Participatory approaches and simulation of social complexity

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Why should you (or not) read this chapter

Participatory approaches appear to be almost everywhere today. When these approaches meet with social simulation, they are typically called “participatory modelling” approaches. This chapter will provide insights into the various ways participation and social simulations meet, explain expectations that arise from the different approaches, clarify the diversity of ways participation is implemented as far as modelling is concerned and give two detailed examples in the field of natural resources management. This is not a cookbook. However, if you want to learn about the possible relations between people and social simulations, and the meaning of these relations, this chapter is worth reading!

Abstract

This chapter provides an overview on the mutual support between two active trends in the study of complex social systems: participatory approaches and social simulations. It highlights the expectations which arise from this association, from increasing quality of social simulation model in capturing better social complexity, to improving the suitability of using social simulations. It considers both objectives of increasing knowledge, as well as of supporting policy making processes. If participation can help to improve models, simulation models are also expected to support participatory processes to extend and share available knowledge among participants. Technically, the association builds upon various trends from computer sciences, social and management sciences, including system dynamics. All these domains have already developed tools, protocols, and devices, making the way to implement "participatory modelling". These allow better elicitation of knowledge, including this knowledge in models, building models as a collaborative process, making models user-friendly for lay people or stakeholders, and ensuring the possibility of proper use of simulation outcomes. However, as far as participation in the modelling process is concerned, existing examples show great diversity, which is inadequately acknowledged. We describe this diversity according to three dimensions: stages in the modelling process, degree of involvement and heterogeneity of stakeholders involved. All the possible settings do not give the same meaning nor the same level of empowerment to participants. The issue of control over dissemination of information through the display of simulation outcomes is particularly at stake. We then give two examples in natural resources management where simulation modelling and participatory approaches are jointly used: fire hazard management in a southern French metropolitan area, and domestic water supply on a Pacific atoll. Both explore various ways in involving stakeholders. Finally the paper points out the various roles participants can play in participatory modelling processes from knowledge providers to simulation users through knowledge brokers. We develop the case that participatory modelling is contingent to people, but also to time and available means. Each implementation must therefore be tuned to its context.

Introduction

In this chapter, social simulation is cross-examined with a very active current trend in policy making: participation or stakeholder involvement. This cross-examination has two main products: the development of tools and methods to improve or facilitate participation; and the development of more grounded simulation models through participatory modelling, which is increasingly present in the literature (Voinov and Brown Gaddis 2008). Technological development provides new devices to facilitate interactions around simulation models: from the phase of conceptual design to that of practical use. In many fields there is a growing requirement for stakeholders and the public to become more actively involved in policy making and to be aware of expected impacts of global policy decisions. These new requirements have pushed for the development of new tools and methods. Some of them include social simulation, such as many Group Decision Support Systems (GDSS), which use computer simulation, including social components, to facilitate communication for the collective formulation and solving of problems (DeSanctis and Gallupe 1987; Shakun 1996; Whitworth, Gallupe, and McQueen 2000). In addition, simulation of social complexity occurs in models whose validation and suitability depend on their close fit to society, as well as on their societal acceptability. These issues are tackled through the use of participatory modelling, such as group model building (Vennix 1996) or participatory agent based simulations (Bousquet, Barreteau, Le Page, Mullon, and Weber 1999; Guyot and Honiden 2006; Moss, Downing, and Rouchier 2000; Pahl-Wostl and Hare 2004; Ramanath and Gilbert 2004). The topic is also related to participatory design, as it is a means of involving end-users of computer systems in their design, including those focussed on social simulations (Schuler and Namioka 1993).

Group Decision Support, as well as Participatory Modelling, stem from the interactions between simulation models and “participants”. There is a diversity of ways by which these interactions may take place. They are related to the diversity of available approaches to simulate society or to organise participation. It is important to make the choices behind these interactions explicit: for distinction between approaches to be possible (Barreteau, Bots, and Daniell 2010); to provide the opportunity for stakeholders to discuss the process; and for them to be prepared to be involved in the process. There is a need to go further than the development of tools, as they are liable to create filters that reshape the understanding of social complexity. Description of the mechanisms behind interactions is a way to qualify the potential effects of these interactions.

This chapter aims to describe the diversity of participatory approaches in relation to social simulation, with a focus on the interactions between the tools and the “participants”. This overview is limited to simulation models. “Model” is considered here as a representation of shared knowledge, which means a collection of pieces of knowledge and assumptions about a system, written altogether in a model so that they might “play” or “work” together. We limit this scope further to simulation model: models including the representation of dynamics. Here we consider potential interactions of participatory and modelling processes at all stages of the modelling process: conceptual design; implementation; use; and simulation outcome analysis.

The first section of this chapter outlines a number of factors which have paved the way for development of the association between social simulation and participation. There is a large body of literature that concentrates on how authors have developed their own participatory modelling approaches, justified by some specific expectations of what participation can bring to modelling or vice-versa. This first section makes a synthesis of these expectations and draws out some principles on which various participatory modelling settings should be assessed. The second section describes some existing techniques and approaches. The third section proposes a classification of these participatory approaches according to three dimensions: the level of stakeholders' involvement in the process; the timeliness of involvement; and the heterogeneity of the population involved. The fourth section describes two case studies with a focus on the integration of various techniques. We discuss the advantages of these approaches, as well as some limits according to the expectations, in comparison with more traditional techniques in the fifth section.

1. Expectations of using participatory approaches with simulation of social complexity

Joint use of participatory approaches with social simulations is based upon three categories of expectations. They vary according to the target of the expected benefits of the association:

i. Quality of the simulation model per se;
ii. Suitability of the simulation model for a given use; and
iii. Participation support.

These three targets are linked to three different components of a modelling process. Target one is linked to the output, target three to the source system, and target two to the relation between both the output and source system. In this section we further develop these three categories.

1.1 Increasing quality of simulation models of social complexity

The objective here is to produce a good quality model to simulate social complexity. Participation is then pragmatically assumed to be a means for improving this quality. There is no normative belief which would value participation by itself in this category of expectations.

Quality of the simulation model is understood here rather classically with the following indicators:

- Realism: is the simulation model able to tackle key features of the social complexity it aims to represent?
- Efficiency: is the simulation model representing its target system with a minimum of assumptions and minimal simulation run-times?

Quality of the representation according to its use is another classic indicator of a simulation model's quality. It is specifically tackled in the following subsection.

1.1.1. Taking social diversity and capacity to evolve into account

One of the key features to be taken into account when representing a social system is its diversity. This diversity is related not only to individual characteristics, but also to viewpoints, expectations towards the system, and positions in the decision making processes. Dealing with diversity in simulation of social complexity involves embracing it, as well as profiting from its existence.

Classically, dealing with diversity is a process of aggregation or selection. Aggregation consists of identifying classes of individuals and representatives for them. Selection consists of choosing a few cases with all of their characteristics. This may lead to very simple simulation models with a generic diversity. Aggregation is typically greedy on data and modelling time and is still dependent on the viewpoint of the observers who provide the information leading to the categorisation. Selection is weaker in coping with relations among various sources of diversity.

Involvement of stakeholders in the modelling process allows them to bring their own diversity. Concerns over representation are then transferred onto the constitution of the sample of participants. Fischer and colleagues have shown through development of situations to support creativity in various fields, such as art, open source development and urban planning, that diversity, as well as complexity, is important to enhance creativity (Fischer, Giaccardi, Eden, Sugimoti, and Ye 2005). This creativity is expected to pave the way for surprises in the simulation model.

Involvement of stakeholders in the modelling process is a way to externalise part of this diversity outside the model towards a group of stakeholders. The issue is then to work on the relation between the model and a number of stakeholders to allow a transfer of knowledge and ideas.

Social systems are open and evolving. Their definition depends on the viewpoint of the analyst. As far as simulation is concerned, this means depending on the viewpoint of the model designer(s). This dependence implies that framing occurs: a number of links around the boundaries of the system studied are cut, as occurs around the interpretation which might occur based on the simulation outcomes (Dewulf, Bouwen, and Tailleu 2006). Firstly, participation provides the opportunity to consider problem boundaries which would be plurally defined, increasing the potential coherence of the model. However, it is still an operation of cutting links out of the real world situation, even though these chosen cuttings are more grounded and discussed. Secondly, interactive use of a simulation model is a means of keeping some of these links open and active, with participants as driving belts. Stakeholders are embedded in social networks which cross the boundaries into the physical and environmental networks. They make the links come alive, which allows them to function and to be updated.

There is thus a need to question the boundaries set in the interactive setting: actors in the neighbourhood; concerns of actors connected to those tackled by the (simulation) model; and how these relations are to be mobilised in the interaction.

