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Article

Playing With Uncertainty: Facilitating Community-Based Resilience Building

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Abstract
Resilience has become a fundamental paradigm for communities to deal with disaster planning. Formal methods are used to prioritise and decide about investments for resilience. Strategies and behaviour need to be developed that cannot be based on formal modelling only because the human element needs to be incorporated to build community resilience. Participatory modelling and gaming are methodological approaches that are based on realistic data and address human behaviour. These approaches enable stakeholders to develop, adjust, and learn from interactive models and use this experience to inform their decision-making. In our contribution, we explore which physical and digital elements from serious games can be used to design a participatory approach in community engagement and decision-making. Our ongoing research aims to bring multiple stakeholders together to understand, model, and decide on the trade-offs and tensions between social and infrastructure investments toward community resilience building. Initial observations allow us as researchers to systematically document the benefits and pitfalls of a game-based approach. We will continue to develop a participatory modelling exercise for resilience planning with university graduate students and resilience experts within academia in Christchurch, New Zealand.

Keywords
community-based resilience; participatory modelling; resilience planning; role-play games; serious games; socio-technical systems

Issue
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1. Introduction: Participation in Community Resilience Building

Community resilience planning needs public participation to include multiple perspectives for effective decision-making and to advance where robust scientific approaches meet decision-making needs (Barton et al., 2020). Consequently, it is difficult to communicate the concept of resilience to decision-makers along with practical implications. For example, Norris et al. (2008) describe resilience as a process rather than an outcome. This process includes social capital, community competence, information and communication resources, and economic development. However, some of these aspects are measurable, others are not, and thus do not provide clear guidance for policymakers in the field (Norris et al., 2008).

Disasters and crises happen in and beyond social, policy, and infrastructure systems. In growing and interconnected systems, it is challenging for decision-makers to comprehend the impact of their actions on other systems or interdependent infrastructure systems (Ansell et al., 2010; van Laere et al., 2018). Disaster researchers, planning managers, and policymakers along with the community need to understand the profound implications of interconnected social and infrastructure networks that deliver essential services (Thacker et al., 2019). For a better understanding of, and ability to apply, knowledge of the distinct dimensions of resilience, these experts have to make their knowledge explicit.

Approaches that support decision-making processes provide an avenue for improving public participation by encouraging the awareness of multiple conflicting tensions to make choices. Participatory modelling seems to be such a promising approach as a decision-support tool for community resilience because of its ability to represent realistic models and the inclusion of the human element in an interactive way (Miles, 2018; Voinov & Bousquet, 2010). We conceptualise simulation and serious games as instruments of participatory modelling. Simulation and serious games have played an important role in bridging the interface between scientific information and decision-making processes since the 1960s (Ampatzidou et al., 2018; Duke, 1980). In addition, simulation games are widely known as a research method for the transdisciplinary integration of concepts, theories, perceptions, information, and techniques (Lukosch & Comes, 2019).

Flood et al. (2018) present a systematic review of the use of serious games for engagement and decision-making specifically in the climate change and adaptation arena, including the application in recovery, analysing prevention, and disaster management. So far, the focus of serious games has been on emergency training, risk management, and educating audiences about disaster preparedness, with less attention on preparedness for investment and engaging with local actors and engineering (infrastructure) stakeholders (Bathke et al., 2019; Flood et al., 2018). Our work aims to close this gap with the exploration and development of an engaging way for different actors such as communities, infrastructure providers, resilience researchers, and policymakers to understand trade-offs and interdependencies when building community resilience. This contribution is part of ongoing research on participatory modelling in building resilience, and its scope is limited to exploring past work on serious games that could inform which physical and digital elements are useful to design a participatory approach used for community resilience planning.

In the first two sections of this article, we explore how game-based participatory modelling can contribute to an understanding of building resilience as a process of addressing both the technical and the social dimensions. In Sections 3 and 4 of the article, we present related approaches and summarise common game elements to inform our participatory methodology. These sections do not include the implementation with practitioners but focus on design choices and first experiences with university students and academic experts in New Zealand. In the last sections, we conclude by analysing the benefits and pitfalls of some game elements from related work applied to our participatory modelling approach.

2. Background

2.1. Dilemmas Between Social and Infrastructure Resilience

The Sendai Framework for Disaster Risk Reduction 2015–2030, adopted by the United Nations (United Nations Office for International Strategy for Disaster Reduction, 2015), because of its emphasis on multi-dimensional and interrelated resilience, supports a need for approaching resilience through both (a) improving infrastructure assets and (b) improving the social capital needed to respond to a future disaster effectively. Currently, it could be argued that decisions toward disaster risk reduction are made by disaster experts, planning managers, and policymakers, assuming independence between social and infrastructure system investments (Avendano-Uribe et al., 2020).

On the one hand, physical infrastructure is the built environment, structures and facilities that provide essential services to sustain human activities (O'Rourke, 2019). Resilience in the context of infrastructure is considered a mechanism by which an infrastructure system can prepare for and adapt itself against disruptive events to reduce vulnerability and increase adaptive capacity (Fuchs & Thaler, 2018; O'Rourke, 2019; Omer, 2013). In particular, the critical infrastructure that supports communities includes transportation and water, energy, and food supplies. Besides transportation buildings (roads, highways, bridges, airports, and public transit), critical infrastructure includes waste-related facilities (wastewater treatment, solid waste, and hazardous-waste services) and other services that are connected to the network of residencies (Chester, 2019; Cutter, 2020; O'Rourke, 2013). Infrastructure resilience centres on engineered and social systems (e.g., an infrastructure network or community as a whole; Davidson, 2015). However, infrastructure resilience as a conceptual framework approached from the perspective of physical-technical systems alone has limitations and drawbacks. Those institutional arrangements that enable infrastructure resilience to operate are the links between social assets and infrastructure assets.

On the other hand, social capital is defined as the cumulative experience of information, trust, institutions, norms, and expectations about behaviours among a community to plan, prevent, mitigate, and prepare for a disaster and the learning experience to respond and recover from a disaster (Aldrich & Meyer, 2015; Cai, 2017; Yan & Galloway, 2017). Social capital includes actions made before, during, and after a natural disaster: prevention, mitigation, preparedness, response, and recovery.

In resilience planning, the context that affects trade-offs and decision outcomes can change over space and time. That is why it is important to enquire not just about the resilience of what, to what, and for whom, but also why and where (Meerow & Newell, 2019). For example, New Zealand is a country that has an international reputation in terms of resilience practice (Wither et al., 2021). The New Zealand Ministry of Social Development defined what matters in communities as social resilience, referring to building connections between people and communities, access to decision-makers, and policy and research communication (Chen et al., 2021). Access to critical infrastructure and essential services is paramount to community resilience (Logan & Guikema, 2020).

One vital challenge in the field of community resilience, and the main motivation for our study, is that resilience itself is a rather ill-defined operationalised concept, which makes it challenging to communicate the concept along with practical implications to decision-makers (Ottens et al., 2006; Wither et al., 2021). Overall, researchers are liable to focus on either the impacts on infrastructure overlooking the social impacts of resilience or vice versa (Doorn, 2019; Doorn et al., 2019). There is an appreciation that the two types of capital are needed. According to Saja et al. (2019), the trend to consider multiple variables as resilience indicators can be confusing for the practice of community resilience building. They suggest that generalising a framework can improve resilience investment decisions across different contexts. Still, current multi-dimensional frameworks lack an adequate measure of social resilience for effective decision making.

Our study upholds integrative approaches to understand resilience in complex systems and create a common stakeholder arena to make decisions. That is why we adopt the conceptualisation of resilience for socio-technical systems (STSs). A STS refers to the interplay and interlinked social and technical parts of a system (Van der Merwe et al., 2018). Complex STSs involve physical-technical elements and networks of interdependent actors. Problems cannot be understood or solved without the knowledge of the system and its actors (de Bruijn & Herder, 2009). Community resilience integrates both social and infrastructure assets, their interactions, and non-linear complexity, and societies should use that integrated understanding to make informed decisions. Our approach aims to develop an understanding of the interdependencies and role of both the physical-technical systems and the social elements in building resilience.

