Their understanding is embedded in an

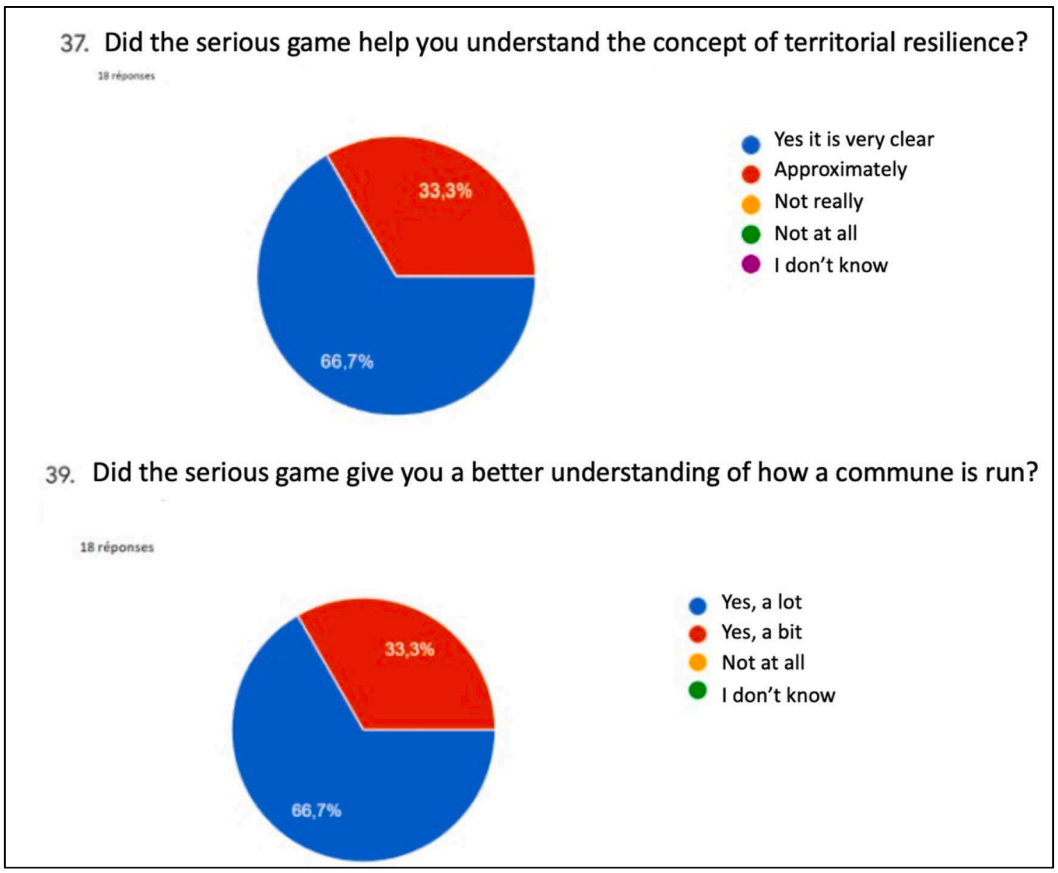

Fig. 14. Players' perceptions of their level of learning through the serious game.

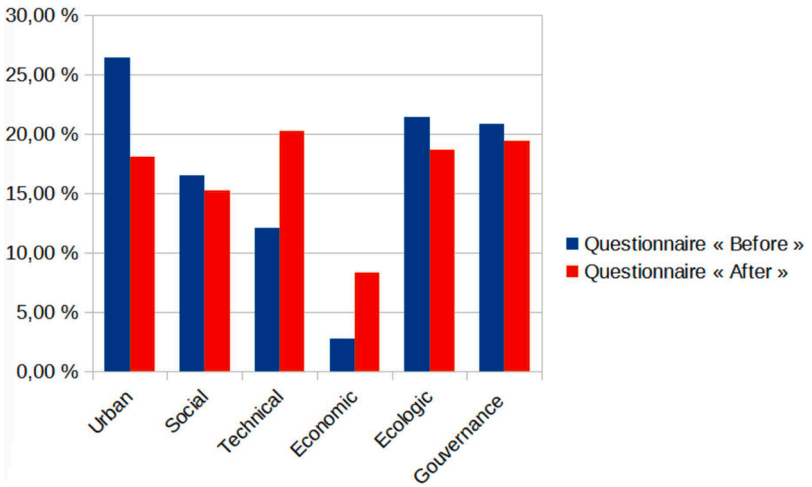

Fig. 15. Importance given to different categories of resilience - difference between before and after the game.