1.1.2 Distribution of control

A key characteristic of social systems which is to be addressed through social simulation is their complexity. This complexity leads to various consequences, such as the emergence of phenomena, delay effects or discontinuities in some trends, which are present in social systems as in any other complex systems. These are usually the effects which one likes to discover or better understand when experimenting with social simulations. From the internal point of view of simulations, Schelling has shown experimentally that reproducing settings with multiple decision centres improves the quality of representation of complexity (Schelling 1961). He could generate complexity through experimental games because of the presence of independent decision centres, “the players”. This result has also been shown with simulations used for forecasting (Green 2002). Green compared the capacity of forecasting the outcome of past social conflicts with: a role playing game with students; game theorists; and a group of experts. He compared the simulated outcomes with those from the real negotiations and found that the role playing game setting produced the best results. This was the one with the main distribution of decisions among autonomous centres.

The purpose of associating participatory processes and social simulation here is then to increase the complexity through interactive use or implementation of a social model. Unless computational agents are effectively used, which is rare (Drogoul, Vanbergue, and Meurisse 2003), formal theories of complex systems that are completely embedded in a simulation model do not simulate complex patterns but implement an explanation of a complex pattern. In other words, they should be implemented in a distributed setting with autonomous entities. Participatory approaches provide such settings. There is then an issue of a deep connection between a simulation model and participants in a participatory modelling setting.

1.2 Improving suitability of simulation model's use

Quality of a model is also assessed according to its suitability for its intended use. In this subsection, two cases of use are considered: knowledge increase; and policy making. In both cases, involvement of stakeholders at any stage of a modelling process is expected to aid better tuning of the model with its intended use: either through interactions with people represented in the model, or with potential users. This is an issue of making viewpoints explicit.

1.2.1 Case of increasing knowledge

The case of use for knowledge increase builds upon the previous subsection. The key element treated here deals with the uncertainty of social systems. The involvement of stakeholders represented in the simulation model is a way to improve its validation or calibration. Participants may bring their knowledge to reduce or better qualify some uncertainties. The simulation model is then expected to provide participants with simulation outputs based on the interactions between their pieces of knowledge. On the other hand, this feedback is sometimes difficult to validate (Manson 2002). The presentation and discussion of feedback with stakeholders represented in the simulation model is a way to cope with this issue. Barreteau and colleagues have explored this approach to improve the validation of an Agent Based Model of irrigated systems in Senegal River valley (Barreteau and Bousquet 1999). The format of this feedback, information provided and medium of communication, makes the model really open to discussion.

This joins another expectation which is probably the most common in works that have so far implemented such participatory approaches with social simulation models: making each participant's assumptions explicit, included the modellers (Fischer et al. 2005; Moss, Downing, and Rouchier 2000; Pahl-Wostl and Hare 2004). This is a requirement from the simulation modelling community: making stakeholders' beliefs, points of view and tacit knowledge explicit (Barreteau, Bousquet, and Attonaty 2001; Cockes and Ive 1996; D'aquino, Le Page, Bousquet, and Bah 2003; McKinnon 2005). Moreover, participants need the model's assumptions, as well as the simulation outputs, to be explicit so that they can discuss them and understand how they become part of the model. This is a condition for translating simulation outcomes into new knowledge for participants, and for eventually transferring into operational processes. Undertaking such an activity is aimed to overcome one major pitfall identified in the development of models: the under-use of decision support models because of their opacity (Loucks, Kindler, and Fedra 1985; Reitsma, Zigurs, Lewis, Wilson, and Sloane 1996). Making assumptions explicit in the modelling process is also a concern at the heart of the participatory approach community. One aim of gathering people together and making them collectively discuss their situation in a participatory setting is to make them aware of others' viewpoints and interests. This process involves and stimulates some explanation of tacit positions.

This means that the interactive setting should allow a bi-directional transfer of knowledge between stakeholders and the simulation model: knowledge elicitation in one direction and validation and explanation of simulation outputs and model's structure in the other direction.

1.2.2 Case of policy making

In the case of simulation focusing on policy issues, there is a pragmatic, moral, and now sometimes legal requirement to involve stakeholders, which may lead to open the "black box" of models of social complexity used in policy making. Postnormal approaches aim to make the decision process and its tools explicit so that stakeholders can better discuss them and appropriate their outcomes. When a decision process involves the use of decision support tools, which might include social simulation models, this means that the models themselves should be opened to stakeholders (Funtowicz, Martinez-Alier, Munda, and Ravetz 1999). Should stakeholders concerned by the implementation of a policy be able to discuss it, the simulation model used as a support tool should be made sufficiently explicit. This legitimisation is socially based, while validation, as mentioned with the previous case of use, is scientifically determined (Landry, Banville, and Oral 1996). Even though validation is still required in this case of use, because it is the mode of evaluation for some participants, in the case of policy making it is rather the legitimisation of the model by the stakeholders which is to be considered.

Participatory approaches may be a means for opening these models up to stakeholders and legitimating them, provided that formats of communication of models' assumptions and structure allow genuine discussion. Stakeholders are involved in order to raise their awareness of the assumptions of the model, as well as their capacity to challenge them. This includes the evolution of underlying values and choices made in the design of models.

1.3 Simulation as a means to support participation

Social simulation may also be of benefit to participation. While the previous subsection was dedicated to appropriateness between models and their use as group decision support tools, we focus here on participation which might be a component of a decision making process. Social simulation is seen here as presenting an opportunity to foster participation and cope with some of its pitfalls (Eversole 2003). Use of simulation models may lead to outcomes such as community building or social learning.

1.3.1. Dynamics and uncertainties

Social systems have to deal with uncertainties just as social simulation models do. This may hamper participatory processes: in wicked problems (Rittel and Webber 1973), encountered in many situations where participatory processes are organised, stakeholders always maintain the opportunity related to these uncertainties to challenge others' viewpoints or observations. As an example: origin, flow and consequences of non point source pollution are uncertain. This leads some farmers to challenge the accusations, made by domestic water companies downstream of their fields, that they are polluting the water sources. Sometimes, disparate viewpoints do not conflict. The gathering of these disparate pieces of knowledge is a way to reduce uncertainty and to allow a group of stakeholders involved in a participatory process to progress; provided that they can work together.

Another characteristic of any social system which might hamper participation is its dynamicity. Socio-ecological systems exhibit a range of dynamics; not only social, but also natural, which evolve at various paces. In the application developed by Etienne and colleagues in Causse Mejan, scotspine tree diffusion has a typical time step of 15 years which is long according to the typical time steps of land use choices and assessment (Etienne, Le Page, and Cohen 2003). In a participatory process it may be difficult to put these dynamics on the agenda. Simulation models are known to be good tools to deal with dynamic systems. Simulation models are therefore a means to gather distributed pieces of knowledge from stakeholders and to cope with scenarios in the face of uncertainties. They can also help make the participants aware of potential changes or regime shifts generated by their interactions (Kinzig, Ryan, Etienne, Allyson, Elmqvist, and Walker 2006) .

1.3.2 Towards social learning

Participation is often linked with the concept of social learning (Webler, Kastenholz, and Renn 1995). However, for social learning to occur, participants should have a good understanding of their own interdependencies, as well as of the system's complexity. Social simulation can provide these bases, provided that the communication is well developed (Pahl-Wostl and Hare 2004).

This learning comes from exchanges among stakeholders involved in the participatory process, as well as from new knowledge which emerges in the interaction. Externalisation of tacit knowledge in boundary objects (Star and Griesemer 1989) is useful for both: it facilitates communication in providing a joint framework to make one's knowledge explicit; and it enhances individual, as well as social, creativity (Fischer et al. 2005).

Simulation models are good candidates to become such boundary objects. Agent based models have long been considered as blackboards upon which various disciplines could cooperate (Hochman, Hearnshaw, Barlow, Ayres, and Pearson 1995). Through simulation outputs, they provide the necessary feedback for reflexivity, be it individual or collective. The question then remains whether such models constrain the format of knowledge which can be externalised.

1.4 Synthesis: a key role of the interaction pattern between model and stakeholders

These three categories of expectations have led to specific needs for the development of participation in relation to social simulation models. In the following section, we provide an overview of these techniques. On the basis of the previous identified needs, these techniques and methods have to be analysed according to the following dimensions:

- Set of connections between the participation arena and simulation model: its structure, its content, and organisation of its use;
- Control of the process; and
- Format of information which can travel from one pole to another: openness and suitability for the diversity of stakeholders' competencies.

2. A diversity of settings

In this section, we describe some examples of participatory techniques and approaches associated with social simulation models. Settings described in this overview stem from various fields and disciplines. Most of these disciplinary areas have already produced their own reviews on participatory approaches. For the purpose of our discussion of social simulation, a synthesis of these reviews is provided here with a focus on the needs identified in the previous section.

2.1 From systems science and cybernetics

Cybernetics and systems science have produced a first category of simulation models of social complexity (Gilbert and Troitzch 1999). These models are based on tools originating from system dynamics theory (Forrester 1961), using specific software. They focus on how the stocks and flows of resources and information can be controlled.

Two main types of interactions between system dynamics models and stakeholders have so far emerged in the form of: group model building (Vennix 1996); and "management flight simulators" or "microworlds" (Maier and Grössler 2000).