2.2. Participatory Approaches to Building Socio-Technical Resilience

There is a need to understand the challenge of integrating social and infrastructure assets, their interactions, interdependencies, and non-linear complexity to make informed decisions. Numerical or quantitative analysis for building resilience should therefore be combined with knowledge on actor networks and social elements when building resilience. As a solution, in our work, we aim to develop an engaging way of participation for communities, infrastructure providers, resilience researchers, and policymakers to develop a collective understanding of trade-offs and interdependencies between both social and infrastructure resilience investments to build community resilience.

Engineers use formal models within their decision-making processes to bridge the perceived actual reality and the intended reality. Challenges remain due to misunderstandings related to the limitation of modelling methods and the role models play to support decisions (Elms & Brown, 2012). Computer-based and mathematical models support planning and decision-making processes by providing quantitative information (Basco-Carrera et al., 2017), and spatial tools for collaborative planning (Schindler et al., 2020; White et al., 2010). However, complex systems cannot be analysed just with numbers themselves (Rosling et al., 2018). The combination of data tools and people's participation in understanding these systems could provide a benefit in the sense of evidence-based support systems to enable informed decisions. That is why participation approaches in modelling and simulation—called participatory modelling—are useful to actively engage stakeholders in the decision-making process for resilience planning and management (Perrone et al., 2020). Designing for participation in systems is designing with stakeholders, for human experience in and of systems, and to enable stakeholders to relate to a larger system (Brazier & Nevejan, 2014).

Modelling with stakeholders allows researchers to better represent the system and understand the multiple connections between the model built and the real system itself. For example, decisions are implemented with less conflict and more success when they are driven by stakeholders (Voinov & Bousquet, 2010). Consequently, simulation models are used as boundary objects or negotiating artefacts to facilitate transparent and verifiable discussions and the proliferation of ideas (van Bruggen et al., 2019). In recent years, resilience frameworks have been utilised in science and policy interventions in natural resources and disaster risk management (Sellberg et al., 2018). Researchers suggest that fostering learning, increasing participation, and facilitating awareness among stakeholders about trade-offs, interdependencies, and interactions in complex adaptive systems is a way to strengthen community resilience (Biggs et al., 2015).

The use of participatory modelling could help policymakers, communities, and engineers understand different perspectives around the same problem (Gray et al., 2015), especially when policymakers need to comprehend interdependencies between social systems and infrastructure (Thacker et al., 2019). However, participatory methodologies combined with quantitative data collection and abstract modelling could be a challenge. An innovative way to solve this gap is using simulation games or serious games in risk and disaster planning to both inform audiences and to empower stakeholders (Barreteau et al., 2021; Bathke et al., 2019).

As a form of participatory modelling, serious or simulation games are used in research to understand interactive decisions in complex engineering systems (Grogan & Meijer, 2017). Serious games are defined as activities used for purposes other than entertainment (Bathke et al., 2019). Abt (1987, p. 6) defines games as "an activity among two or more independent decision-makers seeking to achieve their objectives in some limiting context." Applied to engineering research, games incorporate data from an underlying model but are not quite as realistic as actual fieldwork (case studies; Figure 1).

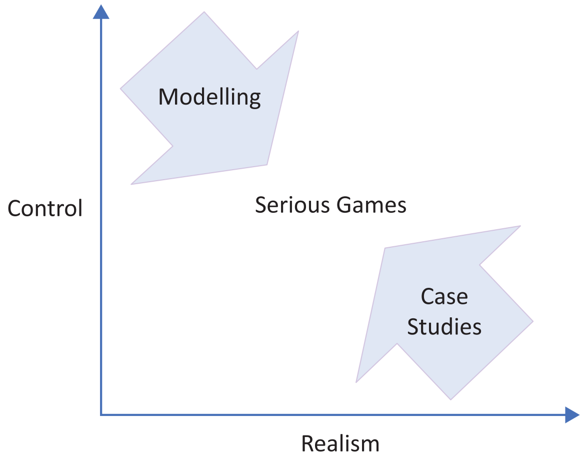

Figure 1. Gaming methods related to other methods in engineering research. Source: Authors' work based on Grogan and Meijer (2017).

Figure 1 illustrates that serious games are in between an abstract representation of reality, controlled by a model and a case study that is close to reality when understood as a case study. Modelling methods help to understand reality by simplifying the complexity using an abstract representation of the real world (Grogan & Meijer, 2017). Simulation games are interactive environments that simultaneously model a technical system through simulation and a social system with role-play participants (Grogan & Meijer, 2017).

Despite existing studies and raising demand for practical guidance on resilience planning and climate adaptation, practical studies on the resilience of STSs are scarce, and more work needs to be done to understand the social domains required to ensure resilience (Preiser et al., 2018; Sellberg et al., 2018; Van der Merwe et al., 2018). The lack of innovative methodologies to encourage systems thinking remains a challenge to tackle wicked problems. We discuss serious games as a participatory method to create a common understanding of the complexity of resilience, especially the concepts of social and infrastructure resilience.

3. Related Work: Serious Games for Community Resilience Building

Our exploration starts with an inquiry into the role of elements from serious games in community resilience building. We analyse common elements of serious games applied to resilience to illustrate what game elements are useful to build our participatory modelling approach. First, we present game settings from general serious games applied in resilience of STS to find which game elements have potential application for our purposes. Secondly, starting from this analysis, we chose three game examples that aim to facilitate resilience-building using participatory approaches and we conduct detailed analysis to inform our findings on game elements useful to apply a research tool for policy making.

The main reason to use serious games for resilience in STSs is to provide an immersive experience crucial for facilitating multi-stakeholder interaction. The work of Solinska-Nowak et al. (2018), which analyses 45 serious games used in disaster risk management, inspires our participatory modelling methodology design. They find that serious and simulation games are powerful tools to assist risk awareness, perspective-taking, and empathy. In addition, they show that in these types of games, players can select between simulated scenarios and observe the consequences of their decisions when the disaster finally develops. For example, two of the games cited by Solinska-Nowak et al. (2018)—Decisions for the Decade and Paying for Predictions—involve investments as the main stakeholder exercise. These games allow participants to increase their awareness about planning investments while choosing scenarios to discuss the implications of each decision. Our lesson is that deliberation processes could foster relevant conversations between multiple agents and perspectives, improving stakeholders' cross-fertilisation of ideas (Ansell et al., 2010). However, there are no games addressing the problem of planning for community resilience based on infrastructure and social assets and related interconnections and trade-offs. We intend to address this problem with our own participatory modelling approach.

Research conducted by van Laere et al. (2018) provides game development combined with role-playing simulations to understand interdependencies in critical infrastructure. They highlight game elements such as learning goals, choice of player roles, degree of realism, the time scale of scenario, and re-play abilities. In their research three challenges remain: (a) Models about infrastructure resilience tend to be too abstract, (b) scenarios are limited to short term disruptions and lack of interactions to explain cascades, and (c) community resilience continues to be difficult to operationalise with simple metrics (van Laere et al., 2018).

Solinska-Nowak et al. (2018) and van Laere et al. (2018) inspired us to search comprehensively for similar work and we found only six simulation games tackling critical infrastructure resilience. In Table 1, we show how different sectors from civil systems engineering related to resilience are covered by serious games.

According to Table 1, common game elements that could provide useful applications in a participatory modelling for analysing STSs in civil systems engineering are

Table 1. Highlights to inform game design from serious games used for community resilience building in civil systems engineering.