experiential dimension, allowing them to connect it to their practical, not just theoretical, previous experiences. As it has been proven by other serious games, "*players have the opportunity to face different (…) perspectives, gaining more multidimensional understanding of a given problem*" (Solinska-Nowak et al., 2018). This acquisition of knowledge, of both practical and sensitive knowledge, is not simply observable by the facilitator but felt by the players themselves. It is therefore a conscious and appreciated process, which favors and participates in the long-term adoption of this knowledge and its implantation in the players' consciousness. When it comes to evaluating serious games and their effectiveness (Mayer et al., 2014), there are several approaches. The two most widely used methods are summative and formative evaluation. It has been shown that formative evaluations are particularly useful and should be used because they can be incorporated into the serious game and become part of the experience, such as through feedback from the user (Bellotti et al., 2010). This game is fully in line with this approach, with pre- and post-game questionnaires to assess the degree of learning, the most popular method in educational studies (Bellotti et al., 2010). For serious games to be considered a viable pedagogical tool, they need to provide assessment methods for their effectiveness and durability. Evaluation during the game seems to be one of the most appropriate and relevant methods, as it integrates its evaluation system into the logic and

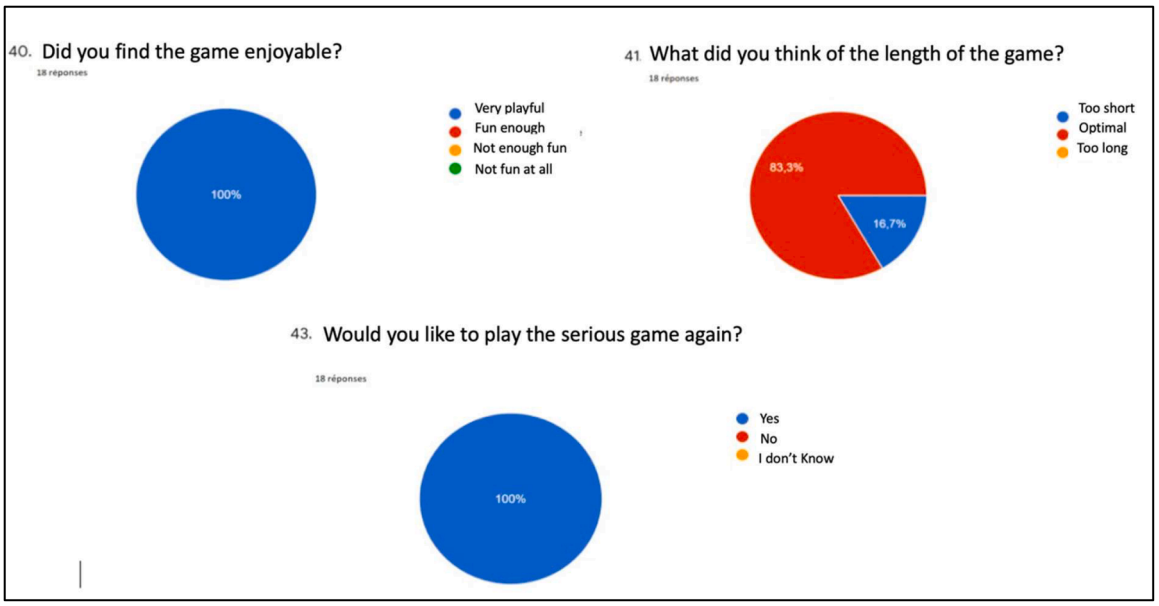

Fig. 16. Appreciation of the players on the construction of the game.

chronology of the game, and therefore does not disrupt the player's experience of the game (Bellotti et al., 2010). It also provides an immediate, direct feedback and enables the player to develop his or her ability to adapt. This game therefore fully meets the learning objectives of serious games, both in the results themselves and in the game's self-assessment process.

In regards to the perspectives of this prototype, they are multiple. The target audience is obviously an aspect to be qualified. Because of the COVID period, the tests were carried out with students. Because of their training or their age, they were perhaps more aware of and interested in these issues. The objective would be to test on socio-economic groups that would not supposedly have a connection to these topics, as well as groups of decision-makers and local actors already involved in risk management. Their different involvements, experiences and sensitivities would make it possible to test the game in other contexts and thus to nuance it and see its effectiveness on different groups of participants. Additionally, given the limitations identified in the literature (Solinska-Nowak et al., 2018), tests on other risks could be extremely relevant, especially in a process of climate disruption and risk interdependence. The cyclonic risk, for example, would be extremely relevant given the devastation of the last cyclone in 2010.