Group Model Building experiments focus on future user and stakeholder interactions in the design stage of a modelling process. They associate system dynamics modelling techniques with brainstorming tools and other forms of group work, mainly based on workshops and

meetings. The participants are supposed to be the “clients” of the modelling process. Rouwette and colleagues analysed 107 cases of such experiments and proposed a number of guidelines to facilitate consistent reporting on participatory modelling exercises. These guidelines focus on three categories: context, mechanisms and results (Rouwette, Vennix, and van Mullekorn 2002). The second category focuses predominately on preparation activities and description of meetings, along with factual elements and the modelling process.
This category of participatory modelling deals with the expectations identified in the first section in the following manner:

- The participation arena is constituted of a well identified small or medium sized group. Participants are supposed to be concerned by and debate on the model entity as a whole. Interactions in the arena may convey information on the tacit knowledge of stakeholders, as well as on their goals. There is however a high heterogeneity across the experiences regarding the information actually provided. The group of stakeholders is mobilised within specific events or workshops, which may be repeated throughout the process. The aim is to feed the model but also to increase the produced models’ probability of use.
- The process is predominately controlled by the modellers; and
- The format of information is generally weakly formalised, even though techniques, such as hexagons brainstorming or causal diagrams (Akkermans 1995), appear to organise the knowledge brought into the arena by stakeholders. This low formalisation allows the issues related to stakeholder diversity to be tackled and alleviated in the problem framing phase. However, it transfers a large responsibility to the modellers and their subsequent interpretations.

Management flight simulators or “microworlds” constitute a complementary technique, which focus more on the stages of use and simulation outcomes analysis. However, this technique may also be used in a design stage to elicit tacit knowledge. A key characteristic of this type of technique is to encourage “learning by doing”. Participants, who might be the clients or other concerned people without any formal relation to the modelling team, have to “play” through a simulation of the model. Martin and colleagues have used this technique to validate a system dynamics model on the hen industry (Martin, Magnuszewski, Sendzimir, Rydzak, Krolikowska, Komorowski, Lewandowska-Czarnecka, Wojanowska, Lasut, Magnuszewska, and Goliczewski 2007). Participants were asked to play with some parameters of the model.

When used to elicit knowledge, microworlds attempt to provide events that are similar to those that participants already face or are likely to face in their activities related to the issue at stake in the model. Le Bars and colleagues have thus developed a game setting to lead farmers to understand the dynamics of their territory with regard to water use and changes in EU Common Agricultural Policy (Le Bars and Legrusse 2008). In flight simulator experiments, interaction between stakeholders and the simulation model is structured around future users of the model, or people whose stakes are represented in the model. There is a slightly deeper connection than with previous group model building approaches. Participants are asked to investigate parameters of the model and are framed in the categories used in the model. There is no a priori differentiation among participants. The connections convey information about the object from the model to participants. It also conveys the participants' reactions to this object, and some behavioural patterns observed that can provide new information for the modellers. This connection is activated by the participants working through specific events and focus on the use of the tool. Control is still on the side of modellers, who frame the interactions. The format of information is largely formalised from model to stakeholders. It is not formalised from stakeholders to model.

2.2 Knowledge engineering: between artificial intelligence and social psychology

Knowledge engineering focuses on a specific step in the process of interaction between stakeholders and a simulation model in the design stage: the process of translating tacit knowledge into conceptual or sometimes computational models. Many knowledge elicitation techniques are useful in transforming written or oral text into parts of simulation models. The purpose of these techniques is to separate the contributions made directly to the model from the design of the model itself. Knowledge engineering aims to provide interfaces for this gap. To deal with this interface, techniques have been developed that are grounded in artificial intelligence, (social) psychology and cognitive science. Behavioural patterns in social simulation models are often borrowed in simplified versions from these fields (Moss, Downing, and Rouchier 2000; Pahl-Wostl and Hare 2004). This cross-pollination of disciplines can be potentially fruitful for model design. As an example, Abel and colleagues have built upon the concept of a "mental model". They assume that individuals have representations of their world which may be formalised using causal rules. Working in the

Australian bushlands, they have designed specific individual interview protocols and analysis frameworks to elicit these mental models (Abel, Ross, and Walker 1998). Interaction with the model occurs through the interviewer, who in this case was also the modeller. There were no collective interactions. Researchers carrying out the interviews and the corresponding model design clearly guide the modelling process. In this elicitation process, the format of information is speech (in the form of a transcribed text), which is transformed into a modelling language.

Building upon Abel's work, Becu has further minimised the involvement of the modeller, still using individual interviews as the knowledge elicitation technique (Becu 2006; Becu, Barreteau, Perez, Saising, and Sungted 2006). He has collaborated with an anthropologist and used ethnographic data for benchmarking purposes. Individual interviews, with the interviewee in the environment suitable to the purpose of the interview, led him to identify "objects" and relations among these objects. These constitute the initial basis for an exercise labelled as "playable stories", where stakeholders, in this case farmers from Northern Thaïland, are asked to choose the key elements to describe their world from their own viewpoints (with the possibility of adding new elements). Then they have to draw relations among them and to tell a story with this support. In this case, interaction between stakeholders and the simulation model is still on an individual basis. The format of conveyed information is finally less formal, and requires less translation work than in previous examples with knowledge engineering above. Hence, control of the process remains largely with the modeller, but to a lesser extent. This technique was further associated with semi-automatic ontology building procedures by Dray and colleagues in order to generate collective representations of water management in the atoll of Tarawa in the Pacific (Dray, Perez, Jones, Le Page, D'Aquino, White, and Auatabu 2006a).

With inspiration coming similarly from the domain of ethnography, Bharwani and colleagues have developed the KNeTS method to elicit knowledge. Apart from a first stage with a focus group, this method is also based on individual interviews. As in Becu's work, interaction occurs in two phases: elicitation through questionnaires and involvement in the model design at the validation stage, which is also considered as a learning phase for stakeholders. These authors used an interactive decision tree to check with stakeholders whether the output of simulation fits their points of view (Bharwani 2006). Control of this process remains on the modeller's side. The stakeholders' interaction with the model is slightly greater than in previous examples, since there is a direct interaction with the model in the validation stage. On the other hand, the ontology which is manipulated seems to be poorer when compared to examples such as a flight simulator, since the categories of choices open in the interaction are quite restricted. The format of information is open in the first phase and very structured in the second phase with the decision tree. The structuration process used in the modelling process occurs outside of the arena of interaction with the stakeholders.

Group Decision Support System design is based on a collective interaction with stakeholders, as early as the model design stage. These systems tend to be used to address higher level stakeholders, such as managers or policy makers with some decision authority over issues portrayed in the GDSS. In the method he developed, ACKA, Hamel organised a simulation exercise with the stakeholders of a poultry company (Hamel and Pinson 2005). In this exercise, the participants were requested to play their own roles in the company. He constrained the exchanges taken place during the exercise by means of an electronic communication platform so that he could analyse and keep track of them later. All of the participants' communication was transformed into graphs and dynamic diagrams. In this case, the format of information was well structured.

2.3 From software engineering

Close to the artificial intelligence trend, working like Hamel and Pinson on the design of Agent Based Models, the use of agent based participatory simulations (Guyot and Honiden 2006) or participatory agent based design (Ramanath and Gilbert 2004) constitute an emerging trend in computing science. This trend focuses on the development of computer tools, multi-agent systems, which originate from software engineering. Guyot proposes the implementation of hybrid agents, with agents in the software controlled by real agents (players), as avatars (Guyot 2006). These avatars help the players' understanding the system (Guyot and Honiden 2006). They can be thought as learning agents: they learn from choices of their associated player and are progressively designed (Rouchier 2003). The approaches based on hybrid agents create a deep connection between participants and the social simulation model. Information conveyed in the interaction is relative to the model assumptions, as well as to the model content.

Ramanath and Gilbert have reviewed a number of software engineering techniques which may be coupled to participatory approaches (Ramanath and Gilbert 2004). This union between software design and participatory approaches is based on joint production, not only between developers, but also with end-users. Not only does interaction with stakeholders contribute to better software ergonomics – the Computer Supported Cooperative Work

(CSCW) conferences series being an example – but their participation tends to improve the software's acceptance and appropriation (Cahour and Salembier 1996).

The implementation of interactive techniques may take place at all stages of a software development process. In early stages, joint application design (Wood and Silver 1995) allows non-technical or technical issues raised by participants during software development phase to be dealt with, attributing a champion to each issue. This process is based on the implementation of structured workshops and may involve other developers, as well as potential users. It may also increase participants' computing literacy.

Joint application design is supported by the use of prototypes. We find here a link with a second technique: prototyping. This technique can be used all the way through a software development cycle. It is based on providing rough versions or parts of the targeted product. For example, it allows the pre-product to be criticised, re-specified, or the interface improved. In the final stages of the process, user panels can be used to involve end-users in assessment of the product. These panels are based on a demonstration or test of the targeted product.

