COMPLEXITY IN FORESIGHT

EXPERIENCES WITH *INTERSECTIONS*:

An Agent-Based Simulation Workbench to Help Achieve Adaptiveness in Strategic Planning

Ph.D Thesis submitted to Erasmus University

by

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Abstract

"Complexity in Foresight" is a new synthetic paradigm that crosses areas in strategic planning and the complexity sciences. It connects the fields of agent-based simulation and complex adapative systems, and provides the overall blueprint for the construction of a new generation of toolkits. The plan is ambitious: to help achieve *adaptiveness* in strategic planning.

My proposal is to start the construction of an agent-based simulation workbench with the ingredients: *would-be worlds*, *building-block approaches* and *learning-action networks*. The workbench will be designed to support learning-action networks; the informal networks of scientists, policy-makers and stakeholders that have a critical role for sustainable development. Their interactions and learning will be facilitated by would-be worlds; agent-based simulation models that function as "laboratories", which the used to generate crude images of transitional change. These images will be treated as *thought experiments*, designed to make it easier for the planners to switch between observable realities and possible realities. Building-block approaches help to organize the modeling, experimentation and learning processes in a very flexible way, so that the overall process becomes adaptive.

In this thesis I present the "Framework for Synthesis" designed to facilitate a *unifying* process to the development and use of would-be worlds. I build tools and methods and integrate them into the "INTERSECTIONS" workbench. I apply different combinations of these tools and methods in two case studies. I evaluate the potential usefulness of the Framework for Synthesis to support learning-action networks. I present the Framework on the CD-ROM included with this thesis, so that the reader can interact with the tools and methods.

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1 INTRODUCTION

This chapter serves as an introduction to the thesis. Its purpose is to familiarize the reader with the reasons leading to the investigations (section 1.1), the formulation of the research objectives and the central scientific questions it poses (section 1.2) and the organization of material within the thesis (section 1.3).

> Note on layout
>
> Every now and then the flow of the text will be interrupted by boxes like the one surrounding this note. The contents of these boxes are concentrated on topics that may be unfamiliar to most readers. They are brief introductions of concepts, overviews of developments, or elaborations of ideas. They provide starting points for further study (by means of the subsequent chapters, the CD-ROM or other sources) but without getting in the way of the main flow of the text or overwhelming the reader.

1.1 Statement of the Problem

The fundamental questions that are addressed in this thesis, as expressed by its title, are: how can complexity thinking strengthen foresight, and what could be the framework, methods and tools that are needed to accomplish this? The paragraphs that follow are dedicated to a discussion of the two paradigms – the foresight paradigm and the complexity paradigm and the prospects of their combined use.

Foresight

Foresight, to begin with, is a way of thinking about planning for the future that has the potential to strengthen the strategic dimension of management and policy-making.

> Foresight
>
> “Foresight can be defined as a systematic, participatory, future intelligence gathering and medium-to-long-term vision-building process aimed at present-day decisions and mobilizing joint actions. The term ‘foresight’ therefore, represents the processes of focusing on the interactions among science, technology and society.
>
> Managers, policy-makers, trade unionists and voluntary organizations should be considered potential users of foresight.”
>
> (European Commission Foresight Handbook)

The foresight paradigm reflects a modernization of strategic planning processes. The innovation of strategic planning processes is necessary to respond to the fact that our world has become ‘more uncertain’ and ‘more complex’. The response put forward by the foresight movement is to explore ways of extending existing practices (forecasting, futures studies) with a range of innovative approaches and with foresight functioning as an ‘umbrella’ concept, rather than being one approach in particular. Possible extensions would include approaches that are used in planning, networking of people, management of group processes and organizational learning. The idea is not to displace existing decision-making and planning processes, but rather, to complement and inform them, so as to increase their effectiveness.

Complexity Thinking

Complexity thinking, the other paradigm central in this study, is a holistic way of thinking about phenomena and processes in nature and human societies, based on an understanding of *complex systems*.

Complexity Thinking

The complexity movement is essentially a shift away from reductionist thinking (studying problems by breaking them into constituent parts) – a shift happening in all scientific disciplines. Indeed, in the sciences of complexity it is standard practice to bring together people and ideas from many disciplines. Complexity is best-known for chaos theory – the 'butterfly effect' – yielding insights into possible causes of sudden and/or surprising changes in the behaviour of systems. However, over the last two decades, complexity thinking has moved on from chaos to the study of complex systems. Therefore, in most contexts, complexity thinking means a holistic way of thinking about phenomena and processes based on an understanding of complex systems.

Complex Systems

Complex systems are those systems 'made of myriad simple parts that interact to create a complicated, baffling whole'. They are systems (physical, biological, social or artificial) that consist of many interacting entities that can exhibit 'emergent' properties and behaviour; i.e. unplanned by-products of the interactions. The cross-disciplinary study of those systems can yield deeper insights into a wide range of phenomena and processes that express evolution, spontaneous self-organization, and constant novelty.

Nowadays, the study of complex systems takes place at cross-disciplinary research centers and laboratories, which are dedicated to the design and testing of complex systems theories and *computational* tools (algorithms, simulation models), for uses in fundamental research and/or practical applications (optimization, forecasting, generation of scenarios) in a wide range of topic areas (organizational design, counter-terrorism, epidemiology, …).

The Prospect of Complexity in Foresight

No doubt, the fusion of both paradigms 'complexity in foresight' is an attractive prospect. On the one hand, it is reasonable to expect that users of foresight are likely to benefit from deeper insights into complex systems, provided that sufficiently exact knowledge on specific complex systems is developed. On the other hand, foresight, when understood as the capacity to plan in the midst of uncertainty and complex changes, is already a hot topic in the study of complex systems[1].

Despite its attractiveness, however, the prospect of 'complexity in foresight' is not entirely clear and much of it has not yet materialized. Based on what has been achieved until now, it is only possible to sketch such prospect, as is attempted in the following paragraphs.

1 Indicative is the current scale of activities in complexity labs focused on ant colonies and other complex systems existing in nature that exhibit stunning capacities for decentralized planning.

First of all, it is currently broadly understood that, in the context of strategic planning processes, complexity approaches can help to push thinking in new directions and shed new light on a wide range of topics. More specifically, it urges planners to embrace the following principles:

Principles for Complexity in Foresight

- MOVE BEYOND REDUCTIONISM,
  TAKE A CRUDE HOLISTIC LOOK,
  ASK THE RIGHT QUESTIONS
  Move beyond reductionistic approaches – since the whole is more than the sum of the parts and aim is to view the big picture. Do not only go deeper into the essence of the studied phenomena, but also proceed wider – by embracing more and more interconnected phenomena and processes. Take a crude holistic look on these interconnections and find the right questions to ask.

- JUMP FAR FROM OBSERVED FACTS
  When building scenarios for the future, do not limit approaches to the traditional methods (extrapolation of trends, forecasting of events) but also conduct explorative studies with the goal to jump far from the observed facts.

- FOCUS ATTENTION BOTH ON THE FUTURE AND ON THE PRESENT
  Do not be obsessed with goals and the future. Focus attention not only on future goals related to large-scale driving forces, but also on the present and the impact of actions on a local scale.

- USE QUALITATIVE STUDIES,
  VISUALIZE PATTERNS
  Complement quantitative studies with qualitative studies to stimulate the process of embracing new interconnections. Use visualizing tools to see patterns with more ease.

- STUDY EVOLUTION AND EMERGENCE IN NETWORKS
  Be keen on identifying interconnected networks in systems that are capable of generating non-linear dynamics (for example, causing small changes to have large impacts). Do not only study states of stability and equilibrium, but also explore evolutions that exhibit sudden change and large-scale transitions. Check what properties and behaviours emerge if the system is pushed far from equilibrium.

- AIM TO CROSS DISCIPLINARY BOUNDARIES
  Open boundaries between disciplines. Bring people and ideas together to gain insight and knowledge. Use multiple perspectives.

- DROP ASSUMPTIONS THAT BLOCK THE PROCESS OF GAINING DEEPER INSIGHTS
  Drop assumptions that limit any of the principles stated above. Consider ways to avoid bias implicit in more traditional systems thinking; e.g. do not confuse questions of order with questions of control, nor with questions of desirability.

It is also broadly recognized that the prospect of complexity in foresight is most likely to materialize in two young cross-disciplinary fields: *agent-based simulation (ABS)* and *complex adaptive systems (CAS)*, which contribute a research model and an organizational model, respectively.

Agent-Based Simulation (ABS)

A suitable research model for complexity in foresight is agent-based simulation (ABS). In short, ABS can be thought of as a technology for modeling on a computer that allows populations of 'agents' to interact and make decisions. The effective use of this technology has however far reaching methodological implications and ABS has been characterized as a 'new way of doing science'.

> "One of the new ways in which scientists are able to conduct research on complex systems is by using computer technology to

> develop ‘agent-based models’, which simulate the likely real-life behaviour of the system being studied. This exciting new technology has been called the ‘third’ way of doing science with traditional experimentation and observation/description being the other two.
>
> An agent-based model requires realistic knowledge of the ‘agents’ or components of the system as well as the written and unwritten rules by which they operate, thus making it possible for the model to provide insights into the collective behaviour of the agents when new information or changes are introduced into the system. After the model is built, it is possible to run simulations on many different aspects of the system to see how a change will affect the interdependencies and overall dynamics of the whole system. This type of research model is being used to look at issues and options related to national security, infrastructure protection, forest ecosystems, climate change, ocean ecosystems, new diseases and disease patterns. It is also changing the ways in which research data are gathered and reported.” (Sanders 2003, pg. 6)

Complex Adaptive Systems (CAS)

An interesting organizational model for complexity in foresight is known as ‘complex adaptive systems’ (CAS). In short, CAS can be thought of as complex systems exhibiting a surprising capability to `manage’ (to survive, evolve, adapt…) in contexts of massive uncertainty.

> “Insights arising from the study of complex adaptive systems are being used to rethink and redesign business, industry and governmental organizations and systems so that they are more flexible, adaptable and able to respond quickly and more effectively to changes in the larger environment. Complex adaptive systems, and models thereof, are characterized by distributed organizations or networks, whose parts all influence each other, either directly or indirectly through feedback loops, which continually evolve and adapt to accomplish the overarching goals.” (Sanders 2003, pg. 6; Sanders and Kadtke 2001)

Based on recent experiences in ABS and CAS, it is possible to expand the overall prospect of complexity in foresight further. Experiences with ABS, to begin with, point out that the research model comes into its own when *a crude look on transitional change* is required:

> “Agent-based simulation models will often identify reforms and policy changes that are not intuitively obvious, but that have the ability to *transform* the system.” (Sanders 2003, pg. 11)

Expanding further, it can be asserted that ABS can help to achieve a crude look not on one transformation only, but on *a set of interlinked transitions*: demographic, technological, economical, social, institutional, informational, and ideological.

CAS, on the other hand, has proven to be a powerful way of thinking about competition, cooperation, diversity, creativity and other phenomena in many types of organizational systems. The generality of the CAS principles, combined with the fact that strategic planning processes are often complicated in terms of organization, make it straightforward to view *the planning entity itself* as a complex adaptive system.

The overall prospect of 'complexity in foresight', then, can be sketched as a way to help achieve *adaptiveness* in strategic planning. In such a sketch, 'adaptiveness' should be understood not only as the flexibility to catalyse thinking in new directions, but also more broadly, incorporating its connotations in CAS theory. Such a sketch should also identify agent-based simulation to be critical for achieving this kind of adaptiveness both as an enabling technology (i.e. achieving a crude look on a set of interlinked transitions) and as a research model (i.e. a new way of doing science).

Gaps in Complexity in Foresight

Formidable gaps remain however to be closed to turn this prospect of complexity in foresight into something more than just a sketch. As is stated earlier, much of what could be considered complexity in foresight has not materialized yet.

One hurdle pertains to the centrality of '*building-block approaches*' in CAS and, consequently, desired in complexity in foresight.

Building-Block Approaches in Foresight: Trial and Error?

Building-block approaches, central in CAS, reflect a way of thinking about adaptive capabilities in which instead of designing in exquisite detail for a particular requirement one develops the building blocks that allow one to deal with diverse challenges as they arise (Simon 1996; Holland 1995). It often escapes our imagination that even a modest set of building blocks make it possible to conceive a daunting number of options for assembly (think for example of the game of LEGO). Although this is good news in terms of flexibility, the difficult problem that planners now have to tackle is discovering the right building blocks and learning rapidly how to assemble them when a specific challenge arises.

It is possible that planners have to continue relying on 'trial and error'. It is anticipated that the CAS field researchers need at least a decade to come up with theory-based alternatives to trial and error, for dealing with systems as complex as those arising in the economy (Holland 2004).

1.2 Research Objectives and Questions

For obvious reasons, it is not feasible to simply sit back and wait a decade or more for progress in fields like ABS and CAS. Today's challenges in strategic planning readily demand more systematic approaches for dealing with complex systems.

What is needed, then, is to pursue a direction to go beyond trial and error and actually commence the design and testing of new frameworks and tools. Experiences with the practical application of those frameworks and tools, specifically to support strategic planning in the intersections of sustainability, innovation and policy, can help to clarify the design principles that are needed as well as the potential of this direction. Doing so should enable those working in the application field to draw valuable lessons out of these experiences and broaden its spectrum for seeking routes toward promising innovative practices.

Research Objectives

Consequently, this thesis aims to:

1) Put forward a new framework, called 'Framework for Synthesis', designed to support learning-action networks for sustainable development, and by doing so,
2) Pursue the direction marked by the cluster of three terms: 'would-be worlds', 'building block approaches', and 'learning-action networks'.

The Meaning of Terms

An overall conceptualization of the Framework for Synthesis and associated terms ('would-be worlds', 'learning-action networks' and other) is provided in the form of a 'roadmap' in Chapter Two (and in section 2.3 in particular). From this roadmap and Figure 2.3, it should be noted that the focus of the study is on the conceptualization of one aspect in particular: 'a unifying process to develop and use would-be worlds'.

Central Scientific Questions

The scientific interest of the thesis is formally expressed in two central questions:

1) Is the Framework for Synthesis a potentially useful practice to support learning-action networks in sustainable development?

   Specific questions:
   1a) What are design criteria for effective support for learning-action networks?
   1b) How does the Framework for Synthesis perform against such criteria?

2) What are further possibilities for innovative problem-solving practices in this direction?

   Specific questions:
   2a) What is learned about the potential usefulness of each of the Framework's methods/tools?
   2b) What is learned about their complementary uses?
   2c) What overall design principles have been crystallized?

1.3 Structure of this Thesis

Chapter One serves as an introduction to the thesis. Chapter Two contains of a roadmap that clarifies the research objectives stated in Chapter One. In Chapter Three, the inter-connections are established among the three key notions in this thesis: would-be worlds, building-block approaches, and learning-action networks. It covers these notions with a yet unanswered question in mind: how to build would-be worlds that offer practical support for tackling problems in the real world? Other key concepts specific to this thesis are introduced as well in Chapter Three.

Chapter Four provides a review of problem-solving practices that can be used in sustainability studies. This chapter provides the foundations on which the subsequent chapters are built. The seven practices that are reviewed in this chapter are all modeling or simulation approaches; hence the chapter is titled “a journey into the land of modeling and simulation”. Important in this chapter are the design criteria that are put forward, called the “BLUEPRINT criteria”. These criteria mark the destination of the journey, and serve, in the final chapter, to test its success.

Chapters Five and Six cover the two case studies put forward in this thesis. The Lisbon case study (Chapter Five) and the Porto Alegre case study (Chapter Six) both document experiences with the application of tools and methods of the Framework for Synthesis. Whereas the Lisbon case study is concentrated on creating and building would-be worlds, the main interest of the Porto Alegre case study lies in the interaction with, and support of, learning-action networks.

Chapter Seven is the concluding chapter. Here it is examined whether the Framework for Synthesis is a potentially useful practice to support learning-action networks in sustainable development (the first central scientific question). Conclusions are based on the experiences in the case studies, as well as an evaluation of the proposed Framework against the BLUEPRINT criteria that were formulated in Chapter Three. The second central scientific question is also addressed, sketching the new possibilities for innovative problem-solving practices that have crystallized.

Resources on the CD-ROM

The CD-ROM contains presentations of the Framework for Synthesis and its tools and methods. These include animations and an “interactive” presentation (“explorer”) of the most important ideas and principles. Reports and data that belong to this thesis are also accessible through the CD-ROM. The CD-ROM contains a page with annotated web links that could prove useful for accessing additional sources online.

Appendices

Appendix A contains the “paper version” of the CD-ROM presentations. Appendix B contains the principal resources from the two case studies. Appendix C contains the score sheets that were used to perform the BLUEPRINT evaluations.

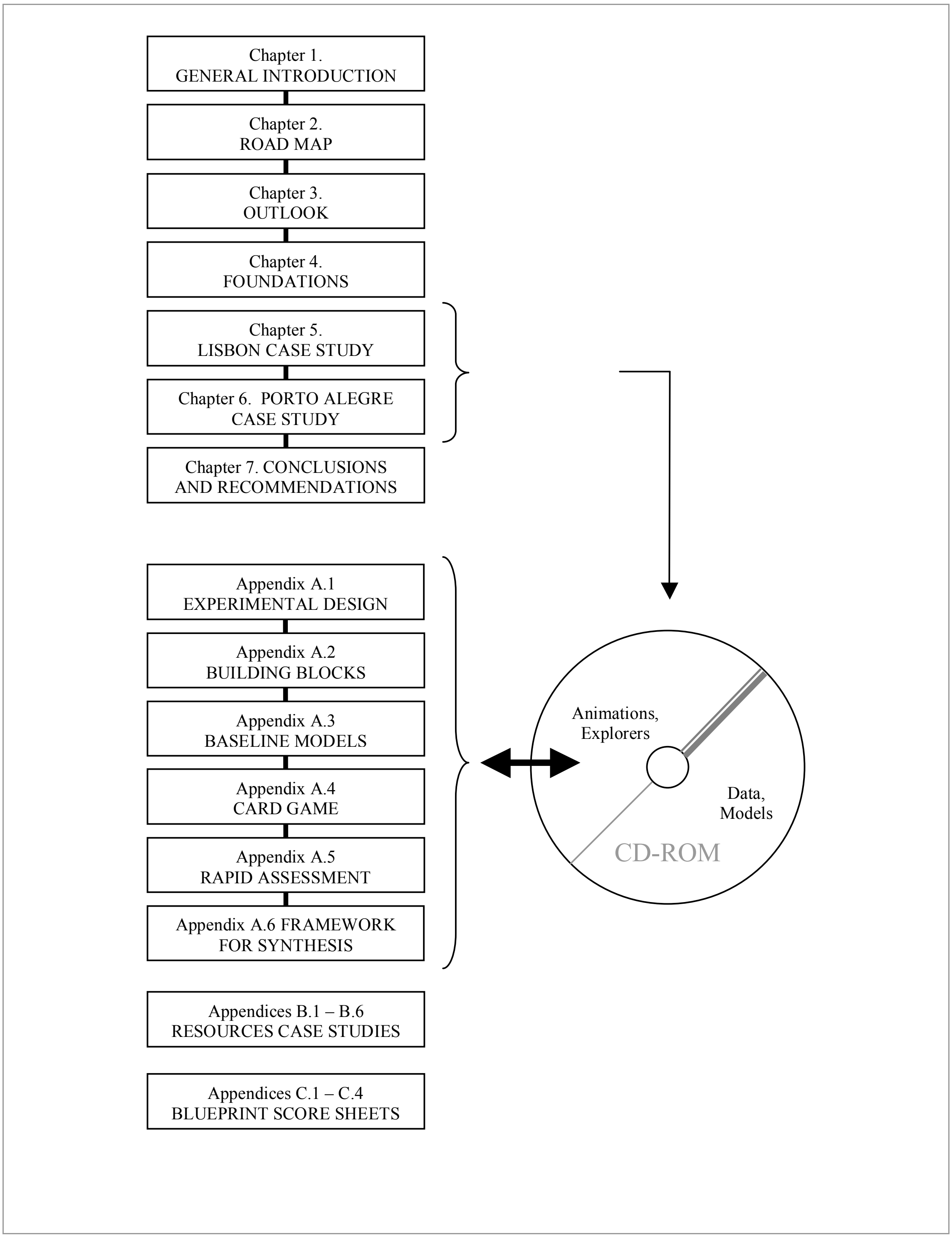


Figure 1.1 Structure of this thesis

2 ROADMAP
How Complexity Thinking Unfolds into Foresight

In section 2.1 the evolution of complexity thinking is rendered as a roadmap of unfolding developments in science and business. An extrapolation of these developments is discussed in section 2.2, arriving at an outlook on ‘complexity in foresight’. Section 2.3 completes the roadmap, adding a sketch of the proposed framework, the ‘Framework for Synthesis’, to accomplish complexity in foresight.

2.1 The Unfolding of Complexity Thinking

Unfolding into the Adjacent Possible

Figure 2.1 (and its elaboration in Figure 2.2) reflect the idea that new technologies, trends, ideas…, rather than being purely the results of human ingenuity or of processes of ‘natural selection’, are often, in part, the surprising consequences of processes of ‘unfolding into the adjacent possible’: i.e. the ongoing exploration of new possibilities that are only one step away from actual existence. This phenomenon was discovered by Kauffman (Santa Fe Institute) in his investigations of biological and technological evolution. Since, at any time in the unfolding into the adjacent possible, there are so many options that prediction is impossible (see the earlier discussion of building block approaches), a roadmap of such evolution should never be ‘too rational’ or ‘too linear’.

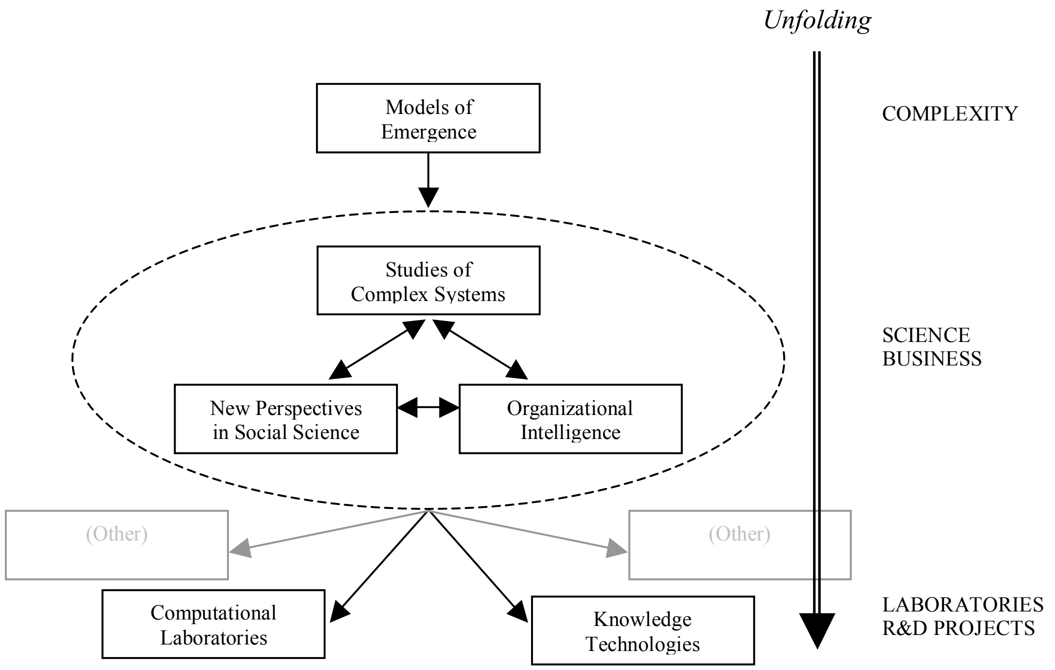


Figure 2.1 Roadmap Part 1: Complexity

The following paragraphs provide a brief discussion of the developments that are highlighted in Figure 2.1.

Complexity Research

Complexity research was introduced in Chapter One as the study of complex systems. These investigations begin with questioning the indiscriminate use of reductionist approaches; i.e. splitting-up a problem into its constituent parts. They are inspired by a collection of well-studied cases – identified in real-life and/or created on computers, demonstrating that, when dealing with complex realities, *we may be unable to comprehend a problem even if parts and their interactions are understood well*. Consequently, an important aspect of complexity research is the design and testing of alternative, more natural approaches to tackle such problems.

The ‘nuts and bolts’ of conducting complexity research were established at the Santa Fe Institute:

<u>Complexity Research at the Santa Fe Institute</u>

Characteristics of complexity research include the pioneer-style collaborations across multiple disciplines, involving computer scientists, physicists, mathematicians, and economists that was started in the mid-1980s at the Santa Fe Institute. These pioneers shared a concern about the long-standing dominance of reductionist thinking in science and the enormous impact it had on the way science is organized, the methods and tools that scientists use, and so on. They believed that ‘reductionist science’ is not capable of fully addressing crucial questions in science, which then, as a result, are disqualified from that science.

<u>Emergence</u>

The pioneers at Santa Fe grappled with an unconventional category of questions about all kinds of complex systems, known in mathematics, physics, biology, psychology, economics, sociology and other disciplines. Their questions had in common that they all referred to *emergent properties* of complex systems.

Emergent properties are large-scale or in other sense ‘overall’ effects of a great many interacting ‘agents’ in these systems that act independently and obey simple local rules. For example, according to such a view, liquidity is an emergent property of interacting water molecules. Analogously, the mind is an emergent property of interacting neurons, a stock market is an emergent property of interacting traders, and so on.

The question that is often placed central in complexity research is: HOW DOES EMERGENCE HAPPEN*?* In connection with the previous examples: how does water turn to ice when cooled down? How does the mind learn from experience? How do stock markets crash? In search for more convincing answers to such questions, complexity research aims to reach beyond the explanatory power of linear reductionist thinking. Indeed, it readily points out the limits of reductionist thinking; if emergent behaviours and emergent phenomena are the result of truly ‘bottom-up’ processes of change, they cannot be explained purely in terms of the individual behaviours of the agents. In other words, they cannot be reduced to the behaviours of the agents.

This last point can be amplified by returning once more to the previous examples. Reductionist thinking leads to questions like: how do molecules behave when water becomes ice? How do neurons interact when the mind is learning? How do traders behave when a market crashes? While these are all valid questions, complexity research departs from the view point that, though the tools from reductionist science provide us the ability to trace and disentangle most of such behaviours, their use will often only produce partial explanations. Notwithstanding the fact that reductionist explanations can be very powerful, *patterns* in these behaviours also need to be identified, so that a more holistic understanding of phenomena can be achieved.

Models of Emergence

'*Models of emergence*' pave the way for developing new approaches that can be used to complement reductionist approaches:

Models of Emergence

Models of emergence can help to put the finger on system properties or behaviours that cannot be reduced to those of constituent parts; those that make the whole more than the sum of the parts; those that emerge out of seemingly random patterns. Classical models of this genre are computer simulations of cities, bird flocks, or stock markets…, each allowing a multitude of 'agents' (e.g. the citizens, birds, or traders in these simulations) to interact and make decisions.

A striking feature of these models is that, when the modeler/experimenter endows agents with small sets of simple properties and behavioural rules, the consequent aggregate (emergent) behaviours can be far from simple, and can also be surprisingly realistic.

Another characteristic of models of emergence is their ability to provoke a '*bottom-up*' way of viewing how systems are, or can be, engineered. This means that they allow us to see how large-scale *macroscopic* properties and or behaviours of systems can emerge 'from the bottom up', i.e. from the interactions of many – human or artificial – agents that obey simple behavioural rules operating only on a local *microscopic* scale.