Concerning the experience of the game itself, the fact that this game is conceived as a board game, required the presence of an animator. Moreover, this choice was explained by the disparity of the digital coverage in French Polynesia. Nevertheless, the transcription of the game into a virtual game has been considered (Fig. 17). One of the crucial factors in determining the long-term relevance and usefulness of serious games is the cost associated with the game and its distribution. In order to reach disadvantaged and therefore more vulnerable populations, this cost must be as affordable as possible (Solinska-Nowak et al., 2018). It was with this in mind that an online game was conceived. Another point of reflection was also the individual experience. The aspect of being alone during this experience could exacerbate the risk-taking, without fear of a potential judgment of the facilitator. At the

Fig. 17. Digital prototype of the serious game.

end of the game, a statistical result illustrates the priorities' of the players underlined by their choices (Fig. 18). A cup is "awarded" to them as an expert in the field of resilience they have chosen. This online game was developed on the JAWA platform. JAWA is a 100 % online tool that allows anyone to create investigation/adventure games simply and without programming knowledge. The games created can be played directly in the browser without installation and can be shared directly on the portal of the site, but also exported to broadcast them on other sites or platforms. It is particularly adapted to the fast and low-cost or free creation of serious-games, or for accelerated prototyping.

This digital game was tested on a group of 10 risk engineering researchers in June 2023. The game lasted 30 minutes, with a 30-minute feedback phase. Several elements emerged from this test session (Table 1).

The next steps are therefore to explore this approach to digital adaptation, as well as to develop new iterations with other groups of actors, taking into account their feedback.

This approach and the associated results are fully in line with this process of decision support and dissemination of knowledge, practical knowledge and soft skills, real or sensitive experiences, as part of long-term approaches. This is why this game is fully in line with the risk and resilience observatory tool and in particular with task 1: increase knowledge on risks and resilience and task 3: integrate local actors. As a decision support tool, engaging actors in situations of simulation, decision making, reflection at different temporal scales, and experimentation with the systemic complexity of risk management and implementation of the concept of resilience is essential. Placing the actors in a playful dimension allows them to be more daring, to leave their comfort zone while ensuring a secure and trusting environment, and encourages them to be innovative and creative. This environment accompanies and supports the creation of links between their sensitive experiences and their theoretical knowledge, allowing them to associate these two dimensions for a better understanding, acceptance and adoption of complex notions, concepts and processes. This serious game is therefore a decision support tool integrated into the French Polynesia Risk and Resilience Observatory. It produces data on the perceptions, sensitivities and priorities of the players, data that is essential for the risk and resilience observatory.

Table 1
Digital game test.

Positive points	Improvement points
Interface easy to use and game easy to play	Hard to know what is a "good" score
Realistic game	Would be great to see each choice on the map
Exhaustive resilience approach with 6 dimensions	Would be great to have a go back button
Great to have a budget for the realistic dimension	Need to optimize the game for cellphones
Variety of social decisions and scenarii	Would be interesting to have several risks
Good feedback on the benefit of actions, good ideas of consequences of each choice	
Clear game play and actions	
Great temporal scale: before, during and after the risk	
Motivating game	
Useful for decision making	

6. Conclusion

This serious game prototype was developed as part of the implementation of a risk and resilience observatory in French Polynesia. French Polynesia is extremely vulnerable to climatic risks, especially to marine submersions. However, risk management practices are essentially focused on crisis management, without integrating a resilience, systemic and long-term dimension. In order to develop knowledge and experiences on the concept of resilience, the objective was to develop a serious game. In a playful dimension of the serious game, the players were placed in a situation of systemic management of a municipality confronted by a risk of flooding. This experience allowed them to establish links between concrete actions and the concept of resilience, to understand the need to develop long-term approaches (before, during and after a crisis), but also to value them in their learning process. This serious game is therefore fully a decision-making tool, allowing players to develop knowledge, sensitive experiences, emotions, but also to bridge their previous knowledge, whether theoretical or practical, and the knowledge acquired through the game. It is therefore an equity of knowledge that is promoted, in a participatory approach, in order to

