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# Understanding and accelerating the diffusion process of energy-efficient buildings:

## Introducing an Action Science Venture

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## Abstract

*This paper describes the innovative research approach of a project that has recently been funded by the Swiss National Science Foundation (SNF). The project aims at analyzing and accelerating managerial and organizational adaptation processes that foster the diffusion of pioneering energy efficient technologies in the building sector. Psychological, managerial, and economic theories as well as results of empirical investigations about antecedents of behavior choices will be synthesized into a simulation model for a middle-sized Swiss city. The model will shed light on dynamic interactions between behavioral factors (e.g., planning, decision making and routines of the relevant actors in the building sector) and contextual factors (e.g., technological innovations, public initiatives, and market conditions), thus explaining the diffusion of energy efficient buildings in a community. The objective of the paper is to discuss the nature of the topic and to present first research heuristics.*

**Keywords:** transdisciplinary modeling, hybrid system modeling approaches, cognitive mapping, system dynamics, building behavior, socio-technological change, behavior change in value creation chains, stakeholder management

# 1 Introduction

This paper describes the innovative research approach of a project that has recently been funded by the Swiss National Science Foundation (SNF). The project team started working in August 2005 and it expects to finish the project in August 2008. The objective of the paper is to discuss the nature of the topic and to present first research heuristics. In addition, it aims at contributing to the ongoing debate on designing transdisciplinary modeling studies.

The project aims at analyzing and accelerating managerial and organizational adaptation processes that foster the diffusion of pioneering energy efficient technologies in the building sector. Psychological, managerial, and economic theories as well as the results of empirical investigations about antecedents of behavior choices will be synthesized into a simulation model for a middle-sized Swiss city. The model will shed light on dynamic interactions between behavioral factors (e.g., planning, decision making and routines of the relevant actors in the building sector) and contextual factors (e.g., technological innovations, public initiatives, and market conditions), thus explaining the diffusion of energy efficient buildings in a community.

The *Integrative System Methodology (ISM)* will be applied. The relevant actors (i.e., public and private decision makers in the value creation chain of buildings) will be involved in the model building process. We will chose actors who were engaged in the recent construction of 3 to 4 reference buildings (buy owner, architects, craftsmen, and investors), the regional energy consultant, and representatives of the national, cantonal, and municipal authorities to form a “system expert group”. This group will be the major partner in this transdisciplinary research project. The selected reference buildings will differ according to their energy efficiency (pioneer energy efficient building with Minergie(-P) standard vs. traditional building fulfilling the minimal legal energy efficiency norms). This will ensure that pioneers and early adopters of innovative energy efficient construction technologies as well as late majorities and laggards will be represented in the “system expert group”.

Two models will be developed and tested: (a) a (static) model of behavioral antecedents of the choices at the point where the path to an energy efficient or non-energy efficient construction processes is entered, and (b) a (dynamic) building stock simulation model. The first model results in valid, empirically tested causal relations about behavioral determinants. These causal relations are integrated as decision functions in the second model.

The model building process will consist of a stepwise procedure involving phases of literature review, empirical data collection (among other things, cognitive mapping with the selected actors and survey data from a larger sample from the value creation chain of the construction sector), and model conceptualization alternating with validating workshops with the system expert group. This will ensure a direct dissemination of the insights of the project and the “validity” of the dynamic theoretical framework for the diffusion management of energy efficient buildings. The framework – represented in the simulation model – will serve as a basis for the development of a “transformation support tool towards energy efficient buildings” for decision makers in the building sector. Based on insights from policy analysis and scenario experiments, this product will not only portray promising collaboration strategies and management instruments, but also include an assessment instrument for action strategies.

# 2 Background

Sustainability requires a significant reduction of energy consumption in industrialized countries. Technically, the vision of a dramatically reduced energy demand in Europe by the year 2050 is a challenge but not an utopia (Jochem 2004), provided that the technical know-how available today is put into practice. An important sector to improve energy efficiency today and in the future is the building sector. If the know-how and practices for building energy efficient houses are disseminated and broadly adopted *today*, an important step towards a “2000 Watt per capita society” by 2050 (Jochem 2004) – a society with only one third of today's energy demand – will be taken.

The Swiss government invests a great deal of money in research on different energy innovations in the building sector and their potential for greater efficiency (Swiss Federal Office for Energy 2004). A widely accepted standard (Konferenz Kantonaler Energiefachstellen and Verein Minergie 2004) and registered trademark for energy efficiency of buildings is the Minergie ® standard, where specific energy consumption in MJ/$m^2$ (only final consumption) is used as indicator for the energy efficiency. For obtaining the label, the building must have a high-grade building envelope, a thick heat insulation and a good ventilation system. A further important precondition for the label is, that the extra costs resulting from these measures do not exceed 10%. A currently developed standard for buildings with a broader focus on sustainability (Poligon 2004) considers also the shape of buildings and architectural characteristics for avoiding heat bridges for the rating of energy efficiency of buildings. A systematic energy monitoring as basis for an energy passport for buildings, as planned in Europe by 2006, is currently under construction (Amstein & Walther and Intep 2004).

Up to present, 3500 buildings have been certified with the Minergie standard (Verein Minergie without year), and since 1998 a growing number of buildings are certified each year. The market potential of the more restrictive Minergie-P label (a building standard corresponding to the German “Passivhaus” standard) is expected to remain within the target group of pioneers (niche marketing, Belz 2001) for another few years, while the classic Minergie standard attracts a larger market segment (Frauenfelder 2002). Kaufmann and Dettli (2002) found that in cantons and municipalities with more consulting activities and information events new buildings are more energy efficient than those in other cantons and municipalities with fewer activities of this type. According to Infras (2002) improvement of the energy efficiency of the Swiss building stock is to a much larger extent due to stricter legislation than to autonomous development.

# 3 Problem focus, research approach and objectives

The desired transformation toward a substantially more energy efficient building stock requires individual, organizational, and societal learning processes as well as profound structural changes.

In the frame model of human action-in-context (Kaufmann-Hayoz and Gutscher 2001; Kaufmann-Hayoz 2005/in press), sustainable development of the built environment is seen as a co-evolution of behavior (e.g., planning, decision making, and routines) and external conditions (e.g., technologies, socio-economic and legal-administrative conditions). The success of policy initiatives (such as the Swiss energy program by the Swiss Federal Office of Energy SFOE) aiming at the diffusion of energy efficient buildings depends not only on technological innovations and fair market conditions (external opportunities) but also on adequate knowledge, decision rules, management, and networking (behavioral variables) of the various actors involved in the value creation chain of energy efficient buildings (e.g., investors, architects, building crafts, producers, political authorities). Today, new practices have often to compete with well established routines favoring energy-*in*efficient construction solutions. This results in policy resistance and inhibits necessary transformation and change: The system is locked in the old structure leading to path dependency, also due to informal rules of conduct. Indeed, there exist many subtle pitfalls such as inherent defensive routines and interpersonal impediments to learning (Argyris 1985; Argyris and Schön 1996) combined with implementation failure. Especially the pressure to maintain performance in the short term for reasons of competitiveness often suppresses new strategies that might yield great profit over the long run.

In order to overcome those pitfalls and path dependency in the evolution of the built environment, decision makers and relevant actors on all levels of the system need to understand such system behavior and to adjust their collaboration and management as well as their planning instruments at the three levels of integrative management (Bleicher 1999; Ulrich 2001; Rüegg-Stürm 2002). This requires an understanding of the factors that guide perception, adoption, and rejection of innovations in society. Such a system understanding is a precondition for systems design that fosters reinforcing processes towards a sustained diffusion of energy efficient buildings within a community.