In these cases, control of the process is dependent on hiring a skillful facilitator. The content of the interactions is typically quite technical, which increases the potential for participants' control over the content to be unbalanced according to their literacy in computer science. An assessment of 37 joint application design experiments has shown that the participation of users during the process is actually rather poor, notably due to the technical nature of debates, which is largely incompatible with the time allocated by users to a joint application design process, compared to the time allocated by developers (Davidson 1999). Interaction tends to be quite superficial and requires translation. However, identification of a champion for specific tasks can give more control to participants, as can their involvement in determining the content of pieces of the software package being developed.

Besides these approaches originating from software engineering, people working in thematic fields such as the environmental sciences propose co-design workshops that focus on the development of simulation models. Such workshops are a type of focus group, organised around the identification of "actors", "resources", "dynamics" and "interactions", which are suitable for a set of stakeholders to represent a socio-ecological system from their own points of view (Etienne, Du Toit, and Pollard 2008). This approach, which occurs at the design stage of the modelling process, is supposed to lead participants to design the simulation model they will use by themselves. They work to formalise a conceptual model through a series of diagrams and a set of logical sentences. The final interaction diagram and the attached logical sentences are then translated by the modeller into computer code. It is in this type of process that a deep interaction can occur between participants and the model. This interaction conveys information on the model content, which is attached to the representations and knowledge of each participant.

2.4 From statistical modelling

Bayesian Belief Networks have been developed to include dependencies on the occurrence of events in the computation of probabilities. They can be useful to represent complex systems and increasingly used in participatory settings because of their graphical nature facilitates discussion (Henriksen, Rasmussen, Brandt, von Bülow, and Jensen 2004). A facilitator asks a group of participants individually or collectively to generate relations between potential events, and possibly to set probabilities for these relations as well. Henriksen and his colleagues propose a method in seven stages which alternates between individual and collective assessment and revision of an existent Bayesian Belief Network diagram (Henriksen et al. 2004).

This approach is reported to still present some difficulties in encouraging strong participant involvement due to the mathematical functions behind the network structure. However, other researchers and practitioners have improved their communication and facilitation of the technique with their own Bayesian Belief Network processes and are receiving positive stakeholder engagement in the modelling processes (Ticehurst, Rissik, Letcher, Newham, and Jakeman 2005). In the example of Henriksen and colleagues, the process is controlled by the modeller and includes only a rather superficial coupling between participants and the model. The translation of participant-provided information into probabilities is mediated by the modeller and is rather opaque, as in many participatory modelling approaches.

2.5 From the social sciences

The association of participatory approaches and social simulation modelling also originates from disciplines not focussing on the production of tools but on understanding social systems. Social psychology, economics, management and policy sciences have all developed their own interactive protocols to involve stakeholders in the design and/or use of their models. Sociology is still at the beginning of this process (Nancarrow 2005). These protocols propose a variety of structures of experimental settings including: laboratory set-ups; *in vivo* experiments; and interactive platforms (Callon and Muniesa 2006). These three categories vary according to their openness, and the influence which participants are allowed. The "*In vivo"* category is beyond the scope of this paper since it does not involve modelling: the society in which the experiment is embedded provides its own model (Callon and Muniesa 2006).

Laboratory settings are controlled experiments, involving human subjects. This is the case for most economic experiments. Participants are encouraged to behave with a given rationality through instructions and receive payment at the end of the session. In canonical experiments, analysis of the experiments is performed by the scientist. The focus of the analysis is to understand the individual and collective behavioural patterns generated by these settings. The purpose of these experiments includes: the testing of theories and models; developing new knowledge on human behavioural patterns in given situations; or the testing of new institutional configurations (Friedman and Sunder 1994). These experiments are particularly efficient for situations with communication issues or with important inter-individual interactivity (Ostrom, Gardner, and Walker 1994). The issue of simulating a real situation is not considered, but rather the testing of a theoretical model. This research domain is currently very active and has evolved along with the emergence of field experiments involving stakeholders playing their own roles idealised in the models (Cardenas, Stranlund, and Willis 2000). With this configuration, there is typically high interaction since participants act as parts of the model. The participants convey choices on action. However, the experimenter strongly controls the process.

A "platform" is an intermediary setting that is more open to compromise and hybridisation than the laboratory. Heterogeneity of participants is also welcomed, since the setting is designed to enhance the sharing of interests. Through experimentation, a platform is supposed to bridge the gap between the world of the model and that of the stakeholders (Callon and Muniesa 2006). Policy exercises and role playing games, as developed in the companion modelling approach, are specific types of these platforms (Richard and Barreteau 2006). Policy exercises embed stakeholders in potential situations they might have to face in the future (Toth 1988). This type of exercises stems from war games that have been developed since the time of Ancient China and are now increasingly used in public policy assessment (Duke and Geurts 2004) or environmental foresighting (Mermet 1993). They are actually quite similar to the business games and system dynamics explained previously in subsection 2.1. However, the underlying social simulation model is more implicit; even though it exists to create the potential situation for simulation and to help identify the participants relevant to the exercise. Participants' association with a computer tool tends to be with a simulation model of the environment, which does not necessary comprise a social component. There is typically high interaction between participants and the social model, since the participants are pieces of the model and connect with the model of their environment. Control of the process is rather diffuse. A genuine empowerment of participants is possible, since they have the possibility of bringing their own beliefs, values and behaviours to the process as parts of the social model, and can adapt it in ways different to what the designers expected. Unlike with laboratory settings, platforms provide information to the modeller about behavioural patterns of the participants. These platforms allow the elicitation of reactions to taboos or innovative behaviours in situations that new to the participants or through tacit routines, as well as the elicitation of collective behavioural patterns, which are elements that are typically difficult to elicit with classical interviewing techniques. Boltanski and Thévenot show that a game can also be used as a tool to investigate social systems. They developed that kind of game, in which there is one player who has to find out the profession of a virtual person and who is given some money that he can use to buy information, or keep it in giving his/her guess (if right). This game informs thus on social representation people hold to classify a priori other people (Boltanski and Thévenot 1993).

Between experimental laboratory settings and policy exercises, the companion modelling approach proposes an association of role playing games and agent based simulations (Bousquet, Barreteau, D'Aquino, Etienne, Boissau, Aubert, Le Page, Babin, and Castella 2002). Even though authors who support this approach claim not to limit themselves to these two categories of tools, they predominately rest in the trend of participatory agent based simulations, and are thus close to the software design and artificial intelligence disciplinary areas presented above. The companion modelling approach makes a full use of similarities in architecture between role playing games and agent based simulations (Barreteau 2003). Both implement autonomous agents that interact within a shared dynamic environment. Joint use of both agent based simulation and role playing games builds upon these similarities to express the same conceptual model. Authors taking this approach use this to reinforce a principle of making all the assumptions underlying a model that is used or designed interactively with stakeholders explicit and understood. At the design stage, this approach aims to incorporate stakeholders' viewpoints in the model. At the model use stage, it aims to improve the appropriation of the tool produced, as well as to increase its legitimacy for further operational use. However, this appropriation is still under discussion and might be rather heterogeneous (Barreteau, Hare, Krywkow, and Boutet 2005).

3. Participation in the modelling process: diversity of phases and intensity

While many authors claim to use participatory approaches for the simulation of social complexity, there remains a large diversity of actual involvement of stakeholders and of activities hidden behind this involvement. Associations of participatory methods with social simulation models are heterogeneous. It is thus important to qualify the actual involvement of stakeholders in these processes, so that these would-be participants in further participatory modelling settings can build more relevant expectations (Barreteau, Bots, and Daniell 2010). This level of participation can range from mere information received by concerned parties related to the output of a process, to the full involvement of a wide range of stakeholders at all stages of a process. There are also many intermediary situations imaginable. Participation should not be thought of as just talking, and diversity should be made explicit so that criticisms towards participation as a global category (Irvin and Stansbury 2004) can focus on specific implementations. This section explores the potential consequences of this diversity in three dimensions: stages in the modelling process, degree of involvement and heterogeneity of stakeholders involved.