Serious Game	Game Elements to Highlight	Sector of Application	Reference
Sustainable Infrastructure Planning Game	Participation of peer graduate students	Lifelines and agriculture	Grogan (2014)
CIPRTrainer	Option to revert a decision: Go back in time	Lifelines	Rome et al. (2016)
Disruption Game	Model: High abstraction level	Port infrastructure	Kurapati et al. (2015)
SimportMV2	Transferability to the policymaking process	Port infrastructure	Bekebrede et al. (2015)
Smart Mature Resilience	User-friendly interface	Lifelines	Iturriza et al. (2017)
SPRITE	What if scenarios: Students play the role of policymakers	Dyke/coastal infrastructure	Taillandier and Adam (2018)

the use of hypothetical scenarios using a model that allows participants to understand the system while interacting in a user-friendly platform. Our lesson from those games is that bringing together stakeholders to discuss a common problem from different social and infrastructure (technical) perspectives can potentially foster systems thinking in the civil system engineering sector. For example, CIPRTrainer is a game to increase the awareness of crisis managers in disasters about interconnected critical infrastructures while understanding possible consequences of a specific scenario evolution (Rome et al., 2016). Revisited serious games aim to provide a tool for decision-makers to train themselves. This is the case of Smart Mature Resilience, where researchers suggest engaging with multiple stakeholders to foster the participation of professionals who will use the gained skills during the game later (Iturriza et al., 2017). In the Sustainable Infrastructure Planning Game, the aim is to build an interactive simulation model with graduate students from the Massachusetts Institute of Technology (Grogan, 2014). A similar approach is chosen for the game SPRITE, which aims to teach risk management to engineering students to raise awareness about the risk of coastal flooding. SPRITE places students in the roles of policymakers and politicians while simulating real situations (Taillandier & Adam, 2018). The Sustainable Infrastructure Planning Game, SimportMV2, and SPRITE show that trials with graduate students that play the role of practitioners are useful for understanding further implementation.

In addition to the games presented previously, we searched for references close to civil systems engineering that use community resilience planning to understand interconnections and trade-offs in STSs. We neglected to choose references on post-disaster analysis, disaster management, or financial aspects of a crisis. We found 11 research-based games and we identified similarities and differences in game elements (Figure 2).

We discovered that elements like role-playing and simulations, scenarios or storytelling, and debriefing are relevant in games associated with STSs. However, systems thinking, negotiation, and discussions are not always present and physical and digital elements vary. Only three games—Kin Dee You Dee, Ready for Drought?, and MoBinn—have common elements from the criteria we analysed in Figure 2. We have chosen these serious games because of the experiences reported with local authorities, the inclusion of decision-making processes enhancing collaboration, and the variety of themes related to resilience covering social/technical systems. Finally, the diversity of locations for these three serious games (Asia, America, and Europe) helps to extract lessons. Here, we compare the three games extracting the purpose of the game, its elements, and the dos and don'ts analysis following Freese et al. (2020; Table 2). We provide a detailed description of the three games described in Table 2 and in the Supplementary File.

The analyses presented in Table 1, Figure 2, and Table 2 serve to extract game elements that could be essential in creating a participatory modelling approach in the context of community resilience in STSs. For example, the use of scenarios, narratives, and storytelling can be useful for facilitating and guiding participants into an immersive experience to easily understand complex concepts and systems thinking. The use of role-playing and physical elements such as tokens, dates, pawns, dices, and boards, can support the game dynamic of the participation using visual cues, adding some physical experience to the game. Finally, negotiation sessions, peer-review feedback, and reflections throughout a debriefing moment can support the communication and interaction between participants (Lukosch et al., 2018). In the following section, we show how game elements from the above analyses are informing our participatory approach for an STS in New Zealand.

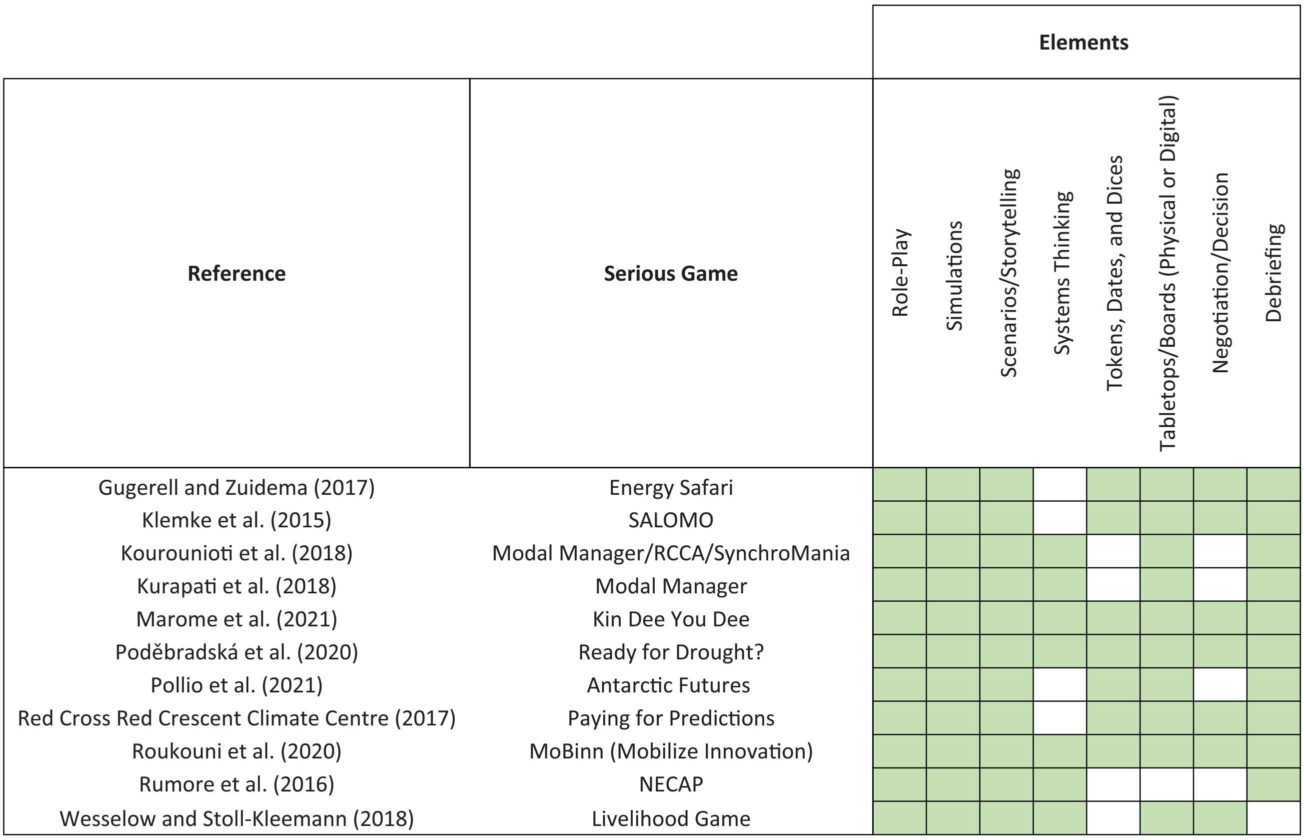

Figure 2. Highlights to inform game design from serious games used for community resilience building in civil systems engineering.

4. Our Prototype: Playing With Uncertainty to Facilitate Community Resilience Building in New Zealand

A unique and internationally recognised community resilience process can be identified in New Zealand, which has emerged over a decade from the Canterbury earthquakes that caused huge urban and suburban damage (Thornley et al., 2015). In addition, New Zealand has seen recent efforts for engaging communities in decision-making processes using digital and physical tools (Cradock-Henry et al., 2020; Lawrence et al., 2021; Schindler et al., 2020), in post-disaster community-led interventions (Dionisio et al., 2016; Dionisio & Pawson, 2016), and infrastructure resilience decision-making processes (Davies, 2019; Davies et al., 2021). A common consensus is that there is a need to engage stakeholders to make risk-informed decisions and use contextual factors to enhance community resilience planning (O'Rourke, 2019). The challenge is to build engagement for a decision tool without losing expertise from the competence and proficiency of experts and at the same time include stakeholders' ideas as a genuine participation exercise and not only as a pre-requisite for engaging with actors.

To address these challenges, we are developing Playing With Uncertainty, a serious game as a participatory modelling approach to facilitate community-based resilience building. We are designing role-playing negotiations as a simulated decision-making process in an STS. The intention behind the game is that participants must trade-off between investing in social and infrastructure resilience. The game recreates tensions in STS and conflicting decisions between multiple stakeholders. Participants play roles as community leaders, infrastructure providers, and policymakers. They need to communicate to negotiate and decide whether to invest and arrange priorities from a list of factors and variables of social and infrastructure (technical) assets that secure resilience building in the long term under potential flooding scenarios due to sea-level rise. The mechanics of the game are constructed so that over-investment in one type of resilience is unfavourable, though the participants are only able to probe the mechanics through trial investments. The context of the exercise is to decide how to use a 10-year budget (2020–2030) from the Coastal Hazards Adaptation Program at the Christchurch City Council in the Canterbury region, New Zealand (Christchurch City Council, 2021).