Artificial Life Models

Particularly inspiring are models of emergence used in *artificial life* ('Alife'); a field in complexity research that concentrates on living systems. Illustrative of Alife-models are *ant colony models* that convincingly demonstrate that the process of an entire ant colony being fed can be understood as an emergent result of a multitude of agents (ants) obeying a few simple rules (that involve leaving trails of pheromones).

Alife-models are inspiring because of their ability to effectively portray the contrast between nature and the human-engineered world since a human engineer would tend to develop systems top-down. Moreover, these models can also have practical uses, since they can help to widen the horizon with regard to considering alternative engineering paradigms. Returning to ants, one practical example is British Telecom that considered ant colony models to be useful analogues for its call-routing network (successful calls leaving an equivalent of pheromone to guide future calls etc.).

NOTE. A way to quickly familiarize oneself with complexity research is to interact with simple models of emergence. Demos of simple models exist on the Internet, some of which are quite user-friendly. The CD-ROM provides links to some particularly instructive demos.

Developments Connected to Complexity Research

Placed in the center of Figure 2.1 is a cluster of three developments that are connected to complexity research:

- Studies of complex systems
- New paradigms in social science
- Organizational intelligence

Studies of Complex Systems

In studies of complex systems, the intellectual excitement that surrounds models of emergence is combined with the seriousness of practical application of complex systems theories.

Complexity in Social Science

In practical applications of complexity to social problems, it is dealt with social and organizational systems that consist of *pro-active* agents (unlike the passive elements of complex systems that are studied in the natural sciences). It is very difficult to ascertain the written and unwritten rules by which these agents operate. Simulated experiments can help to identify those rules, but they also introduce a potential bias: the modeler/experimenter is tempted to select rules that generate desired results.

Therefore, 'complexity in social science' currently involves the application of a myriad of approaches combining computer modeling and simulation with other methodologies; e.g. case studies, applied mathematics (e.g. in the realm of social network dynamics) and so on. Most of the approaches are still under development, as can be illustrated with some well-known applications to problems in economy and business:

The Economy as a Complex Adaptive System

In Santa Fe … considerable energy has been dedicated to the study of 'the economy as a complex adaptive system'. A well-known result in this field is Arthur's theory of 'increasing returns to scale' in the economy; i.e., the tendency of that which gets ahead to stay ahead and go on to lock in a market. Twenty years later, the scientists involved at Santa Fe came to note that the meaning of the complexity perspective in economics is still unclear. The complicating factor is, as stated earlier, how to treat and model agent proactivity, strategy and foresight:

> "Complex systems arise naturally in the economy. Economic agents, be they banks, consumers, firms, or investors, continually adjust their market moves, buying decisions, prices, and forecasts to the situation these moves or decisions or prices or forecasts together create. But unlike ions in a spin glass which always react in a simple way to their local magnetic field, economic 'elements' – human agents – react with strategy and foresight by considering outcomes that might result as a consequence of behaviour they might undertake. This adds a layer of complication to economics not experienced in the natural sciences." (Arthur 1999)

Computational Laboratories (c-Labs)

Computational laboratories are computational frameworks that permit the study of complex system behaviors by means of controlled and replicable experiments. They are broadly considered to be important vehicles for practical application of complex systems theories. Illustrative for c-Labs are the 'Santa Fe Artificial Stock Market' and, more recently, the framework for studying decentralized electricity markets developed at Argonne National Laboratory:

> "Many electricity markets are undergoing or are about to undergo a transition from centrally regulated systems to decentralized markets. Furthermore, several electricity markets have recently undergone this transition with extremely unsatisfactory results, most notably in California. These high stakes transitions require the introduction of largely untested regulatory structures. Therefore, suitable laboratories that can be used to test regulatory structures before they are applied to real systems are needed." (Veselka et al. 2002)

Note also in this application the centrality of strategy and foresight:

> "(…) as the simulation progresses, agents can adapt their strategies, based on the success or failure of previous efforts …" (Veselka et al. 2002)

New Approaches in Social Science

Social scientists seem to have become increasingly willing and prepared to embrace the prevalence of *fundamental uncertainties* and *indeterminacy* in their studies.

Fundamental Uncertainties

Fundamental uncertainties are those uncertainties in an investigation that cannot be removed by means of adding more knowledge and information. Uncertainties of this kind tend to arise when studies are designed to address questions that relate to people's continuous feedback relationships with systems; i.e. people change a system while simultaneously being changed by that system (henceforth referred to as 'reflexivity'). In an increasingly interconnected world, questions of this nature are becoming more frequent and more important (e.g. climate change studies).

Fundamental uncertainties can seriously affect studies, imposing at least two types of restrictions:

- A limit of the extent to which insights can be obtained in an OBJECTIVE manner;
- A limited ability to PREDICT future changes and consequences of such changes.

Indeterminacy

Often, perhaps increasingly so, studies are also affected by indeterminacy, especially if their focus is on strategic interaction in social contexts. The imposed restriction is, as an economist would phrase it:

- A limit to determine what is RATIONAL.

Indeed, such indeterminacy is pervasive in economics. It is pervasive because our choices have social (or interactive) contexts.

It therefore seems only a matter of time, before social scientists will consider computational tools (algorithms, simulation models) to be viable and complementary alternatives to more traditional tools, the latter losing much of their power in contexts of fundamental uncertainties and indeterminacy. Encouraging in this respect are past experiments that demonstrate productive interplay of computational tools and social research paradigms, as illustrated with the Prisoner's Dilemma:

The Prisoner's Dilemma

In the simplest version of the puzzle that is called the Prisoner's Dilemma (PD), two individuals can either cooperate or defect. No matter what the other does, the selfish choice of defection yields a higher payoff than cooperation. But if both defect, both do worse than if both had cooperated. The usual analysis of this puzzle by game theorists notes that the Nash equilibrium is for both players to defect. This simple puzzle has proven to be a powerful means of illustrating a conflict between individual and group rationality. A group whose members pursue rational self-interest may all end up worse off than a group whose members act contrary to rational self-interest. More generally, if the payoffs are not assumed to represent self-interest, a group whose members rationally pursue any goals may all meet less success than if they had not rationally pursued their goals individually. PD attracted widespread attention in a variety of disciplines, and continues to provoke new ways of thinking about human selfishness, competition and collaboration, trust and rationality (e.g. PD has been investigated by RAND for possible applications to global nuclear strategy.)

New Tools and New Prisoner's Dilemmas

Of interest in the history of PD is the dynamic interplay of tools and social research paradigms and the crucial role for experimentation enabled by computer models. Consider for example the four axes of PD-investigations embracing themes like evolution and adaptation (IPD and EPD), geography (SPD) and networks (SWPD):

- ITERATED PD (IPD)

IPD is an iterated version of the game in which players play the PD repeatedly, retaining access at each round to the results of all previous rounds. In these iterated PDs, players who defect in one round can be 'punished' by defections in subsequent rounds and those who cooperate can be rewarded by cooperation. Thus, the appropriate strategy for rationally, self-interested players is no longer obvious.

- EVOLUTIONARY PD (EPD)
  A population of players, employing various strategies, play IPDs among themselves. Lower scoring strategies decrease in number, the higher scoring increase, and the process is repeated. Thus success in an EPD requires doing well with other successful strategies, rather than doing well with a wide range of strategies.

- SPATIAL EPD (SPD)
  In many social and biological situations said to be modeled by an EPD, individuals interact only with those within some geographical proximity. Areas inhabited by less successful individuals might be adopted by more successful neighbors. Alternatively, less successful individuals might adopt the strategies of their more successful neighbors. A spatial PD attempts to add this geographical feature to the game.

- SMALL-WORLD SPD (SWPD)
  Many individuals have access to the media or the Internet. Interactions and social influence no longer occurs only among neighbors, but also via long-distance connections. A SPD with a 'small-world-type network' can be used to model reduced degrees of separation among individuals. For example, SWPD has been used to investigate the dynamics of smoking among teenagers, which is influenced by various factors including local social surroundings and the examples set by media role models.

Organizational Intelligence

Complexity thinking has considerable impact on management research and practice. A hot topic is *organizational intelligence*:

<u>Organizational Intelligence</u>

Organizational intelligence is a way of thinking that expands on the idea that 'smart' organizations have a high 'IQ'; the latter being an indicator of how effective they are in the acquisition and use of knowledge. It is broadly recognized that the ideas about 'learning organizations' connected with cybernetics can yield valuable insights for managers of organizations that are exposed to severe fluctuations in 'stocks and flows' systems (e.g. supply chains). The prospect of organizational intelligence based on a view of organizations as complex adaptive systems rather than stocks and flows systems is to yield insights into ways of (re)designing organizations, with the goal to optimize their 'overall cognitive performance' so that they can adapt more easily to rapidly changing environments.

<u>Knowledge Technologies (KT)</u>

Information technologies, and in particular 'knowledge technologies', may prove very important for designing intelligent organizations. KT concerns an expanding domain of information technologies best characterized by *web services*; i.e. miscellaneous services for businesses and communities that can be deployed on webs (e.g. on the Internet's 'world wide web').

Knowledge technologies are expected to substantively impact organizational life. For example, the unfolding of KT is said to involve developments in organizing work and commerce, new ways of using technologies, new forms of social interactions and coordination and the unleashing of creativity and distributed intelligence. Of particular interest is whether future web services when sufficiently strengthened by experiences with deployment in testing environments and improvements of the underlying web technologies can be used to evolve *ecologies of web services*; a way of thinking about design that may be at the base of an enabling technology for achieving adaptiveness in intelligent organizational systems.

2.2 Outlook on Complexity in Foresight

What could be the essential ingredients of complexity in foresight? In this section, a tentative answer to this question is given in the form of an 'outlook' on complexity in foresight. This outlook marks the starting point of the 'journey' in this thesis and is treated in depth in Chapter Three.

Extrapolation

The overview in Figure 2.2 is an extrapolation of the developments highlighted on the roadmap in Figure 2.1.

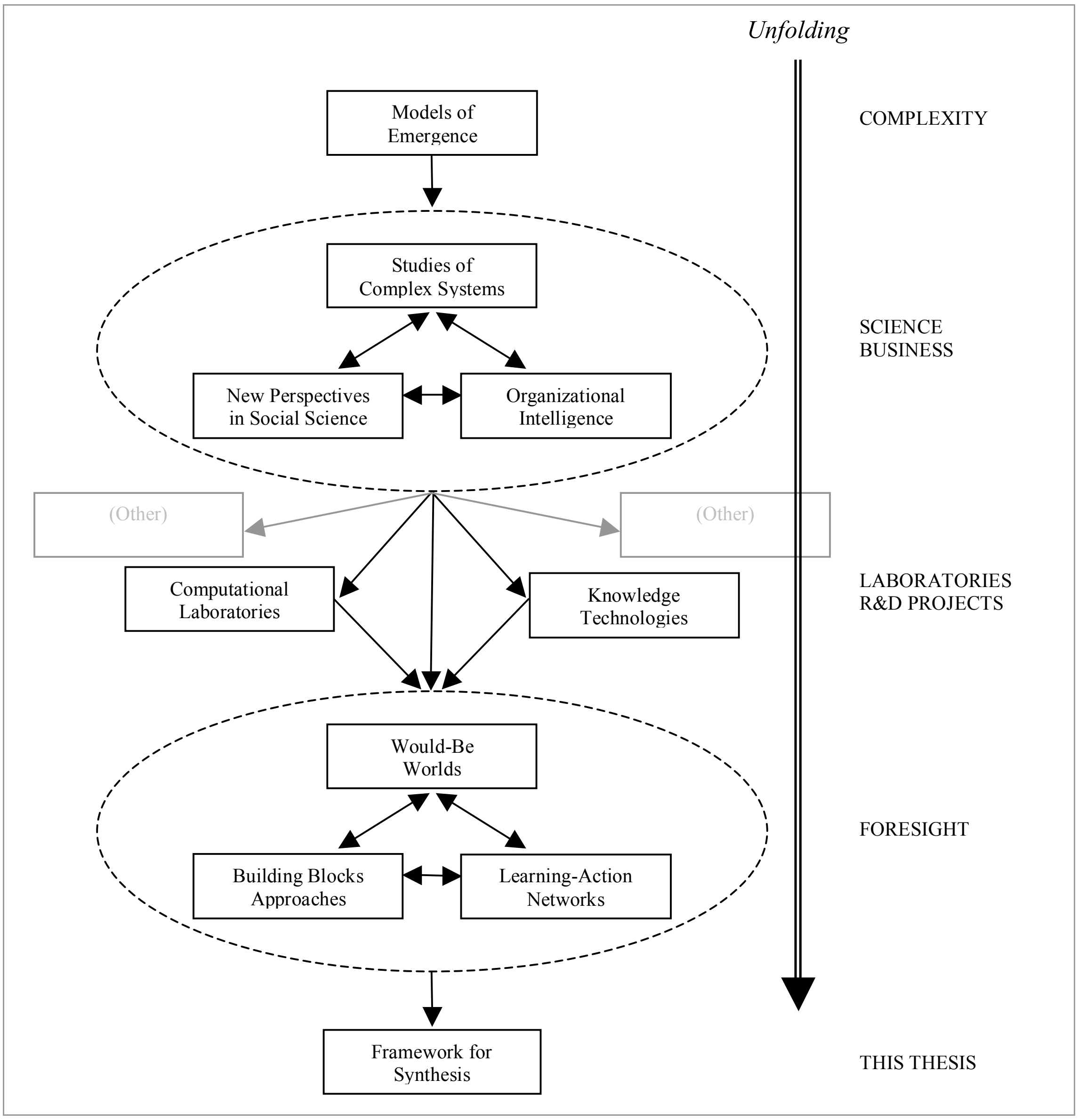


Figure 2.2 Roadmap Part 2: Complexity in Foresight

The following paragraphs are dedicated to a brief discussion of the three proposed ingredients of complexity in foresight:

- Would-be worlds;
- Building-block approaches;
- Learning-action networks.

Would-be Worlds

The first proposed ingredient of 'complexity in foresight' is the centrality of *would-be worlds*; i.e. computational laboratories that can be used for the generation of *would-be scenarios*.

Would-Be Worlds

Would-be worlds are simulation models created on computers that can function as laboratories allowing experiments about the real world (Casti 1997). In principle, this covers a wide range of computer simulations. One important category consists of *microsimulations* that usually work with large quantities of detailed empirical data (e.g. traffic microsimulations for metropolitan areas). Another category could be the simulation *games* on computers meant for education or entertainment (e.g. 'The Sims').

Would-Be Scenarios

Besides microsimulations and gaming, would-be worlds can also be dedicated to the generation of 'would-be scenarios' capturing realities far from observed facts (hence 'would-be'). Such scenarios can be based on unconventional perspectives on reality that are inspired by complexity thinking. Their potential usefulness is in making it easier for planners to switch between reality and intuition.

Building-Block Approaches

Ideally, in *adaptive* strategic planning processes, building-block approaches allow planners to deal with diverse challenges as they arise. In practice, however, it will often not be clear which building blocks to use (e.g. because of lack of clarity about the meaning of the complexity perspective, fundamental uncertainties and indeterminacy). Knowledge technologies can potentially help to bridge this gap.

Building-Block Approaches and Knowledge Technologies

Knowledge technologies can be important enabling technologies for building-block approaches in strategic planning processes.

To see this, consider first the *object-oriented paradigm* (OOP), which is exemplified by the popular Java programming language. With OOP, complex bodies of knowledge can be organized in ways so that it becomes easier to achieve synthesis of that knowledge. For example, in Java, one typically works with 'libraries' of objects, each of which can readily contribute the 'knowledge' that allows that object to effectively solve a very particular problem.

A problem with OOP is that *it must be exactly known which objects to use*. This is often not the case in building-block approaches, since by definition they require the ability to rapidly learn which building blocks to use. Knowledge technologies can potentially help to meet this requirement, mainly by virtue of its recipe of creation and use of *meta-knowledge* (i.e., sets of linkages over and above existing bodies of knowledge). Returning to Java, one could, for example, build meta-knowledge that enables 'smart' programs to reason which objects out of the many objects in libraries are likely to perform well together. Likewise, in building-block approaches, it is conceivable that the creation of meta-knowledge can enable 'smart' tools to facilitate synthesis.

Learning-Action Networks

The third proposed ingredient of 'complexity in foresight' is the concept of *learning-action networks* (LANs). The concept of LANs can potentially help bridge the gap between thinking about organizational intelligence and practices in strategic planning processes.

Learning-Action Networks (LANs)

Learning-action networks (LANs) are sets of *informal* linkages that overlay and complement formal organizational structures to tie individuals together through a flow of knowledge, information and ideas. These networks have been identified to have a critical role for sustainable development (Clarke and Roome 1999).

LANs and Organizational Intelligence

The concept of LANs captures how thinking about organizational intelligence can be applied to communities made up of individually acting agents that are socially connected.

2.3 The Framework for Synthesis

Figure 2.3 shows an overall conceptualization of the ideal Framework for Synthesis and associated terms. Note that the focus is on the conceptualization of one aspect in particular: a *unifying process* to develop and use would-be worlds.

NOTE. This sketch has been elaborated with a particular application field in mind: in the intersection of sustainable development, innovation, and policy. A few examples of such applications are listed below:

Applications in the Intersections of Sustainability, Innovation and Policy

- ECOSYSTEMS
  Investigations into complex ecosystem behaviours ('punctuated equilibria', emergent 'self-organization') can help achieve more robust planning for the management of human interaction with ecosystems and the preservation of ecosystems integrity.

- NATURAL RESOURCES ('THE COMMONS')
  Simulated experiments with populations of agents can lead to the discovery of new mechanisms for governing the commons; e.g., the emergence of institutional arrangements (norms) from social interactions.

- ENERGY SYSTEMS AND TRANSPORT SYSTEMS
  Planning for the transitions toward more efficient, reliable and sustainable energy systems and transport systems requires exploration of many 'what-if scenarios' for 'testing' new policies; e.g., those that anticipate the emergence of new markets. A natural approach for the generation of such scenarios is to conduct simulated experiments with populations of agents that interact in different ways with those systems.

- ECONOMIC DEVELOPMENT OF REGIONS, COUNTRIES AND CITIES

THE FRAMEWORK FOR SYNTHESIS

What is the Framework for Synthesis?

- **The Framework supports learning-action networks (LANs) for sustainable development.**

  What are LANs?

  - They are sets of informal linkages that overlay and complement formal organizational structures.
  - They tie individuals together through a flow of knowledge, information and ideas.

  What kind of support does the Framework provide?

  - The Framework enhances the roles for LANs as:
    - Catalysts for innovation.
    - Platforms for embracing contradictions and tensions.

How does the Framework function?

- **The Framework facilitates a unifying process to the development and use of would-be worlds.**

  What are would-be worlds?

  - They are simulated experiments run on a computer.
  - They are used to test hunches and unconventional perspectives on problematic realities (including, but not limited to, complexity-based perspectives).
  - They are valid objects to be studied in-depth: what would be the consequences of changing the rules in these would-be worlds?

  What kind of unifying process does the Framework facilitate?

  THIS QUESTION IS ANSWERED IN THE THESIS

- **Out of this process evolves a flexible workbench.**

  What kind of workbench?

  - It enhances the capacity to handle a multitude of problem-solving elements rapidly and interactively (what-if questions, posing hypotheses, checking consequences, feeling intuitions).
  - It brings simplicity in dealing with complex processes and scenarios that are evolutionary and open-ended.
  - It provokes serendipities (finding what was not searched anticipated).

- **This workbench can be used to produce would-be scenarios "on demand"**

  What are would-be scenarios?

  - They are simulated experiments with would-be worlds that are well understood.
  - They allow experimenters to jump far from observed facts (hence "would-be").
  - They make it easier to switch between reality and intuition.
  - They contribute to problem-solving.

Figure 2.3 The Framework for Synthesis

3 OUTLOOK
Creating Would-be Worlds out of Building Blocks

3.1 Advances in Agent-Based Social Simulation

This chapter provides insight into the interconnections among the three key concepts upon which this thesis is developed: would-be worlds, synthesis, and learning-action networks. It covers these concepts with the question in mind: *How to build would-be worlds that offer practical support for tackling problems in the real world?*

3.1.1 New Frontiers

Agent-based social simulation (ABSS) has often been called a *bottom-up* approach to social science, placing it in contrast to the *top-down* approach traditional in social science. In this context *'bottom-up'* basically means to leave out the usual ideas[2] about how individual behaviours aggregate to collective outcomes and to let agents generate the collective outcomes by themselves.

Agent-Based Social Simulation (ABSS)

A simple heuristic for ABSS is the following:

- SETTING UP A SIMULATION
  Rules have to be generated that specify how individual agents behave (e.g. how they move around, how they interact with other agents). These rules can be few and simple, using only little pieces of information about the agent world.
- RUNNING A SIMULATION
  Once the rules have been specified, we can run the simulation and observe the aggregate outcomes that are generated by the interactions of the agents. We would hope for some resemblance to social phenomena in the real world, requiring outputs that show some regularities; complete randomness would not be very interesting.
- INTERPRETATION
  By repeating the simulation with different starting situations and with different rules, we learn more about the relationships between the actions of individual agents and the aggregate outcomes, provided that these relationships are tractable. This learning process may help us in theorizing about the relationships between individual behaviours and collective outcomes in the real world.

ABSS and other bottom-up approaches that involve simulated experiments[3] depart dramatically from traditional modeling practices in social science, and have caused some ripples in a number of disciplines[4]. For example, in the mid-1980s a group of leading economists[5] came to share the belief that the possibility of doing this kind of simulated experiments presented a new frontier in economics. Similar beliefs have been expressed expressed by leading scientists in other disciplines in social science. Indeed, the approach is inherently *interdisciplinary* because its only requirement is the

[2] The kind of ideas that social scientists have deeply appreciated; e.g., the idea that equilibrium emerges from *rational* individual agent behaviours.
[3] Social scientists have done interesting simulated experiments with *cellular automata*.
[4] This is remarkable because the technology is a natural development in computing (i.e. *distributed* and *object-oriented* designs).
[5] The story of Brian Arthur, Kenneth Arrow and others is told by Mitchell Waldrop (1992).

specification of local rules for individual agent behaviours, and consequently, on that (*micro*-)level the boundaries between disciplines become meaningless.

In the present, twenty years later, we see that new scientific fields[6] are emerging. Social scientists have committed themselves to interdisciplinary research with crucial roles for computation. This thesis work is based upon some of these domains of new theories and new technologies[7].

3.1.2 Breaking Ground

The advances to the current scale of ABSS-related activities were possible first of all because of the availability of affordable high-quality computing. Another important stimulus was produced by three influential books that were published around the mid-1990s, that created excitement among many social scientists about the possibility of doing their *own* simulated experiments. What these books had in common is that they presented interesting results with ABSS-models that worked with small sets of simple rules for specifying agent behaviours. Also, it was very important that these books presented their materials in ways that made them accessible to social scientists, requiring no background in mathematics or computer modeling. Those three books are highlighted in the following paragraphs.

Sugarscape

In 1996 Joshua Epstein and Robert Axtell published a book and a CD-ROM with a presentation of their simulations with an artificial society that they called *Sugarscape* (Epstein and Axtell, 1996).

> <u>Artificial Societies: Sugarscape</u>
>
> In a series of simulated experiments with an artificial society called "Sugarscape", Epstein and Axtell were able to show how socio-cultural phenomena like trade, wealth and warfare arise naturally out of simple actions of individuals. Artificial societies are would-be worlds that allow agents to do things like engage in combat, exchange cultural traits, sexually reproduce, transmit diseases, and so on. In Sugarscape, the agents live on a landscape that provides them sugar they need to eat in order to survive. Of course, the landscape and sugar merely serve as an easy-to-grasp context for their 'social' or 'anti-social' interactions.
>
> Epstein and Axtell's approach was to use Sugarscape as a laboratory for testing hypotheses with controlled experiments. For each of the socio-cultural phenomena that they investigated they used more or less the same kinds of hypotheses; i.e., they asserted that simple local rules for individual behaviours can be sufficient to generate the phenomena under investigation.

Their work has been influential, mainly because it convincingly demonstrated, to a broad audience, the potential usefulness of ABSS as a new, methodologically sound, way of doing social science and to break disciplinary boundaries at the same time.

[6] Up-to-date overviews are maintained on the Internet. The CD-ROM offers a page on which the most informative web sites are listed.
[7] See previous note.

Evolution of Cooperation

In 1997 Axelrod gathered together the results of a decade of his work on competition and cooperation among agents (Axelrod 1997).

> Evolution of Cooperation: Axelrod's Experiments
>
> Axelrod recognized that ABSS allowed him to relax the assumptions about rationality that game theory typically was based upon. In his book he made the case for a move toward models that allow agents to behave in ways so that aggregate outcomes exhibit processes of adaptation (inspired by Holland's work with CAS and GA's) and presented the rich results of his simulated experiments with simple ABSS-models. For example, in one of these experiments, the Evolutionary Prisoner's Dilemma, he incorporated a mechanism for individual learning (implemented with a genetic algorithm) that allowed agents to evolve their strategies based on their previous experiences.

Axelrod's work has been influential for several reasons. First of all, the problem of cooperation is an important one, and he was able to present simulation results that were rich and often surprising. Also, Axelrod succeeded in bringing fun to the study of a depressing problem, thanks to his particular approach[8] to ABSS which he compared to "doing thought experiments". A very important facet was his engaging style of presentation, with practical suggestions on how to apply ABSS to social problems.

Echo

In 1995 John Holland documented his insights pertaining to complex adaptive systems (CAS) (Holland 1995). CAS is a way of thinking, presented by Holland in the form of a few very general principles, about how certain systems of agents[9] accomplish fascinating behaviours like evolve, adapt, agglomerate, compete, cooperate, and in doing all these, create ever-greater *diversity* and *novelty*. These principles might apply to many important systems that are studied in social science. For example, in the emerging field of economics called *agent-based computational economics* (*ACE*), CAS has now become an important way of thinking about decentralized market economies (Tesfatsion 2002).

> Echo and the Study of Complex Adaptive Systems
>
> Holland advanced his thought experiments about CAS, using a model of artificial life called Echo. Simply stated, Echo is a would-be world that allows populations of agents to evolve into systems that possess features similar to ecological systems that are comprised of communities of organisms: they evolve, adapt, agglomerate, compete, cooperate, and in doing all these, create ever-greater diversity and novelty. The results of his experiments with Echo documented that CAS can simulate fascinating behaviours spontaneously; i.e., with no central planning.
>
> Genetic Algorithms and Agent Learning
>
> Holland's particular approach was based on the *genetic algorithm* (GA) (Holland was the inventor of GA). GA's were inspired by Darwin's theory of evolution. With GA's, the ways agents solve problems, their 'strategies', are outcomes of an evolutionary process resulting in the best (fittest) strategies (the surviving strategies). In other words, their strategies evolved.

---

[8] Famous are his computer tournaments for PD. Axelrod invited people with diverse backgrounds (not only game theorists) to submit strategies, and used a computer to organize a competition among the strategies that he received (pairing them with each other in a round robin tournament).

[9] The examples that Holland used were: cities, immune systems, central nervous systems, and ecosystems.

> This innovative GA-approach grew out of his concern that in ABSS, even if the rules for individual agent behaviours are few and simple, the risk remains that aggregate outcomes depend on the way the simulation is programmed, possibly in ways that are very hard to reveal. If this were the case, he could no longer claim spontaneity. Holland saw that a way to avoid this was to take the GA-approach to the extreme: starting with 'stupid' agents and programming so that everything agents do later on is based on what they have *'learned'*.
>
> His approach raised a new crucial question: HOW DO WE LET AGENTS LEARN? When the programmer selects a learning mechanism, does s/he still (unconsciously) steer the experiment to outcomes that were 'programmed' into the model? Solutions are believed to lie in the realm of algorithms, but have not been found yet.