3.1 Stages in a modelling process

We consider a modelling process as subdivided in the following stages, with possibility of iterating along them:

- Preliminary synthesis / diagnosis (through previously available data). This includes making explicit the goal of the modelling process
- Data collection (specific to the modelling purpose)
- Conceptual model design
- Implementation
- Calibration and verification
- Validation
- Simulation process (might be running a computer simulation model, playing a game session, etc.)
- Discussion of results

Involvement of stakeholders in each of the different stages of the modelling process does not generate the same level of empowerment or learning, even if we assume that this involvement is sincere. Preliminary synthesis, conceptual model design, validation and, to some extent, discussion of results are framing stages; stakeholder involvement at these levels gives power to stakeholders to orientate the process. In the preliminary synthesis/diagnosis, stakeholders have the opportunity to play a part in setting the agenda. This is the stage of problem structuring which is identified as a key one in all participatory processes (Daniell, Ferrand, and Tsoukias 2006). Even if the agenda developed with stakeholder involvement may further evolve, its initialisation generates a strong irreversibility in the process. Data collection, participant selection and some modelling choices (architecture, platform) are related to this agenda and are costly, either directly or through the necessity of re-programming. The modelling process is a sequential decision process, and as shown in theory of sequential decisions: initial decisions are often at the source of more consequences than envisaged (Henry 1974; Richard and Trometter 2001). Conceptual model design constitutes a landmark in the process. It is the crystallisation of viewpoints that serves as a reference in further stages. Validation is the compulsory stage where stakeholders will have the opportunity to check the effectiveness of the computer model in reasonably representing their behaviours and ways of acting. Discussion of results may also constitute a framing phase, according to the purpose of the discussion. If dimensions of discussion are to be defined and the model is open to be modified, there is some place for participants to (re-)orientate the modelling process. Otherwise, if the discussion of results aims to choose from a few scenarios for example, the choice is very narrow and may be completely manipulated. A scenario is a kind of composite basket, gathering a set of assumptions about internal structure and dynamics of the system, and external driving forces. Manipulation comes from the fact that for any vote among composite baskets, it is possible to maintain that one item is always selected according to the way the baskets are constituted (Marengo and Pasquali 2003).

In other stages of a modelling process, the influence of stakeholder involvement on the overall process is less important. When data collection, or calibration and verification involve participants, stakeholders tend to take the role of informants. Among the various levels proposed in the classical “ladder of participation” explained in the following subsection, these stages deal predominately with consultation. Their involvement is framed by the format of information which is expected, and on the parts of the model which are to be calibrated or validated. If the process is open to modification in these frames, the level of participation may be higher, but still with a limited scope.

The implementation stage is another possible phase for empowering participants where implicit framing may occur. But empowering stakeholders by involving them in this technical activity is often orientated towards raising their literacy of the model and the probability of its appropriation. The simulation stage typically provides information to stakeholders on the consequences of decisions. This is a technical stage (running the simulation) which aids the examination of strategic choices (design of scenarios and indicators to track the simulation progress). Provided stakeholders have sufficient technical literacy, their involvement in the simulations, such as through role playing games or the design of specific viewpoints, increases their knowledge of the model's internal makeup. Involvement in this strategic phase is connected to the initial stage where the agenda was set. The more formalised the questions of the initial phase, the less potentially empowering the simulation phase may be for participants.

3.2 Level of involvement

Level of involvement is a more classic dimension. It is inspired by the classical hierarchy of power-based participation levels proposed first by Arnstein (Arnstein 1969). Several reviews and close adaptations have been made since then (Mostert 2006; van Asselt, Mellors, Rijkens-Klomp, Greeuw, Molendijk, Beers, and van Notten 2001), and less closely related classifications of involvement such as the "Democracy Cube" (Fung 2006) or the work of Pateman who associates the level of interactions among participants to the issue of their political power (Pateman 1990) and Rocha who covers empowerment from the individual to the community levels (Rocha 1997). All of these works focus on what "participation" can mean in decision-making terms, as it is at the base of many political or democratic theories. In most of these examples, the emphasis is placed on who ("citizens", "managers" or "policy makers") has the balance of power for final decision-making (i.e. the "choice" phase of a decision process (Simon 1977)) but other issues of process are not specifically mentioned. Such classifications of involvement, although useful in a very general sense for the question of participation in modelling processes, do not explicitly treat the issue of the place of a modeller or researchers with "expert" knowledge in the domain at stake (Daniell, Ferrand, and Tsoukias 2006).
On these bases, we consider here the five following levels in which there are at least some interactions between a group of citizens and a group of policy makers:

- Information supply: citizens are provided access to information. This is not genuine participation since it is a one-way interaction;

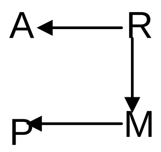
- Consultation: solicitation of citizens’ views;
- Co-thinking: real discussions between both groups;
- Co-design: citizens have an active contribution in policy design; and
- Co-decision making: decisions are taken jointly by members of both groups.

Since a modelling process is a kind of decision-making process, this hierarchy may apply to modelling process as well. This is a little bit more complicated because two processes are behind the modelling process. The network of interactions can not be represented with a group of citizens and a group of decision- or policy-makers only.
A modelling process with the purpose of simulation has two dimensions along which these scales may be assessed: model content and building on one hand; and control over model use on the other. Although these two dimensions are related, it is useful to consider them separately as they provide power and knowledge: either within the process; or in the system in which the process takes place. Each of these dimensions is more closely related to specific stages in the modelling process presented in the previous subsection. However, some stages, such as model design or implementation, contribute to both dimensions.
Therefore we consider the following categories:

- Information on a model’s content and no control over model use;
- Consultation and no control over model use;
- Dialogue with modellers and no control over model use;
- Dialogue with modellers and control over model use;
- Co-building of a model and no control over model use; and
- Co-building of a model and control over model use.

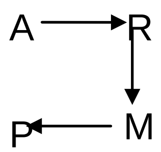
Each category is described in the following sub-section by a flow of interactions within an interaction network based on four poles: **A**; **R**; **M**; and **P**. **A** stands for all people who are involved in and/or concerned by the social complexity at stake in the modelling process. This includes policy makers and citizens. **R** stands for researchers involved in the modelling process. **M** stands for the model. **P** stands for policy makers. **P** is a subset of **A**, which gathers the actors who might use the model and its output for the design of new regulations or policies concerning the system as a whole. We chose to gather citizens and policy makers in **A**, as in the modelling process they are rather equivalent in their interactions with the researchers about the model. However, their distinction is useful for the second dimension: model use and dissemination. We assume that the default situation is an access of **P** members to the output of the modelling process.

3.2.1 Information and no control



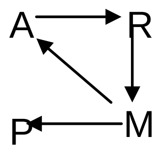
Participants are informed about the model's content and the simulation by researchers, who are the only designers. No control over the model's use or dissemination is deputed to participants as such. Whatever the use of the model may be afterwards, citizens become only better aware of the basis on which this model has been built. However, the model exists and can be used by members of **P**. This is the classical situation with simulation demonstration and explanation of a model's assumptions. This explanation might be achieved by more active means, such as a role playing game. A switch to the following category occurs when this explanation leads to a debate that makes the model open to modifications. Otherwise, it remains mere information.

3.2.2 Consultation and no control



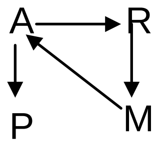
Participants are consulted about the model's content and its simulation that is by the researchers, who are the only designers. They provide information and solicit comments on the model. Mere data collection through a survey does not fall in this category because it assumes active involvement from participants in providing information to the modellers. Some knowledge elicitation techniques, such as BBN design, tend to fall mostly in this category. Translation of the inputs originating from participants into pieces of a model is performed only by researchers. This translation is not necessary transparent. No control over use or dissemination of the model is deputed to participants as such. Compared to previous category, participants have the ability to frame marginally more of what is performed by the model through their inputs to the model's content. However, the extent of this ability depends on the participants' skills to identify potential uses of a model. As in any participatory process, when there is an unbalanced power relation between parties, the process is also a way for policy makers to gain information from stakeholders; information that could be used for strategic purposes. This bias can be alleviated if the involvement of **A** includes all members of **A**, including the subset **P**. The constructed model in this case may be used by the members of **P**.

3.2.3 Dialogue with modellers and no control



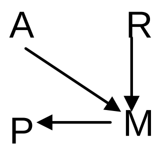
In this category, iterative and genuinely interactive processes between stakeholders and modellers start to appear. There is still a translation of inputs from participants into the model through the researchers, but there is feedback about these developments to the stakeholders. This leads to discussion about the model. Convergence of the discussion remains on the researchers' side. Group Model Building experiments predominately fall into this category. In this case, stakeholders may increase their influence on the framing of the model with better prior assessment of the scope of simulations to be examined. Biases related to strategic information being revealed in the dialogue process are still present if there is unbalanced involvement of Members of **A**, and notably if members of **P** are less active, but still present. However, this category still represents indirect control and no specification of model use is left open to the stakeholders. At the end of the process, the created model can be used by members of **P** without any control or any roadmap set by other members of **A**. Typically in this category, participants may feel cheated because they have provided information which can be used at the end by policy makers in a way they dislike.

3.2.4 Dialogue with modellers and control



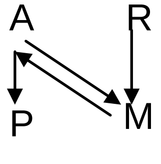
This category is the same as the previous one with translation of stakeholders' inputs and feedback from the researchers about these inputs. However, the output of the discussion, the model, is appropriated by stakeholders. They have control over its use and dissemination of models which may have been produced through the modelling process: who might use them; with which protocol; and what is the value of their outputs. They can decide whether the model and simulations are legitimate to be used for the design of policies that may concern them. However, this appropriation raises issues of dialogue between researchers and stakeholders about the suitability of a model for various uses. Comparison of several participatory agent based simulations has shown that there is a need for dialogue about not only a model's content but also about its domain of validity (Barreteau, Hare, Krywkow, and Boutet 2005).