Community resilience remains to be a concept that is difficult to operationalise (Wither et al., 2021). For that reason, Playing With Uncertainty is using social and infrastructure factors derived from the literature on community resilience building in New Zealand (Cutter et al., 2014; Kwok et al., 2016; Langridge et al., 2016; The Treasury, 2020; Thornley et al., 2015). In our prototype, social factors include (a) increasing community connectedness and opportunities to

Table 2. Derived dos and don'ts analysis based on serious games as research instruments in STSs.

Serious Game	Purpose	Physical/Digital Elements	Dos	Don'ts
Kin Dee You Dee (Thailand)	Facilitate discussion of resilience pathways for flood-impacted communities in Bangkok	Dice, tokens, maps, role cards, and scenarios	• Combine different disasters in different scenarios, multi-hazard perspective • Design user-friendly materials and game testing and revisions with underrepresented communities • Invite local municipal authorities, community members, and government agencies	• Long hours in engagement workshops to avoid withdrawal of participants
Ready for Drought? (USA)	Learn about trade-offs involved in a decision-making process on water banking in the Missouri River Basin region under difficult resource-sharing scenarios	Role-playing, pictograms, cards, and graphical representation of scenarios	• Present what-if scenarios with disaster impacts and consequences • Use fewer roles from different sectors • Implement trials with students • Use low technological requirements • Create simulations based on real data	• Discuss decisions for each of the four phases of events • Allow participants to decide factors in the model • Limit the number of variables involved
MoBinn—Mobilize Innovation (the Netherlands)	Collaborate to design solutions to alleviate the pressure on the road network in the Netherlands, while analysing the consequences of certain decisions and policies	Game board, role cards, roles, action cards per role, event cards, tokens, pawns debriefing, scenarios, rules and decisions, and ex-ante evaluation	• Implement ex-ante evaluation of policies to raise awareness while discussing short- and long-term consequences of decisions made • Collaborative decision-making creates a risk-free environment • Include a minimum of five roles • Include positive events or negative disruptions to the flow of the game	• Overcharge decision options with hypothetical scenarios of different policies and actions • The use of coloured indicators can confuse colour-blind participants

get together, (b) resourcing community-based organisations, and (c) improving community infrastructure (Thornley et al., 2015). Infrastructure factors include (a) building buffer zones and storm barriers, (b) building pontoons/amphibious houses, and (c) property acquisitions removing infrastructure.

According to Geurts et al. (2007), a game is a tool to structure communication in complex systems and, as a research method, can facilitate the analysis of STSs. Games have multiple elements, symbols, and components to support communication between participants (or players; Geurts et al., 2007). Gaming as a research method helps to master complexity. Analysis of multiple components of an STS could help to create game elements (Lukosch et al., 2018).

Playing With Uncertainty collects elements from the related STSs of coastal protection in Christchurch and transforms them into game elements. Every serious game element extracted has a match with the element highlighted from the related STS analysed (Table 3).

Table 3 is the result of our analysis and shows how our design will include the following game elements: graphic displays (dashboard), simulations, scenarios, storytelling, systems thinking, tabletops, decision negotiation, and debriefing. Our design will also include physical game elements: tokens, coins, and a table board. In our effort to create a hybrid game, digital and physical technologies are combined (Kankainen et al., 2017). We can shape our design elements for role-playing negotiation and scenario analysis based on lessons from the analysis of serious games presented in Section 3. This hybridisation seems particularly promising for disaster-related research for being able to process (realistic) data that players can use and the physical elements that support the social aspect of the gameplay, facilitate discussion, and enable the "play" feeling that might be relevant to remove some realistic context. The physical elements will be evaluated on their ability to foster communication between participants, while the digital elements will be evaluated for data visualisation. The intention is to use the design described here first with university graduate students, many of whom are conducting doctoral research into community resilience.

Figure 3 shows physical game material that we intend to use to support scenario thinking and role-taking. Investments in physical (infrastructure) and social resilience are visualised on the game board. 3D printed dice show what scenario is simulated. The board design, role cards, and tokens help to visualise the dynamics for the participants.

Figure 4 shows how an early trial of the game that has been played with graduate students in resilience at the University of Canterbury, New Zealand. A combination of physical elements and digital support is evident. We conducted a trial to test the usability of the elements created. During one hour of the game session, the facilitator introduces the aim of the game, rules, instructions, and usability of the game elements. Every participant (six in total) has a role assigned to play. They also have a budget assigned to invest in every round. If they do not spend it, they cannot save it and lose their score as decision-makers. Participants need to wisely discuss their budget both individually and collectively to make sure all factors for community resilience are included in the investment plan.

Participants play six rounds. Each round has a scenario, and a different adaptation plan defines it. Planning for future events requires modelling scenarios with different factors and test parameters to understand potential consequences to make effective decisions. The scenario is defined by chance using the disaster dice. Once every scenario is shown in the sheet, the facilitator discusses potential interdependencies and trade-offs derived from decisions made with participants. Each participant has a say according to their role, and discussions are encouraged by the facilitator, adding tension and conflict to the conversation while investment negotiations happen. Each participant makes a decision and the facilitator, with the help of a modeller, collects data from multiple investment rounds with the digital dashboard, visualising the consequences of each decision immediately.

5. Summary and Discussion

In our work, we assume that using game elements to facilitate a participatory modelling approach will improve engagement with multiple stakeholders while simulating a decision-making process. This argument is supported by past evidence suggesting that games benefit participatory modelling (Bakhanova et al., 2020). We captured design elements from related serious games to support a game-based participatory modelling approach in building community resilience. We conceptualise resilience as a complex STS and distinguish between physical and social resilience. We have analysed past work on serious games that inform the design of our participatory approach related to a complex STS. Our study is located in the context of resilience in New Zealand and translates the social and technical-physical elements of it into game elements. An early trial with our game prototype suggests the potential of the game elements to foster an understanding of resilience concepts. Implementation and analysis of the game's application are beyond the scope of this article.

Playing With Uncertainty aids investment decision-making while participants discuss resilience interventions using the role-playing negotiations approach. Science-based role-play exercises are a type of serious game that involves face-to-face mock decision-making (Rumore et al., 2016). Contrasting with literature, we could observe that the role-play negotiation elements could inspire collaborative learning, cooperation, and body and oral expression to work collaboratively on solving a challenge in the community (Boal, 2013; Tolomelli, 2016). We built Playing With Uncertainty on this idea

Table 3. Elements from the STS Coastal Protection Plan in Christchurch transformed into game elements in the participatory modelling methodology.

	Element From the STS	Game Element	Comparative Description
System scope	Investment adaptation plan for resilient communities at the Christchurch City Council (New Zealand).	Briefing	Facilitators and researchers introduce aims, define scope, and explain instructions and rules of the game. They are using storytelling to contextualise participants.
Decision-makers	Decision-makers: Six participants in charge of the investment resilience plan. Two engineers or technical experts in infrastructure resilience, two community leaders, and two policymakers.	Role-play cards and tokens	Participants with a role to play are represented in a card/token.
Disasters	Descriptive sheets with statistical information and data-driven statements based on literature review and national standards for each potential natural hazard in the location.	Scenarios	Simulated visualisation of consequences of a natural hazard on the geographical area.
Uncertainty	Hazards are prone to happen in the context. 3D printed dice. Each face shows a different risk: earthquake, flood, tsunami, fire, storm, and volcano eruption.	Disaster dice	Randomisation of events occurring. It gives the game unexpected situations and tension due to uncertain pressures.
Social and technical assets	List conflicting variables or social and infrastructure (technical) factors related to each scenario.	Conflicting variables	The weighting of factors changes with each scenario.
Investment plans	Turns of the decision-making process with a specific time for discussion between participants.	Negotiation rounds	Drivers of the conversation for investment.
Budget	Poker coins are equivalent to the weight of investment for each conflicting variable: social and infrastructure assets.	Coins/money tokens	Amount of money available for each investment round.
Data visualisation	A dashboard engine to visualise the consequences of the investment rounds and results from the negotiated decisions. It contains a model of the STS visualising it in terms of investment weights per round and scenario.	Physical and digital board: Dashboards	Decision visualisation tool representing inputs, outputs, and interaction of system´s elements. Dashboard as a digital element, and table board, dice, coins, and tokens as physical elements. (Figure 3 and Figure 4).
Final decisions	Outcomes from the negotiation.	Debriefing	Participants and researchers reflect on decisions made and the game as a tool to facilitate it.