Holland's work was certainly the most ambitious project in ABSS. His way of thinking about creativity, diversity and novelty were of special interest to economics, and pushed the evolutionary movement in economics.

Summing Up

Axtell and Epstein demonstrated that ABSS can be a legitimate new way of doing social science. Axelrod showed that we can pick out specific problems – the sort of problems that resist major scientific advances despite the attention of several disciplines – and apply ABSS to create the synergetic energy necessary to push forward. And Holland produced an ambitious roadmap toward new social theory in the form of a comprehensive way of thinking about complex systems of agents and what these systems are capable of doing.

3.1.3 Extensions and Reflection

The simulated experiments described in these three books have been repeated and studied by other social scientists, and some extended them with new ideas. Of course many other interesting studies involving ABSS have been done since the mid-1990s, but I will not attempt here to give an overview[10]. Instead I wish to proceed with a reflection on: *what is the novelty that ABSS brings to social science?* I think there are two important ways of how the novelty is usually perceived.

Computer-Based Thought Experiments

ABSS presents a novelty to social science because it offers the possibility to involve populations of artificial agents in experiments that can be repeated more than one time under exactly the same circumstances. This is impossible to do with real agents (people or human organizations).

The technology behind ABSS gives researchers great freedom and flexibility in what they let virtual agents do. They can now do experiments using very sophisticated designs for individual agents, based on artificial intelligence, that allow agents to do things like: perceive, reason, make decisions, communicate, be social, have emotions, visually resemble real agents, and other humanlike behaviours[11]. They are still a long

[10] This thesis author recommends the on-line *Journal of Artificial Societies and Social Simulation* for learning about some of the recent studies involving ABSS - http://jasss.soc.surrey.ac.uk/JASSS.html

[11] This is not to say that experiments with humanlike agents are necessarily more interesting than experiments with simple agents!

way from designing agents with capabilities that match those of humans, but compared to the traditional agent in economics there are enormous possibilities to “give agents more space to breathe”.

Complexity

The novelty of ABSS and other bottom-up approaches to social science is often associated with another frontier in (social) science: *complexity*.

> “Social processes are complex when they are not neatly decomposable into separate subprocesses; economic, demographic, cultural, spatial, whose isolated analyses can be aggregated to give an adequate analysis of the social process as a whole.” (Axtell and Epstein, 1996, pg. 1)

Thus complexity tells something about the nature of (social) processes in the real world, and when processes are "truly bottom-up", the value of analyses using top-down approaches is in question[12].

This indeed captures much of the motivation behind a remarkable chapter in the groundbreaking research on complexity: the pioneer-style collaborations across disciplines involving computer scientists, physicists, mathematicians, economists that started in the mid-1980s in the *Santa Fe Institute* (*SFI*). These pioneers shared a concern about the long-standing dominance of reductionist thinking in science, and the enormous impact it had on the way science is organized, the methodologies and tools that scientists use, and so on. They believed that "reductionist science" is not capable of fully addressing crucial questions in science, which, as a result, are disqualified from that science. Of course social science was no exception (already mentioned was the revolt by a group of leading economists at that time, who were all frequent visitors of Santa Fe).

The pioneers from SFI were trying to grapple with an unconventional category of questions about all kinds of complex systems in mathematics, physics, biology, economics, psychology, and sociology. What these questions had in common is that they all referred to emergent properties of complex systems. *Emergent properties* are the large-scale (or in another sense "global") effects of a great many interacting "agents" in these systems that act independently and obey simple local rules. For example, according to this perspective, liquidity is an emergent property of interacting water molecules, the mind is an emergent property of interacting neurons, and a market is an emergent property of interacting traders, and so on.

The questions that are addressed in complexity research are of the kind: *how do emergent properties produce emergent behaviours or emergent phenomena?* In our examples before: how does water turn to ice when cooled down? How does the mind

[12] Many different interpretations of complexity exist. One interpretation of complexity is that it is a feature of something, a property that can be measured. Bruce Edmonds (1999) proposed a definition of complexity as a property of a model:

> "Complexity is that property of a model which makes it difficult or impossible to formulate its overall behaviour in a given language, even when given reasonably complete information about atomic parts and their interactions".

learn from experience? Why do markets crash? In search for more convincing answers to these questions, complexity research aims to go beyond the level of explanation produced by linear, reductionistic thinking. In fact it readily points out the limits of reductionistic thinking. If emergent behaviours or emergent phenomena are the result of a truly bottom-up process of change, they cannot be explained purely in terms of the behaviour of the agents. In other words they cannot be *reduced* to the behaviour of the agents.

This is an important position, and therefore, I clarify this position by turning back once more to our examples. Reductionistic thinking leads to the questions: how do molecules behave when water becomes ice? How do neurons interact when the mind is learning? How do traders behave when a market crashes? By using tools from reductionist science we might be able to trace back all these behaviours, but they will only produce partial explanations. Complexity research stresses that we also need to identify patterns in these behaviours that hopefully will add to a more holistic understanding of the particular phenomenon.

The all-important implication for bottom-up modeling practices in social science like ABSS is that what counts is not only finding the right answers, *but also finding the right questions to ask.*

A good example of the importance of asking the right questions is demonstrated in the 1971 thought experiment by Thomas Schelling[13].

Asking the Right Questions:
Schelling's Segregation Model

In 1971 Schelling published a well-known thought experiment that illustrates how ABSS can help one to develop the right questions to ask.

Ethnic segregation into distinct geographical neighborhoods is often considered to be a product of discrimination or effects of economic constraints. Schelling's original question was: "Suppose that families have only a slight preference to live in neighbourhoods in which their own ethnic group is a majority: Could this already be sufficient for ethnic segregation to happen? By investigating the properties of a *cellular automaton* – a population of agents situated on a two-dimensional grid (or in Schelling's case: represented by pieces placed on a chess board, Schelling pointed out that if families, both black and white, prefer to live in neighbourhoods in which their own ethnic group is a majority, and they are able to move to the nearest location which satisfies this desire, complete segregation will inevitably emerge.

[13] Ethnic segregation into distinct geographical neighbourhoods is often considered to be a product of discrimination or effects of economic constraints. By investigating the properties of a cellular automaton, Schelling pointed out that if families, both black and white, prefer to live in neighbourhoods in which their own ethnic group is a majority, and they are able to move to the nearest location which satisfies this desire, complete segregation will inevitably emerge.

Considering the course of complexity in social science, there are at least two general directions for finding interesting questions:

Directions in Complexity in Social Science

- MYRIAD SIMPLE PARTS, BAFFLING WHOLE
  Results of experiments with computer models have highlighted that simple local rules are sufficient to generate very rich patterns of behaviour and in some cases the emergent properties, behaviours, and phenomena that have our particular interest. Examples are the *Game of Life* (Conway) and Sugarscape. The surprise might not be in the phenomena themselves, but in the fact that a small set of simple local rules is sufficient to generate them.

- EDGE OF CHAOS
  Certain complex systems are capable of producing sudden large-scale changes and transitions, bringing them from chaotic states to spontaneous order and back. Complexity research has produced theory about such systems capable of self-organization, e.g. complex adaptive systems. Though water is static and passive (not a CAS), the brain constantly organizes and reorganizes its billions of neural connections so as to learn from experience, and markets constantly respond to changing tastes and lifestyles, technologies, prices. This coherence in the midst of continuous interaction and change is often referred to as the 'edge of chaos' (EoC). Insights into EoC-phenomena might challenge the preconceptions of social scientists about stability and order in the systems that they study. In EoC, *diversity* among agents - often overlooked to make things manageable - becomes very important. Order can no longer be associated with the usual idea of an equilibrium that requires no effort to retain its structure and great effort to change it. Self-organizing systems are capable of order when they are *far from equilibrium*. And this self-organized order requires great effort to retain its structure and relatively little to change it.

Summing Up

ABSS offers to social scientists the possibility of doing computer-based thought experiments with virtual agents that mimic the behaviours of real agents (people or human organizations). Complexity research gives us promising directions for finding interesting questions about the virtual worlds that we create. Thus the combination of both novelties that ABSS brings to social science - computer-based thought experiments *and* complexity - is potentially a powerful one, yet the point I wish to make here is that each presents a novelty in its own right.

This reflection about the novelty that ABSS brings social science allows me to make the following point. I think the essence of the new way of doing social science is captured by the verb *amalgamate*; i.e. to find the right elements (interdisciplinarity, simulated experiments on the computer, mathematics, empirical studies) and discover the adequate proportions to combine them into a unified whole[14]. With this general idea in the back of

[14] In this context it is worth studying Axelrod´s comment on induction and deduction:

> "Agent-based modeling is a third way of doing science. Like deduction, it starts with a set of explicit assumptions. But unlike deduction, it does not prove theorems. Instead, an agent-based model generates simulated data that can be analyzed inductively. Unlike typical induction, however, the simulated data come from a rigorously specified set of rules rather than direct measurement of the real world. Whereas the purpose of induction is to find patterns in data and that of deduction is to find consequences of assumptions, the purpose of agent-based modeling is to aid intuition." (Axelrod 1997, pg. 3-4)

our minds, we shift our attention now from building would-be worlds for social science to building would-be worlds for management.

3.1.4 Toward Tackling Problems in the Real World

There is surprisingly little known about how to build agent-based simulation models that offer practical support to tackle problems in the real world. It certainly has not escaped attention, as there is a broad and persistent list of questions about practical application of ABSS that are subjects of ongoing discussions among ABSS communities. This list includes questions like:

- How can we use data from the real world?
- What combinations of methodologies will work?
- How close must the would-be world be to the real world?
- How can we validate the simulation model?
- How can we communicate our experiences with a would-be world to others?
- How can we benefit from building more than one simulation model?

This study adopts the view that the quest for practical solutions cannot be resolved by looking at theory and technology alone, but that it requires addressing all aspects of a modeling project. I propose to seek for solutions along some kind of *unifying process* that integrates many aspects of the modeling project, like the design and development of the would-be world, how people interact with the would-be world, how results are communicated, all the while balancing the trade-offs that are inherent in modeling, and sustaining creativity.

This study aims to contribute to the development of a *framework* to steer such a unifying process in practical situations. In light of what already has been said about would-be worlds for social science, it is important that this framework will be based on insights into how ABSS can be used as a legitimate way of doing social science, and how the novelty that it brings to social science can be perceived in different ways.

The remaining part of this chapter begins the quest for such a framework by zooming in on one crucial aspect of the modeling project: the *creative process* of *building would-be worlds*. Right from the start the focus is on particular, very practical kind of applications for would-be worlds: *management tools*.

Would-be Worlds for Management

Management tools based on simulation have deserved their own place among the endless variety of management tools that currently exist. They differ in the kind of support they offer. Management tools that are often associated with simulation are prediction, *management flight simulators*, and *Monte Carlo simulations*.

Among these simulations, management tools that are based on would-be worlds can fill a specific niche. They are unique in their ability to *jump from observed facts*, meaning that it is possible to embody in a would-be world an unconventional point of view on a broad range of issues and questions that allow management to explore new realities (that otherwise perhaps would be disqualified as being unrealistic).

The particular approach that is proposed here is to use the ABSS-model to generate *would-be scenarios* that allow us to switch from intuition to reality and back.

To narrow it down further, a few more concrete ideas follow about the kind of would-be scenarios that could be of most value to management or policy-makers when dealing with sustainability problems:

Snapshot of Would-Be Scenarios to Support Management or Policy-making

The most valuable would-be scenarios:

- INTRODUCE UNCONVENTIONAL PERSPECTIVES
  The most valuable would-be scenarios introduce unconventional perspectives to a problem, (e.g. as a result of application of complexity thinking and agent-based simulation)

- PROVOKE WITH COUNTERINTUITIVE RESULTS
  They do not aim for an accurate representation of the real situation, but rather aim to provoke new points of view and to surprise, by generating the kind of counterintuitive results that are characteristic of complexity studies.

- HELP EXPLORE ENDOGENEOUS EVOLUTIONS
  - They show a desired large-scale transformation on the macro-level.
  - They demonstrate that a key to that transformation, if not the key, is local change, involving the micro-level decisions and interactions of a great many individual agents.
  - They show that local changes add up to large-scale transformations, when sudden shifts occur away from how things were organized until then, something new happens, there is true synergy (i.e. the idea of self-organization in complexity theory).

3.2 Creating Would-be Worlds

At this stage it is helpful to acquire an overall picture of the creative process of building would-be worlds. A good way to obtain such a picture is to repeat Axelrod's agent-based models[15]. His work is a valuable resource to learn about agent-based modeling, especially because of the excellent introductions he gave to each of the modeling projects. He used the introductions to show how a project grew out of his long-term interests, recounted experiences related to the project, and described how the work was received. One of Axelrod's models is described in the following section, which is a model about the dissemination of culture. The choice of this particular model is mainly because it is a simple model that is strictly adaptive in style.

3.2.1 Example of a Simple Would-be World

Axelrod wrote in the introduction to his model about disseminating culture:

> "I wanted to study the fundamental process of how communities evolve in the first place. It seemed to me that a key part of the process was the development of enough shared culture so that a group of people could work well together. I recognized that in modern times, governments

[15] Axelrod suggests exercises in his book and there are software and other resources on his web-site: http://pscs.physics.lsa.umich.edu/Software/ComplexCoop.html

> themselves promote culture through powerful mechanisms such as universal schooling and the regulation of mass media. But I was primarily interested in how the dissemination of culture works below and indeed before the activities of powerful governments. How do people come to share enough in the way of language, habits, beliefs, and values that they can build the basis of common institutions such as effective government?"

He sketches a rich context for his model. He hints at the possibilities for practical support, and claims the relevance of the model's implications for resolving the tensions inherent in a multicultural society. He also writes about his long-standing interest in *social influence*: the way people tend to change each other in the very process of interaction. He claims that his model offers a new way of looking at the dynamic process of social influence.

The simulation model that Axelrod built is a geographic territory (a ten by ten grid) with agents placed on fixed sites (there is no movement). In the starting situation agents are randomly assigned cultures (Axelrod uses the term "culture" as a generic term for the things over which people influence each other). When the simulation is started, the simulation shows dynamics that are generated by one basic premise: the more similar an agent is to a neighbour, the more likely that actor will adopt one of the neighbour's cultural traits. After some time in the simulation, a number of stable cultural zones emerge. This simulation can be repeated under different circumstances (alteration of four parameters). The reader is encouraged to repeat the experiments[16].

Axelrod lists the several contributions of his simulated experiments:

- Generated counterintuitive outcomes;
- Produced suggestions for interesting interpretations on several topics;
- Clarified warnings about potentially false conclusions from empirical observations;
- Revealed insights for new empirical questions and hypotheses;
- Stimulated suggestions for interesting extensions of his model.

Apparently this was a fruitful modeling project, considering the simplicity of the model. How was the model conceived?

3.2.2 Some Reflections on the Creative Process

On first sight, three activities can be distinguished in the process of creating this model.

Macro-Level

On the macro-level, Axelrod attempted to describe the large-scale changes and transformations that were central to his interests. Using different formulations, he stated that large-scale convergence is the predicted, intuitive outcome, and divergence is the unpredicted, counterintuitive outcome. He adopted the perspective of complexity: cultural homogeneity is an emergent property, a consequence of locally interacting agents. Complexity theory also suggests that under certain conditions emergent

[16] See previous note.

properties can produce emergent behaviours and phenomena. The emergent phenomenon in this case is the formation of stable homogeneous regions, meaning that cultural differences endure (i.e. divergence; the surprising, counterintuitive outcome). In Axelrod's words: "under certain conditions local convergence can generate global polarization". The question is: *how?* It should be noted that the way he presented his ideas at this level is vague, qualitative, about shapes and patterns, and relying on narrative.

Micro-Level

On the micro-level, Axelrod struggled with the question: how do people become more similar when they interact and influence each other? (Social influence). He proceeded by making a few simple assumptions on the micro-level, for example the assumption that communication between people is more effective when people are more similar. He incorporated the assumptions in the model, by specifying agent behaviours with a few simple rules: 1) agents can interact with neighbours and adopt one of the neighbour's cultural traits, and 2) the more similar an agent is to a neighbour, the more likely that that agent will do so. The way he set out his ideas at this level is more concrete, about specific cultural traits and a quantitative measure for cultural similarity, relying on formal description.

Connecting Levels

The central hypothesis of Axelrod is that his unique way of modeling "social influence" on the micro-level is sufficient for the emergent phenomena on the macro-level to occur. With experiments he zoomed in on the circumstances (trying different values for no more than *four* parameters) and on the resultant evolutionary process. It should be noted that this activity involved the specification of experiments and the interpretation of the simulation outcomes.

3.2.3 Can We Do Better? (Systematic Exploration of Hunches)

So in the creative process we can distinguish three activities. Most likely, these activities must be done more than one time, as often formalization of assumptions and implementation in a computer model brings inconsistencies to the surface that force us to reconsider how we proceeded. They are repeated until we like what the model is showing us. All this is business as usual; what in modeling practice is called: "the systematic exploration of the model behaviour".

But then the problems begin. As Axelrod wrote in his introduction, he had a long-standing interest in social influence. Looking at it from a sceptical point of view, he had no more than a *hunch* about fundamental processes that were at work, and built a simulation model that embodied the proof of that version of reality. *But many hunches might need to be considered!* He provided examples of other mechanisms that may be "valid explanations under specific conditions": social differentiation, fads and fashions, preference for extreme views, drift, geographic isolation, specialization, changing environment or technology. Then how can we assess the validity of the model? How do we know if the connections between the macro-level and the micro-level are the important connections? Axelrod defended that what counts is the model's fruitfulness, not its accuracy. But for practical application, say a management tool, this will not be good enough.

Systematic Exploration of Hunches

It is here that I present the basic idea for this thesis research. The solution, I think, is not to complicate the model; I agree with Axelrod that "the realistic representation of many details is unnecessary and even counterproductive" (Axelrod 1997, pg. 6). Yet I think it is worth trying to walk another path and to ask: *is it possible to turn this weakness into strength?* If we consider, in its entirety, the process of building a management tool based on would-be worlds, can we come up with more satisfactory solutions to the problem of validity? In particular, can we do better by facilitating a *systematic exploration of hunches*? (See Figure 3.1)

Systematic Exploration of Hunches

In this context, hunches are much more than sudden insights. Hunches are like thought experiments, that include the kind of questions considered to be interesting, as well as ideas about the kinds of would-be scenarios that can be generated with help of the would-be world(s). Hunches can be vague, purely based on intuition, and can be tested with simulated experiments.

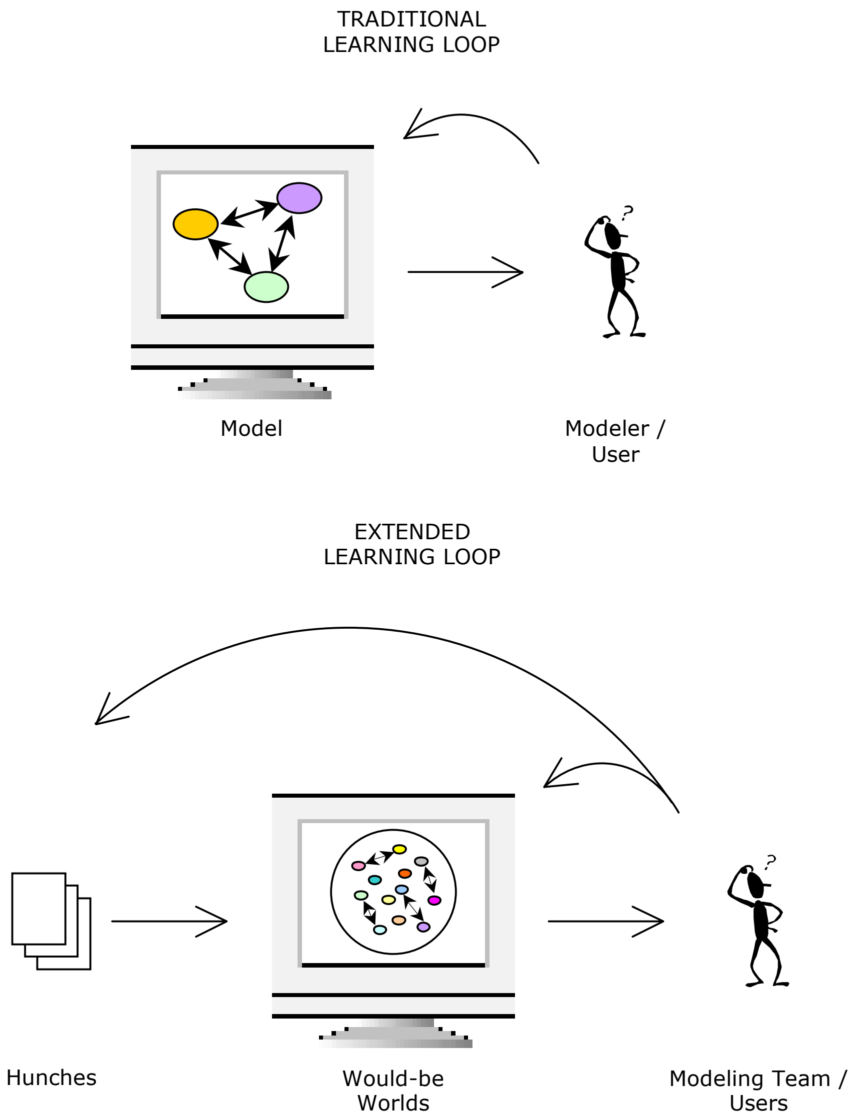


Figure 3.1 The systematic exploration of hunches

3.3 Building blocks from Social Science

3.3.1 Social Theory as a Web of Interconnected Building Stones

> "Theory is crucial. Serendipity may occasionally yield insight, but is unlikely to be a frequent visitor. Without theory, we make endless forays into uncharted badlands. With theory, we can separate fundamental characteristics from fascinating idiosyncrasies and incidental features. Theory supplies landmarks and guideposts, and we begin to know what to observe and where to act." (Holland 1995, pg. 5)

The Basic Idea of Building blocks

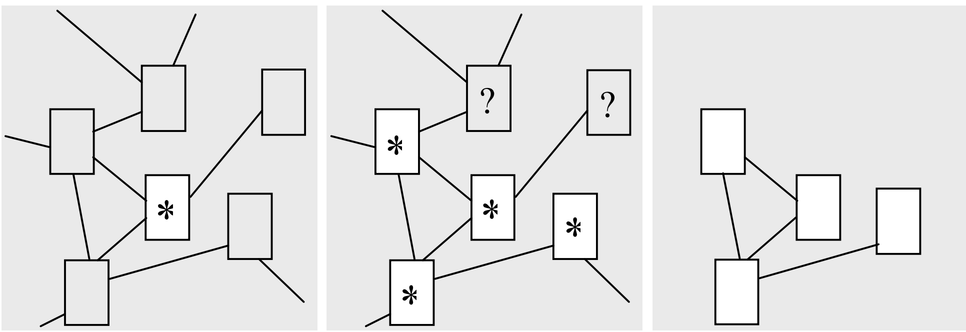
<u>Building Blocks</u>

If we describe theories in social science as "objects", we can develop a list of "properties" to define the specific identity of each theory: its scope of explaining social phenomena (specific to a situation, universal) and indications of how powerful the theory is in explaining these phenomena, its underlying beliefs and paradigms, its popularity among social scientists (e.g. how many theorists subscribe to that theory), etc. It would be an enormously laborious task to do, but it could be done.

Now suppose that in this model we keep all the objects but leave out all the properties; i.e. suppose that we approach theories in social science as syntheses that accomplish one thing in particular: establishing connections between "building blocks", which can be ideas, concepts, or other theories (indeed the idea is very much recursive). If we set ourselves the task of approaching many theories this way, we will eventually obtain a map of social theory as a "web" of interconnected building blocks. This approach reduces the workload of the task considerably, and would yield useful results quickly.

<u>Navigating a Web of Building Blocks</u>

For example, once we have such a web to our disposal, we can navigate that web.



A first building block is selected. | Following the connections, more building blocks are selected. | A small web is assembled.

Figure 3.2 Navigating a web of building blocks

Starting from any building block anywhere in the web, we can simply follow its connections to other building blocks. As we move around, we assemble a small web of interconnected building blocks. It may be that this small web describes an existing synthesis, but it can also be the stepping-stone to a new synthesis. Either way, we stumbled on the raw material for a ‘hunch’ that can be explored with simulated experiments using would-be worlds. This hunch did not come up as a sudden insight, but was produced by systematically exploring the interconnections between building blocks. Thus navigating the web is the ‘systematic exploration of hunches’.

3.3.2 Toward a Navigable Web

How to organize these building stones so that we can find them when we need them? To make our routes in the web more interesting, it is recommended to proceed by an organization of building stones that is "tangent" to the way social science is organized. So the landmarks in our web would typically *not* be the study of the human organizations, the study of the group, the study of the individual, etcetera.

Themes

Instead, in this thesis, a web is presented that is organized around four *themes*, each being ‘attractors’ to interdisciplinary syntheses. (The four themes are: “Integration”, “Complexity”, “Communication” and “Social Networks”. This web is presented in its entirety on the CD-ROM, where it can be explored at the most detailed level).

Interconnections among Building Blocks

The next question is: what kinds of interconnections among building blocks do we recognize? A good way to start seems to attribute to building blocks three kinds of interconnections:

Interconnections Among Building Blocks

- BUILDING BLOCKS FROM THE SOCIAL SCIENCES
  These are the kinds of links that social scientists love to make. For example, Axelrod saw an opportunity to extend his model of cultural dissemination, recognizing that social influence was linked to cultural drift. Thus, he stumbled on a hunch about forming a new synthesis that might lead to more powerful explanations or mechanisms for real phenomena. We can also think of examples when social scientists do not see opportunities but problems. Indeed many of the theories in social science are used to prove that other theories are wrong. The lack of consensus characteristic of the social sciences (think of the historic debate between Habermas and Luhmann[17]) suggests that even if two syntheses explain the same phenomena, their choice of building blocks may harbor intricate but important differences. By applying the principle of recursion to the web, we might succeed in untangling these differences to manageable proportions. In our approach we should recognize when two syntheses of building blocks cannot be connected, e.g. because some of the building blocks are incommensurable (which we will also treat as a type of interconnection between building blocks).

- BUILDING BLOCKS FROM SYSTEMS THINKING
  Often models and the syntheses that they embody adopt a certain strand of systems thinking. For instance, we could distinguish by the kind of feedback structures that they assume in light of a phenomenon, or by the kinds of impacts that actions of its actors have on other actors (linear vs. nonlinear). Contemporary systems thinking has reached a clarity that makes it possible to develop a web of building blocks without too many problems. We can then proceed by connecting the web of building blocks from social science with the web of building blocks from systems thinking.

- AGENT REPRESENTATION
  What kind of information can we attach to building blocks about the representation of agents? What kind of assumptions follow about individual agent behaviours? For example, we saw in Axelrod’s model about disseminating culture that social influence does not require the assumption of fully rational agents, but it required the assumption that they are capable of adaptation (and implicitly it assumed that

[17] Jürgen Habermas and Niklas Luhmann, leading social theorists of the Germany of the 1980’s and 1990’s, considered the notions of “complexity” and “communication” to be of central importance for their respective theory building. They had intense intellectual debates that were rooted in their distinct understandings of “complexity” (e.g. they developed very different notions of “system”).

agents are capable to communicate). Somehow we have to find a way to distinguish different requirements for agent representation. Indeed we will use a categorization by Goldspink for this purpose: passive agents, active agents, reactive agents, adaptive agents, cognitive agents, biological agents. The general idea is not to overreach (minimal agent representation).