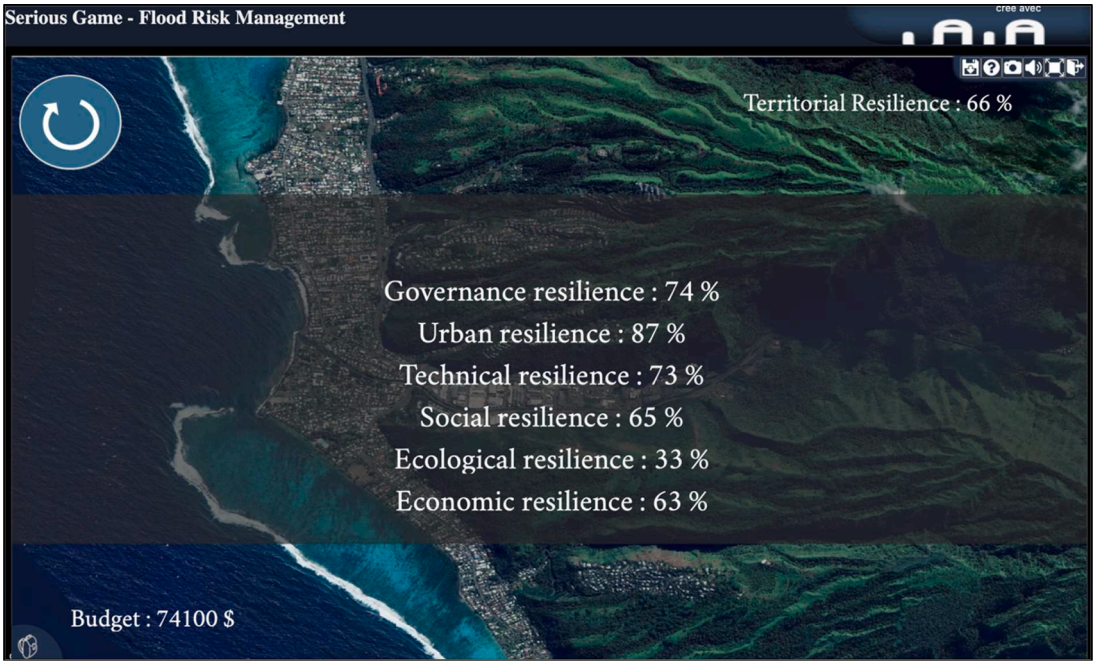

Fig. 18. Digital prototype of the serious game – Final score.

move forward together towards the understanding, perception, awareness, use and adoption in the long term of the concept of resilience.

CRediT authorship contribution statement

Charlotte Heinzlef: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Yoann Lamaury:** Visualization, Software, Investigation, Data curation. **Damien Serre:** Supervision, Project administration, Funding acquisition, Conceptualization.

Declaration of Competing Interest

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

Data availability

The authors are unable or have chosen not to specify which data has been used.

References

Alexander, D.E., 2013. Resilience and disaster risk reduction: an etymological journey. Nat. Hazards Earth Syst. Sci. Discuss. 1, 1257–1284. https://doi.org/10.5194/nhessd-1-1257-2013.

Aubert, A.H., Bauer, R., Lienert, J., 2018. A review of water-related serious games to specify use in environmental multi-criteria decision analysis. Environ. Model. Softw. 105, 64–78. https://doi.org/10.1016/j.envsoft.2018.03.023.

Bahadur, A., Wilkinson, E., Tanner, T., 2015. Measuring resilience: an analytical review (draft under review). https://doi.org/10.13140/RG.2.1.1300.1444.

Balsells, M., Barroca, B., Becue, V., Serre, D., 2015. Making urban flood resilience more operational: current practice. Proc. Inst. Civ. Eng. - Water Manag. 168, 57–65. https://doi.org/10.1680/wama.14.00051.

Bellamy, L.J., Chambon, M., van Guldener, V., 2018. Getting resilience into safety programs using simple tools - a research background and practical implementation. Reliab. Eng. Syst. Saf. 172, 171–184. https://doi.org/10.1016/j.ress.2017.12.005.

Bellotti, F., Berta, R., De Gloria, A., 2010. Designing effective serious games: opportunities and challenges for research. Int. J. Emerg. Technol. Learn. IJET 5, 22–35. https://doi.org/10.3991/ijet.v5s3.1500.

Bourlier, B., 2023. Opérationnaliser la résilience face aux inondations à Tahiti par la modélisation de la gouvernance locale et d'indicateurs spatialisés pour co-déterminer l'intérêt d'un observatoire des risques. Université de Polynésie Française.

Boyle, E.A., MacArthur, E.W., Connolly, T.M., Hainey, T., Manea, M., Kärki, A., van Rosmalen, P., 2014. A narrative literature review of games, animations and simulations to teach research methods and statistics. Comput. Educ. 74, 1–14. https://doi.org/10.1016/j.compedu.2014.01.004.

Canavesio, R., Jeanson, M., Étienne, S., 2014. La gestion du risque cyclonique en Polynésie française et ses limites: exemple du cyclone tropical Oli, février 2010. Bull. Assoc. Géographes Fr. 91, 325–337. https://doi.org/10.4000/bagf.1644.