Our applied research approach is in line with the paradigm of actions science. This paradigm stresses the importance of transdisciplinary research in order to understand context dependent actions. Argyris and Putnam (1985) define action science as a research approach that combines the study of practical problems with research that contributes to theory building and testing. Action science is built on two premises: First, understanding the world is a precondition for successfully managing or transforming it in a desired direction Second, understanding the world can be achieved by attempting to change it. Such an attempt would reveal defensive forces that try to maintain the status quo. With this interpretation Argyris and Putnam (1985) refer to Kurt Lewin and John Dewey, two psychological experimentalists who designed and conducted action or demonstration experiments in order to systematically investigate consequences. Their notion of action science reflects a mix of descriptive and normative interest that would help design “better societies” by fostering a society that is held responsible for being inquiry oriented. They often applied their approach with decision makers addressing issues of organizational learning (Argyris and Schön 1996). The paradigm of action science gives strong weight to problem oriented research approaches and stresses the need for transdisciplinary research approaches that include practitioners in the inquiry process. Action science aims at understanding consequences of interventions by focusing on context-dependent action of human beings and their theories in use. This strategic direction also implies theorizing about interaction between personal factors and contextual factors changing over time.

The *overall objectives* of this project are fourfold:

1. Construction and empirical test of a static behavioral antecedents model explaining the main forces that steer management processes of relevant actors in the value creation chain of energy efficient buildings, hence inhibiting or facilitating the diffusion of energy efficient buildings. Hereby, both external conditions (such as technical and cost factors) and behavioral factors (such as planning, decision making, and routines), will be considered, and particularly their interaction.
2. Specification of decision functions for the system dynamics model (objective 3), according to the empirically tested behavioral antecedents model.
3. Construction of a dynamic simulation model that
   (a) explains observed changes in energy demand per capita and $m^2$ of living space and commercial space,
   (b) allows analyzing and demonstrating the effects of different business and innovation strategies on the variables of interest under different public energy policies.
4. Development of a “transformation support tool” for decision makers in the value creation chain of energy efficient buildings that demonstrates successful managerial adjustment processes in response to various external demands, e.g., public policy initiatives towards a 2000 Watt society and therefore helps to develop adequate collaboration strategies and management instruments.

The *research questions* resulting from the formulated goals are:

1. Who are the key actors and what are the key interactions between actors determining the development path of the building stock?
2. What are the behavioral antecedents of adopting versus not adopting state-of-the-art energy efficient building technology by the key actors?
3. What are the essential system variables and their interaction over time, which determine the rate of change of the energy efficient building stock?
4. From a managerial perspective, what are important learning loops that steer successful or unsuccessful transformation processes towards a 2000 Watt society in the building sector?
5. What are the relevant policy levers and system indicators for an adequate transformation support tool?

### Working hypotheses

The working hypothesis results from the above problem definition and our theoretical approach:

1. Working hypothesis for the static behavioral antecedents model:

Behavioral antecedents of the choices at the point where the path to an energy efficient or non-energy efficient building process is entered depend on the type of required behavior. The key behavior leading to an energy efficient construction path is a stepwise process and does not always involve conscious decisions in the psychological sense but also behavior patterns that have rather a routine character, similar to the emergent strategizing concept.

2. Working hypothesis for the dynamic framework:

Changes in managerial decision rules and action strategies are high leverage points for accelerating the diffusion process of energy efficient buildings. However, the transformation process is slow due to inefficient managerial learning processes, in particular a lack of double-loop learning. Adaptation or modification delays result in policy resistance and in path dependency. An efficient technologically induced transformation process requires changes in cognitive structures and mental models of the relevant actors in the pertinent value creation chain.

## 4 Steps and concepts of the investigation and intervention

The *Integrative System Methodology (ISM)* (Schwaninger 1997; Schwaninger 2004) will be applied within a case study of a typical middle sized Swiss City (Langenthal BE). ISM is a methodological *framework* for dealing with complex dynamic issues and integrating different disciplinary concepts into an encompassing theory (see also Senge, Kleiner et al. 1994). It helps actors in organizations and society to cope with change processes. In several case studies ISM has proved to be suitable for investigating complex issues, drawing on concepts of System Dynamics and Organizational Cybernetics. ISM is especially suited for computer assisted theory development that is guided by a feedback view on human action and public policy (Kaufmann-Hayoz, Bättig et al. 2001; Kaufmann-Hayoz and Gutscher 2001), allowing to analyze co-evolutionary processes (Ulli-Beer 2004), e.g., between technological innovations and behavior. Based on a cyclical investigation process ISM distinguishes four main phases within an intervention project: (M) Modeling, preceded by a framing discussion (0), (A) Assessing, (D) Designing, and (C) Change, see figure 1.

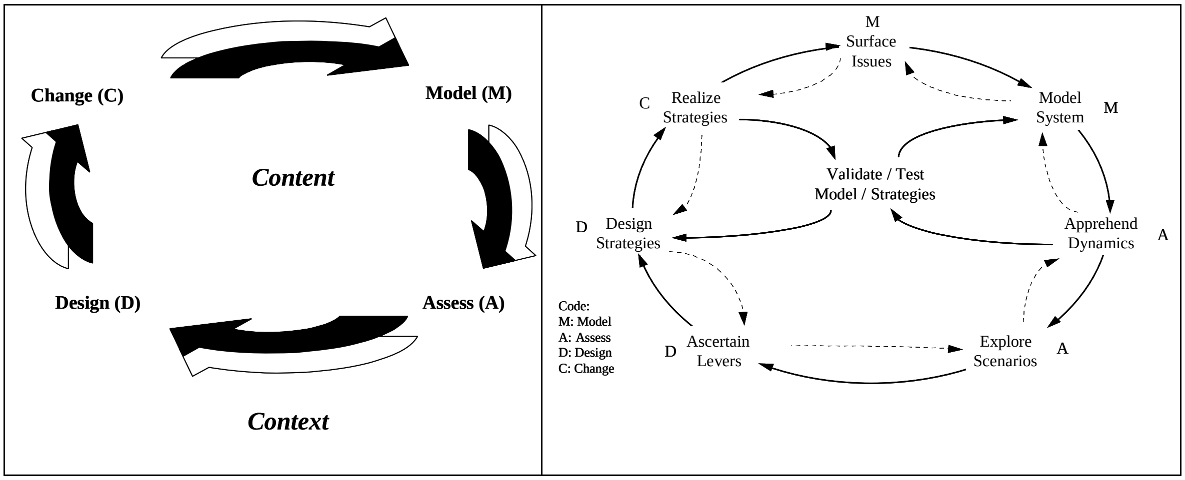

*Figure 1: Integrative Systems Methodology – Overview (Schwaninger 1997)*

Left side: The loop has two sides which are intertwined, one referring to the content of the issue dealt with, to other to the (organizational) context in which the issue is embedded. The scheme on the right side of figure 1represents in more detail the sequences of steps in both the content and context loop.

Following the ISM approach, different methods will be applied in a recursive exploration, which allow for analyzing both content and context conditions of adoption decisions and of diffusion processes of energy efficient buildings from different perspectives.