- OTHER KINDS OF LINKS
  Of course, other kinds of links may be considered, but for a start these are sufficient.

3.4 Creating Would-Be Worlds out of Building Blocks

How should one proceed to create would-be worlds out of building blocks? By assembling a set of building blocks we already set, paraphrasing Holland, "the landmarks and guideposts for our forays into uncharted badlands", but what is it exactly that we hope to find? What kinds of experiments would be interesting to study which kinds of phenomena? Or, rephrasing these questions to our specific purpose: what kinds of would-be scenarios do we hope to produce? This thesis author adopted the view that we should try to *amalgamate*, but now the compounds are not theories but (three) paradigms from systems thinking.

3.4.1 Three Paradigms from Systems Thinking

Three paradigms from systems thinking are discussed and compared in the following paragraphs:

- Reductionist Approaches to Systems Modeling
- Cybernetic Paradigm for the Human Dimension
- Complexity

Reductionist Approaches to Systems Modeling

The first paradigm covered here is behind the many reductionist approaches to systems modeling. This thesis author already wrote about reductionistic thinking in science in the context of bottom-up vs. top-down approaches to social science. Now, the general idea behind reductionistic, or top-down approaches to modeling systems is outlined[18].

Reductionist Approaches to Systems Modeling

1) One starts with developing a representation of the system, by distinguishing a limited number of components of that system, which may be systems themselves. Doing so, we define what the system is, and also what the boundary of the system is to its environment.

2) We express how these components are connected. Since our interest is in change and transformation, the most straightforward way to move forward is to express how change in one component gives rise to changes in other components in the system. We have at our disposal alternative ways for expressing these connections, some being quantitative, others qualitative.

3) We then repeat steps 1 and 2, distinguishing components of components, and connecting them too. With each iteration, one constructs an increasingly rich

[18] This is also the general idea behind software and a method called *Rapid Assessment Program*, which is presented on the CD-ROM and applied in the Porto Alegre case study.

picture by adding lower levels of detail. One typically stops before the lowest level of the system's atomic parts is reached. One abstracts away from these lower levels by using some type of aggregation (e.g. by using averages).

4) Once components and their connections are in place, one can then use the model to produce insights about how changes propagate through the system. The human mind is not very good at this, so one often implements the model on a computer for support. The analysis is designed to increase one's understanding the system, especially of the system's leverage points (where small changes in one part of the system may result in big changes in other parts of the system). To help guide the analysis, one selects the main inputs and outputs out from our representation of the system, and one defines "candidate" leverage points and indicators that are based on them. A good practice is to also express uncertainties in the representation of the system. One then proceeds by systematically exploring the model's behaviour under different circumstances. Part of analysis is meant for testing if the model is a realistic representation. Here empirical data can help in getting it right, but one's own intuition is often the key. Testing continues until one has confidence that the choice of components, and the way they are connected, represent the reality that one knows.

5) Then one may turn to evaluation of strategies, scenarios, or other cases that have our interest, imposing changes on parts of the system (leverage points) and observing other parts (indicators). At this point one should be receptive for counterintuitive results, as they might give new clues about the leverage points in the system.

This is a very old paradigm, one that is embraced by modeling practices that have produced very useful models and will most certainly do so in the future. It requires many skills from the modeler, and this kind of modeling is often compared to a form of art.

Cybernetic Paradigm for the Human Dimension

The cyberneticist Mijalho Mesarovic expressed a concern about reductionist systems thinking: that one runs the risk of building a distorted picture of reality if the paradigm does not correspond to "the true paradigm of the system" that one wishes to represent (Mesarovic 1996). He sketched a different paradigm that he called a *cybernetic paradigm for the human dimension*. The paradigm can be captured in two basics.

Concerns about reductionist systems thinking

- REFLEXIVITY
  Reflexivity means that people have a continuous feedback relationship with a system; in other words, people change the system while simultaneously being changed by that system. According to Mesarovic, reflexivity imposes an uncertainty that is of a more fundamental character than the uncertainties expressed in reductionist approaches. This fundamental uncertainty imposes limits to the insights that we can obtain about how changes propagate through the system, to the extent that we can be objective, and to our ability to predict.

- HUMAN FACTOR
  The human factor means that if human behaviour is central to behaviour of the system, the true nature of the system may be goal-seeking. In order to express the process of goal-seeking it is necessary to take into account non-measurable aspects of reality. According to Mesarovic, if the true paradigm of a system is goal-seeking then under different circumstances (different category of inputs) the system can switch into a different mode. In each mode, the propagation of changes may be very different.

Mesarovic sketched implications of the paradigm for approaches to system modeling. He proposed using a top-down approach, taking into account "the true paradigm of the systems found on each level". Though fundamental uncertainty is recognized by this approach, its modeling of social processes is still based on assumptions of the (limited) rationality of the individual.

Complexity

This thesis author has already written much about complexity in this chapter and the previous chapter (especially in section 2.1). Each time, complexity thinking was put in contrast to reductionist thinking (i.e., bottom-up vs. top-down). Now, for clarity, it is compared with the cybernetic paradigm for the human dimension (the latter can be considered as "middle ground" between the other two paradigms).

Constructionist Social Theory

Models that incorporate both reflexivity and complexity appear in important social theories that are heavily influenced by systems thinking. They share the view that the functions of social systems emerge from the many interactions between atomic parts[19] (hence constructionist theory). Luhmann's adoption of the autopoiesis[20] model for social systems also approached goal-seeking from a complexity paradigm. And though not a social theory (yet), complex adaptive systems should also be mentioned here. Holland's principles for adaptation throw a particular light both on reflexivity ("edge of chaos") and goal-seeking (amounting basically to "survival").

Like in the cybernetics paradigm, the approach to systems modeling is to build models that are multi-leveled, yet they are not developed from the top-down but from the bottom-up, thus using much simpler models for the parts. The parts become a whole not through integration, but by letting properties on higher levels emerge from the interactions of the parts on lower levels, using simulation or computation.

3.4.2 Let's Talk!

Because these paradigms were popular in different times in the history of systems thinking, we learn about them in a kind of "black and white" manner; i.e. one paradigm criticizing the other. Literature that addresses an audience of managers does not bother so much about these debates, and with some frequency calls for reconciliation of these differences[21]. Several tools have been suggested to benefit more of the diversity of approaches, and indeed, to amalgamate them. This thesis author provides two examples of such tools, and then discusses how ABSS fits in all this.

Tools to amalgamate systems thinking approaches

- METAPHORS
  A good example of the use of metaphors is the 'Total Systems methodology' of Flood and Jackson (1991). They founded their pluralist systems thinking approach on the use of five metaphors (machine, organism, brain, politics, and culture). Their metaphors function as a tool to make an informed choice among alternative approaches to systems modeling that were based on different ways of thinking about systems. The choice would not necessarily be limited to one methodology, but could

[19] Yet they differ in the choice of atomic parts and their interactions (remarkable is Luhmann's theory with as atomic parts not people but communications).
[20] Autopoiesis is a model of *living* systems, based on an understanding of *cognitive* systems.
[21] This author recommends that the reader access the special issue of the *Systems Dynamic Review* called "System Thinkers, Systems Thinking".

involve a combination of methodologies (one dominant and others supporting).

- SOURCES OF ORDER
  McKelvey (1999) has argued that when examining social behaviour we are concerned to understand the interrelationships and interactions of three sources of order: 1) organic order is the result of natural selection, 2) rational order is the result of rational actor decision effects, and 3) complexity: the order that results from emergent phenomena and self-organization. Thus in a sense McKelvey, like Flood and Jackson, suggested the use of a tool to choose among alternative approaches to systems modeling, yet going beyond metaphors (functionalist) toward order-creating principles (constructionist).

Indeed, this thesis author believes that with ABSS we could harness the power of these tools. Instead of metaphors, we think of thought experiments (agent-based simulation models) which can be much more powerful and specific. Goldspink already stressed the potential benefits of considering all sources of order in an experiment with an agent-based simulation model:

> "Agent-based models need to avoid adoption of social concepts that assume away many of the phenomena of interest. There is a need to develop an ontology that accepts as legitimate dynamics that emerge as a consequence of complex interplay of different sources of order because this may be where the phenomena of greatest interest are to be found." (Goldspink 2002)

The thesis author proposes an approach different from developing one unifying ABSS-model, by seeking to develop more than one model, possibly using other modeling approaches as well. The technology to do this is already available; yet as is shown below, it is not without problems.

<u>Sources of Order and Respective Challenges for ABSS</u>

- ORGANIC SYSTEMS
  For organic order we can base ourselves on the considerable attention that has been given to agent-based simulation models of organic systems. This is evident in the increasingly sophisticated use of artificial life and genetic algorithms.

- ARTIFICIAL INTELLIGENCE
  Attempts to accommodate rational order by artificial intelligence have involved agent designs that incorporated simplified rule sets, representationalist cognitive theory, contextual intelligence, etc. Here, we encounter some major problems. The extensive simplification when using rule sets may lead to model results that are misleading. Incorporating representationalist cognitive theory is computationally expensive. We do not know if researchers working on artificial intelligence will develop solutions, any time soon.

The suggested approach uses ABSS in combination with systems modeling practices and, following Flood and Jackson, distinguishes between dominant and supporting methodologies. Models are formulated in languages that are simple and intuitive, so that we can establish a way of communication between different modeling languages. More specifically, this thesis author uses an approach that allows him to switch repeatedly between the narrative and the formal.

3.5 Interacting with Would-be Worlds

3.5.1 Learning-Action Networks

The state of the art in modeling tools for management shows a trend toward tools that facilitate *rapid learning*. The key of rapid learning processes is the interaction between individuals with the tool in a supporting role, guiding these processes and facilitating communication. Modern tools also tend to help create a platform to let tensions and contradictions emerge during the interaction of individuals with diverse backgrounds, as they might be crucial to discover the hidden connections that should not be left out in the modeling effort.

In this study this thesis author seeks to *amalgamate* (indeed the third kind of amalgam, next to his attempts to unify building blocks from social science and paradigms from systems thinking). In this case, the compounds are design principles that can be distilled from the state of the art in modeling tools.

Indeed, this thesis author believes that it is possible to design management tools based on would-be worlds that integrate many of the features offered by the state of the art modeling tools. A philosophy for how to design such tools is close to the realm of complexity, or rather *complex networks*.

Management Tools and Complex Networks

- NETWORKS
  McKelvey wrote about how networks of individuals can speed up the rate of learning on the level of management. By establishing parallels to the study of systems of agents, he pointed out that intelligence (the effective acquisition and use of knowledge) in human organizations is not only the insights of individuals, but also the *connections* among those individuals. The claim that networks can speed up the rate of learning follows from treating intelligence on the level of management as an emergent property of these networks.

- LEARNING-ACTION NETWORKS
  A very useful concept here is the learning-action network (LAN) proposed by Roome (1997). In a sense Roome's ideas about LANs place McKelvey's philosophy in context where breaking boundaries is essential for effective learning, whether they are disciplinary, organizational, related to language, or otherwise. In this study this thesis author assumes such contexts, since management tools are often applied on the intersections of management, science, and technology. LANs are certainly relevant for the two case studies (innovation management and environmental management).

3.5.2 Toward a Competition of Hunches

Figure 3.3 sketches a consultancy context in which management tools based on would-be worlds can be applied.

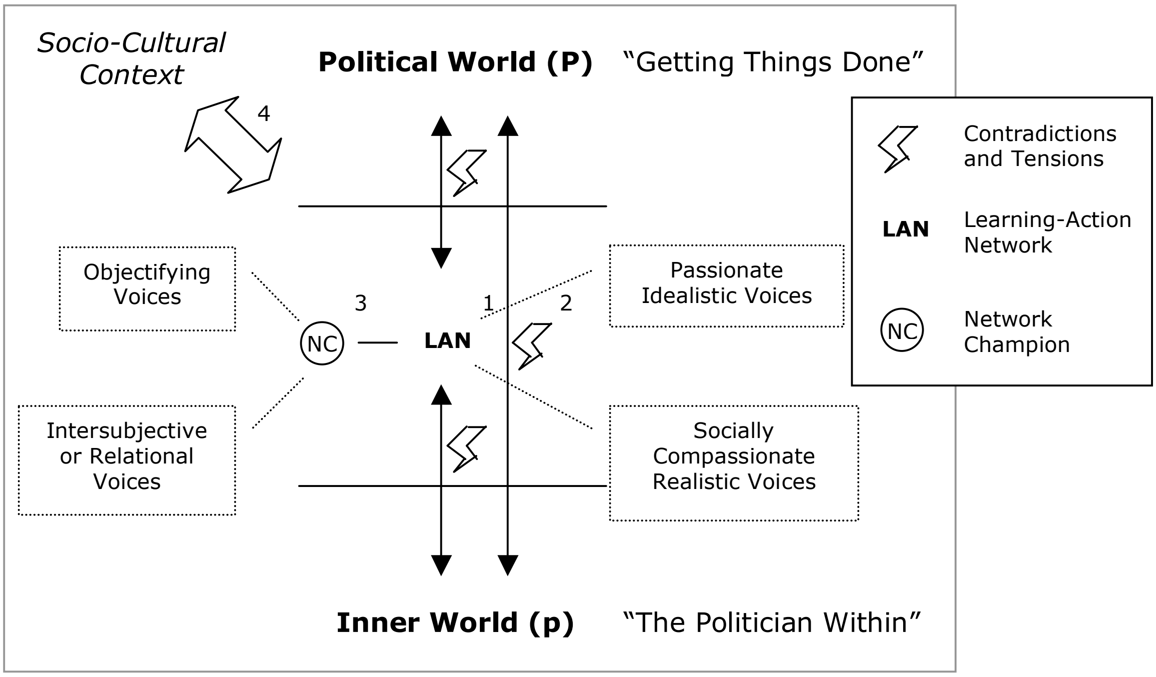


Figure 3.3 Support for learning-action networks

(1) LEARNING-ACTION NETWORK (LAN)
The management tool is designed to support interactions between individuals, thereby facilitating the mechanisms of the LAN.

(2) CONTRADICTIONS AND TENSIONS
The basic idea is to have the LAN function as a platform to embrace contradictions and tensions, with support from the tool. Contradictions and tensions follow from parallel voices such as:

- OBJECTIFYING VOICES who speak of systems as pre-given external realities and stand outside them as observers, modeling them in order to identify their dynamics
- INTERSUBJECTIVE / RELATIONAL VOICES who speak as subjects interacting with other subjects in co-evolution of a jointly constructed reality

- VOICES OF CONTROL who are concerned with the functional aspects of a system, searching for causal links that promise a more sophisticated tool for predicting its behaviour
- VOICES EMPHASIZING EMERGENCE emphasizing emergence and the radically unpredictable aspects of self-organizing processes and their creative potential

- VOICES CENTERED ON THE INDIVIDUAL centered on the individual positioning their ability to act as primary agents in the evolution of the system
- VOICES OF DECENTRED AGENCY who understand agents and the social world in which they have to live as mutually created and sustained, so that agency lies at both the individual and the collective level

- ALTERNATIVE ECONOMICS that speaks about how to radically change the present system
- MODIFIED MARKETERS who speak about how to make the present system work better

(3) NETWORK CHAMPION (NC)
The tool supports the role of the network champion, allowing voices to become hunches that can be tested with simulated experiments.

(4) SOCIO-CULTURAL CONTEXT
The working of LANs may depend on the socio-cultural context.

4 FOUNDATIONS
A Journey into the Land of Modeling and Simulation

4.1 Scope and Key Concepts

Modeling

We begin with a broad definition of a model:

Model

> "A model is a simplified and generalized image of reality." (Meadows et al., 1982).

Modeling is the process of making a model and working with that model. Jim Doran and Nigel Gilbert state that modeling comes into its own when there are difficulties with direct access or direct observation of reality:

> "We wish to acquire knowledge about a target entity *T*. But *T* is not easy to study directly. So we proceed indirectly. Instead of *T* we study another entity *M*, the "model", which is sufficiently similar to *T* that we are confident that some of what we learn about *M* will also be true of *T*." (Doran and Gilbert 1994)

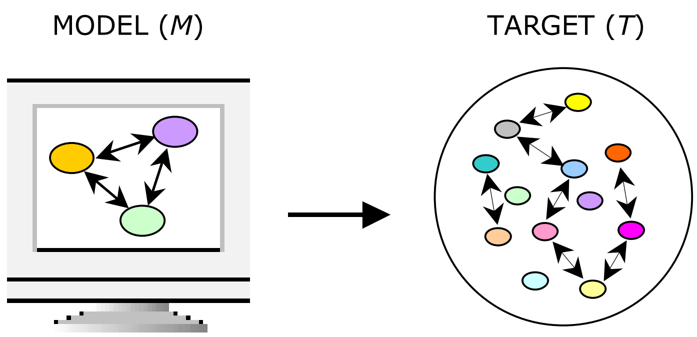


Figure 4.1 The relationship between model and target

In this chapter this thesis author addresses *systems* modeling, which means that all models are representations of essential system aspects, with knowledge being presented in a workable form. This frequently refers to a computer program; however this may also refer to some notes on paper, a mathematical model, a diagram or a figure.

More specifically, the author focuses upon *dynamic* systems modeling, which means that models and targets are thought of as dynamic; they change with time. A model is thought of as comprising "structure" and "behaviour". At a moment in time the model has *structure*. With the passage of time the structure changes and that is *behaviour*. The precise scope is depicted in Figure 4.2.

Scope of this Chapter's Journey

In this chapter the author focuses upon models that can be studied to learn about the dynamic behaviour of a target system. Further, they contain *rough and broad* representations of their target (as applied in policy analysis) and require, as inputs, primarily *process knowledge* rather than measured data. This frequently refers to computer programs and computer simulations, but is not necessarily restricted to them.

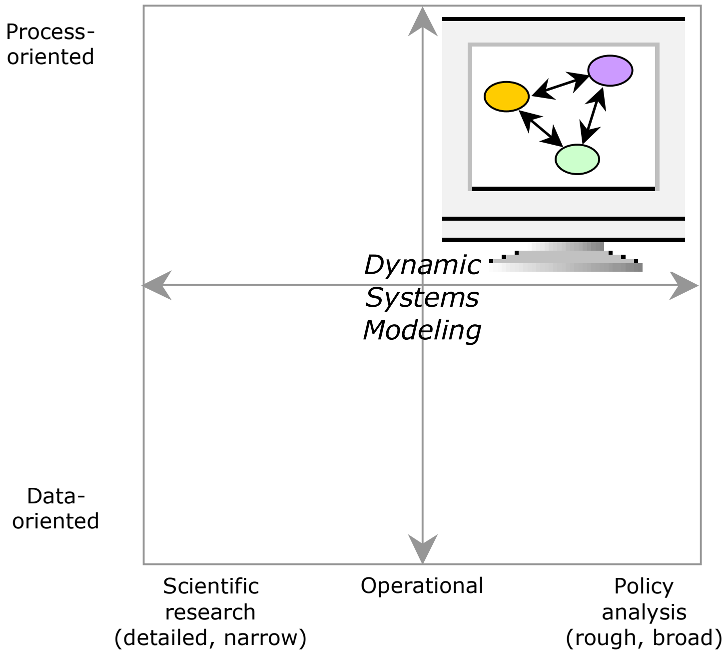


Figure 4.2 Models reviewed in this thesis

The result of modeling is thought to be a set of *multiple autonomous* models; this in contrast with the much more common practice of building a single model that is merely instrumental for the specific research purposes.

Building Multiple Autonomous Models

- AUTONOMY OF MODELS

> "All models are themselves entities in the world. One entity may function as a model for many different target systems. Further, there is no logical problem with the concept of a model of a model." (Doran and Gilbert 1994)

> "Once the progress of modeling has been accomplished, the model achieves a substantial degree of autonomy. It is an entity in the world and, as much as any other entity, it is worthy of investigation. Models are not only necessary instruments for research, they are themselves

[22] The question of simple versus complex models is rephrased in a more meaningful way by Rotmans who makes a distinction between "complicated" and "complex" models (Rotmans 1999). He considers models to be *complicated* if they include a variety of processes, many of which may be interlinked. He adds that models are *complex* if incremental changes in processes may result in considerable changes in the behaviour of the model. Rotmans emphasizes that complicated models can be not complex at all, and that complex models may contain relatively few processes.

also legitimate objects of enquiry." (Conte and Gilbert 1995)

- MULTIPLICITY OF MODELS
  There is not just one model for any particular target. The modeler faces many choices about the model; s/he has freedom to decide upon the aspects of the target system that the model should address. Should it be concrete or abstract? Should it be simple or complex? [22]

Simulation

Computer programs are important tools in dynamic systems modeling. The software may assist in the modeling process (e.g. visual modeling tools) and/or may constitute the actual model itself, as for example in simulation:

Simulation

> "Simulation is reproducing the behaviour of the target entity over time in a computer model." (Doran and Gilbert 1994)

Simulation comes into its own when the *analytic* approach although desirable is not possible:

> "Simulation contrasts with a second, 'analytic', way of obtaining insights into the behaviour of a model. This is by reasoning directly from knowledge of its structure. The reasoning may be informal and subjective or, if the model is specified or is describable in some formal language (a language of mathematic or a formal logic), we may be able to infer something about its behaviour from the specification or description from formal reasoning. Either way, the model's behaviour does not have to be observed directly at all." (Doran and Gilbert 1994)

It is the author's intention to focus on *contexts for modeling* in which it is likely that the behaviour of a model is very difficult or impossible to comprehend analytically, so that a model's behaviour needs to be reproduced through designing and running simulated experiments. Such contexts for modeling are characterized in 4.2.

4.2 A Bird's Eye View on Modeling and Simulation Practices

4.2.1 The Land of Prediction

Stabilized Theoretical Context for Modeling

The use of models is traditionally associated with problems that allow modeling to be relatively well focused and conducted within a stabilized theoretical context. In such context the typical aim for modeling is *prediction*, i.e. to predict reliably the behaviour of the target in certain key conditions which may or may not be under our control.

Stabilized Theoretical Context for Modeling

Doran and Gilbert point out that a "stabilized theoretical context for modeling" tells something about the relationship between modeling and two bodies of theory:

> "Theory impacts upon modeling in important ways that need to be distinguished and considered. By (established) theory we mean an agreed body of concepts and relationships between them, together with agreed processes of inference, and possibly conclusions linking structure to behaviour. It is important to recognize that two bodies of theory are at issue in any modeling exercise: one associated with the target, and the other associated with the model." (Doran and Gilbert 1994)

This relationship between modeling and theory is sketched in Figure 4.3.

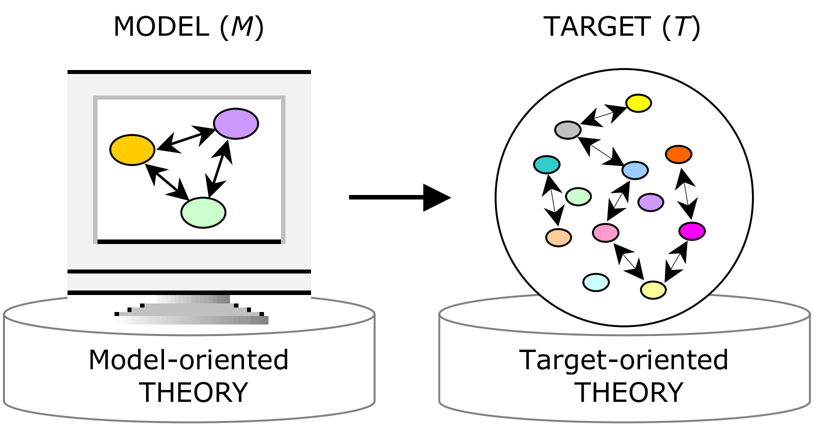


Figure 4.3 The relationship between modeling and theory

- TARGET-ORIENTED THEORY
  Those aspects of the target deemed relevant to the goals of the study are likely to be strongly determined by (target-oriented) theory, in the sense that there are certain presuppositions about what is and what is not of importance.

- MODEL-ORIENTED THEORY
  On the other hand, in order to express target phenomena in a suitable model, it is necessary to know how versions of those phenomena can be created (to some acceptable degree of approximation) out of the available elements. It is therefore necessary to have some general theoretical understanding of how relevant phenomena may be synthesized.

Traditional Good Modeling Practice

Even in a stabilized theoretical context there is no "recipe" for what constitutes good modeling practice. Figure 4.4 was designed to convey that good modeling practice always involves managing a network of "variables" that are causally related (Van Waveren et al. 2000)[23].

<u>Good Modeling Practice</u>

Traditionally "good modeling practice" comes down to managing the interplay of five variables (see Figure 4.4).

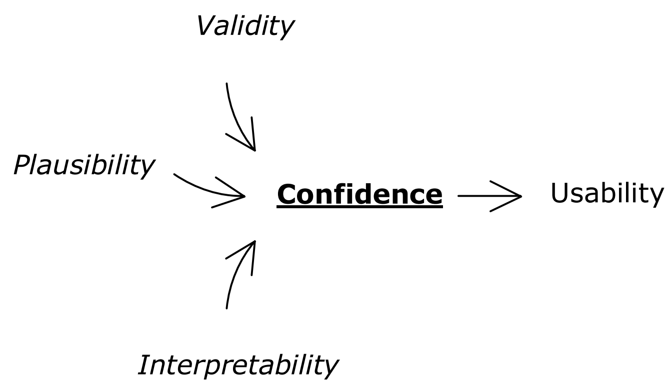


Figure 4.4 Good modeling practice in the context of stabilized theory

- VALIDITY
  A model's behaviour should be explored systematically to determine whether it is "good enough" in describing the target system. It is easier to have confidence in a model that can be validated (e.g. after successful completion of procedures or tests) but validation is no substitute for judgment considering ALL variables.

- PLAUSIBILITY OF ASSUMPTIONS
  Assumptions should be at least plausible and preferably well grounded in empirical evidence. Many models involve some explicit "constraint assumptions" that make it possible to predict model behaviour by asserting that one or more constraints will always be satisfied (e.g. the "rational man" of economic models). Typically, constraint assumptions are based on hypotheses rather than on specific evidence.

- INTERPRETABILITY OF MODEL BEHAVIOUR
  Even when a model has been validated and its assumptions have been justified the interpretation of behaviour obtained from a model can be difficult. Because a model is *only* a model, it will always be possible to dispute claims about parallels between its behaviour and the target's behaviour. They are, after all, two different things.

- CONFIDENCE
  Confidence in a model is the variable that traditional modeling practices tend to seek to optimize.

- USABILITY
  If a model is used for prediction, its usability is, to large extent, determined by the reliability of those predictions.

---

[23] This diagram shows only five variables and is therefore drastically simplified. A more precise picture is offered by Akkermans, covering over 30 variables that correspond to the concepts of model quality, organizational platform, process effectiveness, implementation results, organizational contingencies, problem contingencies and project design elements (Akkermans 1995).

4.2.2 The Land of Exploration

Not Yet Stabilized Theoretical Context for Modeling

A certain class of problems – that modelers call "messy" or "wicked" – pose extra challenges to modeling that cannot be met by traditional good modeling practice. Characteristically, wicked problems turn modeling into an ill focused endeavour to be conducted within a theoretical context that has not stabilized yet. In those less favourable contexts, the typical aim of modeling is no longer prediction but *exploration*, i.e. to construct a model that is valid at least to some degree, that is, whose behaviour does match that of the target in at least some significant respects. The modeler may hope to gain new insights into the target itself, and modeling may involve theory building.