Carson, M., Köhl, A., Stammer, D., Slangen, A., Katsman, A.B., W. van de Wal, C.A., Church, R.S., White, J., 2016. Coastal sea level changes, observed and projected during the 20th and 21st century. Clim. Change 134, 269–281. https://doi.org/10.1007/s10584-015-1520-1.

Castellnou, M., Prat-Guitart, N., Arilla, E., Larrañaga, A., Nebot, E., Castellarnau, X., Vendrell, J., Pallàs, J., Herrera, J., Monturiol, M., Cespedes, J., Pagès, J., Gallardo, C., Miralles, M., 2019. Empowering strategic decision-making for wildfire management: avoiding the fear trap and creating a resilient landscape. Fire Ecol 15, 31. https://doi.org/10.1186/s42408-019-0048-6 s42408-019-0048–6.

Cazenave, A., Palanisamy, H., Ablain, M., 2018. Contemporary sea level changes from satellite altimetry: what have we learned? What are the new challenges? Adv. Space Res. 62, 1639–1653. https://doi.org/10.1016/j.asr.2018.07.017.

Clerveaux, V., Spence, B., Katada, T., 2010. Promoting disaster awareness in multicultural societies: the DAG approach. Disaster Prev. Manag. Int. J. 19, 199–218. https://doi.org/10.1108/09653561011038002.

Clerveaux, V., Spence, B., Katada, T., 2008. Department of Civil Engineering, Gunma University, 1-5-1 Tenjin-cho, Kiryu, Gunma 376-8515, Japan, Lecturer, Department of Geography & Geology, the University of the West Indies, Mona, Kingston 7, West Indies, Jamaica. Using game technique as a strategy in promoting disaster awareness in caribbean multicultural societies: the disaster awareness game. J. Disaster Res. 3, 321–333. https://doi.org/10.20965/jdr.2008.p0321.

Cremers, A., Stubbé, H., van der Beek, D., Roelofs, M., Kerstholt, J., 2015. Does playing the serious game B-SaFe! make citizens more aware of man-made and natural risks in their environment? J. Risk Res. 18, 1280–1292. https://doi.org/10.1080/13669877.2014.919513.

Cutter, S.L., Ash, K.D., Emrich, C.T., 2014. The geographies of community disaster resilience. Glob. Environ. Change 29, 65–77. https://doi.org/10.1016/j.gloenvcha.2014.08.005.

Cutter, S.L., Burton, C.G., Emrich, C.T., 2010. Disaster resilience indicators for benchmarking baseline conditions. J. Homel. Secur. Emerg. Manag. 7 https://doi.org/10.2202/1547-7355.1732.

Davoudi, S., Shaw, K., Haider, L.J., Quinlan, A.E., Peterson, G.D., Wilkinson, C., Fünfgeld, H., McEvoy, D., Porter, L., Davoudi, S., 2012. Resilience: a bridging concept or a dead end? "Reframing" resilience: challenges for planning theory and practice interacting traps: resilience assessment of a pasture management system in northern afghanistan urban resilience: what does it mean in planning practice? Resilience as a useful concept for climate change adaptation? The politics of resilience for planning: a cautionary note: edited by simindavoudi and libbyporter. Plan. Theory Pract. 13, 299–333. https://doi.org/10.1080/14649357.2012.677124.

de Ruiter, M.C., Couasnon, A., Ward, P.J., 2021. Breaking the silos: an online serious game for multi-risk disaster risk reduction (DRR) management. Geosci. Commun. 4, 383–397. https://doi.org/10.5194/gc-4-383-2021.

Direction Générale de l'économie numérique. Les usages numériques des individus et ménages en Polynésie Française. Direction Générale de l'économie numérique, Tahiti https//www.service-public.pf/dgen/wp-content/uploads/sites/3/32020/11/2020-09-26-DGEN-USAGES-MENAGES-LOW.pdf.

Dominey-Howes, D., Goff, J., 2013. Tsunami risk management in pacific island countries and territories (PICTs): some issues, challenges and ways forward. Pure Appl. Geophys. 170, 1397–1413. https://doi.org/10.1007/s00024-012-0490-8.

Dörner, R., Göbel, S., Effelsbeg, W., Wiemeyer, J., 2018. SERIOUS GAMES: Foundations, Concepts and Practice. Place of publication not identified, SPRINGER.

Fox-Lent, C., Bates, M.E., Linkov, I., 2015. A matrix approach to community resilience assessment: an illustrative case at Rockaway Peninsula. Environ. Syst. Decis. 35, 209–218. https://doi.org/10.1007/s10669-015-9555-4.