3.2.5 Co-building of a model and no control



A further stage of empowerment of stakeholders through participation in a modelling process is their co-building of the model. The design and/or implementation of such a model are joint activities between the researchers and stakeholders. Co-design workshops or joint application development fall into this category, provided that there is genuinely no translation of stakeholders' inputs by the researchers. Techniques originating from Artificial Intelligence and knowledge engineering, as presented above, aim to reach this level, either through the implementation of virtual agents extending stakeholders, or through constraining the interactions between actors through a computer network. This involvement increases the fidelity of the model to match stakeholders' viewpoints and behavioural patterns. However, at the end of the process, the created model can still be used by members of **P** without any control or any roadmap set by other members of **A**.

3.2.6 Co-building of a model and control



This category is the same as the previous one, but actors now have control over use and dissemination of models which may be produced through the process. This leads to possible stakeholder appropriation of the models, raising the same issues as in section 3.2.4.

3.3 Heterogeneity of actors

Eversole points out the need for participatory processes to take into account the complexity of the society involved including: power relations; institutions; and the diversity of viewpoints (Eversole 2003). This is all the more true when applied to the participatory process of social simulation modelling. Most settings presented in section 2 have a limited capacity to involve a large numbers of people in interactions with a given version of a model. When interactions convey viewpoints or behavioural patterns, heterogeneity may not appear if no attention is paid to it. Due to limits in terms of number of participants, participatory approaches that deal with social simulation modelling usually involve representatives or spokespeople. The issue of their statistical representativeness is left aside here, as the aim is to comprehend the diversity of possible viewpoints and behavioural patterns. There is still an issue of their representativeness through their legitimacy to speak for the group they represent, as well as their competency to do so. The feedback of these spokespeople to their group should also be questioned. When issues of empowerment are brought to the fore, the potential for framing or controlling the process is dedicated to the participants. This may induce echoes in power relations within the group, notably due to training.

Van Daalen and Bots have proposed a categorisation of participatory modelling according to this dimension with three scales: individual involvement; a group considered as homogeneous, and a heterogeneous group (Bots and van Daalen 2008). Table 1 provides examples of each level according to the two processes involved that were explained in previous subsection.

Level	**Model construction**	**Model use**	
		Computer model	Gaming simulation

1 Individual stakeholders	Knowledge elicitation involving one or more individuals separately; depending on the modelling method this may consist of interviews about (perceptions on) a system or questionnaires related to the aspects being modelled (e.g. (Molin 2005))	Model can be executed and individual stakeholders are informed of the result (e.g. (Dudley 2003))	Individuals can ‘play’ an actor in a flight simulator setting (e.g. (Maier and Grössler 2000; Sterman 1992))
2 Homogenous group	Same as 1, but group model building includes interaction between stakeholders (e.g. (Castella, Tran Ngoc T., and Boissau 2005))	Use of a model in a homogenous group means that the model can be run in a workshop setting and model results are discussed (e.g. (Daalen, Thissen, and Berk 1998))	Multi-player gaming simulation can be conducted, the game is followed by a debriefing (e.g. (Mayer, Bueren, Bots, Voort, and Seijdel 2005))
3 Heterogeneous group	Same as 2, but group model building interaction between stakeholders with different perceptions/beliefs (e.g., (Van den Belt 2004))	Same as 2, but results discussed with stakeholders with different perceptions/beliefs	Same as 2, but full stakeholder group involved (e.g. (Etienne, Le Page, and Cohen 2003))

Table 1: Categories of participation according to level of heterogeneity embraced (from (Bots and van Daalen 2008))

These three categories are represented in the diagrams below, as expansions of the relation between A and (M ∪ R) in the previous subsection. The third category corresponds to the "deep connection" mentioned in the first section.

Some other ways are currently explored with hybrid agents to technically overcome the difficulty of dealing with representatives: by involving them all in large systems. The internet or mobile phone networks provide the technical substrate for such interaction. A large number of participants have a virtual component in a large system, interacting with other components, possibly with the purpose of building a model (Klopfer, Yoon, and Rivas 2004). However, in this case it is rather an individual interaction of these participants with the system, than genuine interactions amongst the participants.

3.4 Which configurations can meet the expectations of the first section?

In this subsection we revisit the expectations towards the joint use of participatory approaches and social simulation presented in the first section, through the categorisations above. This is a tentative mapping of participatory approach categorisation with model expectations. Table 2 below synthesises this mapping.

Expectation	**Key stage(s) for participation**	**Minimum level of empowerment**	**Level of heterogeneity**
Increase model's quality with social diversity and capacity to evolve	Simulation	Information and no control	Heterogeneous group
Increase model's quality through distribution of control	Simulation	Information and no control	Heterogeneous group
Improve suitability of simulation model's use for increasing	Design	Dialogue and no control	Individual

knowledge			
Improve suitability of simulation model's use for policy making	Design and discussion of results	Dialogue and control	Homogeneous group
Simulation as a means to support participation to deal with dynamics and uncertainties	Discussion of results	Consultation and no control (depends on participatory process to be supported)	Homogeneous group
Simulation as a means to support participation through social learning	Preliminary diagnosis, design and discussion of results	Co-building and control (to be preferred)	Heterogeneous group

Table 2: Matching expectations on joint use of participatory approaches and social simulation modelling with categories of participation

The two expectations dealing with increasing a model's quality often use participants as (sometimes cheap) resources in the simulation modelling process. The most important stage is simulation, because participants are supposed to bring missing information to the simulation, as well as the missing complexity. The minimum level of empowerment can be low. These processes are hardly participatory in that sense, because participants are not supposed to benefit from the process, except a potential payment. A higher level of empowerment may increase the quality of participants' involvement in the process through a deeper concern in the outcome of the simulation. Finally, the heterogeneous group level is obviously to be respected because it can instil a deep connection between stakeholders and the model, and decrease the distance between the initial knowledge providers and the model. Stakeholders can also concurrently profit from their interactions with each other.

To make simulation models match their intended use, the key stage is the design process. Stakeholders are supposed to aid the building of an "appropriate" model. The main difference between targets of a simulation model's use is in the necessity to give control over the process to stakeholders in cases of policy making. New knowledge is of individual benefit to all participants and the emergence of fruitful interactions can also become an individual benefit. There are few direct consequences of this new knowledge. Therefore, control over the process in this case is useless and involvement may be individual, as with knowledge elicitation techniques. However, a higher level of stakeholder heterogeneity may raise the quantity of knowledge acquired in the process.

When simulation is used to support participation, discussion of results is a key stage. Previous stages aid in the problem framing and increase participants' literacy that allow them to reach more solid interpretations. The empowerment level is dependent on the participatory process that is being supported. However, consultation in the modelling process should be a minimum requirement so that uncertainties and dynamics tackled by the simulations are relevant to the stakeholders. When focusing on social learning, co-building and control should be preferred because this category increases the potential for exploration and creativity. However, some social learning may take place in lesser levels, provided that group heterogeneity is encouraged in the process.

4. Combining approaches and techniques at work

We present in this section two case studies implementing various methods for joining social simulation modelling and participatory approaches. The first deals with fire hazard prevention in southern France, and the second one with groundwater management in the Atoll of Tarawa, Republic of Kiribati.

4.1 The fire hazard case study

In December 2005, the Forest Service of the Gard Department of Agriculture (DDAF), decided to start a fire prevention campaign focused on fire hazard at urban and forest area interfaces. This administrative service had become aware of the participatory approaches developed by INRA researchers on fire prevention and forest management planning, such as with the SylvoPast model (Etienne 2003; Etienne, Le Page, and Cohen 2003), during outreach meetings on this companion modelling approach. The Service asked them for an adaptation of their SylvoPast model to the periurban context, in order to raise local politicians' awareness of the increasing problem of fire hazard in relation to crop abandonment in the space separating urban neighbourhoods from forest areas. The Nîmes Metropolitan Area institution (NM), who was already interested in the use of role playing games for empowering stakeholders and decision makers, asked the Ecodevelopment Unit of the INRA of Avignon to develop a companion modelling approach based on social simulations and a participatory involvement of all the mayors of the district.