Indeed, we have now come to the main attention point from our bird's eye view: to see how some modelers have begun to rethink good modeling practice as a reaction to the persistence with which wicked problems have resisted modeling attempts. But first, wicked problems need to be characterized further; they make modeling unusually hard, but why?

To provide insight, the following paragraphs are designed to throw some more light on the relationship between theory and modeling, by distinguishing two cases: “complexity” and “social constructivism”. The thesis author argues that in both cases the theoretical context has not stabilized yet because of the demand for the capacity to adequately describe (with a model or otherwise) the dynamic behaviours generated by *systems of interacting heterogeneous agents* in human societies. There are great difficulties with finding such descriptions, difficulties that are rooted in *epistemological* issues. Wicked problems are therefore characterized as problems that introduce at least one of two types of *fundamental uncertainties* to modeling (fundamental in the sense that these uncertainties cannot be removed by incorporating more knowledge or information into the model).

The first case to be distinguished when considering the relationship between theory and modeling is “complexity”.

Complexity: An Epistemological Concept

> “Complexity, emergence, simplicity, order, disorder, and so on are epistemological concepts. They are relative to our descriptions of reality. Thus, they apply to any given phenomena only contingent upon our use of a particular descriptive framework.” (McIntyre 1998) [24]

If our description of reality is a model, complexity is a concept relative to our model. This brings us to Edmonds’s definition of complexity:

> “Complexity is that property of a model which makes it difficult or impossible to formulate its overall behaviour in a given language, even when given reasonably complete information about atomic

[24] McIntyre's argument basically goes like this: if we would choose complexity to be an ontological concept, that choice would raise great difficulties in postulating the ontological nature of complexity. By choosing it to be an epistemological concept, these difficulties are solved at once.

parts and their interactions." (Edmonds 1999)

Fundamental Uncertainties Type I

Suppose that we want to describe the behaviour of a target that is a system *T* of interacting heterogeneous agents. Further, suppose that we are skilled enough to make an intelligent choice about the modeling language and that we know enough about the behaviour of the identified components and about the overall behaviour (i.e. ignorance is not an issue). If our aim for modeling is to obtain a formalization of the global (or emergent) behaviour of the model, the body of model-oriented theory is at issue to the extent that fundamental uncertainties are introduced.

Complexity theory points out that there is likely to be a gap between component knowledge and knowledge of global (or emergent) behaviour - the source of which is irreducibility. However, there is not yet established model-oriented theory that provides any information about that gap specific for the chosen modeling language (for example a measure of complexity, see Edmonds 1999). Related, there is not yet a way of comparing top-down vs. bottom-up approaches to modeling *T*. Obviously the concept of irreducibility does not help much here.

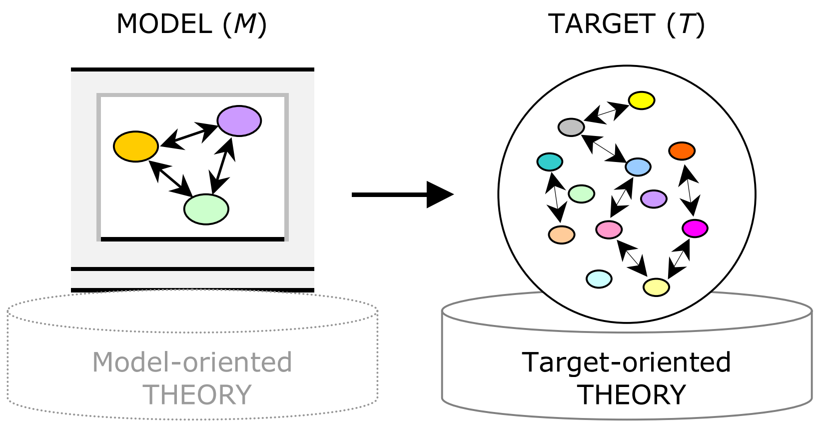


Figure 4.5 The context of not yet stabilized model-oriented theory

The second case, "social constructivism", throws a different light on the relationship between theory and modeling.

Social Constructivism

Social constructivism is a school in philosophy that claims that social reality cannot be described scientifically because it is construed by and is only accessible through the minds of heterogeneous agents[25]. Constructivist epistemology can be deduced to the following theses (Van Asselt 1999):

- What knowledge is produced and how it is to be used are socially driven decisions. Social factors play a large role in the direction of research, the drawing of boundaries between acceptable and unacceptable, relevant and irrelevant research, and so on.
- Key processes in theory building such as consensus formation, assessments of credibility, the acceptance and rejection of theories are entirely social.
- What scientists expect to observe, are able to observe, and want to observe are outcomes of social negotiations.
- There is no single scientific method to which all scientists can refer. Decisions on appropriate methods are influenced by social factors such as rhetoric, politics, disciplinary cultures, and personal reputations.
- Social constructivism argues that it is possible to distinguish between valid and invalid scientific statements, but the criteria for making such judgments cannot be derived from an 'abstract and universal faculty of reason', but have to be socially-

[25] Constructivism, like *post-modernism*, is an attack on positivist science, the latter more extreme, challenging *all* endeavours to explain processes and events.

constructed.

Fundamental Uncertainties Type II

Suppose again that we want to describe the behaviour of a target *T* that is a system of interacting heterogeneous agents. If we take the constructivist claim seriously, we cannot justify the assumption that the agents that have complete knowledge of that system and are fully rational in basing their individual actions upon that knowledge. Constructivism points out that the way agents choose their actions must be of a different nature, based on constructions of reality in the minds of these agents that are impossible to access directly, and with roles for diversity, different types of knowledge (codified and tacit), information processing, experience and so on that are not well understood yet. If our aim for modeling is to obtain a formalization of the global behaviour of the model, the body of target-oriented theory is at issue to the extent that fundamental uncertainties are introduced. The modeler must proceed indirectly through some kind of agreed upon "filter" so that aggregation can be done. Yet in the end one can always put doubt on the conclusions about the model's behaviour by attacking the (lack of) established theory associated with the target.

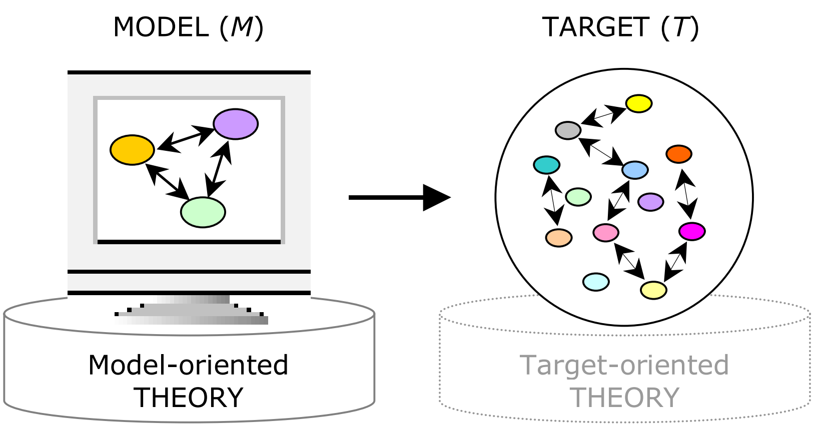


Figure 4.6 The context of not yet stabilized target-oriented theory

CORROLARY

Fundamental Uncertainties Type I and II:
Are They Not Really the Same?

Important social theorists (e.g. Luhmann) developed rich, comprehensive theories that subscribe fundamental uncertainties type I and II to the same source. These theories point out that the specific and unique character of human functioning can only be explicitly recognized from the background of reflexivity, emergence and self-organization. However, there is not yet consensus about the validity of these theories. Therefore, they will continue to be associated with two separate design criteria.

Rethinking Good Modeling Practice

In both cases, complexity and social constructivism, the management of variables becomes more difficult for the modeler (see Figure 4.7).

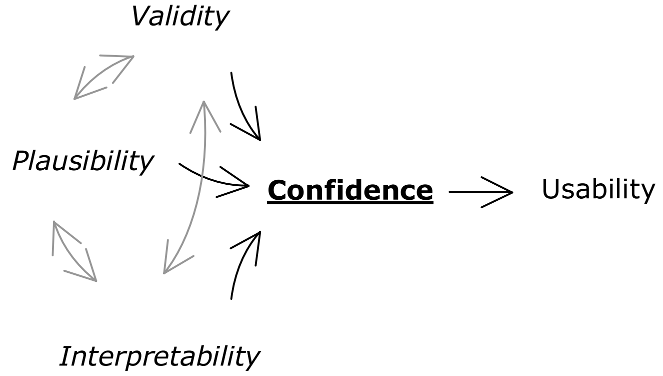


Figure 4.7 Fundamental uncertainties introduce new difficulties for the modeler

New Uncertain Relations among Variables

Compared to Figure 4.4, the new uncertain relations among variables in Figure 4.7 are:

- *Plausibility of assumptions ↔ Validity*
- *Plausibility of assumptions ↔ Interpretability of model behaviour*

Any choice of high-level assumptions will be hard to justify. A more viable strategy may be to use many low-level assumptions rather than few high-level assumptions (bottom up perspective). This could make it harder to validate the model and to interpret the model behaviour because relativistic, post-modern assumptions – or other kinds of low-level assumptions – may introduce non-linearity into that behaviour. For example, one of the ensuing difficulties might be sensitivity to initial conditions and consequent history dependence.

Conversely, the plausibility of assumptions can increase when the model behaviour is better explored:

> "What if a model requires many low-level assumptions, but there is no evidence to support them? Perhaps unexpectedly, this is not necessarily fatal. It may be that low-level assumptions may be at least partially justified by their joint higher-level consequences. Consider, for example, a computer-based model that captures the chess play of a human grand master. This behaviour is so difficult to achieve that whatever assumptions are made in the model's creation immediately gain plausibility. However, it is clearly dangerous to rely heavily upon this type of justification." (Doran and Gilbert 1994)

- *Validity ↔ Interpretability of model behaviour*

Exploratory modeling will often mean that a significant range of model behaviours cannot be validated. Bringing the model closer to the target may compromise on the possibility of validation, and vice versa. Hence the idea of exploiting a model to be able to "jump from observed facts" is gaining more acceptance, as is the idea of "a non-validated model that can be useful" (Doran and Gilbert 1994).

Innovations of Modeling Practices

To address these uncertainties modeling is being applied in broader contexts and in combination with other methods. Recently proposed innovative practices are *uncertainty management* (Van Asselt 1999) and *exploratory research* (e.g. Conte and Gilbert 1995).

A main concern in the design of such innovative practices is providing tools that make it possible to better manage the interplay of the variables Figure 4.7. A good start for designing these tools is to clarify further the two types of fundamental uncertainties (type I and type II), as the following two examples illustrate:

- The first example illustrates the potential of new conceptions that are designed to be precise about senses of emergence in complex systems and in connection types of biases that are likely to be introduced by modelers of those systems.
- The second example makes a case for participatory approaches in modeling complex systems.

Example 1: The Potential of New Conceptions

New Senses of Emergence

Although it is recognized as important by social scientists, the notion of emergence[26] remains vague and ill-defined (Conte and Gilbert 1995). Castelfranchi states (also in Conte and Gilbert 1995) that at least the following senses of emergence need to be kept distinct (although they might be intertwined empirically):

- DIACHRONIC OR EVOLUTIONARY EMERGENCE
  Starting from some forerunners, a phenomenon reaches maturity over time.

- GESTALT-LIKE OR LAYERED EMERGENCE
  Reality is seen as a multi-layered set of phenomena, with different levels of complexity. At some higher level, emerging properties (be they aggregational, collective, relational or Gestalt-like) might be observed which cannot be detected at lower levels of complexity. The emerging properties that are assigned to the higher levels cannot be attributed to the formal elements belonging to the lower levels.

- REPRESENTATIONAL EMERGENCE
  Structures (e.g. social structures) may variously affect phenomena at a given level of analysis B without being represented (known, learned) at the higher level A. However, at some point later in time, agents may acquire a representation at level A. We could call emergence the process by which a given phenomenon is learned or recognized at the cognitive level (e.g. agents becoming aware of given objective relations occurring in their social world).

- ADAPTIVE EMERGENCE
  Emergent properties are often meant as adaptive or functional, since they increase the fitness of the overall system to which they belong. This is one of the most widely used meanings of "emergence", and raises a host of problems that resemble those once encountered by functionalist explanations. In practice, the notion of emergence is often confined to the description of positive effects such as self-organization, a usage that comes close to the idea of function, i.e. a feedback mechanism operating

[26] Chapter 2 already addressed emergent properties, behaviours and phenomena. Emergent properties were introduced as the large-scale (or in other sense global) effects of a great many interacting agents in complex systems that act independently and obey simple local rules (e.g. liquidity is an emergent property of interacting water molecules). Complexity theory points out that under certain circumstances emergent properties can produce emergent behaviours and phenomena (e.g. water turns to ice when cooled down) that are results of truly bottom-up processes of change – i.e., they cannot be reduced to the behaviours of the agents.

on actions and responsible for the regulation and evolution of systems.

Castelfranchi's distinction of four senses of emergence helps to reveal likely biases of the modeler of complex systems:

Likely Biases in Modeling Complex Systems
(Castelfranchi, in Conte and Gilbert 1995)

- SUB-COGNITIVE BIAS
  The modeler starts building models keeping the assumptions that emergent phenomena are the effects of interacting "subcognitive" (reactive) agents rather than "cognitive" agents, thereby neglecting the role of knowledge, calculation, "cognitive structures" (the capacity for knowledge-based reasoning, planning, decision-making, etc.).

- BEHAVIOURAL BIAS
  The modeler tends to look primarily for behavioural patterns, and neglects to verify what happens when there is the possibility of emergence of cognitive structures.

- INDIVIDUALISTIC BIAS
  The modeler tends to look only at how micro-properties generate macro-behaviours, and neglects to verify whether macro-social phenomena do not also cause the emergence of micro-properties (for example "social norms" constrain not only the actions of agents, but also their minds and their beliefs, etc.)

Put simply, Castelfranchi offers some conceptual tools for looking at many levels of complex systems at the same time and avoiding short-sighted assumptions that keep us from observing important mechanisms in those systems. These conceptions also make it possible to reach better decisions about a strategy to manage the variables in Figure 4.7 (i.e., how to make the tradeoffs between plausibility of assumptions, interpretability of model behaviour, and possibilities for validation).

Example 2: The Potential of Participation in Modeling

Example 2: Participation

> "Participatory methods are methods to structure group processes in which non-experts play an active role and articulate their knowledge, values and preferences for different goals." (Van Asselt 2001)

There are many ways of incorporating elements of participation in the modeling process (reviewed in Van Asselt 2001). Often the broader context for modeling calls for participation of some kind, to ensure that the potential contribution of modeling is well understood by users.

The choice of participatory method is typically based on an assessment of the context for modeling by the consultant. In the context of theory that has not (yet) stabilized, the consultant's best choice may be mutual learning methods, where participants are co-producers of knowledge to complement scientists' expertise and knowledge. Typically these methods introduce elements of interaction that are aimed at divergence (e.g. the consultant attempts to make tacit knowledge of participants explicit and to map the diversity of insights) or aimed at convergence (e.g. the consultant attempts to reach consensus about an agreed body of concepts and their relations to be associated with the target system).

If the target is a complex system of interacting heterogeneous agents, participants need to reach consensus about what "filter" to apply for obtaining a formalization of the global system behaviour, the rationale why it is applied, and what are its shortcomings.

In other words, participation functions as a "tool" for reaching better decisions about a strategy to manage the variables in Figure 4.7.

Further, like in the first example, *new conceptions* can help participants take inventory of essential system aspects about the target that cannot be accessed directly and the reasons why this is not possible (e.g. a "typology of uncertainties") and incorporate them in the modeling process (for example, as "perspectives" in Van Asselt and Rotmans 1995, 1996; Rotmans and de Vries 1997).

4.2.3 A Horizon (Would-be Worlds)

The Potential of Would-be Worlds

Agent-based social simulation can potentially help modelers to address and resolve some of the difficulties that were described previously[27]. It offers the possibility to straightforwardly represent and study large populations of interacting heterogeneous agents, and allows great flexibility in specifying the properties and behaviours of virtual agents. It comes into its own when the theoretical context, model-oriented, target-oriented, or both has not been stabilized.

Agent-Based Social Simulation and Would-be Worlds

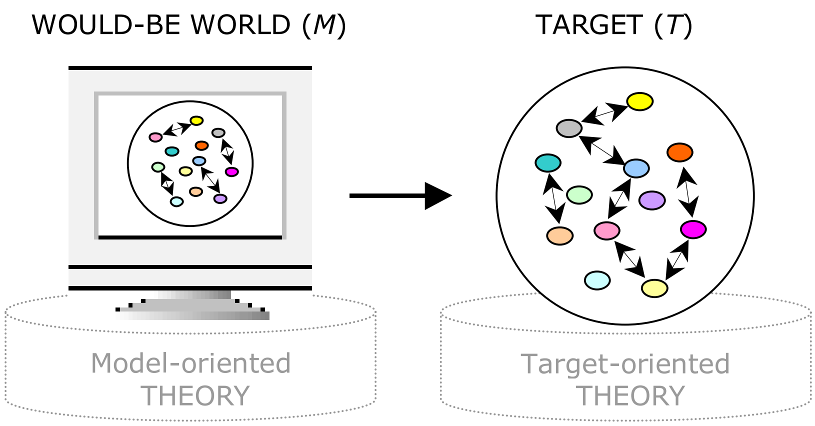


Figure 4.8 The context of not yet stabilized model-oriented and target-oriented theory

Agent-based social simulation (ABSS) is a new, promising possibility for development of innovative modeling practices that help address fundamental uncertainties. Illustrative for its potential is that, despite a relatively short existence, it has already proven possible to use the ABSS to push for new conceptions and participation (Epstein 1999; Ramanath and Gilbert 2004).

Toward Good Agent-Based Social Simulation Practice

[27] Despite the excitement, simulation still has a bad name in social science. A commonly perceived stumbling block is that a simulation is likely to involve many assumptions and details that will need to be justified. A simulation can also be time-consuming if the "computational load" of running a particular trial is high.

Figure 4.9 illustrates that agent-based social simulation urges us to rethink modeling practices even further (compare with Figure 4.7).

Additionally, Figure 4.10 illustrates that rethinking good simulation practice involves rethinking the *role of learning* in modeling; more particularly, it involves *extending the traditional learning loop*.

These two ideas are elaborated further on the CD-ROM.

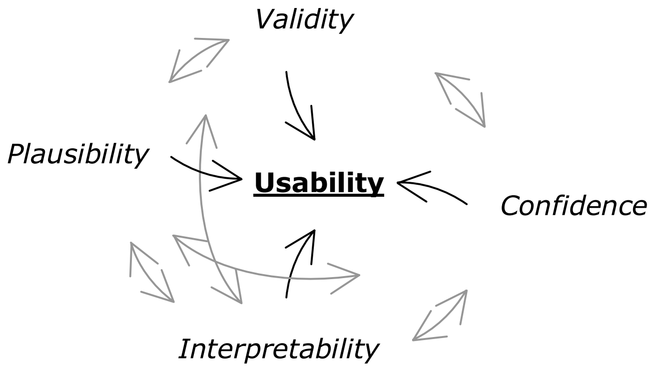


Figure 4.9 A sketch for good simulation practice using would-be worlds

In Figure 4.9 the central variable is no longer *Confidence*, but *Usability*. This has to do with the new (uncertain) relations between *Confidence* and other variables.

New Uncertain Relations among Variables

Compared to Figure 4.7, the new uncertain relations presented in Figure 4.9 are:

- *Confidence* → *Validity*
- *Confidence* → *Plausibility of assumptions*
- *Confidence* → *Interpretability of model behaviour*

You either see it or you don't. There is truth in this statement when it concerns complexity and constructivism in general, and emergence and participation in particular. Confidence takes the meaning of confidence as familiarity. Even if a model user knows all there is to know about a model and what is behind it, the user can still find it difficult to see something that is usable and may continue to have doubts about whether the model is just a very smart delusion away from reality. Confidence as familiarity can make the difference for how well the other variables can be managed. This barrier has driven modelers to consider alternative ideas about validity, plausibility and interpretability.

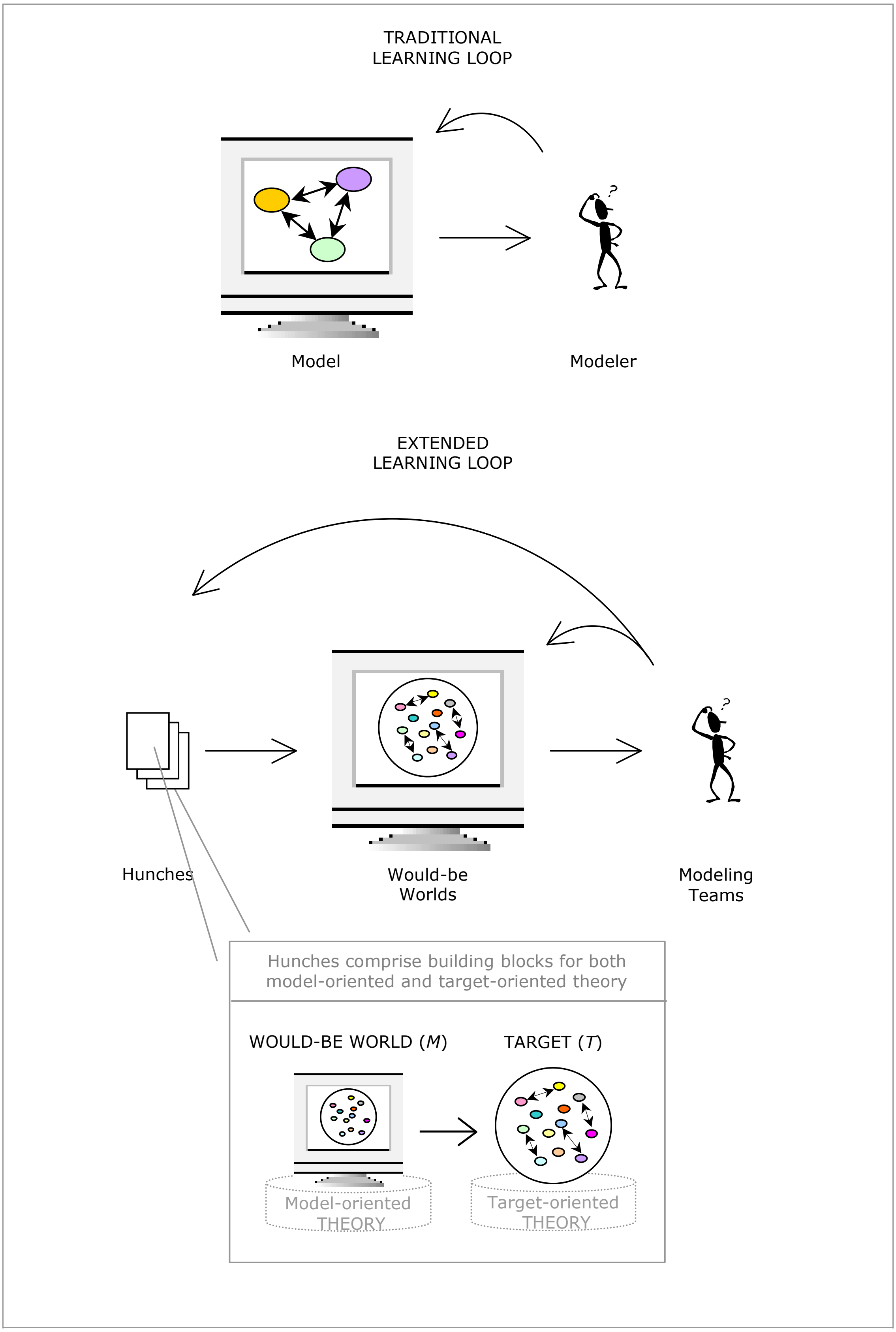


Figure 4.10 Rethinking the role of learning in good simulation practice

4.3 A Destination (BLUEPRINT)

Modeling and simulation practices are really about *design*. Design issues are involved in all aspects of modeling: the models, the modeling process, the modeling project, and so on. In the previous section, a horizon was sketched from a perspective that was obtained by shifting from favourable to less favourable theoretical contexts for modeling and simulation. In order to frame this outlook, the author developed a set of five *design criteria* that can be applied to all kinds of design proposals. The five design criteria can be represented by the acronym: "BLUEPRINT".

The BLUEPRINT Criteria

Back-**L**oops (Reflexivity)
H**u**man - **E**nvironment
Problem-oriented
Integrative and **Int**eractive

= **BLUEPRINT**

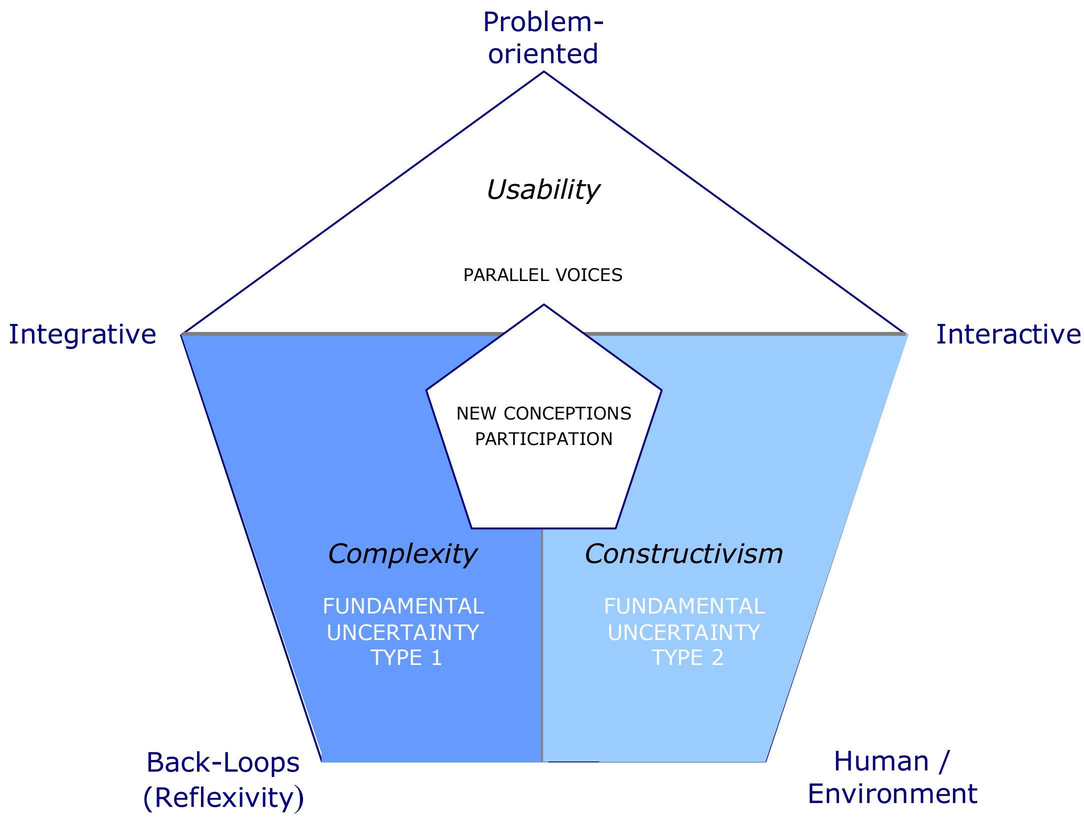


Figure 4.11 The BLUEPRINT outlook on modeling and simulation practices

Articulation of the BLUEPRINT Criteria

Back-Loops (Reflexivity) Inputs about relationships between higher level system components and subsystems should be treated as parallel voices, not absolute truths	
BL.1	Are fundamental uncertainties about relationships between higher level system components and subsystems expressed?
BL.2	Do "voices of control" dominate over "voices emphasizing emergence and self-organizing processes"?
BL.3	Do "voices centered on the individual" dominate over "voices of decentred agency"?