Gampell, A., Gaillard, J.C., Parsons, M., Le Dé, L., 2020. 'Serious' disaster video games: an innovative approach to teaching and learning about disasters and disaster risk reduction. J. Geogr. 119, 159–170. https://doi.org/10.1080/00221341.2020.1795225.

Garcia-Aristizabal, A., Gasparini, P., Uhinga, G., 2015. Multi-risk assessment as a tool for decision-making. In: Pauleit, S., Coly, A., Fohlmeister, S., Gasparini, P., Jørgensen, G., Kabisch, S., Kombe, W.J., Lindley, S., Simonis, I., Yeshitela, K. (Eds.), Urban Vulnerability and Climate Change in Africa, Future City. Springer International Publishing, Cham, pp. 229–258. https://doi.org/10.1007/978-3-319-03982-4_7.

Giardino, A., Nederhoff, K., Vousdoukas, M., 2018. Coastal hazard risk assessment for small islands: assessing the impact of climate change and disaster reduction measures on Ebeye (Marshall Islands). Reg. Environ. Change 18, 2237–2248. https://doi.org/10.1007/s10113-018-1353-3.

Hamari, J., Keronen, L., 2017. Why do people play games? A meta-analysis. Int. J. Inf. Manag. 37, 125–141. https://doi.org/10.1016/j.ijinfomgt.2017.01.006.

Heinzlef, C., 2020. La résilience urbaine en question: enjeux, contexte et propositions d'opérationnalisation. Risques Urbains 4. https://doi.org/10.21494/ISTE.OP.2021.0601.

Heinzlef, C., 2019. Modélisation d'indicateurs de résilience urbaine face au risque d'inondation. Co-construction d'un système spatial d'aide à la décision pour contribuer à l'opérationnalisation du concept de résilience. Avignon Université, Avignon.

Heinzlef, C., Barroca, B., Leone, M., Serre, D., 2022. Urban resilience operationalization issues in climate risk management: a review. Int. J. Disaster Risk Reduct., 102974 https://doi.org/10.1016/j.ijdrr.2022.102974.

Heinzlef, C., Becue, V., Serre, D., 2019. Operationalizing urban resilience to floods in embanked territories – application in avignon, provence Alpes Côte d'azur region. Saf. Sci. 118, 181–193. https://doi.org/10.1016/j.ssci.2019.05.003.

Heinzlef, C., Robert, B., Hémond, Y., Serre, D., 2020. Operating urban resilience strategies to face climate change and associated risks: some advances from theory to application in Canada and France. Cities 104, 102762. https://doi.org/10.1016/j.cities.2020.102762.

Heinzlef, C., Serre, D., 2020. Urban resilience: from a limited urban engineering vision to a more global comprehensive and long-term implementation. Water Secur 11, 100075. https://doi.org/10.1016/j.wasec.2020.100075.

Heinzlef, C., Serre, D., 2019. Dérèglement climatique et gestion des risques en Polynésie française: conception d'un Observatoire de la résilience. Cah. O.-m. 72, 531–563. https://doi.org/10.4000/com.10666.

Horton, B.P., Kopp, R.E., Garner, A.J., Hay, C.C., Khan, N.S., Roy, K., Shaw, T.A., 2018. Mapping sea-level change in time, space, and probability. Annu. Rev. Environ. Resour. 43, 481–521. https://doi.org/10.1146/annurev-environ-102017-025826.

Jankowski, P., Nyerges, T., 2001. GIS-supported collaborative decision making: results of an experiment. Ann. Assoc. Am. Geogr. 91, 48–70. https://doi.org/10.1111/0004-5608.00233.

Jankowski, P., Nyerges, T.L., Smith, A., Moore, T.J., Horvath, E., 1997. Spatial group choice: a SDSS tool for collaborative spatial decisionmaking. Int. J. Geogr. Inf. Sci. 11, 577–602. https://doi.org/10.1080/136588197242202.

Jessin, J., Heinzlef, C., Long, N., Serre, D., 2022. Supporting a resilience observatory to climate risks in french polynesia: from valorization of preexisting data to low-cost data acquisition. Water 14, 359. https://doi.org/10.3390/w14030359.

Khoury, M., Gibson, M.J., Savic, D., Chen, A.S., Vamvakeridou-Lyroudia, L., Langford, H., Wigley, S., 2018. A serious game designed to explore and understand the complexities of flood mitigation options in urban–rural catchments. Water 10, 1885. https://doi.org/10.3390/w10121885.