The modelling process was subdivided into seven stages:

1. Collection and connection on a GIS of relevant cartographic data on forests, land-use and urbanisation, and individual interviews with local extensionists on farmers, foresters and property developers practices.
2. Co-construction with DDAF and NM of a virtual but implicit map representing three typical villages from the northern part of Nîmes Metropolitan Area and validation of the map (shape, land-use attributes and scale) by a group of technical experts (EX) covering the main activities of the territory (agriculture and livestock extensionists, forest managers, hunting manager, land tenure regulator, fire brigade captain and town planner).
3. Co-construction, with NM, DDAF and EX of a conceptual model accounting for the current functioning of the territory and the probable dynamic trends to occur during the next 15 years. This participatory process followed the ARDI methodology mentioned in section 2.3 (Etienne, Bourgeois, and Souchère 2008).
4. Implementation of the NimetFeu model on Cormas multi-agent platform by INRA researchers and validation of the model by simulating with the co-construction group, the current situation and its consequences on urban development, crop abandonment, fire hazard and landscape dynamics for the 15 following years.
5. Co-construction and test of a role-playing game (RPG), NimetPasLeFeu, adapted from the NimetFeu model, as a way to simulate automatically natural processes and some social decisions (vineyard abandonment, horse herding, fire fighting). The other social decisions were programmed to be taken directly by the players and used as an input to the model.
6. Use of the RPG during several sessions gathering 6 players (3 mayors, 1 developer, 1 NM representative, 1 DDAF technician) until the 14 villages involved in the project did participate to a session.
7. Adaptation of NimetPasLeFeu to other ecological conditions, and decision of the Gard Department to become autonomous in running RPG sessions. A facilitator and a data manager were trained and tested during sessions organized in the framework of an INTEREG project with mayors and fire prevention experts from France, Spain, Italy and Portugal

This adaptation came out with the organisation of a first set of new RPG sessions on the northern part of the Gard Department after adapting the model's environment to this local context.

The approach is based on a mutual comprehension of the elements of the territory that make sense with the issue of dealing with fire hazard on the fringes of a Mediterranean Metropolitan Area. This sharing of representations is done by means of a series of collective workshops. These implemented the ARDI protocol, in order to elicit and identify the various stakes regarding this issue within the Nîmes city surrondings. To facilitate this sharing, the answers to the questions are formalized into comprehensible diagrams, with a minimum of coding, making it possible to classify the information provided. The role of the facilitator only consists in calling upon each participant, writing down the proposals in a standard way, and asking for reformulation when a proposal is too generic, enounced with a polysemous word, or one that can lead to confusion.

In both models, the environment is divided into three neighbouring villages covering the gradient of urbanisation and agricultural land/woodland ratio currently observed around Nîmes city. It is visualised by means of a cellular automaton through a spatial grid representing 18 land-use types that can change according to natural transitions or human activities.

Four categories of social entities are identified: property developers, mayors, farmers and fire prevention managers. The developers propose new urban developments according to social demand and land prices. They have to respect the government regulations (flood hazard, protected areas, urban zoning). Mayors select an urbanisation strategy (to densify, to develop on fallow land, olive groves or forests), update their urban zoning according to urban land availability and social demand and make agreements with the developers. When updating the urban zoning, they can create new roads. Farmers crop their fields deciding on what current practices to use (vineyards weeding, stubble ploughing) that have different impacts on fire hazard, or they adapt to the economic crisis of certain commodities by uprooting and setting aside lowland vineyards or olive groves nearer to urban zones. The fire prevention manager establishes a fuel-break in a strategic place, selected according to fire hazard ranges in the forest and the possible connections with croplands, as well as available funds and forest cleaning costs.

Four biophysical models issued from previous research and adjusted to the local conditions are integrated to the MAS to account for fallow development, shrub encroachment, pine overspreading and fire propagation. The model is run at a one-year time step, the state represented on the map corresponding to the land cover at the end of June (beginning of the wildfire period). Each participant is invited to propose a set of key indicators that permit them to monitor key changes on ecological or socio-economic aspects. A common agreement is made on what to measure, on which entity, with which unit, and on the way to represent the corresponding qualitative or quantitative value (visualizing probes on graphs or viewpoints on maps). They are encouraged to elaborate simple legends, in order to be able to share their points of view with the other participants while running the model.

The NimetFeu MAS was exclusively used to support the collective thinking on which procedures and agents will be affected to players, and which ones would be automatically simulated by the computer. In the RPG NimetPasLeFeu, the playing board was strongly simplified with only 4 types of land cover. Running the game gave participants the opportunity to play individually or collectively by turns, according to a precisely defined sequence. While the players, endorsing a role of mayor, drew the limits of the urban zone for new developments and rank the price of constructible land according to its current land-use, the developer player randomly drew a development demand and elaborated a strategy (village, density, livelihood). Then a series of negotiations began between the developer and the three mayors in order to decide where to build, at which density and with which type of fire prevention equipment. All the players' decisions were input into the computer and landscape dynamics were simulated by running the model. Players obtained different types of output from the simulation run: budget updating, new land-use mapping, popularity scoring. Each round corresponded to a three-year lapse and was repeated 3 to 4 times according to players' availability.

A specific effort was made in the RPG design to account for physical remoteness and territory identity among participants: the playing room was set up into 3 neighbouring but distinct boxes for the 3 mayors (each box represents one village), one isolated small table for the developer, and another game place with 2 tables, one small for the DDAF and a huge one for NM. Lastly, in a corner, the computer equipment was placed with an interactive board that could be both used as a screen to project different viewpoints on the map, or as an interactive town plan to identify the parcels' number.

At the end of the game, all of the participants were gathered in the computer room and collective discussion took place, with the support of fast replays of the game played. Different topics were tackled related to ecological processes (effect of fire, main dynamics observed), attitudes (main concerns, changes in practices), and social behaviours (negotiations, alliances, strategies).

Once finished the 5 sessions, a global debriefing was organised at NM to give the opportunity to all participants to exchange on how they feel, what do they think about the realism of the model, what was their individual strategy, did they become aware of vegetation dynamics and its impact on fire propagation, and what they still remind about the periods of negotiation.

Along these various stages, this experiment featured a diversity of levels of involvement, as well as of structure of interactions. This is synthesised in the table 3 below.

	involvement	heterogeneity	nb
Preliminary diagnosis	consultation	individuals	10
Data collecting	consultation	individuals	3
Conceptual model designing	co-design	heterogeneous group	14
Implementing	information	individuals	2
Calibrating and validating	co-thinking	heterogeneous group	14
Role-Playing game designing	co-design	heterogeneous group	14
RPG playing and debriefing	co-decision making	heterogeneous group	30
Getting self sufficient	information	individuals	3

Table 3: classification of type of participation in various stages of the NimetPasleFeu experiment

4.2 The AtollGame experiment

This study was carried out in the Republic of Kiribati, on the low-lying atoll of Tarawa. The water resources are predominantly located in freshwater lenses on the largest islands of the atoll. South Tarawa is the capital and main population centre of the Republic. The water supply for the urban area of South Tarawa is pumped from horizontal infiltration galleries in groundwater protection zones. These currently supply about 60 per cent of the needs of South Tarawa’s communities. The government's declaration of water reserves over privately owned land has lead to conflicts, illegal settlements and vandalism of public assets (Perez, Dray, Le Page, d' Aquino, and White 2004).

The AtollGame experiment aims at providing relevant information to the local actors, including institutional and local community representatives to facilitate dialogue and to help collectively devise sustainable and equitable water management practices. Knowledge elicitation techniques, as well as Multi Agent-Based Simulations (MABS) coupled with a role-playing game, have been implemented to fulfil this aim. In order to collect, understand and merge viewpoints coming from different stakeholders, the following 5-stage methodology was applied: (1) collecting local and expert knowledge; (2) blending the different viewpoints into a game-based model; (3) playing the game with the different stakeholders; (4) formalising the different scenarios investigated in computer simulations; and (5) exploring the simulated outcomes with the different stakeholders (Dray, Perez, Le Page, D'Aquino, and White 2006b).

Initial knowledge elicitation (Stages 1 and 2) relies on three successive methods. First, a Global Targeted Appraisal focuses on social group leaders in order to collect different standpoints and their articulated mental models. These collective models are partly validated through Individual Activities Surveys focusing on behavioural patterns of individual islanders. Then, these individual representations are merged into one collective model using qualitative analysis techniques. This conceptual model is further simplified in order to create a computer-assisted role-playing game (AtollGame). The range of contrasted viewpoints confirms the need for an effective consultation, and engagement of the local population in the design of future water management schemes in order to warrant the long-term sustainability of the system. Clear evidence of the inherent duality between land and water use rights on one hand, and between water exploitation and distribution on the other hand, provides essential features to frame the computer-assisted Role Playing Game.