Back-loops, an important concept in the modeling of complex systems, are *continuous feedback relationships*; i.e. system components or subsystems change other parts of that system while *simultaneously* being changed by those parts. Such relationships are also called *reflexive*.

Complexity theory suggests that complex systems capable of producing emergent behaviours or phenomena typically have back-loops *deeply nested* into their structure. Earlier the possibility of such behaviours was associated with fundamental uncertainties (type I):

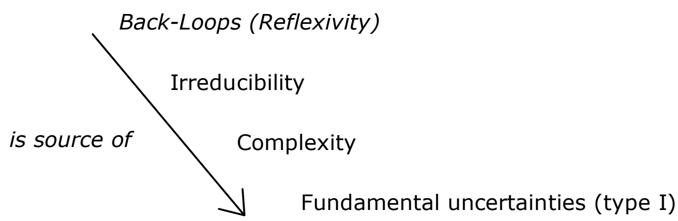


Figure 4.12 The relationship between reflexivity and fundamental uncertainties

Design Implications

The reflexivity criterion reminds us that caution should be taken for how to treat inputs about the relationships among system components, especially relationships among *higher level* components and subsystems. Because complexity cannot yet be measured, and top down and bottom up approaches cannot yet be compared, these inputs should not be treated as absolute truths. Instead, designs should reflect fundamental uncertainties by the tension of the conversational field amongst *parallel voices* (Griffin, Shaw et al. 1998):

Voices of control who are concerned with the functional aspects of a system, searching for causal links that promise a more sophisticated tool for predicting its behaviour	vs	*Voices emphasizing emergence* and the radically unpredictable aspects of self-organizing processes and their creative potential
Voices centered on the individual positioning	vs	*Voices of decentred agency* who understand

their ability to act as primary agents in the evolution of the system	agents and the social world in which they have to live as mutually created and sustained, so that agency lies at both the individual and the collective level

Human / Environment Human goal-seeking behaviour is represented and non-measurable aspects are taken into account	
UE.1	Are goals of human subsystems, or goals of individual agents within these systems, represented?
UE.2	Are processes to pursue these goals represented?
UE.3	Are non-measurable aspects represented?
UE.4	How is the imperfect nature of human-decision making dealt with?
UE.5	Do objectifying voices dominate, or intersubjective / relational voices?

The second design criterion concentrates on the *human / environment* interface. Earlier in the discussion about constructivism, the behavioural repertoire of individual *human* agents was contrasted with the *economic* agents; i.e. agents that have complete knowledge of their environment and are fully rational in basing their individual actions upon that knowledge. Likewise, the behavioural repertoire of *systems of* individual human agents can be contrasted with repertoires of *systems of* agents that are less humanlike in their behaviours. Constructivist social theory aims to find explanations for the surplus in behavioural repertoire.

In the same discussion, the possibility of gaps in the body of target-oriented theory and the modeler's lack of ways to find adequate descriptions of that extra behavioural repertoire were associated with fundamental uncertainties (type II).

Design Implications

From a design perspective, the main dilemma is how explicitly the specific and unique character of human functioning, on the individual level and on the system level, should be recognized in modeling.

Most models are not at all explicit in this respect, because they use the *state-transition* paradigm. According to that paradigm, a system can be fully described in terms of the state of the system at a given time and the system transformation (mapping, transfer functions) of that state to another state as well as the input between two instances in time:

$$S_0 \text{ and } T(S_n) \rightarrow S_{n+1}$$

S_0 is the initial structure of the model
S_t is the structure of the model at time t
T is the transition function between structures

Mesarovic (1997) elaborates an alternative "*goal-seeking*" representation with which the functioning of the human systems is represented by two items: (1) the goal(s) of the system; and (2) the processes which the system possesses to pursue these goals and to respond to the influences from the environment. Unfortunately these two items require a much larger number of items to be described on a more detailed level (including in the most general case: a range of alternative actions, a range of consequences of actions, a range of uncertainties, an evaluation set, a tolerance function, and several other items). Indeed representation of human goal-seeking is *inherently* problematic. Mesarovic gives us his overviews of the dilemma:

> "The state-transition paradigm is far easier to model and should be legitimately used whenever it does not result in a large distortion of reality. However, if the behaviour of the system is truly purposive, i.e., goal-seeking, this might not be possible."
>
> "State-transition representation appears to be simpler in the sense that it requires fewer items to be described. This, however, can be misleading. If the system is truly goal-seeking, the state-transition representation depends on the range of environmental influences. Under different circumstances (different category of inputs) the state-transition representation becomes different. The system appears to 'switch' from one mode of behaviour to another. If the environmental change is extensive, a large number of alternative representations are needed with the system appearing to switch, in time, from one mode of behaviour to another. On the other hand, if the goal-seeking representation is achievable, it remains invariant over a large range of environmental inputs."
>
> "Goal-seeking representation requires a deeper understanding of the system and is often difficult, if not prohibitive. However, even if state-transition descriptions have to be used, the results of the analysis should be interpreted in reference to the true paradigm of the system."

The Human/Environment criterion also stresses the importance of taking into account *non-numerical* and *non-measurable* aspects of reality, which, if omitted, can lead to a major distortion of the representation.

Some modelers have tried to tentatively resolve the dilemma by designing modeling practices in which humans interact with computer models in exploratory, *experiment*-like fashions (e.g. symbiotic human-computer modeling with *GlobeSight*, Mesarovic, 1997; agent-based simulation with interaction between agents and the experiment designer, Antunes 2002). These practices are discussed in the next section.

In conclusion, again, similar to what is dictated by the design criterion previously covered, inputs should not be treated as absolute truths. Designs should reflect fundamental uncertainties (type II) adding more parallel voices to the conversational field:

Objectifying voices who speak of systems as pre-given external realities and stand outside them as observers, modeling them in order to identify their dynamics	vs	*Intersubjective / relational voices* who speak as subjects interacting with other subjects in co-evolution of a jointly constructed reality

Problem-oriented At some point, ends (goals, objectives) are placed vis-à-vis means (strategies, measures)	
PR.1	Are ends (goals, objectives) represented?
PR.2	Are means (strategies, measures) represented?
PR.3	Is there a confrontation of ends vis-à-vis means?
PR.4	Does this confrontation touch upon the 'big issues'?

In designs for modeling, placing ends vis-à-vis means in general increases usability. There are different rationales for doing this, depending on the type of model application:

- *Capacity Building*. For capacity building, modeling is most effective when it revolves around sets of pre-selected goals and pre-selected measures, together with a representation of the links between the two (e.g. a simple computer-based model).
- *(re)Presentation*. Idem. To increase usability further, *meta-information* can be generated about the two sets and their links. For example, links to knowledge or information can be incorporated into the model that allow the user to infer what is important in a particular problem context.
- *Integration*. Integrative modeling requires finding ways to *codify* knowledge (sometimes tacit) from different sources. Preferable ways of codification can be straightforwardly molded into designs that place ends vis-à-vis means. For example, with *Rapid Assessment Methodology* all system knowledge can be *uniformly* codified into relations between components (describing which components change directly as a result of the change of another component). Consequently, placing end vis-à-vis means can be achieved simply by identifying which components are the ends (criteria linked to objectives) and which components are the means (strategies, measures).
- *Facilitation*. Consider for example *multi-criteria analysis*. At the core of this methodology is a hierarchical structuring of ends (objectives, criteria, subcriteria), aiming at a meaningful confrontation of ends vis-à-vis means at the lowest level in that hierarchy.

Design Implications

Problem-oriented designs should balance the extent to which the other design criteria are met. For example, the difficulties posed by fundamental uncertainties can make it very hard to focus modeling on the 'big issues' (e.g. the *problem drift* phenomenon, Birrer 1996). Neither is problem-orientedness solely a design issue. The choice of ends and means to achieve these ends are often *political*. Andrew Samuels sees these fundamental uncertainties reflected in two political approaches:

Alternative Economics that speaks about how to radically change the present system	vs	*Modified Marketers* who speak about how to make the present system work better

He too, points at the tension of the conversational field amongst parallel voices. Samuels: "This debate is a nightmare: both sides are right". He suggests that answers for how to address fundamental uncertainties should be found in psychology. More concretely, he proposes a *psychological praxis* that allows both approaches to exist in parallel and to compete, and that allows contradictions to be embraced. Unfortunately, Samuels provides little specific information about this praxis, which makes it hard to judge if and how it can be adopted in modeling practices. A scheme for such praxis is suggested in the conclusion of this chapter.

Integrative Modeling integrates what is already there (science, models, expert opinions)	
INTg.1	What manner is used to codify (sometimes tacit) knowledge from different sources?
INTg.2	Is the structure of the integrated problem representation clear or has it become too complicated?
INTg.3	Is the level of aggregation acceptable or is it too high?
INTg.4	Can different types of uncertainties, introduced along the process of integration, be easily recognized?
INTg.5	Does the model represent, in transparent manner, the inputs of those involved in the modeling process; will they have confidence in the integrated representation?

Integrative modeling implies finding ways to *codify* knowledge (sometimes tacit) from different sources. Deciding on ways of codification may be problematic, sometimes involving disputes among experts that are very hard to resolve.

Design Implications

Considerations when deciding on ways of codification include:

- The chosen codification may result that the structure of the integrated problem representation becomes too complicated, or that the level of aggregation becomes too high. This danger is more apparent when a choice of codification is motivated by the desire to swiftly resolve a dispute among experts.
- Preferable ways of codification make it easier to recognize types of uncertainties (e.g. the “TARGETS” approach covered in the next section).

Interactive Modeling is quick, participatory and offers valuable scripts	
INTa.1	Are the responses produced timely, or afterward only to justify past events?
INTa.2	What is the interaction between people (model users) and the model? Is there participation during the modeling process?
INTa.3	What kinds of scripts are offered? (intuitive / counterintuitive)

In light of the first two design criteria, *Back-Loops (Reflexivity)* and *Human / Environment*, participatory designs are particularly attractive. In the next section the author emphasises that the most important modeling practices have participatory variants, e.g. system dynamics: (Akkermans 1995; Vennix 1996), integrated assessment (Van Asselt 2001) and agent-based simulation (Downing, Moss, Pahl-Wostl 2001). Yet participation should not be a goal in its own. Instead it should serve a more important design criterion: *Interactivity*.

Interactivity in modeling is easily mistaken for computer-based modeling tools that use gadgets (e.g. "wizard" dialogs, visualizations reacting to the user's mouse actions) to bring to life what is presented on the screen. However, interactivity stresses the importance of miscellaneous factors that determine the interaction between people and decision-support (Vennix 1990).

A brief overview of the possibilities for interactive designs includes:

- Designs that facilitate multiple-loop learning, or even co-evolution of people and tools;
- Designs that offer quickly a minimal level of usability even when people are not able to provide all inputs directly (e.g. Robijn et al. 2001);
- Designs in agent-based simulation that bridge the agent's and the experiment designer's mind (e.g. Antunes 2002).

Design Implications

"All depends on the adequate fiction, or *script*". (Antunes 2002)

It makes sense to compare scripts of people (model users) with that of the model. *Intuitive* designs have scripts that are comparable in this sense, while *counterintuitive* designs have scripts that are surprisingly different. Forrester (1995), for example, sees the value of system dynamics primarily in the possibilities for counterintuitive designs, as does Axelrod (1997) with regard to the value of agent-based simulation. In contrast, rapid assessment methodology is an intuitive design, which offers value in facilitating communication first, and analysis second.

Of course, participatory designs that offer valuable scripts are still far from interactive if they are lagging in producing *timely* responses.

4.4 Forerunners

The BLUEPRINT criteria were used to evaluate seven modeling and simulation practices that represent the state of the art problem-solving practices in strategic planning (see 4.4.1). It was this thesis author’s expectation, prior to evaluation, that practices would typically perform well against some of the BLUEPRINT criteria, whilst performing less well against other criteria. If this expectation was found to be correct, it would be possible to formulate a more concrete design challenge for this thesis:

> *Can the Framework for Synthesis be designed in such manner that it scores positively for ALL the five BLUEPRINT design criteria (see Table 4.1)?*

Table 4.1 Ideal performance of the Framework for Synthesis

	Back-loops (Reflexivity)	Human / Environment	Problem-oriented	Interactive	Integrative
Framework for Synthesis*	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

(*) The Framework for Synthesis is the main deliverable of this thesis.

4.4.1 Seven Research Tracks

The Evaluation Set

Seven research tracks were picked that represent the state of the art in modeling and simulation practices (see Table 4.2 and Figure 4.13).

Table 4.2 The seven research tracks that were evaluated against BLUEPRINT

Research Track	Short Description	Modelers/ Models
System dynamics	System dynamics (SD) is a field for better comprehension of systems, and especially for understanding how things change through time.	Forrester
Integrated assessment	Integrated assessment (IA) is a multi- or interdisciplinary process of structuring knowledge elements from various scientific disciplines in such a manner that all relevant aspects of a social problem are considered in their mutual coherence for the benefit of decision-making.	Rotmans (the TARGETS model)
Visual modeling tools	Visual modeling tools (VMTs) are software-based instruments that can be used to facilitate the modeling process.	
Dynamic actor network analysis	Dynamic actor network analysis (DANA) is a workbench to support policy analysts in their representation and analysis of information on actors (organizations, stakeholder groups, or individuals) that play a role in some policy situation.	Bots, Van Twist, Van Duin
Rapid assessment program	Rapid assessment program (RAP) is software which implements – through a graphical interface – a methodology to qualitatively evaluate the consequences of policies.	Kouwenhoven
Symbiotic human/computer modeling	Symbiotic human/computer modeling consists of "putting the human inside the model"; in other words, the human user is put in the position of being an integral part of the model (a component, a subsystem).	Mesarovic (the Globesight model)
Agent-based simulation	Agent-based simulation (ABS) is a technique in computer modeling that allows large populations of human-like software agents to make decisions and interact with another.	See Chapter 2

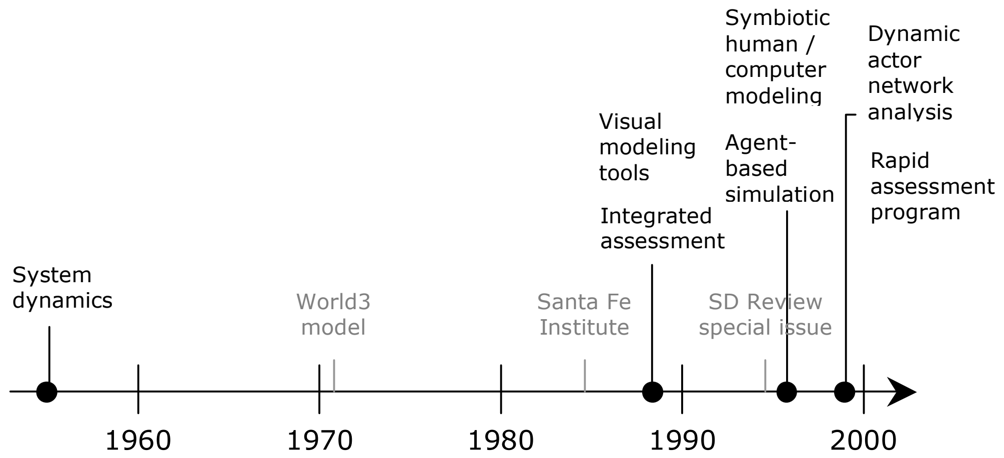


Figure 4.13 The seven research tracks in historical perspective

Evaluation Results

Table 4.3 contains the scores of the seven research tracks that were evaluated against the BLUEPRINT criteria: [28] These results confirm the author's prior expectation that practices typically perform well against some of the BLUEPRINT criteria, whilst performing less well against other criteria.

Table 4.3 The BLUEPRINT scores of seven research tracks

	Back-loops (Reflexivity)	Human / Environment	Problem-oriented	Integrative	Interactive
System dynamics	**No**	**No**	**Yes**	**Possible**	**Possible**
Integrated assessment	**No**	**Possible**	**Yes**	**Yes**	**Possible**
Visual modeling tools	**Yes**	**No**	**Yes**	**No**	**No**
Dynamic actor network analysis	**No**	**Yes**	**Yes**	**Yes**	**No**
Rapid assessment	**No**	**No**	**Yes**	**Yes**	**Yes**

[28] The detailed results of this evaluation are discussed in a separate document that can be accessed on the CD-ROM.

Symbiotic human/computer modeling	**Yes**	**No**	**No**	**Yes**	**Yes**
Agent-based simulation	**Possible**	**Possible**	**Possible**	**Possible**	**Possible**

4.4.2 Promising Trails

Besides focusing on seven "forerunners", attention was put on "promising trails":

Promising Trails

- NEW INDUSTRY STANDARDS FOR CODIFICATION OF KNOWLEDGE
  A strong interest from business in knowledge management has resulted in the availability of increasingly flexible ways of codifying knowledge. These more flexible ways for codification should make it easier to build integrative models. Also because of this development, integrated knowledge now becomes more accessible and easier to mold into a particular desired structure. Since some of these codifications have become new industry standards (e.g. XML), integrated designs might become more common in modeling and simulation.

- EVOLUTION OF ARTIFICIAL INTELLIGENCE AS A SCIENTIFIC FIELD
  Artificial intelligence as a scientific field becomes more and more integrated into the map of scientific activities, "evolving from the duality science/engineering into an interdisciplinary and empirical science" (Antunes 2002). A related development is that artificial intelligence is being rearranged under the keynote concept of "agent". Research tracks in modeling should benefit from these developments, especially because of potentially powerful applications where modeling of social phenomena overlaps with interests of fields like philosophy, psychology, ergonomy (socio-technical systems) and cognitive science. Examples of promising research areas are *self-motivated / autonomous agents* (Castelfranchi 1995) and *socially intelligent agents* (Dautenhahn 1999).

Since a considerable part of the Framework for Synthesis is (agent-based) software, these trails may, now or in the near future, provide valuable ingredients that will mean better (software) support for codification and integration of knowledge, better agent architectures and possibly other interesting developments.

4.5 A Better Tentative Roadmap

In conclusion, this chapter has thrown light on what design principles might apply for better support for learning-action networks:

Design Principles for the Framework for Synthesis
(hypothesized by this thesis author)

1) Human subsystems are represented using the goal-seeking paradigm; natural subsystems are represented using the state-transition paradigm.

2) Representations of these systems are developed interactively: members of the learning-action network participate in a collaborative efforts in which the problem is defined and ends are placed vis-à-vis means. The codification(s) that are used for the systems representations are qualitative, facilitate the interaction of participants and ensure that their knowledge is integrated properly.

3) The system representations are used to develop alternative scripts (intuitive and

counterintuitive) that mirror the parallel voices in the learning action-network and, in addition, offer new (unvoiced) fictions.

4) The study of these scripts provides, among other things, insights into the match of the system representation and the voices in the learning-action network. As a result of the competition between voices and/or the introduction of new voices, the system representations may be changed or the balance between voices may shift.

5) Over this process, interactivity is maintained.

These initial design principles were no more than tentative; a much clearer picture emerged from the thesis author's experiences in actually designing, building and testing the Framework for Synthesis.

5 The Lisbon Case Study

5.1 Introduction

The “Complexity in Social Science” (COSI) project was a research training network initiated within the Framework 5 of the European Commission. What distinguished the COSI research projects from other complexity research initiatives was that complexity concepts were applied in practical case studies. In Lisbon, the case study concerned a Portuguese science and technology park. The research project was named "The Spatial Dynamics of Innovation".

The Lisbon-based research team for COSI was an interdisciplinary team comprised of computer scientists, economists and geographers. The team members shared interest in learning how concepts from the complexity sciences could yield a better understanding of innovation processes. Based on the assumption that no single approach existed that could enable such learning, the team decided to use a combination of methodologies:

a) *Case study*. The Taguspark is a S&T park in the Lisbon area. The research team conducted a survey in Taguspark using an extensive questionnaire to obtain data on thirty firms in the park. Data were collected concerning the linkages among in-park firms as well as the links among firms and other types of in-park entities such as research labs and institutions. Attention was also given to the links that went outside Taguspark.

b) *Conceptual modeling*. The team’s modeling ideas were organized in a “meta-model” that integrated their ideas on an abstract level. The team used the meta-model for example to identify which ideas needed to be explored further through the other project activities.

c) *The application of mathematical models*. Models have been used by researchers to mathematically derive properties of different types of (social) networks. Well-known examples are “random graphs”, “scale-free models” and “small worlds”. These models and ideas were used in the case study.

d) *Agent-based simulation*. The team used agent-based simulation to explore the simulated behaviors in a population of “agents”, representing in-park firms, interacting and making decisions. The simulation model was capable of generating both the innovation dynamics and the evolution of the social network among agents. The micro-level interactions and the consequent macro-level patterns (population level) could be observed, with particular attention put on the technological trajectories of firms and the evolution of their social networks.

The research was structured around the development of the S&T management tool:

- Ideas from the meta-model were integrated into new theoretical perspectives.
- An agent-based simulation model was developed that allowed the team to switch from intuitive ideas about Taguspark to reality, and back to intuition, using the model as a “halfway house” between the theories and the empirical data.

- For the most promising perspective, the simulation model was used to generate "would-be scenarios" that helped to identify, test and evaluate new management options for Taguspark.

5.2 The Development of a Science and Technology Management Tool

5.2.1 The Development Process

The development of the S&T management tool passed through four stages:

1) "Start": Ideas in this stage were connected with the backgrounds and interests of the individual team members, as well as relevant literature;
2) "Prototype": An early prototype of the agent-based simulation model inspired the team to look at things differently;
3) "Meta-model": The team's ideas were integrated on a more abstract level; the meta-model also helped to structure the questionnaire;
4) "Case Study": Interviews helped to assess the relevance of the team's ideas.

During the development procees ideas surfaced and disappeared. The dominant ideas in each of these stages are presented in Appendix B.1.

5.2.2 Description of the Simulation Model

The simulation model can be described on four abstraction levels:

1) The focus of the model; i.e., the description of the essential features of the processes that are represented;
2) The abstractions of these processes that allowed the team to link them;
3) The modeling concepts that allowed the team to recreate these linked processes in an agent-based simulation model;
4) The observable mechanisms, at work in the simulations, that were studied by the team to gain insight into the complexity of the real world.

The following paragraphs are dedicated to a description of the model's major features on each abstraction level. The full description of the model is presented in Appendix B.2.

1. Focus

The focus of the science and technology management tool was on the dynamic interplay of innovation processes and social processes. This focus is relevant not just for S&T parks, but for many cases in a "knowledge based society".

The team developed new theoretical perspectives on the innovation/sociality interplay using the following starting points:

- the links among innovation theories and social networks theories;
- evolutionary perspectives on complex socio-technological systems;

- the key roles for innovation of the interactions of a variety of actors;
- attention for both goal-seeking and contingencies;
- the specific focus on bottom-up processes of change;
- the assumption of far-from-equilibrium dynamics.

The team's central theoretical perspective was captured by a theoretical notion of the "emergence of a climate for innovation", that was developed during the case study. This kind of transitional change was considered to involve agents organizing themselves to produce a new pattern that could not be reduced to the individual behaviors of the agents; something new would happen and there would be true synergy. The team did not expect to find a blueprint for these patterns; their focus was upon truly "bottom up" processes of change. It was expected that if and when an innovative climate emerged, it would not be at equilibrium. Instead, it would require great effort to be maintained and relatively little effort to change it.

2. Abstractions

The abstraction of the innovation process was achieved through:

- use of genetic systems metaphors; The concept of "kenes" ("knowledge genes") was used to capture how individual actors (firms) updated their skills and technologies. Kenes were subject to mutation and crossover as consequence of the interactions of actors;
- the assumption of an exogenous pressure to innovate; The model did not express why actors innovated;
- adaptive agents; In simulation actors were seeking to respond to the pressure to innovate by updating their kenes. This was not a rational process. It mirrored the presence of local markets with very weak demand for innovation;
- the notion of "compatibility" of actors that was based on comparison of kenes;
- the assumption of no market feedbacks (again conform local markets with very weak demand for innovation).

The abstraction of social interaction was achieved through:

- social interaction; Actors developed social ties among them;
- implied notion of trust; Social ties were treated as a reflection of trust building;
- a chance that new social ties were developed when actors physically met;
- the concept of "events"; Events were used to realistically simulate the impact of different sort of meetings, encounters, etc;
- erosion of social ties, based on small chance.

3. Modeling Concepts

The principal modeling concepts were: "agents", "kenes" and "events". See Appendix B.2 for the description of these and other concepts.

4. Mechanisms

The observed mechanisms with regard to the innovation/sociality interplay included:

- consequences of the interplay of innovation and social interaction; For example, collaborative innovation strategies were assumed to strengthen the social ties among the actors involved. Reversely, it was assumed that strong social ties improved the opportunities for imitative or collaborative innovation strategies. These dependencies required more study, because their large-scale consequences in big actor populations were uncertain.

- mechanisms that involved patterns of "coupling" and "clustering". Coupling is the co-evolution pertaining to the technological trajectories of a group of actors. Clustering is the formation of new or stronger social ties within groups of actors that already were socially interconnected. These patterns were considered to be keys to understanding how a potential for self-organization developed in the system under study.
- the role of (micro)geography; The impacts of (micro)geography were considered to be indirect, through the impacts of events. It was assumed that geographic proximity of actors implied that they were more likely to encounter each other, and, depending on chance, to establish social ties. The resultant mechanism(s) would be more expressive than the abstract "spill-over" mechanism that is used in most innovation diffusion models.

5.2.3 The Experiments

After the initial prototyping and the analysis of the Taguspark survey data, there were three hunches left in competition:

1) "Microgeography", the locations of firms, restaurants, libraries, etc. in the park needed reconsideration, using certain principles from urbanism;
2) "Missing Ingredients"; certain entities in the park were still lacking or not yet functioning to full potential;
3) "Microfirms", most of the very small firms in the park still needed to make the step from passive to pro-active innovation behavior.

More detailed descriptions of these hunches are presented in Appendix B.3.

Due to time constraints, only the first hunch, "Microgeography", could be explored in a systematic manner by the team. First, the prototype was developed to the point that a series of experiment could be conducted. Then, a "base" scenario and a set of "would-be" scenarios were produced:

- The "base" scenario captured the team's observations with regard to the actual situation in the Taguspark;
- The "would-be" scenarios were based on different schemes for the articulation of the park's microgeography. These schemes stimulated the social interactions of in-park actors and, in combination with other management options, gave more significance to patterns of coupling and clustering.

The CD-ROM contains a presentation of the model, the base scenario and the would-be scenarios[29].

[29] From the main menu, select "Baseline Models". Then click the tab "Animation".