Figure 3. Prototype of table board printed containing all physical elements from the game interacting: Rounds, scenarios, coins, variables, dice, and role-play cards.

Figure 4. Playing With Uncertainty: Trial exercise with graduate students at the University of Canterbury, New Zealand.

as a tool to involve stakeholders in resolving a problem in uncovered tensions between social and physical-technical resilience. Role-playing and negotiation of conflicting values foster discussions and facilitate the decision-making process within the context of realistic scenarios. This game-based participatory modelling exercise could alleviate tensions between participants as it represents a safe, experiential environment without the risk of real-world consequences.

We have learned that designing game elements that connect the game back to the STSs, such as briefing and debriefing, is crucial. Participants require processes and spaces that allow them to meaningfully contribute their ideas, needs, knowledge, and perspectives toward decision-making processes (Hore et al., 2020). Related to resilience, Playing With Uncertainty offers an immersive experience to highlight that participation is crucial to reducing vulnerability, enhancing local capacities to face disasters, and effectively reducing the impacts of hazard events. Integration of complex systems modelling using participatory approaches is a solution for engaging stakeholders in building resilience. Our approach makes use of planning activities for resilience investments. This helps participants to improve their understanding of the system, reduce conflicts between different points of view, and facilitate community engagement in the process (Carmona et al., 2013; Ganapati & Ganapati, 2008; Henly-Shepard et al., 2015). The advantages are that participants make sense of the complexity of policy issues and reflect on system inter-linkages and stakeholder plurality (Beaven et al., 2016).

The use of dos and don'ts analysis shown in Table 2 helped us to reiterate best practices and avoid mistakes from others. For example, the serious game MoBinn shows how physical elements (board) can be used to enable a better understanding of the complexity of the interests of the stakeholders involved, and the need for collaboration. It also shows that the use of dice can foster a sense of uncertainty. It helps stakeholders to understand the variability of the consequences and level of unpredictability that they might need to confront while stakeholders are deciding on resilient alternatives of investments under potential disasters. That inspired the creation of our disaster dice.

The serious game Ready for Drought? presents disaster scenarios as the core element of the game. Researchers included contextualised problem definitions to enable participants to understand the complexity of the problem tackled. The use of coins and tokens accompanies the element of role-playing and adds context to the problem to be addressed. The serious game Kin Dee You Dee considers trialling role-play games with tertiary education students. This inspired our role-play negotiations and encouraged us to think about implementing qualitative tools such as questionnaires and debriefing sessions. This could foster awareness among participants while discussing short- and long-term consequences of decisions made.

In our game, a digital element of the data dashboard together with a physical game board aims to support data-driven decision making. The hybrid nature supports the social and behavioural aspects while understanding tensions in social and infrastructure resilience investments. The translation of elements of the STS of resilience into digital and physical game elements as shown in Table 3 allows us to learn, adjust, and develop our game design based on player feedback and observation.

Finally, our participatory modelling approach is based on a simulation game that represents a real STS at a certain level of abstraction, and participants who work together to complete the aim of the game (Kourounioti et al., 2018). The idea behind engaging with stakeholders this way is to promote:

1. A holistic system understanding: Participants understand while participating on a system level, so the system includes stakeholders' perspectives;
2. Ownership of modelling techniques: Participants could learn modelling techniques along with researchers to simulate decision making and use the model built;
3. Legitimacy of decision-making processes: Participants could express their genuine ideas and bring their insights to the negotiation process leaving room for transparent discussions for deciding.

Further research is required in these three aspects, considering the cross-fertilisation of ideas drawn to STSs from similar work in the field of environmental sciences and disaster risk reduction through participatory modelling (Gray et al., 2016; Lane & Videira, 2019; Smetschka & Gaube, 2020; Vieira Pak & Castillo Brieva, 2010; Voinov & Gaddis, 2008; Voinov et al., 2018; Wesselow & Stoll-Kleemann, 2018).

6. Concluding Thoughts

6.1. Key Considerations

Public engagement with multiple stakeholders for decision-making and planning is paramount for building community resilience. We propose modelling with stakeholders as an engaging way of participation for communities to understand complex systems and support their decisions under uncertainty. Our participatory modelling approach is aimed to allow multiple stakeholders to understand trade-offs and interdependencies between social and technical dilemmas, framed by the concept of STS.

The use of a dos and don'ts analysis helps to systematise a participatory modelling design process that requires theoretical and methodological frameworks for serious games. It allows us to understand how our methodological approach for conducting research on the resilience of STSs can be improved. Game elements such as role-playing negotiations, digital game elements to visualise decisions and scenarios, and physical elements that represent tensions and conflicts in STSs foster a safe and game-based approach that turns difficult conversations into a simulation of decision-making negotiations.

Our ongoing research in Playing With Uncertainty combines physical and digital elements from serious games to foster community engagement to understand tensions in STSs' investments when planning for a potential disaster. It is intended to increase participants' awareness of multiple perspectives on social and infrastructure tensions. The end goal of our ongoing research is a tested and developed methodology that can be used for resilience challenges in local governance, informing both theory-building and practical application in New Zealand or contexts with similar resilience challenges overseas.

6.2. Limitations of the Study

Scientific literature reporting on serious games for resilience in STSs is still rare. The challenges of using game-based approaches remain. This prototype design relies on the possibility to conduct in-person meetings. We acknowledge that the number of people participating, the interaction between participants, and the usability of a game to facilitate engagement between stakeholders are vital aspects in exploring the usefulness of our approach. We have not explored an online version as an alternative. Further systematic implementation and evaluation of the prototype design are needed.

6.3. Future Work

The next steps of our research will involve the refinement of our prototype design through further iterations of the game design by experts and practitioners. We will then encourage the participation of stakeholders from local governments, industry members, and community leaders to validate the usability of the methodology as a tool to raise resilience planning awareness. Systematic work for data collection during game sessions needs to be improved. The use of artificial intelligence and automatised tools to highlight, organise, and categorise ideas from the debriefings and participants' conversations could improve qualitative data collection. The methodology has potential practical use as a decision visualisation environment, as John et al. (2020) propose. Future research is also needed on methods to assess the effectiveness of this and similar methodologies.

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Conflict of Interests

The authors declare no conflict of interests.

Supplementary Material

Supplementary material for this article is available online in the format provided by the authors (unedited).

References

Abt, C. C. (1987). *Serious games*. University Press of America.

Aldrich, D. P., & Meyer, M. A. (2015). Social capital and community resilience. *American Behavioral Scientist*, *59*(2), 254–269. https://doi.org/10.1177/0002764214550299

Ampatzidou, C., Gugerell, K., Constantinescu, T., Devisch, O., Jauschneg, M., & Berger, M. (2018). All work and no play? Facilitating serious games and gamified applications in participatory urban planning and governance. *Urban Planning*, *3*(1), 34–46. https://doi.org/10.17645/up.v3i1.1261

Ansell, C., Boin, A., & Keller, A. (2010). Managing transboundary crises: Identifying the building blocks of an effective response system. *Journal of Contingencies and Crisis Management*, *18*, 195–207. https://doi.org/10.1111/j.1468-5973.2010.00620.x

Avendano-Uribe, B., Milke, M., Beaven, S., & Hughes, M. W. (2020, December 7–8). *The use of participatory modelling to integrate social and infrastructure resilience-building* [Poster presentation]. QuakeCoRe Annual Meeting, Nelson, New Zealand.