## Phase 0 Stakeholder analysis and framing

Three foci of analysis are distinguished (see figure 2):

(1) Strategies and decisions of the actors involved in the supply chain of energy efficient buildings – forming the guiding policies within the system (micro-level)
(2) Distinctive characteristics of adopter categories (e.g. differences with regard to innovativeness)
(3) System structure and behavior patterns of variables of interests over time (macro-level)

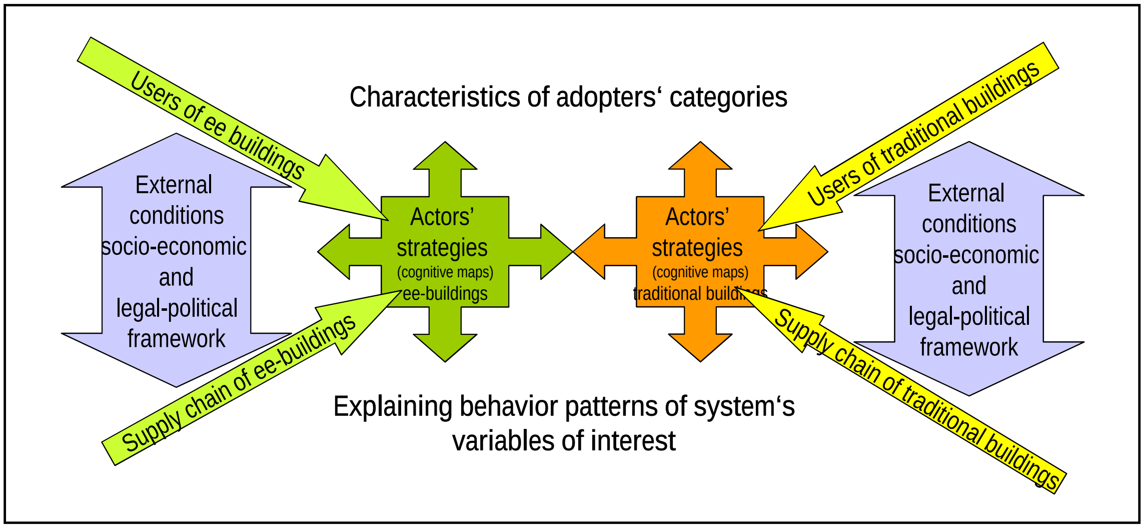

*Figure 2: Overview of the level of analysis: action theories, system behavior, characteristics of adopter categories*

Two distinctive actor-groups of the value creation chain of buildings will be identified and described (see figure 2). They differ with respect to the type of building they were involved with: a traditional building with an average energy consumption level vs. an energy efficient building. The two samples are seen as representing late majorities and laggards (traditional building technologies) on the one hand and pioneers and early adopters (energy efficient buildings) on the other hand.

Basis for the identification and analysis of the crucial actors and their networks are expert talks with locals, impact considerations, and a literature review of different theories of decision making, behavior modification, and learning (e.g., Argyris and Schön 1996; Gardner and Stern 1996; Bruppacher 2001; e.g., Flury-Kleubler and Gutscher 2001; Bruppacher and Truffer 2004). Based on the results of this first step of investigation the system expert group will be formed. This group comprises researchers and representatives of the target audience: Public and private decision makers in the value creation chain of energy efficient buildings, i.e. actors who were involved in the construction of 3 to 4 selected reference buildings (buy owner, architects, craftsmen, investors), representatives of the national, the cantonal and the municipal authorities, the regional energy consultant, and professional associations, e.g. SIA. Reference buildings are selected according to the following criteria:

- Energy efficiency: The energy consumption of reference buildings varies over a large range. We include relatively energy efficient buildings (Minergie standard with or without label), and traditional buildings (just fulfilling the minimal legal requirements of the construction year).

- Size of the building project: We include large development projects as well as small one-family houses.
- Involved actors: A broad spectrum of actors with respect to innovativeness is represented. In particular, the most influential architectural bureaus will be chosen.

In **a first workshop** the purpose of the overall study, emerging hypotheses about important actors, actor networks and interactions, factors in the system, and antecedents of different actors' decision making are discussed with the system expert group.

## Phase 1 Modeling (M)

Following an exploration strategy, **expert interviews and cognitive mapping** with actors described above will be conducted with the method „visible thinking“(Bryson and Ackermann 2004). The interviewees' action theories in use will be represented in cognitive maps. For each building the mental models of about five key actors will be mapped separately (resulting in about 15 cognitive maps). In a parallel process a **literature review** on scientific concepts stemming from decision and management science will be pursued that helps interpret and structure the empirical mental models. The analysis of the scientific concepts and the system experts' mental models will be presented and discussed within a **second workshop** with the system experts.

The aim of this phase is to describe the initial situation within the system under focus, to ascertain the relevant perspectives, goals and factors critical for attaining them and to surface present issues. It helps to sketch first conceptual heuristics, to identify relevant terms and variables as well as to identify first causal assumptions.
The cognitive maps should shed light on the most crucial points of decision making, leading to energy efficient or non-energy efficient constructions, e.g.

- at what point and why did a buy-owner consider building an energy efficient building in the first place,
- at what point and why did an architect consider suggesting an energy efficient building to a client.

After the comprehensive conceptualization phase two different models will be developed.

(A) **A (static) model of behavioral antecedents of the choices at the point where the path to energy efficient or non-energy efficient building processes is entered**, based on a synthesis of the literature review and the (grounded theory) analysis of the cognitive maps. The dependent variable at the crucial point will be refined and defined as a result of the analysis of the cognitive maps. Since the evaluation process of an innovation goes stepwise (Rogers 1995; Völlink, Meertens et al. 2002) more than one crucial point may be modeled. Considering an energy efficient building in the sense of it coming to one's mind and being evaluated an effective option (Tanner 1998) may be a first crucial point. Also, different model versions for different actors may be necessary, e.g. antecedents of buy owners asking for an energy efficient building and architects advising clients to invest in energy efficiency. Antecedents for a positive evaluation of the advice and implementation of an energy efficient building may take place at another crucial point.

**(B)** **A building stock simulation model** based on differential equations describing the overall structure and behavior of the variables of interest over time will be developed. The model incorporates micro-level behavioral antecedents and decision structures as well as macro level factors describing behavioral patterns of the variables of interest such as energy consumption of the building stock. For this purpose the grounded theory approach will be further elaborated with a broader focus on guiding principles **and processes of observed energy consumption stemming from characteristics and** usage of the building stock. The model structure will be visualized with the help of the specialized System Dynamics Software Vensim©. This computer-assisted theory building process integrates the different issues of the context of discovery and justification in an iterative process, resulting in a model that is highly consistent with the real system and aligned with the purpose of the investigation.

## Phase 2 Assessing (A)

In this phase, both models will be tested with respect to consistency, correspondence and robustness.

(A) The static model(s) of behavioral antecedents will be tested with empirical data gathered from a sample of buy owners (and probably also architects and planners) who were involved in the construction of the building stock of the last five years. The data will be gathered with a questionnaire and analyzed with adequate statistical multivariate methods (Bortz 2005).

(B) The building stock simulation model will be profoundly tested following the system dynamics “testing”-theory (Barlas 1996; Sterman 2000) in order to establish confidence in both the structure and the behavior of the simulation model. Subsequently, the simulation model can be used for back-casting experiments revealing the dynamics of the past energy demand. The main feedback processes will be identified and termed.

A **third workshop** will be conducted in order to share insights from model building and simulations with the system expert group and to negotiate a shared understanding of both the static model(s) of behavioral antecedents and the building stock simulation model as well as the main dynamical insights.

## Phase 3 Designing (D)

In this phase effective control levers will be identified. For this purpose different kinds of policy experiments deduced from the actual political discussion and from theoretical considerations will be designed and simulated under different scenario conditions. These forecasting and scenario experiments illustrate possible development paths under the well specified assumptions made in the model.

Sensitivity analysis helps to discriminate “sensitive” parameters in reference to changes in behavior patterns of variables of interest such as energy demand per $m^2$ (behavior mode sensitivity) and to contradicting policy implications (policy sensitivity). These experiments help dealing with uncertainty in model assumptions as well as with uncertainty regarding the future development path in the real world. The aim of sensitivity analysis is to come up with the identification of robust policies that are effective also under uncertainty and within a broader future development space of the real system under focus. A simple “flight simulator” (i.e. a simple hands on interface with important policy levers and parameters) will be developed that allows to simulate different policy and scenario experiments and enables the audience to replicate the various policy tests with the simulation model. In this form the simulation model can be used as a transformation support tool that facilitates the discussion of different energy strategies and their policy implications in a **fourth workshop**.

## Phase 4 Change (C)

As is described above, research and implementation are narrowly intertwined in this project. Referring to figure 3, we may say that in the steps listed on the right-hand side the knowledge transfer and implementation aspects predominate. The four workshops to be held with the system experts group are steps in a mutual learning process and opportunities for networking and knowledge exchange among the involved transdisciplinary project partners.