Lamaury, Y., Jessin, J., Heinzlef, C., Serre, D., 2021. Operationalizing urban resilience to floods in island territories—application in punaauia, french polynesia. Water 13, 337. https://doi.org/10.3390/w13030337.
Larrue, S., Chiron, T., 2011. Les îles de Polynésie française face à l'aléa cyclonique. VertigO. https://doi.org/10.4000/vertigo.10558.
Mani, L., Cole, P.D., Stewart, I., 2016. Using video games for volcanic hazard education and communication:an assessment of the method and preliminary results. Nat. Hazards Earth Syst. Sci. 16, 1673–1689. https://doi.org/10.5194/nhess-16-1673-2016.
Marome, W., Natakun, B., Archer, D., 2021. Examining the use of serious games for enhancing community resilience to climate risks in Thailand. Sustainability 13, 4420. https://doi.org/10.3390/su13084420.
Mayer, I., Bekebrede, G., Harteveld, C., Warmelink, H., Zhou, Q., Van Ruijven, T., Lo, J., Kortmann, R., Wenzler, I., 2014. The research and evaluation of serious games: toward a comprehensive methodology. Br. J. Educ. Technol. 45, 502–527. https://doi.org/10.1111/bjet.12067.
Meerow, S., Newell, J.P., Stults, M., 2016. Defining urban resilience: a review. Landsc. Urban Plan. 147, 38–49. https://doi.org/10.1016/j.landurbplan.2015.11.011.
Michael, D., 2006. Serious Games: Games That Educate, Train and Inform. Thomson Course Technology, Boston, Mass.
Mossoux, S., Delcamp, A., Poppe, S., Michellier, C., Canters, F., Kervyn, M., 2016. Hazagora: will you survive the next disaster? – a serious game to raise awareness about geohazards and disaster risk reduction. Nat. Hazards Earth Syst. Sci. 16, 135–147. https://doi.org/10.5194/nhess-16-135-2016.
Neset, T.-S., Andersson, L., Uhrqvist, O., Navarra, C., 2020. Serious gaming for climate adaptation—assessing the potential and challenges of a digital serious game for urban climate adaptation. Sustainability 12, 1789. https://doi.org/10.3390/su12051789.
Nunn, P., 2009. Responding to the challenges of climate change in the Pacific Islands: management and technological imperatives. Clim. Res. 40, 211–231. https://doi.org/10.3354/cr00806.
Nurse, L., MacLean, R., Agard, J., Briguglio, L., Duvat-Magnan, V., Pelesikoti, N., Tompkins, E., Arthur, Webb, 2014. Small Islands, in: Climate Change 2014: Impacts, Adaptation and Vulnerability. Part B:Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, pp. 1613–1654.
Olivares-Rodríguez, C., Villagra, P., Mardones, R.E., Cárcamo-Ulloa, L., Jaramillo, N., 2022. Costa resiliente: a serious game Co-designed to foster resilience thinking. Sustainability 14, 16760. https://doi.org/10.3390/su142416760.
Oppenheimer, M., Glavovic, B.C., Hinkel, J., Van de Wal, R., Magnan, A.K., Abd-Elgawad, A., Cai, R., Cifuentes-Jara, M., DeConto, R.M., Ghosh, T., Hay, J., Isla, F., Marzeion, B., Meyssignac, B., Sebesvari, Z., 2019. Sea level rise and implications for low-lying Islands. Coasts and Communities 169. IPCC Special Report on the Ocean and Cryosphere in a Changing Climate.
Reghezza-Zitt, M., Rufat, S., Djament-Tran, G., Le Blanc, A., Lhomme, S., 2012. What resilience is not: uses and abuses. Cybergeo. https://doi.org/10.4000/cybergeo.25554.
Roy, B., 1985. Méthodologie multicritère d'aide à la décision, Collection Gestion. Série Production et techniques quantitatives appliquées à la gestion. Economica.
Rumore, D., Schenk, T., Susskind, L., 2016. Role-play simulations for climate change adaptation education and engagement. Nat. Clim. Change 6, 745–750. https://doi.org/10.1038/nclimate3084.
Scherzer, S., Lujala, P., Rød, J.K., 2019. A community resilience index for Norway: an adaptation of the Baseline Resilience Indicators for Communities (BRIC). Int. J. Disaster Risk Reduct. 36, 101107 https://doi.org/10.1016/j.ijdrr.2019.101107.
Schindelé, F., Hébert, H., Reymond, D., Sladen, A., 2006. L'aléa tsunami en Polynésie française: synthèse des observations et des mesures. Comptes Rendus Geosci 338, 1133–1140. https://doi.org/10.1016/j.crte.2006.09.010.