Bakhanova, E., Garcia, J. A., Raffe, W. L., & Voinov, A. (2020). Targeting social learning and engagement: What serious games and gamification can offer to participatory modelling. *Environmental Modelling and Software*, *134*, Article 104846. https://doi.org/10.1016/j.envsoft.2020.104846

Barreteau, O., Abrami, G., Bonté, B., Bousquet, F., & Mathevet, R. (2021). Serious games. In R. Biggs, A. De Vos, R. Preiser, H. Clements, K. Maciejewiski, & M. Schlüter (Eds.), *The Routledge handbook of research methods for social-ecological systems* (pp. 176–188). Routledge. https://doi.org/10.4324/9781003021339

Barton, T. M., Beaven, S. J., Cradock-Henry, N. A., & Wilson, T. M. (2020). Knowledge sharing in interdisciplinary disaster risk management initiatives: Cocreation insights and experience from New Zealand. *Ecology and Society*, *25*(4), Article 25. https://doi.org/10.5751/ES-11928-250425

Basco-Carrera, L., Warren, A., lvan Beek, E., Jonoski, A., & Giardino, A. (2017). Collaborative modelling or participatory modelling? A framework for water resources management. *Environmental Modelling and Software*, *91*, 95–110. https://doi.org/10.1016/j.envsoft.2017.01.014

Bathke, D. J., Haigh, T., Bernadt, T., Wall, N., Hill, H., & Carson, A. (2019). Using serious games to facilitate collaborative water management planning under climate extremes. *Journal of Contemporary Water Research & Education*, *167*(1), 50–67. https://doi.org/10.1111/j.1936-704x.2019.03311.x

Beaven, S., Wilson, T., Johnston, L., Johnston, D., & Smith, R. (2016). Research engagement after disasters: Research coordination before, during, and after the 2011–2012 Canterbury earthquake sequence, New Zealand. *Earthquake Spectra*, *32*, 713–735. https://doi.org/10.1193/082714EQS134M

Bekebrede, G., Lo, J., & Lukosch, H. (2015). Understanding complexity: The use of simulation games for engineering systems. *Simulation and Gaming*, *46*(5), 447–454. https://doi.org/10.1177/1046878115618140

Biggs, R., Schlüter, M., & Schoon, M. L. (Eds.). (2015). *Principles for building resilience: Sustaining ecosystem services in social-ecological systems*. Cambridge University Press. https://doi.org/10.1017/CBO9781316014240

Boal, A. (2013). *Theatre of the oppressed*. Theatre Communications Group.

Brazier, F., & Nevejan, C. (2014, June 8–11). *Vision for participatory systems design* [Paper presentation]. 4th International Engineering Systems Symposium, Hoboken, NJ, USA.

Cai, Y. (2017). Bonding, bridging, and linking: Photovoice for resilience through social capital. *Natural Hazards*, *88*(2), 1169–1195. https://doi.org/10.1007/s11069-017-2913-4

Carmona, G., Varela-Ortega, C., & Bromley, J. (2013). Participatory modelling to support decision making in water management under uncertainty: Two comparative case studies in the Guadiana river basin, Spain. *Journal of Environmental Management*, *128*, 400–412. https://doi.org/10.1016/j.jenvman.2013.05.019

Chen, Y., Liu, T., Ge, Y., Xia, S., Yuan, Y., Li, W., & Xu, H. (2021). Examining social vulnerability to flood of affordable housing communities in Nanjing, China: Building long-term disaster resilience of low-income communities. *Sustainable Cities and Society*, *71*, Article 102939. https://doi.org/https://doi.org/10.1016/j.scs.2021.102939

Chester, M. V. (2019). Sustainability and infrastructure challenges. *Nature Sustainability*, *2*(4), 265–266. https://doi.org/10.1038/s41893-019-0272-8

Christchurch City Council. (2021). *Long term plan 2021–2031*. https://ccc.govt.nz/the-council/plans-strategies-policies-and-bylaws/plans/long-term-plan-and-annual-plans/long

Cradock-Henry, N. A., Blackett, P., Hall, M., Johnstone, P., Teixeira, E., & Wreford, A. (2020). Climate adaptation pathways for agriculture: Insights from a participatory process. *Environmental Science & Policy*, *107*, 66–79. https://doi.org/10.1016/j.envsci.2020.02.020

Cutter, S. L. (2020). Community resilience, natural hazards, and climate change: Is the present a prologue to the future? *Norwegian Journal of Geography*, *74*(3), 200–208. https://doi.org/10.1080/00291951.2019.1692066

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

Davidson, R. A. (2015). Integrating disciplinary contributions to achieve community resilience to natural disasters. *Civil Engineering and Environmental Systems*, *32*, 55–67. https://doi.org/10.1080/10286608.2015.1011627

Davies, A. (2019). *Increasing the disaster resilience of remote communities through scenario co-creation* [Doctoral dissertation, University of Canterbury]. The University of Canterbury Repository. https://ir.canterbury.ac.nz/handle/10092/16841

Davies, A. J., Zorn, C., Wilson, T. M., Wotherspoon, L. M., Beaven, S., Davies, T. R. H., & Hughes, M. W. (2021). Infrastructure failure propagations and recovery strategies from an alpine fault earthquake scenario: Establishing feedback loops between integrated modelling and participatory processes for disaster impact reduction. *Bulletin of the New Zealand Society for Earthquake Engineering*, 54, *254*(2), 82–96. https://hdl.handle.net/10092/101971

de Bruijn, H., & Herder, P. M. (2009). System and actor perspectives on sociotechnical systems. *IEEE Transactions on Systems, Man, and Cybernetics—Part A: Systems and Humans*, *39*(5), 981–992. https://doi.org/10.1109/TSMCA.2009.2025452

Dionisio, M. R., Kingham, S., Banwell, K., & Neville, J. (2016). Geospatial tools for community engagement in the Christchurch rebuild, New Zealand. *Sustainable Cities and Society*, *27*, 233–243. https://doi.org/https://doi.org/10.1016/j.scs.2016.04.007

Dionisio, M. R., & Pawson, E. (2016). Building resilience through post-disaster community projects: Responses to the 2010 and 2011 Christchurch earthquakes and 2011 Tōhoku tsunami. *Australasian Journal of Disaster and Trauma Studies*, *20*(People in Disasters Special), 107–116. https://www.massey.ac.nz/trauma/issues/2016-2/AJDTS_20-2_Dionisio.pdf

Doorn, N. (2019). How can resilient infrastructures contribute to social justice? Preface to the special issue of sustainable and resilient infrastructure on resilience infrastructures and social justice. *Sustainable and Resilient Infrastructure*, *4*(3), 99–102. https://doi.org/10.1080/23789689.2019.1574515

Doorn, N., Gardoni, P., & Murphy, C. (2019). A multidisciplinary definition and evaluation of resilience: The role of social justice in defining resilience. *Sustainable and Resilient Infrastructure*, *4*(3), 112–123. https://doi.org/10.1080/23789689.2018.1428162

Duke, R. D. (1980). A paradigm for game design. *Simulation & Games*, *11*(3), 364–377. https://doi.org/. 10.1177/104687818001100308

Elms, D. G., & Brown, C. B. (2012). Professional decisions: The central role of models. *Civil Engineering and Environmental Systems*, *29*(3), 165–175. https://doi.org/10.1080/10286608.2011.640752

Flood, S., Cradock-Henry, N. A., Blackett, P., & Edwards, P. (2018). Adaptive and interactive climate futures: Systematic review of "serious games" for engagement and decision-making. *Environmental Research Letters*, *13*(6), Article 063005. https://doi.org/10.1088/1748-9326/aac1c6

Freese, M., Lukosch, H., Wegener, J., & König, A. (2020). Serious games as research instruments—Do's and don'ts from a cross-case-analysis in transportation. *European Journal of Transport and Infrastructure Research*, *20*(4), 103–126. https://doi.org/10.18757/ejtir.2020.20.4.4205

Fuchs, S., & Thaler, T. (Eds.). (2018). *Vulnerability and resilience to natural hazards*. Cambridge University Press. https://doi.org/10.1017/9781316651148

Ganapati, N. E., & Ganapati, S. (2008). Enabling participatory planning after disasters: A case study of the World Bank's housing reconstruction in Turkey. *Journal of the American Planning Association*, *75*(1), 41–59. https://doi.org/10.1080/01944360802546254

Geurts, J. L. A., Duke, R. D., & Vermeulen, P. A. M. (2007). Policy gaming for strategy and change. *Long Range Planning*, *40*(6), 535–558. https://doi.org/10.1016/j.lrp. 2007.07.004

Gray, S., Paolisso, M., Jordan, R., & Gray, S. (2016). *Environmental modeling with stakeholders: Theory, methods, and applications*. Springer. https://doi.org/10.1007/978-3-319-25053-3