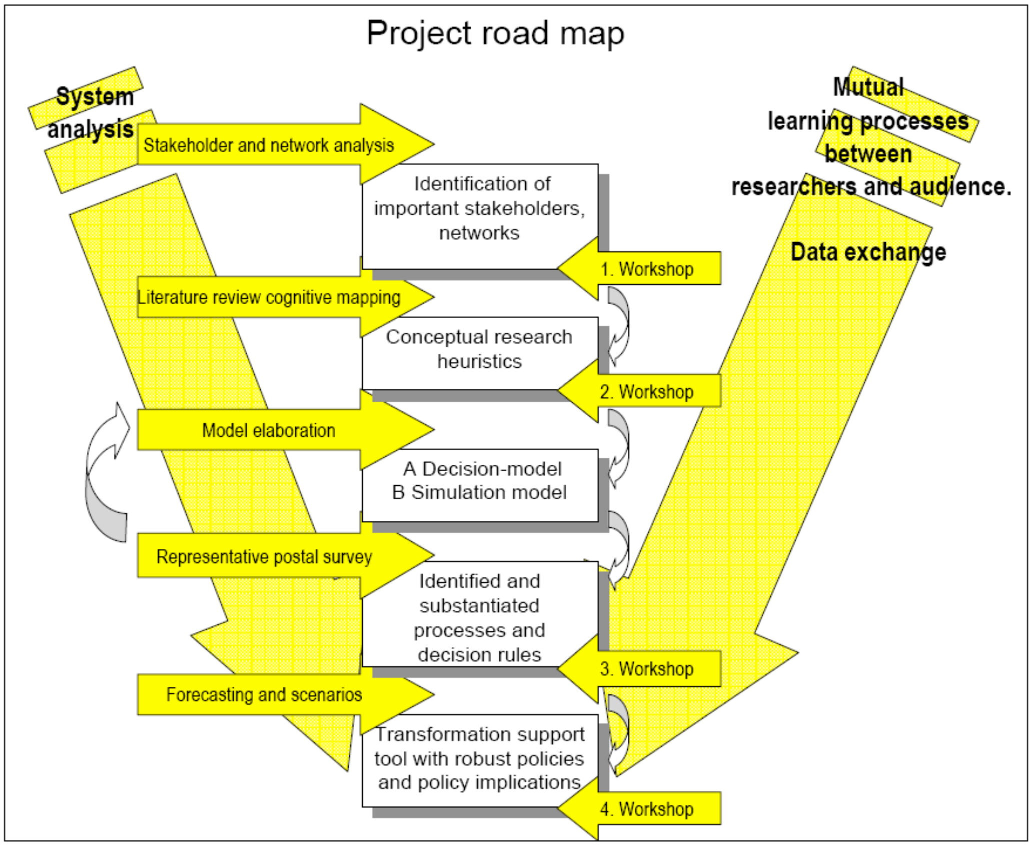

*Figure 3 Project road map – integrating system experts into the system dynamics analysis in order to foster a mutual inquiry attitude during the investigation*

# 5 First research heuristics

In the following paragraph first research heuristics will be introduced.

Research heuristics are found to be especially helpful within a problem-oriented research approach fostering a continuous knowledge exchange between researchers and practitioners (Ulli-Beer 2006). Throughout the study the different insights will be organized and structured in frameworks serving as “inquiry catalysts” for both the investigation but also for practical policy design. A heuristic serves as a device that helps generating new insights and tackling problems. It is the “art of finding” (see Schwaninger 1997:113) that includes an inherent evaluative process according to some criteria (see Beer 1990).

### Stakeholder and actors analysis

In the academic literature about practitioners two terms are often used: stakeholders and actors. These terms will be specified for our investigation.

A general accepted definition of a stakeholder does not exist. Mitchell et al. list in a recent article 27 different stakeholder definitions used in the business literature only (Mitchell, Agle et al. 1997). For instance, “a stakeholder is any group or individual who can affect, or is affected by, the achievement of a corporation’s purpose.” (Freeman 1984). The concept of an actor is slightly distinct from the concept of a stakeholder. For system analysts, an actor is “a person who carries out one or more of the activities in the system” (Checkland 1981). The difference between actor and stakeholder is therefore the level of activity in the observed system. Stakeholders can be both actively triggering or just passively absorbing or observing actions in the system. Actors, on the other hand, are defined as purely active entities. For our purpose we will use the term actor, if the research focus lies on specific human behavior, action and decision concepts and stakeholder if we try to describe the main agents and their network within the system boundary.

A “Stakeholder analysis can be defined as an approach for understanding a system by identifying the key actors or stakeholders in the system, and assessing their respective interest in the system.” (Grimble and Chan 1995). The main purpose to employ a stakeholder analysis is to understand complexity and compatibility problems between objectives and stakeholders, e.g., in turbulent business environments by discovering existing patterns of interaction (Freeman 1984). Additional purposes are to improve interventions analytically and to guide policy-making (Grimble and Wellard 1996). The question of who is a stakeholder or actor and when to consider their opinions and knowledge is most important during a stakeholder analysis. Different research fields appreciate this important role of stakeholders, e.g., political and policy sciences (Riker 1986; Dahl 1990), strategic management (Freeman 1984; Bryson 1995; Eden and Ackermann 2002; Ackermann and Eden 2003), and planning (Christensen 1993).

### Researching stakeholders

For the ‘DeeB’-research project, it seemed important to start with a very open conception of stakeholders in the building system: We began the analysis with the notion that a stakeholder is „a person or an organization that somehow matters when building in the chosen location.“ This open approach allowed us to identify stakeholders in an empirical way, drawing on „qualitative“ social science research methods. For the conceptualization of the actual building process we relied on Porter’s value chain approach (Porter 1985). The following section describes in greater detail the iterative process of identifying stakeholders, conceptualizing the building system and finding reference buildings:

The practical process of identifying the building-system’s stakeholders started with an expert-interview: With his many years of local experience and with his professional background as an architect, the regional energy consultant seemed the right expert to begin the investigation with. The interview was conducted as a semi-structured interview; it was recorded and subsequently transcribed. In a next step, the transcript of the interview was analyzed and mined for relevant information using an ad-hoc approach based on the social science methodology of grounded theory. In particular, we were seeking to distill information related to three clusters of questions:

- How can the construction-process of reference projects be represented by a stylized (or as Max Weber would say: “ideal-typical”) story? How can the activities of the actors in the value creation chain be conceptually integrated with the activities of stakeholders that do not participate directly within the value creation chain?
- What legal regulations governing energy-related issues in the construction process are in place? Who applies the rules? Who makes the rules? Who is affected by rules?
- Who are significant players in the reference city? Which persons and organizations should be invited to represent stakeholder positions? Which buildings could serve as reference buildings?

The insights of the first interview were used to prepare the second interview, with the head of the city’s building-division. Like the first interview, this interview was mined for relevant information. Following hints from the two experts, we researched further information on specific stakeholders from the professional literature as well as from respective stakeholder’s websites. In an iterative process, all these information was collected, analyzed and cross-referenced with each other. In this way, empirically founded knowledge emerged out of the many bits of information we gathered.

In the following three sections, we summarize some preliminary results from our stakeholder research:

### *A) Understanding the innovation system of the building sector*

Figure 4 shows our latest concept of the building system with important stakeholders in the system: The most fundamental differentiation is between actors located in the value creation chain and stakeholders located in the support system. Stakeholders in the support system mostly do not directly interfere with the construction of a specific building. These stakeholders generally try to regulate or change the environment of the building process, such as the legal or political environment or the market. Among the important stakeholders identified are the three levels of government, professional associations of actors in the value creation chain, interest groups of buy-owners, NGOs promoting energy-efficient building standards and companies from the energy sector.

Individual actors in the value creation chain perceive the environment of the building process as exogenous. They cannot change the environment all by themselves. Their decisions and actions therefore are "framed" by the structure of the environment. In particular, the actor's expectations about future developments guide present actions. On an aggregated level however, the sum of all actions in the building process certainly feed back and change the environment of the building process.