The assistance of a computer is needed as far as interactions between groundwater dynamics and surface water balance involve complex spatial and time-dependent interactions (Perez et al. 2003). The use of Agent-Based Modelling (ABM) enables full advantage to be taken of the structure of the conceptual model. The AtollGame simulator was developed with the CORMAS© platform (Bousquet, Bakam, Proton, and Le Page 1998)[1].
A board game version reproduces the main features of the AtollGame simulator (Dray et al. 2006a). 16 players – 8 on each island – are able to interact according to a set of pre-defined rules. Their choices and actions are directly incorporated into the simulator at the end of each round of the game. During the game, players can ask for more information from the simulator or discuss the results provided by the simulator (salinity index, global demand). Landowners, traditional or new buyers, are the essential actors in the negotiations with the government. The

[1] More details on AtollGame on http://cormas.cirad.fr/en/applica/atollGame.htm

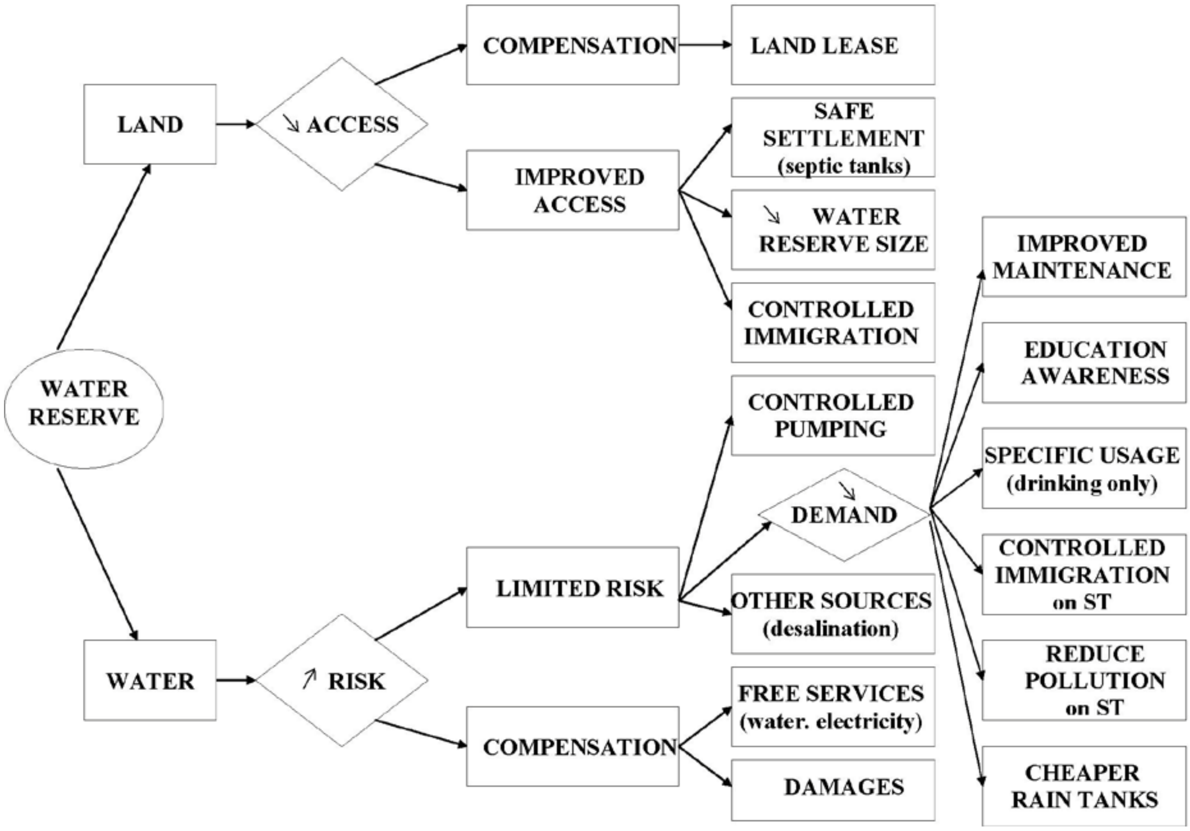
connection between land tenure issues and water management is essential. It drives the land use restrictions and land leases discussions. The population increase, mainly through immigration, is perceived as a threat in terms of water consumption, pollution generation and pressure on the land. Financial issues linked to water management usually deal with land leases, equipment investment and, occasionally, with water pricing. Hence, the model features:

- agents/players who become local landowners;
- conflicting land and water allocation rules, and various sources of incomes; and
- an increasing number of new settlers on agents/players' land.

The individual objective of the players is to minimise the number of angry or sick people in their house. People may become ANGRY because they did not have enough water to drink during the round. People may become SICK if they drank unhealthy (polluted or salty) water during the round. POLLUTION depends on the number of people living on the island and the contamination of the freshwater lens. SALTY WATER depends on the recharge rate of the fresh water lens and the location of the people on the island.

At first, representatives from the different islands displayed different viewpoints about the Water Reserves. Hence, the group meetings organised in the villages prior the workshop allowed for a very open debate. On the institutional side, the ranking and decisional level of most officers attending the workshop demonstrated a clear commitment to the project. All the participants showed the same level of motivation either to express their views on the issue or to genuinely try to understand other viewpoints. Participants also accepted to follow the rules proposed by the project team, especially the necessity to look at the problem from a broader perspective. During the first rounds, the players quickly handled the game and entered into interpersonal discussions and comparisons. The atmosphere was convivial and the game seemed sufficiently well constructed to maintain the participants' active interest. The second day, the introduction of a Water Management Agency and the selection of its (virtual) Director created a little tension among the participants. But, after a while, the players accepted the new situation as a gaming scenario and started to interact with the newly created institution. At this stage, players started to mix arguments based on the game with other ones coming directly from the reality. On Island 1, players entered direct negotiations with the (virtual) Director of the Water Management Agency. On Island 2, discussions opposed players willing or not to pay the fee.

Finally, the project team introduced the fact that the Water Management Agency was no longer able to maintain the reticulated system due to a poor recovery of the service fees. It had for immediate consequence a sharp decrease of the water quantity offered on Island 2.
Then, players from both tables were asked to list solutions to improve the situation on their island. When the two lists were completed, the project team and the participants built a flowchart of financial, technical and social solutions, taking into account issues from both



islands (figure 1).

A collective analysis of the flowchart concluded that the actual situation was largely unsustainable both from a financial and social viewpoint. The flowchart above provides a set of inter-dependent solutions that should be explored in order to gradually address the present situation.

Figure 1: Flowchart of financial, technical, and social solutions agreed on by the participants of the AtollGame experiment

5. Discussion: relations between participants and models

The diverse categories of joint implementation of participatory approaches and social simulation modelling feature a diversity of relations between a set of people, participants, and a model.

Classical social simulation models do not feature any participants. People are represented in the model, sometimes from assumed or theoretical behavioural patterns, as a means of exploring potential emergent phenomena from interactions among behavioural patterns. Some participatory approaches involve only an implicit social model. Within this scope, there is a large diversity of relations. This diversity is based on the roles undertaken by stakeholders, their actual involvement in the modelling process and issues tackled by the model.

In all the processes linking social simulation models and participation, stakeholders take on various roles as: parts of a simulation, interfaces for coupling various sources of knowledge, beneficiaries of the process, key informants, etc. Managers are overwhelmed by the complexity to be managed. Participation is a way to share this burden (Ryan 2000). Stakeholders provide the missing interactions and add missing pieces of knowledge, such as tacit knowledge (Johannessen, Olaisen, and Olsen 2001). If involvement of stakeholders is useful for principal agents such as managers, we propose that, as a rule, these stakeholders should gain some empowerment through their participation in the process.

Stakeholders can also be key pieces of the modelling process itself. In the simulation they are an alternative to computer code to provide the engine (Hanneman 1995). They also provide an answer to issues of coupling several viewpoints, acting themselves as broker among various viewpoints (Robinson 1991).

However actual involvement of people in a participatory modelling process may largely differ from planned formal involvement. Leaving aside cases of manipulation and announce effect, people also have to find their place in the participatory process. Suitability of participatory approaches in specific societal contexts has to be taken into account. Context (including social context) is a key driver for success in stakeholder involvement (Kujala 2003), and practice of interactive policy making processes depends on local culture (Driessen, Glasbergen, and Verdaas 2001). Representation mechanisms have already be pointed out as a major factor. It has to be tuned to local social and cultural contexts. At a finer grain, facilitators have a key role to lead people towards the level of involvement for which they are invited (Akkermans and Vennix 1997).

6. Conclusion

This chapter provides a review of the diversity of association of participatory approaches and social simulation, for their mutual benefit. This diversity of approaches allows expectations about increasing a model's quality, a model's suitability to its intended use, and improving participation. Their diversity is built upon ingredients stemming from various disciplines including the social sciences, computer sciences and management. It is expressed according to the implementation of interactions between the participants and the simulation model, the control of the process and the format of information. This leads to an expansion of the classical ladder of participation towards a categorization based on the stage in the modelling process when participation takes place and the structure of the interactions to cope with the heterogeneity of stakeholders.

This diversity requires a cautious description of each implementation in its own situation, so that any evaluation is specific to the implementation of a given association in context. Generalisation based on the relation of this practice of participatory simulation and its suitability to its context and purpose may then be carried out. Efficiency to induce changes in practice or knowledge means to consider that collective decision processes are contingent to time, people, and means (Miettinen and Virkkunen 2005). In other words, the following must be respected: taking into account the dynamics of the social system at stake, allowing full participation of people (including tacit knowledge, networks, relations to the world), and being adaptive to means and competencies present within the system (Barreteau 2007). Another dimension of evaluation should include the enhancement of democracy, due to it often being a purpose of participatory approaches. This raises the issue of the existence of a control of the process. Does it rely only on modellers, who are often endorsing a role of facilitator, or is it more greatly shared? Finally, there is a growing necessity to make the kind of participatory process which is used more explicit because of the potential rejection of the whole family of approaches, if expectations of participants are not met.

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