Gray, S. A., Gray, S., de Kok, J. L., Helfgott, A. E. R., O'Dwyer, B., Jordan, R., & Nyaki, A. (2015). Using fuzzy cognitive mapping as a participatory approach to analyse change, preferred states, and perceived resilience of social-ecological systems. *Ecology and Society*, *20*(2), Article 11. https://doi.org/10.5751/ES-07396-200211

Grogan, P. T. (2014). *Interoperable simulation gaming for strategic infrastructure systems design* [Doctoral dissertation, Massachusetts Institute of Technology]. MIT Repository. http://seari.mit.edu/documents/theses/PHD_GROGAN.pdf

Grogan, P. T., & Meijer, S. A. (2017). Gaming methods in engineering systems research. *Systems Engineering*, *20*, 542–552. https://doi.org/10.1002/sys.21409

Gugerell, K., & Zuidema, C. (2017). Gaming for the energy transition. Experimenting and learning in co-designing a serious game prototype. *Journal of Cleaner Production*, *169*, 105–116. https://doi.org/10.1016/j.jclepro.2017.04.142

Henly-Shepard, S., Gray, S. A., & Cox, L. J. (2015). The use of participatory modeling to promote social learning and facilitate community disaster planning. *Environmental Science and Policy*, *45*, 109–122. https://doi.org/10.1016/j.envsci.2014.10.004

Hore, K., Gaillard, P. C., Davies, T., & Kearns, R. (2020). People's participation in disaster-risk reduction: Recentering power. *Natural Hazards Review*, *21*(2). https://doi.org/10.1061/(ASCE)NH.1527-6996.0000353

Iturriza, M., Abdelgawad, A. A., Labaka, L., Radianti, J., Sarriegi, J. M., & Gonzalez, J. J. (2017). Smart mature resilience, system dynamics based interactive learning environment: A beta version. *International Journal of Safety and Security Engineering*, *7*(3), 367–379. https://doi.org/10.2495/SAFE-V7-N3-367-379

John, B., Lang, D. J., von Wehrden, H., John, R., & Wiek, A. (2020). Advancing decision-visualization environments—Empirically informed design recommendations. *Futures*, *123*, Article 102614. https://doi.org/10.1016/j.futures.2020.102614

Kankainen, V., Arjoranta, J., & Nummenmaa, T. (2017). Games as blends: Understanding hybrid games. *Journal of Virtual Reality and Broadcasting*, *14*(4). https://doi.org/10.20385/1860-2037/14.2017.4

Klemke, R., Kurapati, S., Lukosch, H., & Specht, M. (2015). Transferring an educational board game to a multiuser mobile learning game to increase shared situational awareness. In P. Zaphiris & A. Ioannou (Eds.), *Learning and collaboration technologies* (pp. 583–594). Springer.

Kourounioti, I., Kurapati, S., Lukosch, H., Tavasszy, L., & Verbraeck, A. (2018). Simulation games to study transportation issues and solutions: Studies on synchromodality. *Transportation Research Record*, *2672*(44), 72–81. https://doi.org/10.1177/0361198118792334

Kurapati, S., Kourounioti, I., Lukosch, H., Tavasszy, L., & Verbraeck, A. (2018). Fostering sustainable transportation operations through corridor management: A simulation gaming approach. *Sustainability*, *10*(2), Article 455. https://doi.org/10.3390/su10020455

Kurapati, S., Lukosch, H., Verbraeck, A., & Brazier, F. M. T. (2015). Improving resilience in intermodal transport operations in seaports: A gaming approach. *EURO Journal on Decision Processes*, *3*(3/4), 375–396. https://doi.org/10.1007/s40070-015-0047-z

Kwok, A. H., Doyle, E. E. H., Becker, J., Johnston, D., & Paton, D. (2016). What is "social resilience"? Perspectives of disaster researchers, emergency management practitioners, and policymakers in New Zealand. *International Journal of Disaster Risk Reduction*, *19*, 197–211. https://doi.org/10.1016/j.ijdrr.2016.08.013

Lane, D. C., & Videira, N. (2019). Modelling sustainability pathways: Bridging science, policy, and society. *Systems Research and Behavioral Science*, *36*(2), 147–155. https://doi.org/10.1002/sres.2586

Langridge, R. M., Howarth, J. D., Buxton, R., & Ries, W. F. (2016). *Natural hazard assessment for the township of Franz Josef, Westland District* (GNS Science Consultancy Report 2016/33). Institute of Geological and Nuclear Sciences Limited. https://www.wcrc.govt.nz/repository/libraries/id:2459ikxj617q9ser65rr/hierarchy/Documents/Publications/Natural%20Hazard%20Reports/Westland%20District/Franz%20Josef/GNS%20Final%20Franz%20Josef%20Report%202016.pdf

Lawrence, J., Stephens, S., Blackett, P., Bell, R. G., & Priestley, R. (2021). Climate services transformed: Decision-making practice for the coast in a changing climate. *Frontiers in Marine Science*, *8*. https://doi.org/10.3389/fmars.2021.703902

Logan, T. M., & Guikema, S. D. (2020). Reframing resilience: Equitable access to essential services. *Risk Analysis*, *40*(8), 1538–1553. https://doi.org/10.1111/risa.13492

Lukosch, H., & Comes, T. (2019). Gaming as a research method in humanitarian logistics. *Journal of Humanitarian Logistics and Supply Chain Management*, *9*, 352–370. https://doi.org/10.1108/JHLSCM-06-2018-0046

Lukosch, H. K., Bekebrede, G., Kurapati, S., & Lukosch, S. G. (2018). A scientific foundation of simulation games for the analysis and design of complex systems. *Simulation and Gaming*, *49*(3), 279–314. https://doi.org/10.1177/1046878118768858

Marome, W., Natakun, B., & Archer, D. (2021). Examining the use of serious games for enhancing community resilience to climate risks in Thailand. *Sustainability*, *13*(8), Article 4420. https://doi.org/10.3390/su13084420

Meerow, S., & Newell, J. P. (2019). Urban resilience for whom, what, when, where, and why? *Urban Geography*, *40*, 309–329. https://doi.org/10.1080/02723638.2016.1206395

Miles, S. B. (2018). Participatory disaster recovery simulation modeling for community resilience planning. *International Journal of Disaster Risk Science*, *9*(4), 519–529. https://doi.org/10.1007/s13753-018-0202-9

Norris, F. H., Stevens, S. P., Pfefferbaum, B., Wyche, K. F., & Pfefferbaum, R. L. (2008). Community resilience as a metaphor, theory, set of capacities, and strategy for disaster readiness. *American Journal of Community Psychology*, *41*(1/2), 127–150. https://doi.org/10.1007/s10464-007-9156-6

O'Rourke, T. (2013). Infrastructure interdependencies and resilience. In A. K. Tang & J. M. Eidinger (Eds.), *Chile earthquake of 2010: Lifeline performance* (pp. 365–386). American Society of Civil Engineers. https://doi.org/10.1061/9780784412824.ch10

O'Rourke, T. D. (2019). Editor's note: The rapidly growing need for resilient infrastructure. *The Bridge*, *49*(2). https://www.nae.edu/212189/Editors-Note-The-Rapidly-Growing-Need-for-Resilient-Infrastructure

Omer, M. (2013). The resilience of networked infrastructure systems. In M. Omer (Ed.), *The resilience of networked infrastructure systems: Analysis and measurement* (Vol. 3, pp. 63–88). World Scientific Publishing. https://doi.org/10.1142/8741

Ottens, M., Franssen, M., Kroes, P., & Poel, I. V. D. (2006). Modelling infrastructures as socio-technical systems. *International Journal of Critical Infrastructures*, *2*(2/3), 133–145. https://doi.org/10.1504/ijcis.2006.009433

Perrone, A., Inam, A., Albano, R., Adamowski, J., & Sole, A. (2020). A participatory system dynamics modeling approach to facilitate collaborative flood risk management: A case study in the Bradano River (Italy). *Journal of Hydrology*, *580*, Article 124354. https://doi.org/10.1016/j.jhydrol.2019.124354