The process of building a construction project usually follows an "ideal-typical" building process that might look as follows: A buy-owner with land and an architect get into contact. The architect proposes a project and works out the details together with his client, until the buy-owner is satisfied. Then, the architect hands over the project to a specialized engineer who checks if the project is in accordance with regulations. In a next step, the project and the report of the engineer are handed to the city's building division. The building division either accepts or rejects the project. In the case of rejection, the project must be changed until it fulfills minimum regulation. Once the building permit is issued, the architect starts contracting sections of the implementation to construction firms and specialized craftsmen. During the actual construction work, the architect and inspectors from the building division verify if the plans were implemented correctly. Once the project is finished, the buy-owner begins using or renting the building. Warranty generally runs two years for obvious deficiencies and five years for hidden deficiencies.

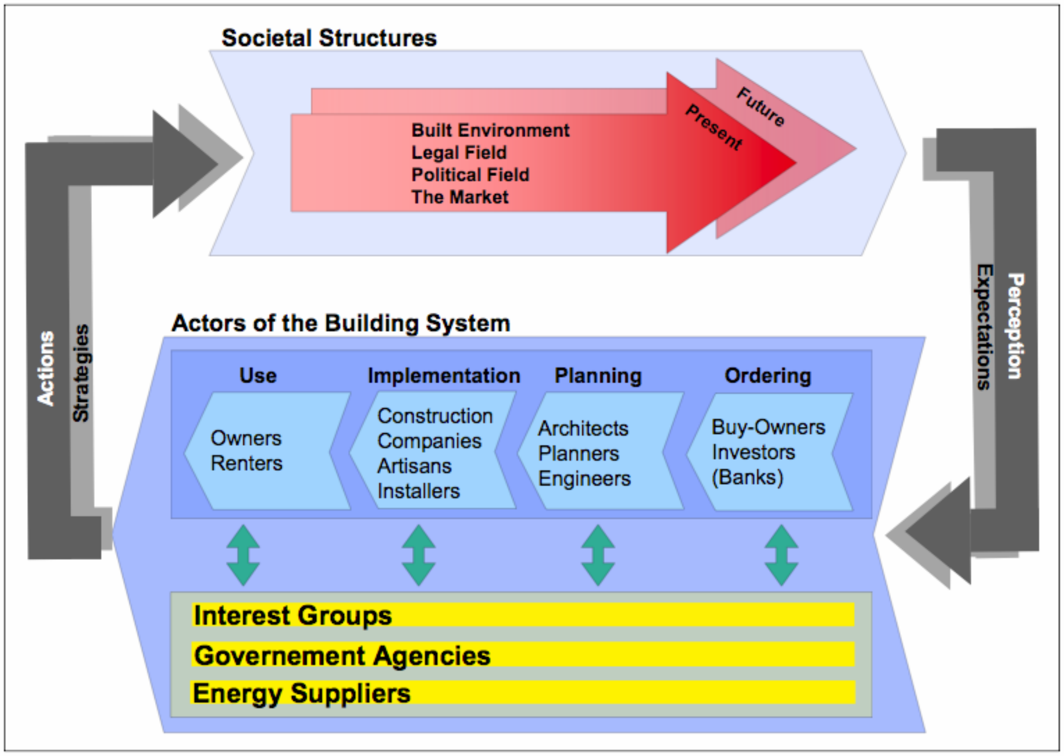

*Figure 4 A systemic view of the building sector*

*B) Understanding energy relevant instruments*

The energy relevant regulations are implemented on the cantonal level: The cantonal law on energy[1] and the regulations on energy[2] serve as a general framework for the regulation of energy-matters in the building sector within the canton Berne. With this body of legislation, the standards developed by the Swiss engineers and architects association (SIA) addressing thermal energy (SIA 380-1) and electrical energy (SIA 380-4) in the building sector are made legally binding. In addition to the mentioned cantonal laws, there are regulations put in place by the local government. The local regulations, however, aim more at guiding the development of the city and do not substantially alter energy-related aspects of the cantonal legislation.

Presently, SIA standard 380-1 demands that buildings use not more than 360 Megajoules heating energy per m2 per year (MJ/m2a). In order to obtain a MINERGIE certificate, a building may not use more than 150 MJ/m2a. To get a Minergie-P certificate a building must use less than 110 MJ/m2a. Based on these legal requirements, we propose the following classification as a working heuristic:

| Classification of Buildings | |
|---|---|
| Outdated | > 360 MJ/ m2a |
| Conventional | 359 to 160 MJ/ m2a |
| Energy-efficient | 159 to 110 MJ/ m2a |
| Highly efficient | < 109 MJ/ m2a |

*Table 1 A heuristic classification of buildings according to their demand for heating energy.*

*C) Motivating significant stakeholders to actively participate in the research project*

Getting actors from the value creation chain involved in our research project was not straightforward and quite time consuming – since interesting reference buildings and the main actors involved in the construction process had to be identified according to the above mentioned evaluation criteria.

In the public administrations of the canton of Berne the principle of "transparent administration," is implemented. This means that administrative information is public as long as it does not conflict with specified personal interests for privacy. Thanks to this principle, and with the helpful assistance of the building-division of the reference-city, it was possible to obtain the building-permits of major building projects of the last two, three years. We cross-referenced these projects with architects that we previously found significant. We then selected two big reference projects in order to have an energy-efficient and a conventional project in our sample (see Figure 2). In a next step, important stakeholders (major architects and buy-owners of selected reference buildings) were invited to become research-partners of our project. Additionally, we asked participating architects to invite buy-owners of small residential housing projects to participate in

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[1] Energiegesetz des Kantons Bern, EnG, 6. 6. 2000. Accessible online: http://www.sta.be.ch/belex/d/7/741_1.html

[2] Kantonale Energieverordnung des Kantons Bern, KEnV, 13. 1. 2003. Accessible online: http://www.sta.be.ch/belex/d/7/741_111.html

our research. Here too, we paid attention to get a range of buildings that differ in their demand for heating energy. The identification of the relevant stakeholders located in the supportive system was much straighter – the most prominent could be already identified and contacted during the national Minergie-fair 2005. Subsequently, applying sophisticated contact management and project documentation, the selected stakeholder were formally invited to participate by phone and in written.

This first exploration and stakeholder motivation phase was quite time consuming and required quite a bit of administration efforts that kept the research team partially busy for about 5 months. In a parallel activity stream the team elaborated on interview guidelines for the cognitive mapping interviews. In the following, this process will be summarized.

### Getting ready for cognitive mapping interviews: Interview guidelines

As pointed out previously, the methods of cognitive mapping (Ackermann, Bryson et al. 2004) and System Dynamics (Forrester 1961) will be used in distinct phases of the research process. In the first explorative phase, cognitive mapping is employed to elicit preliminary mental constructs of participating stakeholders. We developed three different versions of interview guidelines (see figure 5): one version for interviewing buy-owners, one for architects and one for stakeholders from the industry subsystem (such as construction firms). In addition, each version has a branch for users of energy-efficient technology and one for users of more traditional technology.

The guidelines consist of three major parts: In a first part, we briefly present the project and the extended project-team including the practitioners to the interviewee. Then, we explain how we would like to conduct the interview. In a second part, we encourage the interviewee to tell us the individual experiences he made with the building process. In this part, we try not to interfere too much with the narrative flow, in order to obtain an undistorted story. In the third part of the interview, hesitations about guiding the interviewee are explicitly dropped. Now we try to get a more consistent picture about the energy relevant issues of the story told in the second part. This is achieved by asking detailed questions about motivations, temporal and causal relations – a process Bryson et al. (2004: 48) call “laddering up and down.” In addition, we try to get the interviewees to define fuzzy concepts on the map.