5.3 Evaluation of the Case Study

5.3.1 Reflection on the Experimental Design

The Lisbon case study portrayed the development process of an agent-based simulation model, involving a number of steps, some of them implicit, that the research team took to develop their ideas into simulated experiments. The first evaluation of this case study was a critical reflection on the actual steps in the development process. The exercise served to address the question:

> Did the actual steps in the model development process match the six steps of the proposed Experimental Design framework (EDF)?
>
> Step 1: Select building blocks;
> Step 2: Produce perspectives;
> Step 3: Define models;
> Step 4: Conduct experiments;
> Step 5: Produce scenarios;
> Step 6: Evaluate building blocks.

The EDF is explained in Appendix A.2.

The results of this reflective exercise are presented in Appendix B.3. These outcomes were reconsidered also taking into account the chronology of the development process that is presented in Appendix B.1.The key observations are:

- In the EDF, the first step is to select building blocks. In the actual development process, building blocks were integrated into the meta-model, however, after the team had already produced a prototype. This prototype then became crucial for the entire research project.
- Despite the fact that team performed steps 1-6 of the EDF, there has been only a limited competition of hunches and no competition of models.
- Experimentation was limited; only one hunch was tested with experiments.

Obviously, time was a limiting factor. Since there were no baseline models available at the start of the research project, much of the project time was consumed by building a full-fledged management tool.

However, the observations may point at an entirely different and possibly more serious limit: an early “lock-in” of ideas in the development process and in the research project. The lock-in of ideas and its implications are addressed in section 5.4.

5.3.2 Evaluation of the Building Blocks Approach

This case study was also used to test the Building Blocks Approach (BBA) that is proposed in this thesis. The BBA involves the creation and application of “webs” of conceptual “building blocks” that show interconnections among theories. Webs of building blocks can help modeling teams assemble alternative "blueprints for synthesis" that lead up to diverging experiments with agent-based simulation models.

(The BBA is explained in Appendix A.3)

The test covered three main questions:

1) Did the steps in the actual development process correspond with the BBA?
2) Would the results be the same?
3) Did the experiences in this case study point to limitations regarding the practical application of the BBA?

The results of this test are presented in Appendix B.4.

The key observations are:

- The focus of the S&T management tool can be captured by a very small set of 7 building blocks that correspond to the themes “Integration” (3 building blocks), “Complexity” (3) and “Social Networks” (1). See Figure 5.1.
- The 7 building blocks were mostly interconnected; i.e., they formed a very small web within the larger web.
- Starting from the positions of these 7 building blocks in the web, it was possible to identify the missing links among these 7 building blocks. It was also possible to identify potentially interesting new links to other building blocks. Both types of links; i.e., missing and new, were shown to have led the research team to ideas that would have either clarified their axiomatic base (e.g. a more explicit notion of “trust”) or would have put their attention on potentially interesting new ideas (e.g. the “immune system perspective”).

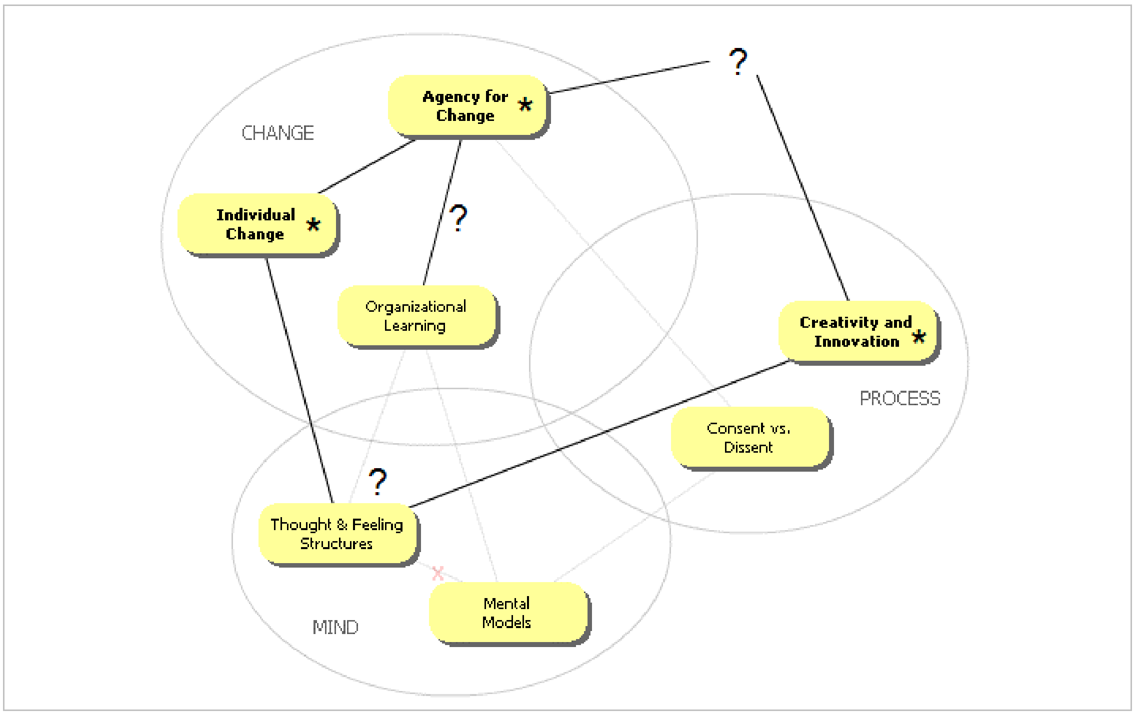


Figure 5.1 A small web of building blocks from the theme Integration

The richness of expression with building blocks, when applied to capture the model’s focus, seems to be in contrast with the lock-in of ideas that had occurred during the research project. How exactly did this lock-in happen, what were its consequences, and how can it be prevented? In other words; what is the *strategy*?

5.4 Conclusions

The Lisbon case study was an agent-based simulation study that has shed light on the working of the Framework for Synthesis' foundation layer, the "ABS Support" layer:

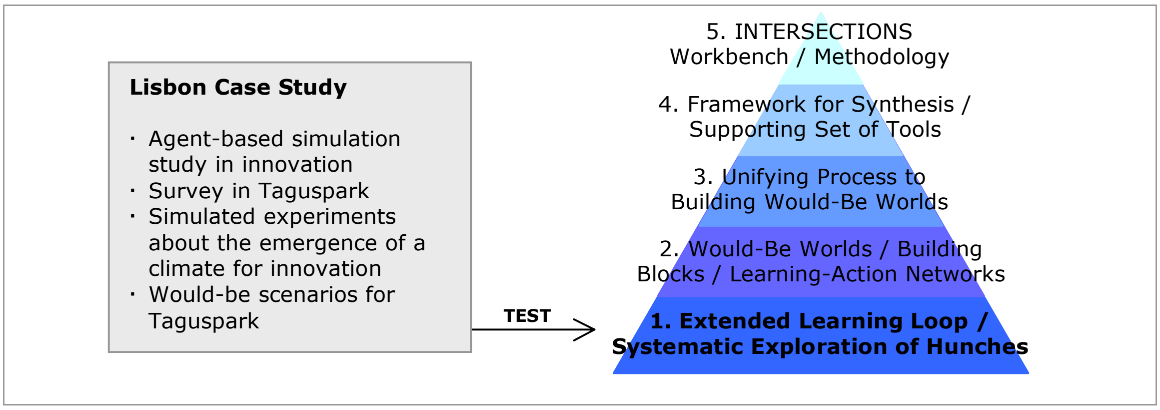


Figure 5.2 Test of the Framework's first foundation layer: ABS Support

The Systematic Exploration of Hunches?

First of all, the discussions made it very clear that the learning process that occurred in this case study conforms to the "Traditional Learning Loop" rather than the "Extended Learning Loop". This means that the use of agent-based simulation has NOT made a significant difference to the learning process. No new learning loops were successfully supported, in spite of the fact that several project elements could have done so; i.e., the cross-disciplinary interactions among team members, the use of a meta-model and the generation of alternative perspectives. Why did the new learning not happen?

On closer look, the chronology in Appendix B.1 shows that the model development process featured an early "lock-in" on a set of ideas and primitives that were put forward at the start and incorporated in the prototype. The logic of why this lock-in happened can be the following:

- From the start, the modelers in the research team were intrigued by the problem of "the emergence of a climate for innovation", and the question whether "social time" in a science and technology park could be sufficient for such emergence to happen. The team knew that the most likely answer would be negative, since it had already become clear from previous investigations that the Taguspark did not constitute an environment for yielding any potential benefits of social time, and the park management had shown little interest to change this. So, aside from the intellectual excitement, there was another challenge: to convince management to take this issue more seriously.
- Early in the project, two powerful modeling concepts, "kenes" and "network events," made it easier to rethink the problem by adopting an "agent-based simulation way of looking at things," and the prototype could be built without further hesitation. This prototype showed some patterns of interest, like clustering and instances of small changes having large impacts, which constituted food-for-thought for further study.

- Despite the success of the prototyping, the team still did not have a concrete idea about a "baseline model" of innovation that could describe the "core" processes that needed to be expressed in the team's study. What was missing was a fairly accurate description of how innovation and social interaction actually happened in the park, the actors involved and their roles and motivations, etcetera. A meta-model helped to structure all the open questions, and a survey for Taguspark was designed to obtain the necessary answers.
- More than anything else, the Taguspark survey confirmed the lack of a climate for social interaction. Though the analysis of the survey data provoked a new set of questions that seemed to be connected to the team's main question about the emergence of a climate for innovation, the data were unfortunately too weak to provide a basis for modeling the "core" processes.
- Meanwhile, the study and further development of the prototype increasingly locked-in the theoretical idea of "adaptation"; i.e., the basic idea that complicated collective behaviors of the in-park firms, universities, and laboratories evolving a climate for innovation, can be generated by simple behaviors on local scale; for example, in-park firms and people reacting to changes in their direct environment.
- The momentum of the prototyping and the not so successful case study led to a change of the team's basic approach; the team's best bet was that insights into the core process were to be found through experimentation with the model, rather than mining the empirical data further.

A direct consequence of the team's changed strategy was that the case study was closed by elaborating the "a priori" main question in one perspective, and framing the new but yet out-of-reach questions in alternative perspectives; thereby postponing the study of those perspectives until the moment that the core processes were understood.

In hindsight, what happened was that the interesting, though confusing, prototype and the weak survey data locked-in the model development process and also the team's learning process, with both desirable and undesirable effects.

On the positive side:

- There was a heightened expectation that the prototype captured "a world in itself" that merited further study.
- The positioning of the model seemed to be clever enough; it was fairly close to the first diagnosis of the Taguspark and had a reasonable chance of success, in terms of being able to describe and simulate the emergence of a social phenomenon, and generate ideas for the management of Taguspark.
- The prototype tentatively provided a very minimal model of the sought-after core processes. In a way, this minimality was desirable, since this way a model could be developed, the behavior of which, could be traced back to its underlying assumptions.

Toward a Strategy for ABS Support

The main conclusions for this case study, concerning the first foundation layer of the Framework for Synthesis: the "ABS Support layer", can be made along the three principal points made so far:

- *The need for strong reference points*
  The match of the actual development and learning processes into the six steps of the Experimental Design framework and the subsequent test with building blocks suggest that the Framework for Synthesis can potentially help to provide strong reference points.
  Key to those additional reference points installed by the framework are "building blocks", and the test shows that it is easy and straightforward to capture the essence of where the team stood by using a set of interconnected building blocks (and, moving to a more abstract level, by using the interconnected "themes" to which these building blocks belong).
  Most importantly, what the test showed is that the new learning that is facilitated by these maps is *unique* and *complementary* to the learning that happened in the case study. For example, each of these figures highlights "missing links", which are distinct places on the maps that can be used as temporary reference points by themselves, for example to clarify part of the connections between theories and model and compare what each of those might suggest.

- *The need to prevent a lock-in*
  The test of the Framework's Building Blocks approach, presented in 5.3.2, showed that the framework's building blocks could help to infuse new ideas into the model development process, thus preventing a lock in. Webs as illustrated in Figure 5.1 not only highlight the links that are still missing, but also provide suggestions ("hunches") for establishing new links.
  The usefulness of these hunches is, to a certain extent, indicative of the potential usefulness of the "Systematic Exploration of Hunches" that is facilitated by the overall Framework. The hunches produced within the test were certainly not trivial. Indeed, on closer look, the missing links that were identified pointed mostly at problematic spots that may well lie at the root of why the theoretical context for modeling was not yet stabilized in the first place. (For example, the webs highlighted the gap between views of innovation as endogenously evolving processes and views as processes involving rationality that can be controlled; which is what current models and theories about innovation diffusion and adoption models are still stumbling on.) This is exactly where agent-based simulation is considered to come to its own; as a modeling approach to create the synergistic energy necessary to push forward.

- *The impact of powerful modeling concepts*
  The test presented in 5.3.2 also suggests that building blocks can help to find powerful modeling concepts that can facilitate new learning. Although building blocks do not hand these concepts on a silver platter, they do offer the possibility of simply tracing their interconnections regardless of their "degrees of separation", thus making it less far-fetched to "import" concepts from one realm of ideas to another. To an extent, this use was exemplified in the test when links were sketched between Figure 5.1 and the concept of an "immune system".

In conclusion, what the test showed is that the Systematic Exploration of Hunches makes it possible to put some "out of the box" thinking concepts right there on the map, not as distant model evolutions, but rather as straightforward extensions of combinations of building blocks that were already used.

6 The Porto Alegre Case Study

6.1 Introduction

The “Interdisciplinary Group for Environmental Management” (GIGA) was a learning-action network in Porto Alegre, Brazil, that linked people from local universities, a local petro-chemical industry and the municipality of Porto Alegre. They shared interest in the future of post-consumer municipal solid waste (MSW) in Porto Alegre, especially in the possible consequences of the expected sharp increase of this city’s consumption of plastics.

GIGA had initiated various activities to develop and implement a model for integrated management of MSW in the metropolitan area of Porto Alegre. This thesis author worked, with GIGA, on a research project that was designed to support these activities, using a combination of methodologies:

e) *Modeling*. The “Rapid Assessment Program” (RAP) software[30] was used to build a systems representation of the MSW problem in Porto Alegre. The RAP model was then used to qualitatively evaluate the consequences of promising strategies, identify missing knowledge, and identify synergies among the strategies.

f) *Actor analysis*. This thesis author developed “RAP+”, an extension of RAP, that was used to integrate the knowledge about the MSW actors into the RAP model. The RAP+ model was then used to analyze the arenas associated with strategies, so that an actor perspective on the MSW problem could be developed.

g) *Application of agent-based simulation models*. Agent-based simulation models have been used by researchers to simulate social and cultural change processes and to test their ideas about endogenous change scenarios. A few of those ideas were used to enrich the RAP+-based actor perspective.

h) *Participation*. The RAP/RAP+ models were partly developed during workshops, with active participation of people from the GIGA network.

The research was structured around two workshops:

a) The first workshop was designed to guide the participants through the six steps of RAP, resulting in the RAP model;
b) The second workshop was designed to guide the participants through three more steps, that were necessary to develop the RAP model into the RAP+ model;
c) The analyses of these models were performed after the respective workshops.

[30] The RAP software had already been applied in several other projects, and in different ways: to support the integration of knowledge, the identification of promising policies, the development of indicators, and most recently, to facilitate the interaction of policy-makers.

6.2 The Development of Perspectives on Municipal Solid Waste Management

6.2.1 The First Workshop (RAP)

In the first workshop the participants performed most of the 6 steps of "standard" RAP.

1) First, the participants agreed on the description of the MSW problem.

2) They also agreed on the description of their common goal; to develop a model for the integrated management of MSW;

3) The participants then defined the essential elements in the MSW system. First, they defined the "components" to outline the content of the model. Then, to be more specific, they defined "characteristics" for each component[31].

4) They also defined the essential interactions between these elements; First, the participants established consensus about the interactions between components; again, to outline the content of the model. The, in order to be more specific, interactions between characteristics were defined[32].

5) The RAP software, fed with the inputs from step 3 and step 4, provided new insights into how changes propagate through the system[33]. The participants then defined their "criteria" (the characteristics they considered most important) and their "strategies" to influence these criteria[34].

6) The RAP software provided a scorecard that listed the strategies and the impacts of those strategies on the criteria. Later, this scorecard was verified by the participants.

The principal result of the first workshop was the system representation of the MSW problem; the "RAP model".

6.2.2 The Second Workshop (RAP+)

During the second workshop the participants extended the RAP model with elements related to the "actors" that are mutually responsible for the management of the MSW system.

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[31] Examples of components: Recovery, Legislation and Market. Characteristics of these components: the Quality of Recovery, the Scope of Legislation and the Volume of the Market.

[32] Example of a relation between components: Recovery has a certain (unspecified) direct influence on the Environment. A relation between the characteristics of the two components: the Volume of Recovery has a direct influence (score: +++) on the Quality of the Environment. See Appendix B.5 for an explanation of scores.

[33] This is comparable to asking: "If I change something in this part of the system, what happens in other parts of the system?"

[34] This is comparable to asking: "What is the best way to influence my criteria?" Of course, strategies can only be defined on the basis of characteristics that can be controlled.

1) First, the participants indicated eight actors that they considered most important to include in the analysis.

2) Then, in order to integrate their knowledge about the network in the system model, the participants established relations between the actors and the strategies[35].

3) In similar manner, participants established relations between the actors and the criteria[36].

Figure 6.1 A moment in the first workshop

Analysis of the RAP Model

The analysis of the RAP model that the model did not provide an integrated perspective; it was too much focused on the tendencies that promote the recovery of the residues and potential synergies therein. Still lacking for was the participants' knowledge about: the economic and environmental costs, the function of markets, and the alternatives for treatment and disposal.

The model's analysis, focused on waste recovery, led to the conclusion that potential synergies to improve recovery could be achieved through an approach that would be predominantly institutional (training, education, legislation) with synergies in technical and social programs; in particular by:

- increasing the quality of recovery (training, education, technical);
- decreasing the quantity of residues (training, education, legislation, social);
- increasing the product reintegratability (legislation, technical, social).

The complete proceedings of the first workshop are contained in Appendix B.5.

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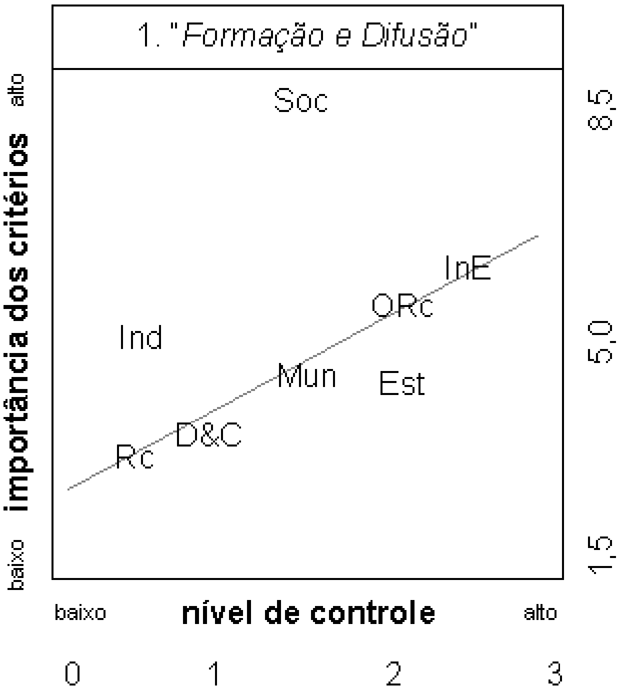
[35] These relations were expressed using the concept of "proximity"; the "distance" between an actor and a strategy or a criterion tells something about the relation between the two.
[36] See previous note.

Analysis of the RAP+ Model

The analysis of the RAP+ model was performed based on visual representations of the "arenas" that corresponded to each of the strategies (see Figure 6.2).



The horizontal axis corresponds to control over strategies
The vertical axis corresponds to importance of criteria

Figure 6.2 The arena for the training and diffusion strategy

The study of the visual representations of "arenas" was focused on the disproportions in control over strategies, taking into consideration the differences among the actors with regard to the importance of criteria[37]. For example, in the case of the strategy "Training and Diffusion" (Figure 6.2) increased control for both industry ("Ind") and civil society ("Soc") over that strategy may be desirable.

The complete proceedings of the second workshop are contained in Appendix B.5.

6.2.3 The Development of New Perspectives

This thesis author performed an exercise to test whether the RAP/RAP+ models could be used in combination with other resources, such as building blocks and agent-based simulation models, to achieve a more integrated perspective on the MSW problem.

[37] The coordinates of the actors in the two-dimensional arenas were calculated based on the information in the RAP+ model.

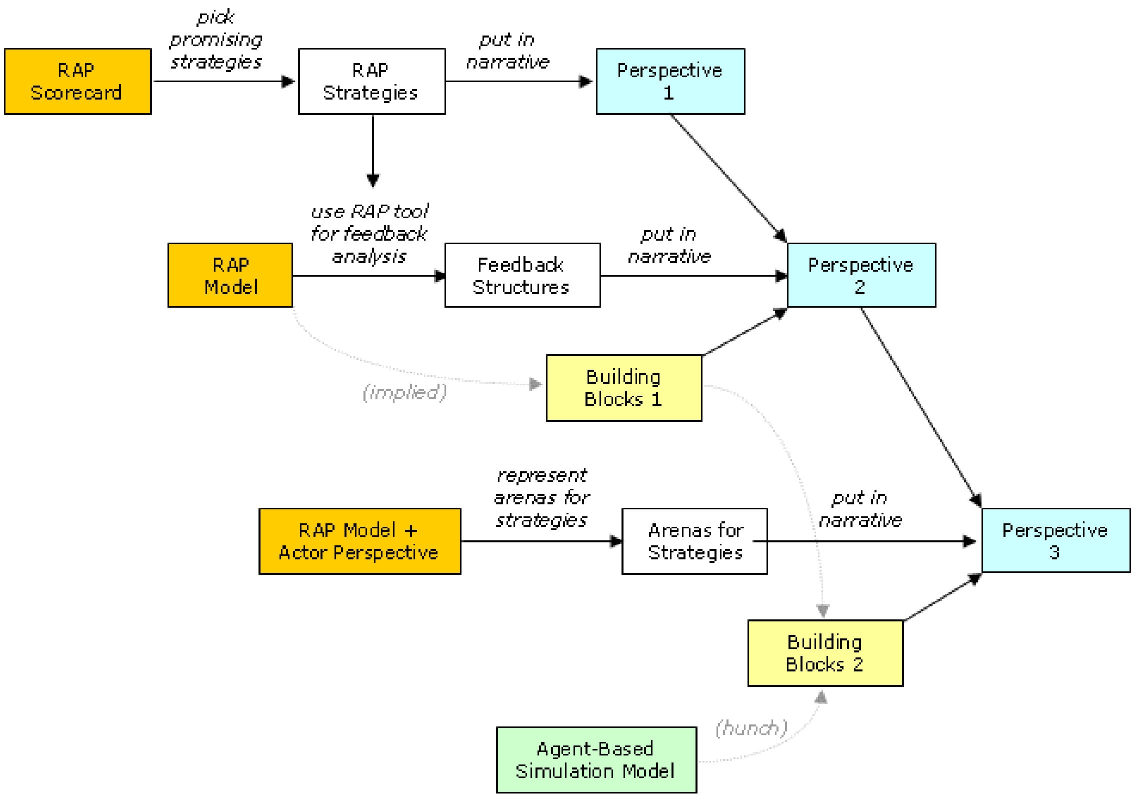


Figure 6.3 The path from RAP via RAP+ to agent-based simulation

Figure 6.3 shows how three versions of a perspective on improving the quality of MSW recovery were developed:

1) The first version was based on scorecard from the first workshop (RAP). This perspective was concentrated on the synergies for training and diffusion that were identified in the analysis of the RAP model (in 6.2.2).

2) The second version was based on feedback analysis using the RAP model. This analysis led to the identification of an "innovation loop" that was enforced by a "learning loop".

3) The third version was based on the analysis of the arenas that were represented in the second workshop (RAP+). This analysis led to the inclusion of ideas about "social influence" and the "dissemination of culture" that were "imported" from an existing agent-based simulation model. This third perspective provided took into account the possibility of endogenous change.

The complete exercise is contained in Appendix B.6.

6.3 Conclusions

The Porto Alegre case study shed light on the working of the Framework for Synthesis' second foundation layer, the "LAN Support layer":

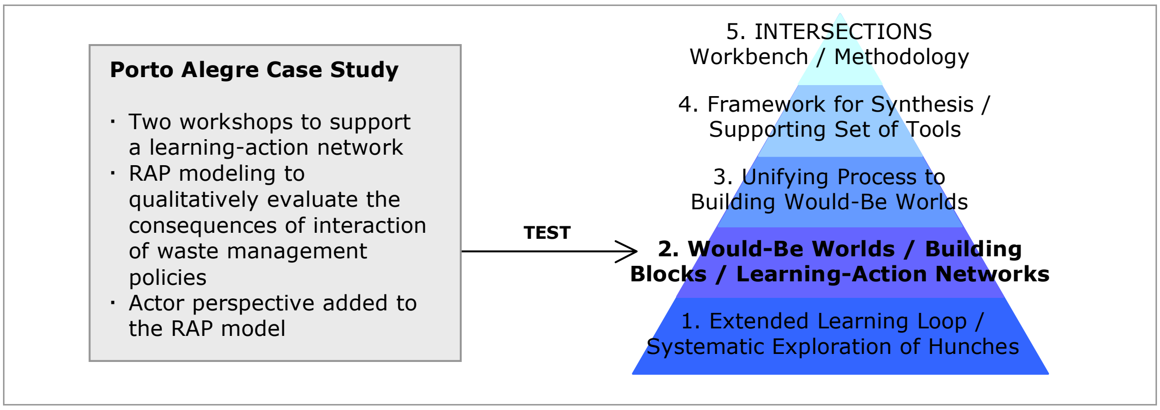


Figure 6.4 Test of the Framework's second foundation layer: LAN Support

Challenges for LAN Support

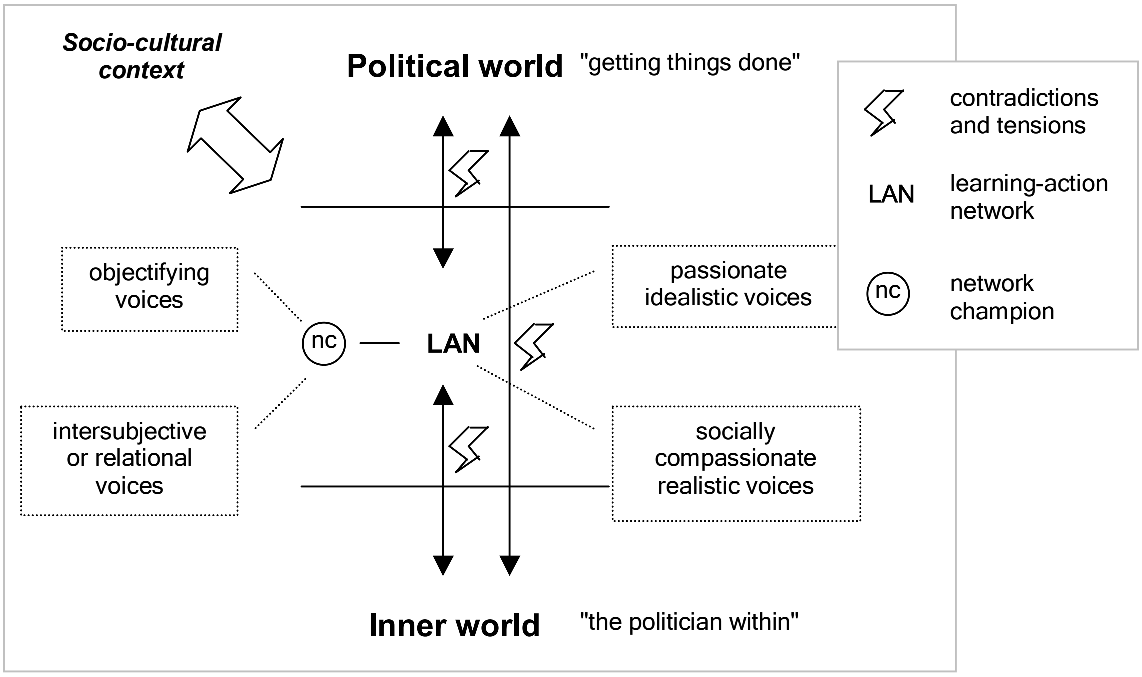


Figure 6.5 The distinctive challenges for LAN Support

The experiences in the workshops provided the opportunity to empirically test Figure 6.5:

- *Competing parallel voices / contradictions and tensions*
  In preparation of the workshops, it was considered that one distinctive challenge of LAN support is to help dealing with contradictions and tensions that arise as consequence of parallel competing voices inherently present in LANs.