Schipper, L., Langston, L., 2015. A comparative overview of resilience measurement frameworks: analyzing indicators and approaches. https://doi.org/10.13140/RG.2.1.2430.0882.
Serre, D., Heinzlef, C., 2022. Long-Term Resilience to Climate Change Risks in French Polynesian Community: An Observatory Design, in: The Palgrave Handbook of Climate Resilient Societies. Springer International Publishing, Cham, pp. 1–28. https://doi.org/10.1007/978-3-030-32811-5_129-2.
Serre, D., Heinzlef, C., 2018. Assessing and mapping urban resilience to floods with respect to cascading effects through critical infrastructure networks. Int. J. Disaster Risk Reduct. https://doi.org/10.1016/j.ijdrr.2018.02.018.
Service public de polynésie française, 2019. Les risques et le changement climatique.
Shao, K., Liu, W., Gao, Y., Ning, Y., 2019. The influence of climate change on tsunami-like solitary wave inundation over fringing reefs. J. Integr. Environ. Sci. 16, 71–88. https://doi.org/10.1080/1943815X.2019.1614071.
Sharifi, A., 2016. A critical review of selected tools for assessing community resilience. Ecol. Indic. 69, 629–647. https://doi.org/10.1016/j.ecolind.2016.05.023.
Shaw, D., Scully, J., Hart, T., 2014. The paradox of social resilience: how cognitive strategies and coping mechanisms attenuate and accentuate resilience. Glob. Environ. Change 25, 194–203. https://doi.org/10.1016/j.gloenvcha.2014.01.006.
Sladen, A., Hébert, H., Schindelé, F., Reymond, D., 2007. Evaluation of far-field tsunami hazard in French Polynesia based on historical data and numerical simulations. Nat. Hazards Earth Syst. Sci. 7, 195–206. https://doi.org/10.5194/nhess-7-195-2007.
Solinska-Nowak, A., Magnuszewski, P., Curl, M., French, A., Keating, A., Mochizuki, J., Liu, W., Mechler, R., Kulakowska, M., Jarzabek, L., 2018. An overview of serious games for disaster risk management – Prospects and limitations for informing actions to arrest increasing risk. Int. J. Disaster Risk Reduct. 31, 1013–1029. https://doi.org/10.1016/j.ijdrr.2018.09.001.
Taillandier, F., Adam, C., 2018. Games ready to use: a serious game for teaching natural risk management. Simul. Gaming 49, 441–470. https://doi.org/10.1177/1046878118770217.
Teague, A., Sermet, Y., Demir, I., Muste, M., 2021. A collaborative serious game for water resources planning and hazard mitigation. Int. J. Disaster Risk Reduct. 53, 101977 https://doi.org/10.1016/j.ijdrr.2020.101977.
Terti, G., Ruin, I., Kalas, M., Láng, I., Cangròs i Alonso, A., Sabbatini, T., Lorini, V., 2019. ANYCaRE: a role-playing game to investigate crisis decision-making and communication challenges in weather-related hazards. Nat. Hazards Earth Syst. Sci. 19, 507–533. https://doi.org/10.5194/nhess-19-507-2019.
Toubin, M., Laganier, R., Diab, Y., Serre, D., 2015. Improving the conditions for urban resilience through collaborative learning of parisian urban services. J. Urban Plan. Dev. 141, 05014021 https://doi.org/10.1061/(ASCE)UP.1943-5444.0000229.
Tsai, M.-H., Chang, Y.-L., Shiau, J.-S., Wang, S.-M., 2020. Exploring the effects of a serious game-based learning package for disaster prevention education: the case of battle of flooding protection. Int. J. Disaster Risk Reduct. 43, 101393 https://doi.org/10.1016/j.ijdrr.2019.101393.
Turkay, S., Adinolf, S., 2012. What do players (Think They) learn in games? Procedia - Soc. Behav. Sci. 46, 3345–3349. https://doi.org/10.1016/j.sbspro.2012.06.064.
Villagra, P., Peña Y Lillo, O., Ariccio, S., Bonaiuto, M., Olivares-Rodríguez, C., 2023. Effect of the Costa Resiliente serious game on community disaster resilience. Int. J. Disaster Risk Reduct. 91, 103686 https://doi.org/10.1016/j.ijdrr.2023.103686.
Weichselgartner, J., Kelman, I., 2015. Geographies of resilience: challenges and opportunities of a descriptive concept. Prog. Hum. Geogr. 39, 249–267. https://doi.org/10.1177/0309132513518834.
Yamori, K., 2007. Disaster risk sense in japan and gaming approach to risk communication. Int. J. Mass Emergenc. Disasters 25, 101–131. https://doi.org/10.1177/028072700702500201.