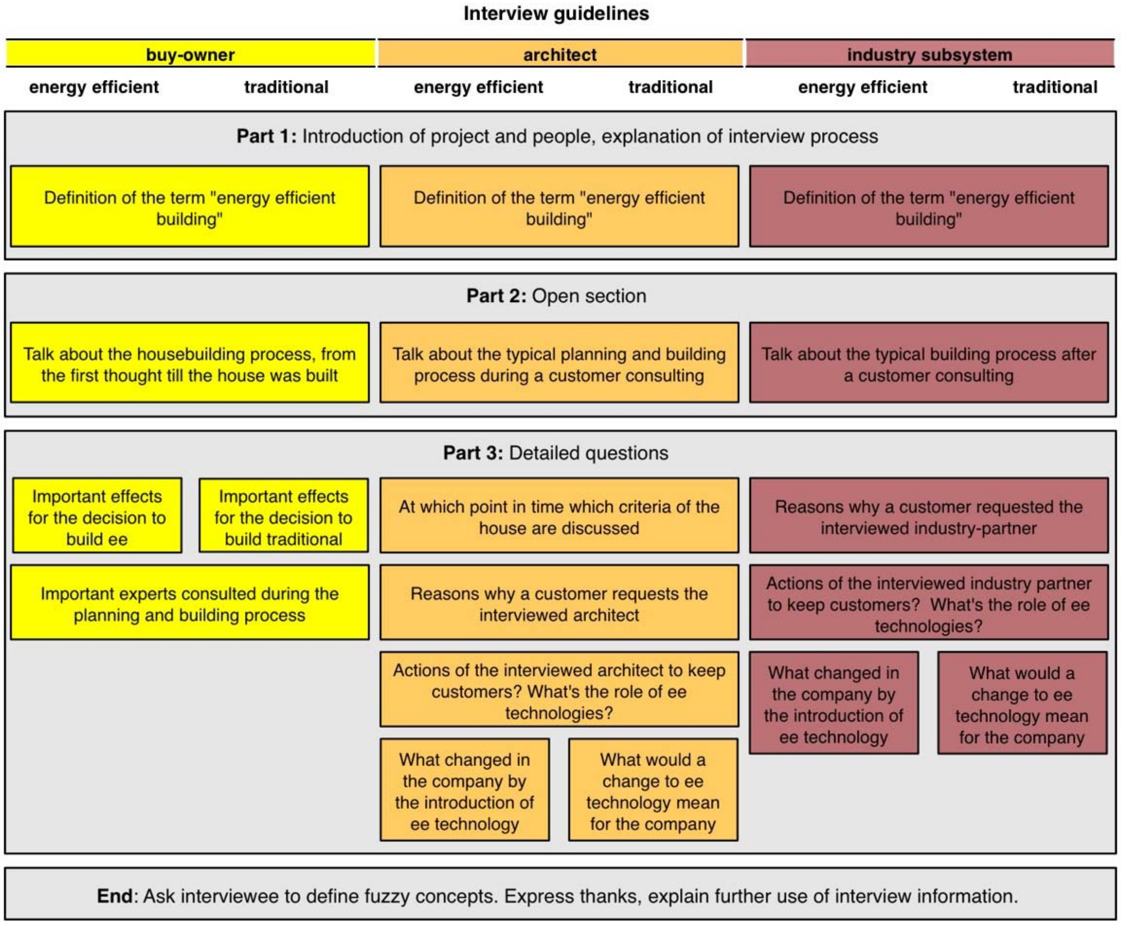

*Figure 5 Concept of the interview guidelines*

The composition of the interview guidelines reflects our aim of building consistent maps of the building process. With the detailed questions we hop to focus on significant concepts.

## The cognitive maps

The maps we develop during the interviews are structured according to two dimensions (see figure 6).

The first dimension (horizontal) is temporal and indicates the main steps in the building planning and construction progress. On the map itself it builds the horizontal middle layer. It starts on the left side of the page and progresses to the right side as the building reaches its completion. The second dimension (vertical) shows where causal factors influence the building process. This dimension is explored by “laddering up and down” in order to find values, goals and strategies and options that are related to the causal factors. In the map, these ideas are placed above and below the building progress. Our goal is to see out of the maps, how important variables e.g. the willingness to pay for energy efficient building technology evolve over time during the building process.

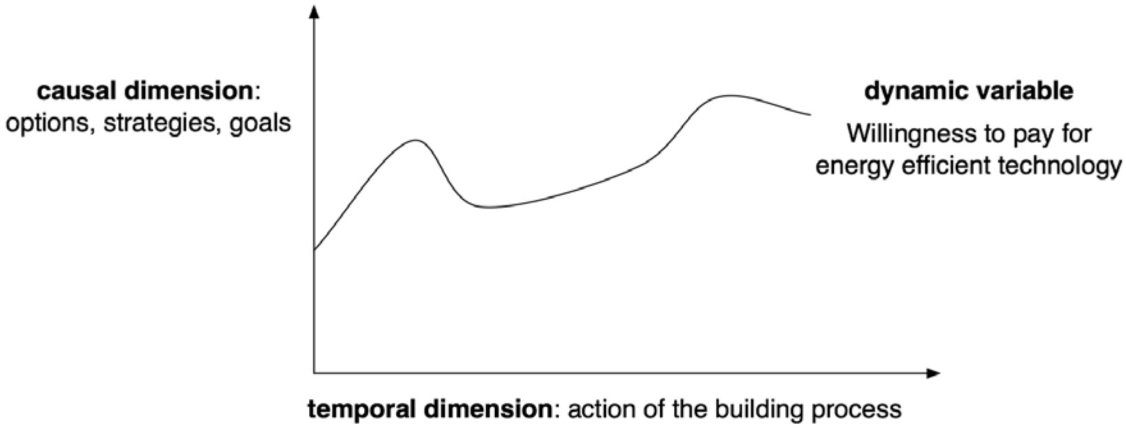

*Figure 6 Different level of analysis within the cognitive mapping exercise*

According to the interviewee’s category (buy-owner, architect, industry subsystem) we expect slightly different maps:

The buy-owner’s maps will contain the milestones of the building process. These maps will show factors that motivated the building of the house and factors that determined the level of energy-efficiency implemented. In addition, the buy-owner’s maps will show when which experts were consulted.

The maps of architects and members of the industry subsystem will provide information about the perceived influence of architects and members of the industry subsystem on the buy-owner’s building decisions. In addition, we expect to find factors that affect this group’s business-strategies towards energy-efficient building technology.

The insights of these explorative investigations will be fed into the conceptualization of the static as well as the system dynamics model formulation and testing process.

## Towards a first conceptual system dynamics model

In order to get an overview about existing dynamical simulation models, a literature review on housing construction or urban development-models was conducted. The review puts forward that less than a dozen articles are publicly available. In sum, the literature review shows that several studies about the building environment have been conducted, either on the side of demand generation, or from the perspective of single actors, or analysing effects of a specific policy. However, a comprehensive representation of the system ‘building environment’ does not exist, which would enrich the dynamical understanding of the interactions between involved actors, such as home owners, architects, building firms, and official authorities. Therefore the main source and entry point to a first conceptual system dynamical model remained a group-model-building-exercise that was conducted in the course of a SD-training week with students.

In the following, a first sketch simulation model will be outlined that was inspired by the afore mentioned group model building session (see also Groesser, Ulli-Beer et al. 2006). The main described artefacts are: a sector diagram, definition of key variables, first feedback loops and simulation runs.

The sector diagram consists of three sectors which are depicted in Figure 7. In addition, main variables for each sector are shown. The architect sector provides the supply of architect services both for the traditional and energy-efficient houses. The sector about the physical building structure shows the physical consequences of decisions about the different building types and the interplay between supply and demand of traditional and energy-efficient architect services. In the building owner sector, the formation of the demand for energy-efficient or traditional buildings is formulated; in other words, future home owners' decisions about what type of building they will build.