The "stakeholder profiles" based on interviews with participants, pointed out the existence of both passionate idealistic voices and socially compassionate realistic voices. However, there have not been clear instances during the workshops when these voices have led to contradictions and tensions. The socio-cultural context can account for this (see Appendix B.5).
The emergence of contradictions and tensions is however reflected in the features of the RAP model that the participants produced. See the analysis proceeding in Appendix B.5.

- *Network champion*
  Figure 6.5 emphasizes the role of a "network champion" (NC) who is capable of acting as a catalyst by synthesizing ideas that are voiced differently. The moderator in the Porto Alegre workshops (from a local university) already had acted as a NC prior to the workshops. It was expected that the RAP modeling tool would make it easier for the moderator, or other NCs present in the workshops, to act as catalysts. However, from the workshop proceedings it was evident that the tool's impact in this sense has been extremely modest. Without doubt, this was due to the moderator's little experience with the RAP tool, as well as a sceptical attitude of participants toward computerized support for resolving their issues. See the discussion of socio-cultural context in Appendix B.5.

Based on the former observations, the following points can be made about the modeling and learning processes that occurred in the workshops:

- *The modeling process*
  In hindsight, given the particular challenges for LAN support in this case study set out previously, RAP simply could not be expected to deliver the kind of performance that it had delivered in other settings (e.g. the support of expert working groups). It is therefore not surprising that the RAP model that was produced by the workshop participants is not an "integrated" model, since it lacks representation of important systemic interconnections. See Analysis 1 in Appendix B.5.
  What is surprising, however, is the extent to which the RAP model – with its flaws – proved to be a useful reference point for the introduction of new voices, both during the workshops and afterwards. For example, by using the model of the first workshop as a reference, the participants in the second workshop were able to provide their inputs needed for elaborating an "actor perspective", thereby extending the model from the first workshop. As a result, the modeling process started to embark on the inclusion of some of the "intersubjective voices" that are expressed in Figure 6.5 (unfortunately, there was not enough time do this in the second workshop). Afterwards, their inputs proved to be sufficiently accurate to derive meaningful representations of the "arenas" related to previously identified strategies. See Analysis 3 in Appendix B.5.

- *The learning process*
  Little learning happened in the workshops and afterwards. This fact is reflected in the declining number of participants over the two workshops – the second workshop receiving fewer participants than the first workshop, and the second day of the first workshop having fewer participants than the first day. Arguably,

if the learning would have been more intense, the attendance would not have dropped as it did.

Based on the previous points, the overall point can be made that the LAN support that was provided through the two workshops cannot be defined as "just" a modeling and/or learning process. This point underlines a distictive property of RAP: that the modeling that is facilitated by the RAP tool is often not a goal in itself, but rather a vehicle for achieving other things; better communication, interaction, synergies, etc. Instead, the LAN support that was provided in Porto Alegre can be defined in terms of new reference points that can serve in various conceivable ways as a "backbone" to help the GIGA project's initiators executing their LAN-based strategy.

Toward a LAN Support Strategy

To push ahead with this "modern" concept of LAN support, an exercise was added to the case study (in 6.2.3) that served to test to what extent the RAP+ model can provide a strong backbone to subsequent modeling and analysis with agent-based simulation. In a broader sense, this exercise also served to explore what can be achieved with LAN support strategies that are designed on the basis of the combination of would-be words, building blocks, and learning-action networks.

- *RAP model*
  The RAP model, generated by LAN participants, locks-in on the problem that needs to be studied and the traditional voices that surround that problem. These voices tend to be *objective*, since RAP recognizes strategies as sets of planned changes that can be imposed on a system from the outside. These voices tend also to be *realistic*, since in RAP the impacts of strategies are assessed based on an agreed upon model of how changes propagate through a system irrespective of any particular time frame (in RAP the time dimension is entirely abstracted). Consequently, RAP provides only a limited platform for envisioning new change scenarios, because the "rules of the game" are considered to be fixed[38].

- *Perspectives (in narrative)*
  The perspectives capture distinct visions on the problem, put in narrative, and are closely connected to one or more of the resources that are represented in Figure 6.3: the RAP model, building blocks and/or other resources. As the perspectives are being evolved further using the various resources at disposal, they tend to reflect new voices that are distinct from the traditional voices. This is illustrated in the exercise for two resources in particular:

  1. *RAP with actor perspective (RAP+)*
     With the actor perspective, strategies in RAP no longer seem to "come from nowhere", since they now also exist in arenas that are connected to the system. Extension of the RAP model with an actor perspective can help to introduce *intersubjective* voices, since the extended model sheds light on the connections between the changes that actors may trigger, the consequence

[38] RAP offers the possibility to define scenarios (uncontrollable events like climate change impacts) that can be taken into account in the assessment. However, from a modeling viewpoint, such scenarios are treated equally as strategies – as sets of exogenous changes. Therefore, the anticipation of future events with RAP scenarios does not really help to envision radically new change scenarios in the RAP process.

impacts of these changes, and how the actors are affected by those impacts. However, this does not change the fact that strategies in RAP are essentially treated as sources of exogenous change.

2. *Agent-based simulation*
   A subsequent step can be taken by evolving perspectives that use agent-based simulation models as resources. Agent-based simulation models tend to treat strategies as sources of endogenous change, and are therefore particularly suitable to embody intersubjective voices.
   In case the agent-based simulation models are “would-be worlds” – i.e., meant for experimentation about the real world rather than for assessment of the real world – they are suitable for encapsulate voices that are *idealistic* as well as intersubjective. In contrast to the scenario building in RAP, the generation of “would-be scenarios” with simulated experiments can help to envision change scenarios if the “rules of the game” change.

- *Building blocks*
  An evolving set of building blocks – that could be evolved *interactively* by the workshop participants using the “Building Blocks Card Game” (in Appendix A.4) - spell out the path for having the workshop participants move to more complex dynamics with endogenized model components.

On the outset, the use of multiple resources as is illustrated in Figure 6.5 would perhaps seem overwhelming since it involves switching among modeling languages, which could pose certain difficulties especially for non-modelers. The exercise showed however that the process is mostly intuitive because of the visualized and narrative style used in most resources.

7 Conclusions and Recommendations

The preceding chapters sketch pieces of the puzzle of how agent-based simulation can be used to materialize the prospect of "complexity in foresight", as a way to help achieve adaptiveness in strategic planning. The ideas, frameworks, methods and tools elaborated in those chapters add up to the proposed five-layered architecture for the Framework for Synthesis that is represented in Figure 7.1.

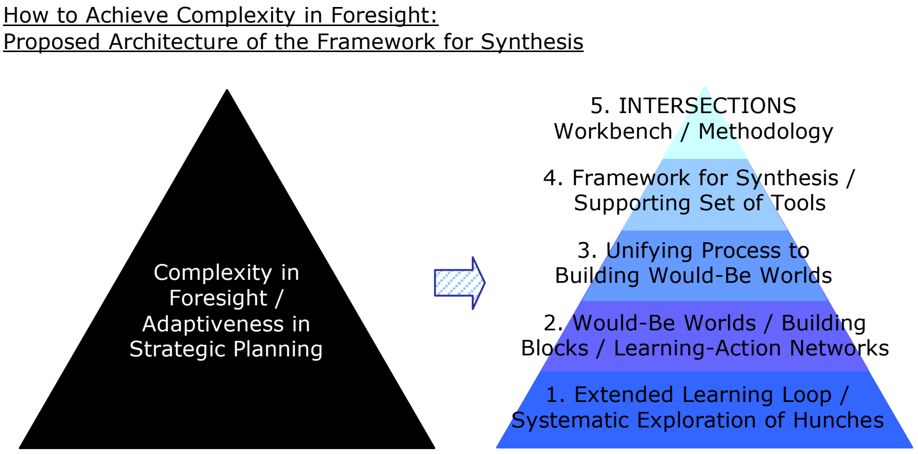


Figure 7.1 Complexity in Foresight: from black box to a multi-layered architecture

- LAYER 1. The centre piece of the puzzle is the systematic exploration of hunches, which is a basic idea (introduced in chapter 3) of how the traditional learning loop in modeling can be extended if it is opted to use agent-based simulation models.
- LAYER 2. Other pieces of the puzzle fall into place when moving in the direction marked by the cluster of terms: would-be worlds, building blocks, and learning-action networks (also introduced in chapter 3). This direction helps to envision what is needed to take agent-based simulation out of the sphere of 'computational laboratories' into the modern practices of strategic planning processes.
- LAYER 3. The pieces of the two foundation layers can be glued together to constitute a unifying process to building would-be worlds. On this level, the basic idea is that complexity in foresight can be achieved by rethinking the role for modeling and simulation, in a way that useful results can be achieved even in case the theoretical context for modeling has not yet stabilized.
- LAYER 4. The ideas for the layers 1-3 have been elaborated into the Framework for Synthesis and its supporting set of tools (described in chapters 5-10). Essentially, this framework outlines the six steps that guide a unifying process to building would-be worlds, and the tools that can be used in those steps. The crux of this process is that synthesis (using building blocks) and experimentation (using agent-based simulation models) can go hand-in-hand. Along this process, users transform their hunches into insights, and increase their ownership of both building blocks and models.
- LAYER 5. Based on the experiences in the two case studies, it is possible to envision a new practice – exemplified by the INTERSECTIONS workbench and methodology – that can be applied in strategic planning, with interesting applications conceivable in for example the intersections of sustainable development, innovation and policy.

This chapter is dedicated to putting the prospect that is framed in Figure 7.1 to test – as the saying goes: "the proof of the pudding is in the eating". Since it was not possible to test all the ideas, frameworks, methods and tools based on the practical experiences of potential users, other ways of testing have been pursued:

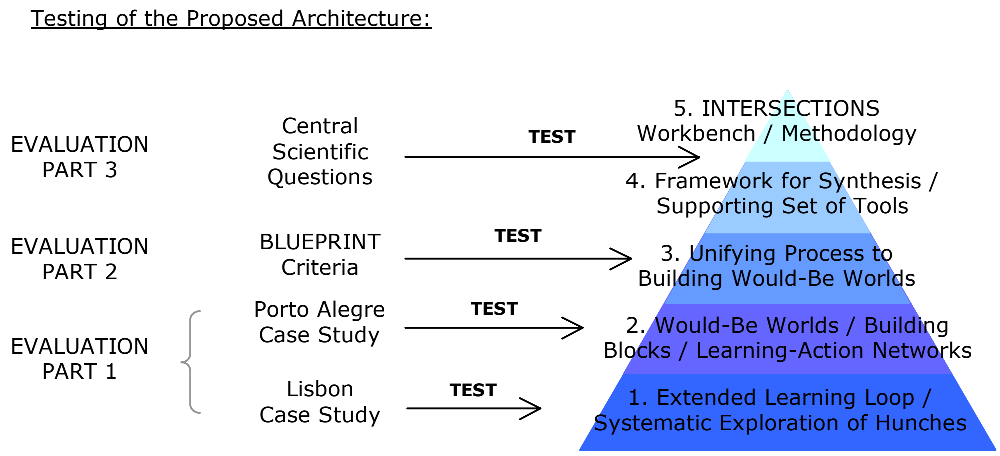


Figure 7.2 The tests of the Framework's proposed architecture

- EVALUATION PART 1: CASE STUDIES
  For evaluation purposes, exercises were added to the two case studies (covered in Appendices B.4 and B.6) that expand on the proceedings. The conclusions based on each of these exercises were merged into the overall conclusions that are given in section 7.1.

- EVALUATION PART 2: BLUEPRINT CRITERIA
  In chapter 4, a set of criteria – referred to as the BLUEPRINT criteria – are derived that set the requirements for "good simulation practice" in the presence of a not yet stabilized theoretical context for modeling. For evaluation purposes, the proposed Framework was scored against these criteria. A summary of the evaluation scores can be found in section 7.2. Appendix C.4 contains the complete score table.

- EVALUATION PART 3: CENTRAL SCIENTIFIC QUESTIONS
  In section 7.3 answers are formulated to the central scientific questions stated in chapter 1. These answers are based on the conclusions reached in parts 1 and 2 of the evaluation.

7.1 Evaluation Part 1: Case Studies

The case studies demonstrated the working of the foundation layers of the Framework for Synthesis' architecture (Figure 7.1), and made it possible to evaluate their design philosophies based on the experiences of a research team (Lisbon case study) and a learning-action network (Porto Alegre case study). The main evaluative points (in sections 5.4 and 6.3) add up to a concrete picture for how these foundation layers can be designed:

Architecture of the Proposed Framework:
The Foundation Layers

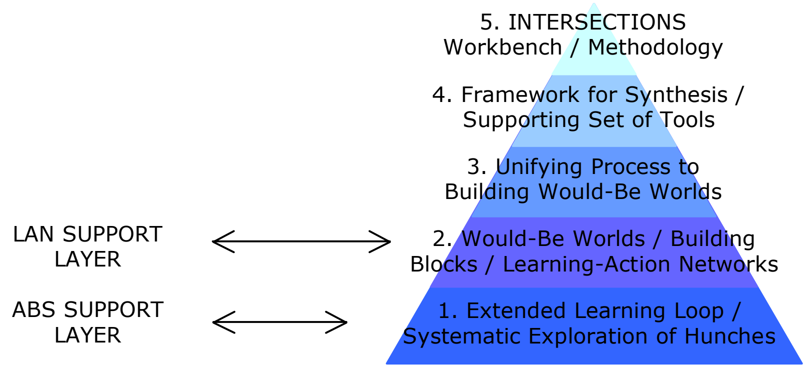


Figure 7.3 The two foundation layers of the Framework's proposed architecture

- ABS SUPPORT LAYER
  The ABS support layer provides a framework that supports agent-based simulation studies in which the theoretical context for modeling has not stabilized yet. Such instability implies that the connections between simulation model(s), theory about the core processes that are modeled, and possibly empirical data, are likely to remain blurry throughout even the later stages of the model development process.

  In ABS studies that are plagued by such instability, the ABS support layer provides a framework that helps a research team to create strong reference points that enforce their modeling and learning processes. In other words, the philosophy of this layer's framework is to facilitate a team in extending the new learning loops that agent-based simulation can support.

  The design of this layer's framework is based on maps of building blocks that a team can use interactively in their ABS study. Based on experiences in the Lisbon case study, there are at least two ways of using building blocks: 1) the team generates hunches based on missing links that they have visually identified on the maps, and this way they systematically explore and unblur connections between their model(s), theory and data, and 2) the team uses the maps to keep the flow of ideas going and to prevent lock-in of their modeling and learning processes. It is also anticipated that building blocks can help a team to find powerful new modeling concepts; however, the Lisbon case study has not shed more light on this potentially interesting use.

- LAN SUPPORT LAYER
  The LAN support layer provides a framework designed to support a learning-action network that is embarking on a strategic planning process. This framework helps to embrace the contradictions and tensions that arise as consequences of the parallel competing voices that are inherently present in LANs. Though the framework involves interactive workshops in which LAN members actively participate in model development, their modeling and learning processes are not goals by themselves, but rather means to an end.

  The LAN support that is provided by this layer's framework can be defined in terms of the creation of new reference points, that can serve in a number of conceivable ways as a "backbone" for executing a LAN-based strategy. The framework's philosophy is to create reference points that can help to reflect and synthesize new voices distinct from the traditional voices surrounding policies. The role for these reference points is connected with the role for network champions; i.e., LAN members who can act as catalysts by synthesizing these voices.

  The design of this layer's framework is based on the creation of perspectives, which are being evolved using a constellation of resources. Based on the experiences in the Porto Alegre case study, it is demonstrated possible to evolve a set of interesting perspectives by using three types of resources interchangeably: 1) a RAP model with actor perspective 2) building blocks, and 3) agent-based simulation models. With help of this particular constellation of resources, it is possible to steer toward new change scenarios in which the sources of change (the "strategies") are either exogenous or endogenous to the system that is modeled. Indeed, if ABS models are used as would-be worlds, it is possible to have a full range of voices compete with each other (realistic, idealistic, objective, intersubjective).

7.2 Evaluation Part 2: BLUEPRINT Criteria

The second part of the Framework's evaluation concentrates on glueing the two foundation layers together, which is solved in the middle layer in Figure 7.3.

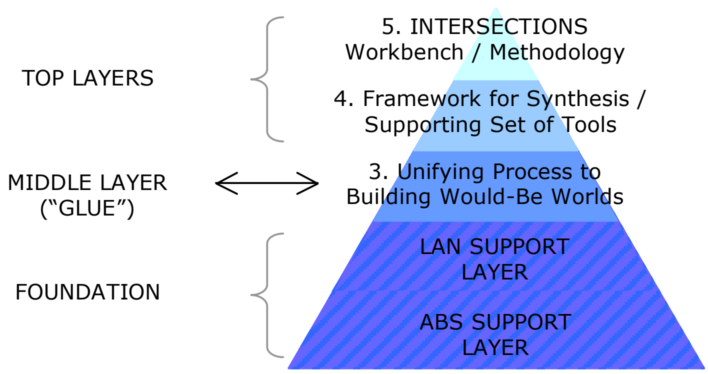


Figure 7.4 The middle layer of the Framework's proposed architecture

Let us be reminded that there are good reasons why the two foundation layers should work in conjunction:

- If a LAN-based strategy involves a considerable body of scientific inputs, the discussions that would merit the most from a "championed" competition of voices (taking place on the LAN support level) are those that, from a modeling viewpoint, are plagued by theoretical instability (at issue on the ABS support level).
- There are straightforward opportunities to use resources from the LAN support level also on the ABS support level, and vice versa (i.e., building blocks, perspectives, models).
- This is also true for the human resources involved; the LAN workshops are valuable opportunities for direct interaction between LAN members and a modeling team.

But what exactly can be achieved by having this foundation at work?

The answer is found using an evaluation method based on the BLUEPRINT criteria. As is set out in section 4.3, these criteria served to frame an outlook on designs of modeling and simulation practices that do well in unfavourable theoretical contexts. These criteria were also used to review the state of the art modeling practices (in section 4.4).

The results of the evaluation are summarized in Table 7.1(the detailed results can be found in annex 1). The scores in Table 7.1 suggest that the Framework for Synthesis, in comparison with other modeling practices, potentially constitutes an interesting new way of dealing with the modeling tradeoffs that are expressed by the BLUEPRINT criteria.

Table 7.1 The BLUEPRINT scores of the Framework for Synthesis

	Back-loops (Reflexivity)	*Human / Environment*	*Problem-oriented*	*Integrative*	*Interactive*
Framework for Synthesis	**Possible**	**Possible**	**Yes**	**Yes**	**Yes**
1. System Dynamics	**No**	**No**	**Yes**	**Possible**	**Possible**
2. Integrated Assessment	**No**	**Possible**	**Yes**	**Yes**	**Possible**
3. Visual Modeling Tools	**Yes**	**No**	**Yes**	**No**	**No**
4. Dynamic Actor Network Analysis	**No**	**Yes**	**Yes**	**Yes**	**No**
5. Rapid Assessment	**No**	**No**	**Yes**	**Yes**	**Yes**
6. Symbiotic Human /Computer Modeling	**Yes**	**No**	**No**	**Yes**	**Yes**
7. Agent-Based Simulation	**Possible**	**Possible**	**Possible**	**Possible**	**Possible**

For example, Table 7.1 shows that the Framework can be interpreted as a way to achieve applications with agent-based simulation in a more problem-oriented, integrative and interactive fashion. This is exactly the reason why the Framework's third layer should be dedicated to the facilitation of a *unifying* process to building would-be worlds.

The results also point out that in order to fulfil its full potential, the Framework needs to be strengthened in relation to two criteria: Back-Loops (Reflexivity) and Human/Environment:

- With regard to the Reflexivity criterion, improvement can be made by incorporating the use of a practical measure of complexity. Such a measure could "strengthen the glue" between the two foundation layers, as it provides a means for assessing the fundamental uncertainties and for having an early indication of the new learning that can be facilitated with agent-based simulation.
- As regards the second criterion, Human/Environment, progress would require more advanced baseline models that can shed light on human goals and/or goal-oriented processes.

7.3 Evaluation Part 3: Central Scientific Questions

First Central Scientific Question

1) Is the Framework for Synthesis a potentially useful practice to support learning-action networks in sustainable development?

Specific questions:
1a) What are design criteria for effective support for learning-action networks?
1b) How does the Framework for Synthesis perform against such criteria?

Starting with question 1a), there are good reasons to believe that the BLUEPRINT criteria form an accurate set to frame the design requirements for LAN support:

- Throughout this study "threads" have been established between the voices represented in Figure 6.5 and the fundamental uncertainties discussed in chapters 2-4 in different philosophical contexts: the problems of reflexivity and indeterminacy in social science, not yet stabilized theoretical contexts for modeling and simulation, (three) paradigms in systems thinking and the competition of parallel voices in group support design.
- Since these threads are framed by the BLUEPRINT criteria, it follows that these criteria are sufficient to tell good designs for LAN support from bad ones.

As regards question 1b), the Framework for Synthesis' scores against the BLUEPRINT criteria in Table 7.1 suggest that the Framework is indeed a potentially useful practice to support learning-action networks. It should be reminded however, that:

- For the Framework to fulfil its full potential, certain improvements need to be put into place. See the discussion in evaluation part 2, section 7.2.
- The scores against the BLUEPRINT criteria are based on a comparison of the Framework's *design features* versus *design criteria*. The scores do however *not* tell about the Framework's actual performance in practice. All conclusions about the Framework's potential usefulness are therefore tentative.

Second Central Scientific Question

2) What are further possibilities for innovative problem-solving practices in this direction?

Specific questions:
2a) What is learned about the potential usefulness of each of the Framework's methods/tools?
2b) What is learned about their complementary uses?
2c) What overall design principles have crystallized?

The second set of questions does not concern the Framework for Synthesis in particular, but expands to cover the lessons learned about the direction that the Framework is taking – a direction that is marked by the combination of three terms: would-be worlds, building blocks and learning-action networks.

The answering of questions 2a) and 2b) begins to expand on the complementary uses of the Framework's methods and tools that are not foreseen yet in the Framework's current architecture. It can be concluded from Figure 7.5 that the possibilities for such complementary uses mainly depend on how well the top layers and foundation layers are glued together, which is essentially taken care of by the middle layer. The Framework's middle layer currently works with perspectives, put in narrative, that help to tie various resources together (e.g., sets of building blocks, parts of the rapid assessment model, concepts from agent-based simulation models). The exercise covered in Appendix B.6 demonstrated that this "modular approach" can work quite well[39].

<table>
<tr><th colspan="2"></th><th>Experimental Design</th><th>Building Blocks</th><th>Simulation Models</th><th>Building-Block Card Game</th><th>Rapid Assessment</th></tr>
<tr><td rowspan="2">Top Layers</td><td>5</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2">X</td><td rowspan="2">X</td></tr>
<tr><td>4</td></tr>
<tr><td>Middle Layer</td><td>3</td><td colspan="5">Perspectives</td></tr>
<tr><td rowspan="2">Foun-dation Layers</td><td>2</td><td rowspan="2">X</td><td rowspan="2">X</td><td></td><td></td><td>X</td></tr>
<tr><td>1</td><td>X</td><td></td><td></td></tr>
</table>

Figure 7.5 The interactions of the Framework's layers, tools and methods

This brings us to question 2c): have new overall design principles crystallized through designing the Framework for Synthesis? Section 4.5 listed a set of hypothesized design principles based on the review of state of the art modeling and simulation practices. A more concise design plan is laid out in this chapter, in the form of the Framework's architecture (Figure 7.5 and previous figures).

7.4 Recommendations and Further Research

This thesis was designed to lay the *groundwork* for development of a workbench to help achieve adaptiveness in strategic planning, utilizing agent-based simulation and other approaches. It was founded on this thesis author's outlook (in Chapter 4) that certain 'less favourable' theoretical contexts for modeling and simulation urge us to rethink 'good' modeling and simulation practices. On the foundation, the author has added his experiences with designing, building and testing tools and the 'Framework for Synthesis' – the framework that organizes how these tools can be used in conjunction (on the CD-ROM). The two case studies helped to test the potential usefulness of the Framework and tools for the support of learning-action networks – informal social linkages among people across organizations that are likely to have a critical role for strategic planning in a world that has become 'more uncertain' and 'more complex'.

In order to achieve a *solid* groundwork, this thesis author has put focus on one aspect of myriad design challenges involved: developing a "unifying process to building would-be worlds". This particular focus helped the author culminate his experiences with proposed designs of tools into the 5-layered architecture for the 'Framework for Synthesis' (in Chapter 7) – an architecture that is designed to achieve flexibility in the combined use of agent-based simulation and other approaches. This focus also allowed the author to highlight the potential positive impact of the Framework's tools on interdisciplinary learning in the two case studies. Further, it made it possible to "assess" progress made with the Framework through its evaluation against the 'BLUEPRINT' criteria (Table

[39] The main advantage of modularity is that it creates the possibility to expand on a modeling idea or resource without compromising their competition with other ideas or resources.

7.1) – a set of design criteria that the author developed to frame his outlook on how to rethink modeling and simulation practices.

Because of this thesis' focus on one (major) design challenge only, plenty opportunities remain for *further research* based on the same groundwork. In the author's opinion, the two most directions for further research are:

Directions for Further Research

- DEVELOPMENT OF A HIGH LEVEL LANGUAGE
  The conclusions in this chapter underline development of a high level language for the middle layer of the Framework's architecture (see Figure 7.4). This language could 'streamline' the systematic exploration of hunches, since it could be used to glue together two of the Framework's key activities: (1) navigating webs of building blocks and (2) utilizing various resources to evolve perspectives into would-be scenarios. This language could be similar to the popular *XML* language – a language for the modeling of concepts that can be processed by machines and read by people. A good starting point for development of this language is the current format in which perspectives are written (see 12.5), which could be evolved into a XML-like format while preserving their narrative style as much as possible.

- DEVELOPMENT OF SPECIFIC WEBS OF BUILDING BLOCKS
  A second direction for further research is development of webs of building blocks that are specific to an application area. The two case studies of this thesis are good starting points, since they provide sets of building blocks that are specific for *innovation management* (Lisbon case study) and *waste management* (Porto Alegre case study). It is this thesis author's expectation that development of a specific web will be essentially comparable to mapping a 'giant yet unspecifiable model' that nurtures the ideas of academics and practicioners in a particular interdisciplinary area. For this reason, development of specific webs should be supported by a prototype workbench that has two types of uses: (1) an interactive learning tool for scholars (2) a modeling tool to support foresight institutions.

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