Poděbradská, M., Noel, M., Bathke, D. J., Haigh, T. R., & Hayes, M. J. (2020). Ready for drought? A community resilience role-playing game. *Water*, *12*(9), Article 2490. https://doi.org/10.3390/w12092490

Pollio, A., Magee, L., & Salazar, J. F. (2021). The making of Antarctic futures: Participatory game design at the interface between science and policy. *Futures: The Journal of Policy, Planning and Futures Studies*, *125*, Article 102662. https://doi.org/10.1016/j.futures.2020.102662

Preiser, R., Biggs, R., De Vos, A., & Folke, C. (2018). Social-ecological systems as complex adaptive systems: Organizing principles for advancing research methods and approaches. *Ecology and Society*, *23*(4), Article 46. https://doi.org/10.5751/ES-10558-230446

Red Cross Red Crescent Climate Centre. (2017). *Paying for predictions*. https://www.climatecentre.org/games/2501/paying-for-predictions

Rome, E., Doll, T., Rilling, S., Sojeva, B., Voß, N., & Xie, J. (2016). The use of what-if analysis to improve the management of crisis situations. *Studies in Systems, Decision and Control*, *90*, 233–277. https://doi.org/10.1007/978-3-319-51043-9_10

Rosling, H., Rosling, O., & Rönnlund, A. R. (2018). *Factfulness: Ten reasons we're wrong about the world—And why things are better than you think*. Flatiron Books.

Roukouni, A., Lukosch, H., Verbraeck, A., & Zuidwijk, R. (2020). Let the game begin: Enhancing sustainable collaboration among actors in innovation ecosystems in a playful way. *Sustainability*, *12*(20), Article 8494. https://doi.org/10.3390/su12208494

Rumore, D., Schenk, T., & Susskind, L. (2016). Role-play simulations for climate change adaptation education and engagement. *Nature Climate Change*, *6*(8), 745–750. https://doi.org/10.1038/nclimate3084

Saja, A. M. A., Goonetilleke, A., Teo, M., & Ziyath, A. M. (2019). A critical review of social resilience assessment frameworks in disaster management. *International Journal of Disaster Risk Reduction*, *35*, Article 101096. https://doi.org/10.1016/j.ijdrr.2019.101096

Schindler, M., Dionisio, R., & Kingham, S. (2020). Challenges of spatial decision-support tools in urban planning: Lessons from New Zealand's cities. *Journal of Urban Planning and Development*, *146*(2), Article 04020012. https://doi.org/10.1061/(asce)up.1943-5444.0000575

Sellberg, M. M., Ryan, P., Borgström, S. T., Norström, A. V., & Peterson, G. D. (2018). From resilience thinking to resilience planning: Lessons from practice. *Journal of Environmental Management*, *217*, 906–918. https://doi.org/10.1016/j.jenvman.2018.04.012

Smetschka, B., & Gaube, V. (2020). Co-creating formalized models: Participatory modelling as method and process in transdisciplinary research and its impact potentials. *Environmental Science and Policy*, *103*, 41–49. https://doi.org/10.1016/j.envsci.2019.10.005

Solinska-Nowak, A., Magnuszewski, P., Curl, M., French, A., Keating, A., Mochizuki, J., & Jarzabek, L. (2018). An overview of serious games for disaster risk management—Prospects and limitations for informing actions to arrest increasing risk. *International Journal of Disaster Risk Reduction*, *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. *Simulation and Gaming*, *49*(4), 441–470. https://doi.org/10.1177/1046878118770217

Thacker, S., Adshead, D., Fay, M., Hallegatte, S., Harvey, M., Meller, H., & Hall, J. W. (2019). Infrastructure for sustainable development. *Nature Sustainability*, *2*(4), 324–331. https://doi.org/10.1038/s41893-019-0256-8

The Treasury. (2020). *Our living standards framework*. https://www.treasury.govt.nz/information-and-services/nz-economy/higher-living-standards/our-living-standards-framework

Thornley, L., Ball, J., Signal, L., Aho, K. L.-T., & Rawson, E. (2015). Building community resilience: Learning from the Canterbury earthquakes. *Kotuitui*, *10*(1), 23–35. https://doi.org/10.1080/1177083X.2014.934846

Tolomelli, A. (2016). Theatre of the oppressed: Linking research, political commitment and pedagogical perspectives. *Revista Internacional Interdisciplinar INTERthesis*, *13*, 43–60. https://doi.org/10.5007/1807-1384.2016v13n3p43

United Nations Office for International Strategy for Disaster Reduction. (2015). *Sendai framework for disaster risk reduction 2015–2030*. http://www.wcdrr.org/uploads/Sendai_Framework_for_Disaster_Risk_Reduction_2015-2030.pdf

van Bruggen, A., Nikolic, I., & Kwakkel, J. (2019). Modeling with stakeholders for transformative change. *Sustainability*, *11*(3), Article 825. https://doi.org/10.3390/su11030825

Van der Merwe, S. E., Biggs, R., & Preiser, R. (2018). A framework for conceptualizing and assessing the resilience of essential services produced by sociotechnical systems. *Ecology and Society*, *23*(2), Article 12. https://doi.org/10.5751/ES-09623-230212

van Laere, J., Berggren, P., Ibrahim, O., Larsson, A., & Kallin, S. (2018). A simulation-game to explore collective critical infrastructure resilience. In S. Haugen, A. Barros, C. van Gulijk, T. Kongsvik, & J. E. Vinnem (Eds.), *Safety and reliability: Safe societies in a changing world* (pp. 1305–1312). CRC Press.

Vieira Pak, M., & Castillo Brieva, D. (2010). Designing and implementing a role-playing game: A tool to explain factors, decision making and landscape transformation. *Environmental Modelling and Software*, *25*(11), 1322–1333. https://doi.org/10.1016/j.envsoft.2010.03.015

Voinov, A., & Bousquet, F. (2010). Modelling with stakeholders. *Environmental Modelling and Software*, *25*(11), 1268–1281. https://doi.org/10.1016/j.envsoft.2010.03.007

Voinov, A., & Gaddis, E. J. B. (2008). Lessons for successful participatory watershed modeling: A perspective from modeling practitioners. *Ecological Modelling*, *216*(2), 197–207. https://doi.org/10.1016/j.ecolmodel.2008.03.010

Voinov, A., Jenni, K., Gray, S., Kolagani, N., Glynn, P. D., Bommel, P., & Smajgl, A. (2018). Tools and methods in participatory modeling: Selecting the right tool for the job. *Environmental Modelling and Software*, *109*, 232–255. https://doi.org/10.1016/j.envsoft.2018.08.028

Wesselow, M., & Stoll-Kleemann, S. (2018). Role-playing games in natural resource management and research: Lessons learned from theory and practice. *Geographical Journal*, *184*(3), 298–309. https://doi.org/10.1111/geoj.12248

White, I., Kingston, R., & Barker, A. (2010). Participatory geographic information systems and public engagement within flood risk management. *Journal of Flood Risk Management*, *3*(4), 337–346.

Wither, D., Orchiston, C., Cradock-Henry, N. A., & Nel, E. (2021). Advancing practical applications of resilience in Aotearoa-New Zealand. *Ecology and Society*, *26*(3), Article 1. https://doi.org/10.5751/ES-12409-260301

Yan, W., & Galloway, W. (Eds.). (2017). *Rethinking resilience, adaptation and transformation in a time of change*. Springer.

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Heide Lukosch, PhD, is an associate professor and head of the Applied Immersive Gaming Initiative at the Human-Interface Technology Lab at the University of Canterbury. With her research, Heide aims to understand how applied immersive games, games that have a specific purpose such as training and learning and use immersive technologies such as virtual or augmented reality for this, must be designed and used to achieve the intended effect. Heide investigates how realistic, in terms of representation, social interaction, and experience, these games have to be to be valid and engaging games. She applies games to domains such as education, (mental) health, resilience, and disaster management.

Mark Milke, PhD, CPEng, is a professor and researcher in the Department of Civil and Natural Resources Engineering, University of Canterbury. His research spans a wide range of topics in solid waste management, civil engineering systems, and engineering education. His current research is on facilitating better disaster response through linked improvements in infrastructure and social resilience, and on developing a catchment impact exchange to aid in indigenous management of water. He is co-editor-in-chief for the international research journal *Civil Engineering and Environmental Systems*.