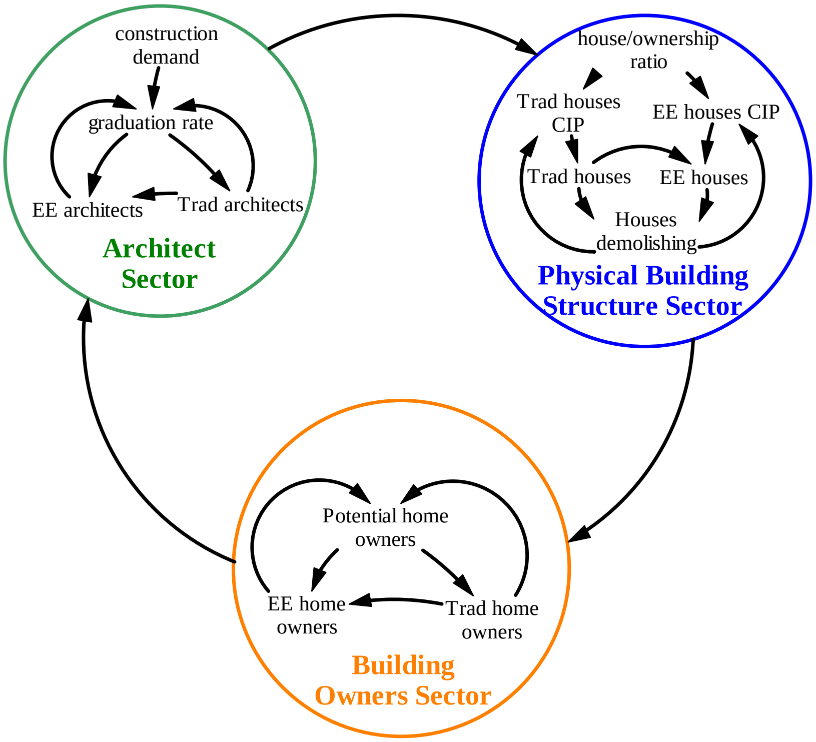

*Figure 7 Sector Diagram (Groesser 2006)*

In the following, some key variables of the model will be shown to give more details about the content of the model. The house building population is the maximal amount of people which can build houses. Once they became 'potential home owners', they made the decision to build a house; the type of houses is not yet determined. The decision about the type of house is influenced by the 'decision for ee-fraction' which is a high-aggregated variable embodying factors important to the potential home owner. Once people inhabit and own a single family house, they are named as 'current home owners'. In case a home owner has built a traditional house, refurbishment with energy-efficient materials is a possibility to change the characteristics of the house resulting in the 'transition to an energy-efficient home owner'. Completed houses are physical building structures which either belong to energy-efficient ('ee-houses') or traditional standards ('traditional houses'). Architects are distinguished between those that offer only traditional building layouts ('Architects with traditional knowledge') and those that offer building layouts in compliance with traditional and energy-efficient standards ('architects with ee-knowledge'). These key variables are interconnected and create several feedback loops. Figure 8 shows some basic feedback loops.

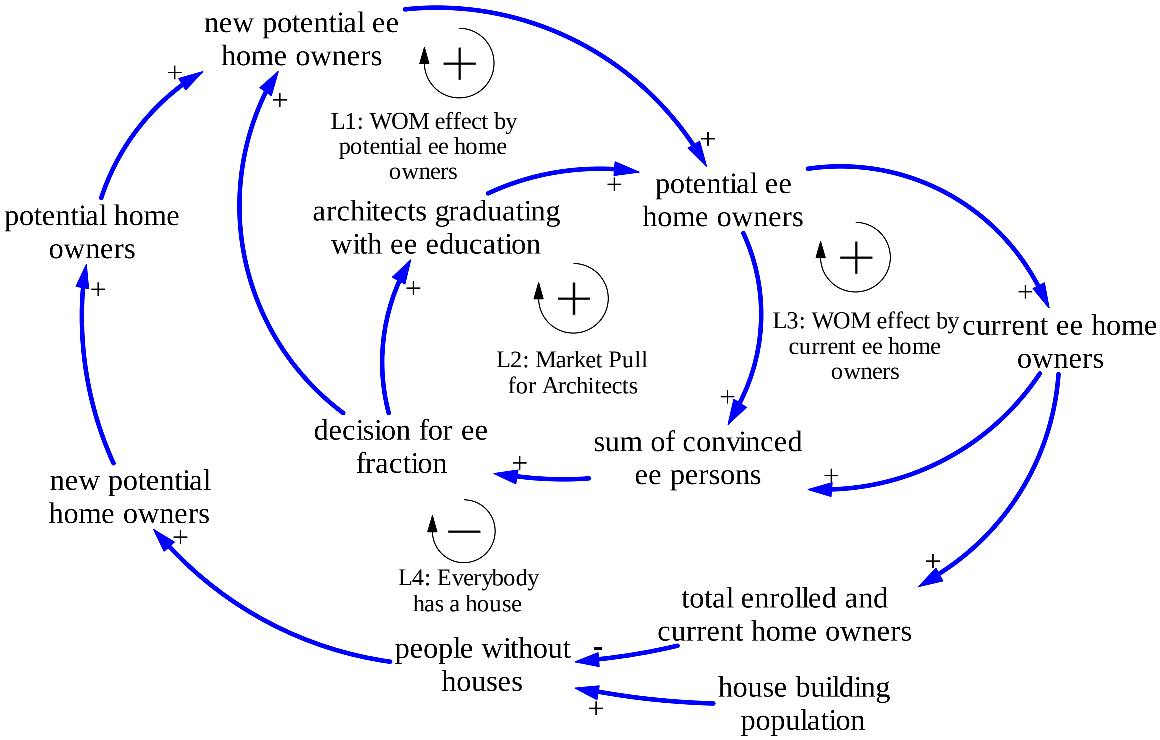

*Figure 8 Key Feedback Loops (Groesser, Ulli-Beer et al. 2006)*

Feedback loop L1 and L3 are both reinforcing feedback loops representing the word of mouth effect, but are caused by the two different groups of potential ee-home owners and current ee-home owners. We assume the effects of both groups differ in their strength. The word of mouth effect is a phenomenon that fosters diffusion processes. People with knowledge about a new technology pass it to people who do not have this knowledge. Loop L2 is named 'market pull for ee architects' and reveals the effect that potential owners' decision for energy-efficient houses has on the supply of architects with special knowledge about energy-efficiency. The negative loop 'Everybody has a house' (L4) captures the fact that the finite house building population will be reduced by the building activity and limit the diffusion process once the whole population is either owner of an energy-efficient home or in the phase of building such a home. In the simulation, the interaction of these feedback loops creates system's behavior. Figure 9 shows the development of some key variables.

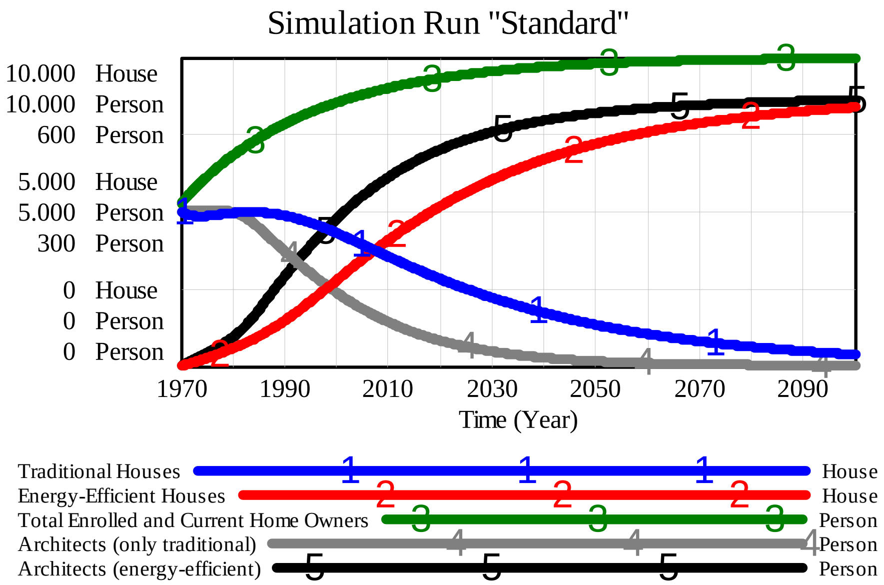

*Figure 9 First simulation of key variables (Groesser, Ulli-Beer et al. 2006)*

Figure 9 shows the development of some key variables. Traditional houses show a slightly increasing tendency which peaks at the year 1998 followed by a decreasing trend. The market powers, especially the word of mouth effect and supply of ee-architects, foster energy-efficient instead of traditional building designs. But these effects are only active when a large enough pioneer group exists. Time is required for the group to evolve, thus, explaining the time delay before the traditional houses number decreases. The amount of energy-efficient houses (red graph) increases from the early beginning. The growth rate peaks at the inflection point around 2010 and thereafter reveals a diminishing rate of growth. The growth rate will be equal to the demolition rate of traditional houses, after the house building population has been satisfied. This leads to a slow transition from the traditional building stock to energy-efficient houses. The very same development can be seen for the number of traditional architects (grey graph) and energy-efficient architects (black graph). The changes of the architect quantities antecede the changes in the house quantities. It seems that the architect variables can be used as antecedents for the development of the building stock. The green graph shows the development of the total enrolled and current home owners indicating a goal seeking behavior towards the goal ‘total building population’. This graph relativises the considerably fast spread of energy-efficient houses because the demand for houses is nearly satisfied at the end of the simulation. A further spread of energy-efficient houses can only occur when traditional houses are demolished which have a life time of 50 to 100 years (or when they are energy-efficiently refurbished – however this option is not yet included in the model).

In the course of the study this high level overview on diffusion dynamics on ee houses will be disaggregated in order to understand the interaction and time scales of managerial adjustment processes and preference building of building owner for ee-technologies. In order to yield a descriptive representation of these processes the cognitive maps will be analyzed. However, first some methodological challenges have to be overcome.

# 6 Identifying and overcoming methodological challenges

In the first explorative phase, cognitive mapping is employed to elicit preliminary mental constructs which, in turn, will be utilized in the System Dynamics model formulation. The analyses and integration process of these maps holds severe risks and problems.

- One could be that identical constructs are named differently by the interviewees. Consequently, the individual constructs could not be assigned to each other in a clear way. To prevent this incoherency, a certain amount of time is allocated to define fuzzy constructs together with the interviewees after the completion of the cognitive mapping interviews in order to better comprehend them and carve out interfaces between the actors different maps. The aforementioned temporal structure of the cognitive mapping interview provides relevant means to aggregate the cognitive maps, because the building process unfolds along elemental milestones, which foster the integration. Furthermore, the interview guidelines are created with the objective to ease aggregation of individual cognitive maps. Several questions are asked in order to enable a coherent comparison between cognitive maps.
- After having discussed the guidelines and the outcomes of the cognitive mapping interviews, the results need to be transformed to meaningful constructs that can correctly be exploited for the subsequent System Dynamics modeling phase, especially for the creation of causal loop diagrams. This task seems to be very challenging because the two approaches have different purposes. On the one hand, cognitive maps aim at providing new ways of examining and improving managerial judgments by helping interviewees to make sense of complexity. Complexity is captured by context-rich graphical representations of the interviewee’s mental maps (Fiol and Huff 1992). On the other hand, the purpose of causal loop diagrams (CLD), is to represent effectively the feedback structure of observed phenomena offering a dynamical hypotheses about the causes of dynamics. CLD also can be used for elicitation of mental models of individuals or teams and to communicate important feedback structures of a system (Sterman 2000). Hence, the major difference between CLDs and the cognitive mapping techniques is the level of richness embodied in the graphical structure of the CM.

Only little methodological research about merging the two approaches has been done so far. Ackermann et al. created an exemplar to use both cognitive mapping and System Dynamics in one research project (Ackermann, Howick et al. 2004). For our project, we agreed on several institutions in order to facilitate the knowledge transfer from the first stage (the CM exploration) to the second (the system dynamical formalization):

- The researcher responsible for the System Dynamics model will participate in the cognitive mapping interview sessions as external observer
- Both interviewer and System Dynamicist will together reflect about the results of the interviews to ensure common understanding
- The interviewer will observe and critically comment on the resulting causal loop diagrams
- The stakeholders will reflect and inquiry first CLD representations derived from the exploration phase

In addition we do have clear questions relevant for the creation of the CLD that we expect to be addressed by cognitive mapping in the explorative phase of the research project. We are especially interested in gaining insights about causal links between the several subsystems forming the innovation system for ee buildings.

- How do architects decide to offer energy-efficient building designs? (Architect subsystem)
- In what way and how strong is the building owner in a counseling interview influenced by the architect? (Architect and building owner subsystem)
- How is the decision process of future building owners to build an energy-efficient house? (Building owner subsystem)
- How do future building owners accept technological innovations? (Building owner subsystem)
- What decisions have to be made by a future building owner in the whole construction process? (Building owner subsystem)
- How do companies of the building industry set the supply capacity for energy-efficient technologies? (Industry subsystem)
- When do architects or companies decide to educate their employees about new technological developments? How will these learning processes occur? (Architect and industry subsystem)

Besides the elicitation of answers to the aforementioned questions, the cognitive maps resulting from the interviews will further be employed as means to start the reflection process in a group discussion conference that will contribute to the development and validation of the System Dynamics simulation model (Groesser, Ulli-Beer et al. 2006).[3]

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[3] Groesser (2006) explains and discusses a simulation model of the building environment, which was build during a group model building session

# 7 Expected results and deliberations on impact-evaluation

The project combines three modeling approaches in an innovative way: In addition to the explorative cognitive mapping analysis, the strength of the static behavioral-antecedents model and the strength of the dynamic building stock model will be combined in order to reach a highly consistent dynamical theory. The static model provides the causal relationships of behavioral determinants that will be integrated in the dynamic model as decision functions.

Within this project, generic processes guiding the development of energy consumption of buildings in Swiss communities will be identified. These processes rely *both* on behavioral (e.g. planning, decision making, and routines) and on contextual factors. In particular, the dynamic interactions between private managerial decision rules and public energy initiatives will be highlighted. The understanding of these processes is important for designing and implementing effective strategies on the different levels of energy policy for accelerating the diffusion of energy efficient buildings. In addition, an innovative approach to transdisciplinary computer assisted theory building is demonstrated. In the setting of innovation diffusion this is seen as highly relevant, since it enhances discussions and strategy alignment processes between the different stakeholders in the building sector.

Target audiences are actors in the value creation chain of energy efficient buildings, especially private and public decision makers. They can use the model to learn and communicate about the diffusion system.

In this transdisciplinary project close cooperation with experts of the building sector is essential. The mayor of the city will be the gatekeeper of the “system expert group” that will include the relevant actors of the value creation chain in the building sector, representatives of NGO’s, and representatives of the local, cantonal, and national authorities. Cooperation with the target group allows access to important data and the integration of practical knowledge and experience in order to create an adequate and useful tool for practice. Conversely, with its close involvement in the system inquiry, the target group will gain a broader system understanding and may reflect its own action strategies and strengthen commitment to implement energy efficient innovation strategies.

The model illustrates how different decision rules and factors may influence the system's behavior. The transformation support tool provides indicators for monitoring and controlling the diffusion process. This helps decision makers to efficiently implement energy efficient technologies in the building sector. Better organizational performance can thus be achieved, and the full potential of energy efficient technologies can be realized.

### Deliberations on impact-evaluation

It is highly desirable to evaluate both, the effectiveness of the transdisciplinary research approach (which is seen as a system intervention) and the subsequent implementation of the policy recommendations. However, within the scope of this project only modest actions can be taken in this direction. Nevertheless, this research project may provide an excellent setting for follow-up studies assessing the relevance of our trans- and interdisciplinary research approach. Such a follow-up study should focus in particular on the usefulness of computer based system interventions. More specifically, the overall research design will allow an appropriate evaluation of the cognitive mapping and group model building approach in further investigations.

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