CHALMERS

Towards Environmental Informatics for Building Stocks

A Conceptual Model for an Environmental Building Stock Information System for Sustainable Development - EBSIS^{SD}

LIANE THUVANDER

Department of Built Environment & Sustainable Development
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2002

THESIS FOR DEGREE OF DOCTOR OF PHILOSOPHY

Towards Environmental Informatics for Building Stocks

A conceptual model for an Environmental Building Stock Information System for Sustainable Development - EBSIS^{SD}

LIANE THUVANDER

Department of Built Environment & Sustainable Development
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2002

Towards Environmental Informatics for Building Stocks

A conceptual model for an Environmental Building Stock Information System for Sustainable Development - EBSIS^{SD}

LIANE THUVANDER

ISBN 91-7291-242-1

Doktorsavhandlingar vid Chalmers tekniska högskola
Ny serie nr 1924
ISSN 0346-718x

ISSN 1650-6340 2002:11
Publikation - Chalmers tekniska högskola
Sektionen för arkitektur

Department of Built Environment & Sustainable Development
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone + 46 (0)31-772 1000

Majornas Copyprint
Göteborg, Sweden 2002

TOWARDS ENVIRONMENTAL INFORMATICS FOR BUILDING STOCKS

A conceptual model for an Environmental Building Stock Information System for Sustainable Development - EBSIS^{SD}

LIANE THUVANDER
Department of Built Environment & Sustainable Development
Chalmers University of Technology

ABSTRACT

The building sector uses a considerable amount of all materials and energy used in Sweden. Knowledge about the existing building stock, its impact on the environment in relation to the use of material and energy, however, is limited and targeted environmental objectives and decision-making are based on vague information. To achieve environmental improvement and to pursue environmental objectives, descriptions of the environmental performance of building stocks are needed in a structured form. In the thesis a conceptual model for a computer-based Environmental Building Stock Information System for Sustainable Development (EBSIS^{SD}) is developed and the conditions for establishing such a system are examined. The *relevance* and *feasibility* of EBSIS^{SD} have been investigated through interview studies and literature studies. *Modelling* aspects have also been elaborated through studies of state-of-the-art, field trips and test runs of data sets with the City of Göteborg as a case in particular. In terms of *modelling,* issues regarding time, space and flows and deposits of material, energy and water related to buildings have been formulated. A broad scan of the building stock research field in Sweden and internationally and the environmental informatics field has identified the existing information structures BSAB, SPINE and GIS as the bricks for construction of the EBSIS^{SD} database structure. Moreover, a top-down and bottom-up approach is proposed in combination with a spatial age-use matrix. Concerning *relevance,* several potential users are identified both on the regional and local levels, such as property managers, municipal authorities and researchers. Potential applications comprise benchmarking, planning issues and scenario studies. Concerning *feasibility,* existing data and data sources are surveyed. The available energy-use data are adequate, whereas the material-use data are less satisfactory. In the Göteborg case study, an energy model based on delivered data is produced that shows the potential of a spatial age-use matrix. In conclusion, it is possible to construct EBSIS^{SD}, there are certainly interest groups and data are available. However, it is recommended to develop EBSIS^{SD} in close co-operation with users and to start on the local level.

Keywords: Building, Building stock, Building stock information system, Energy flows, Environment, Environmental informatics, Environmental System Analysis, Information system, Material flows, Sustainable Development, Urban System Analysis

PREFACE

This thesis is the result of a broad scan of the building stock research field with a focus on environmental issues. It has been both an exciting and challenging task to examine the subjects of building stock descriptions and sustainable development, and finally, to tie them together.

The research project, initiated in May 1998 and finished in December 2002, is part of the national interdisciplinary research programme MISTRA-Sustainable Building. The project is being carried out at Chalmers University of Technology at the Department of Built Environment & Sustainable Development in close co-operation with the Department of Environmental Systems Analysis and the Department of Visualisation and Modelling. MISTRA is thanked for the fundamental financial support of the project and so is Chalmers University of Technology, Architecture, for giving me the financial support needed to complete the research.

The thesis is an extended version of my licentiate thesis *The Building Stock: A Complex System Changing over Time. Towards a Model for Description and Analysis.* Selected parts of the licentiate are reused (sections of Chapters 2, 4, 5, 6, 8), other parts are only referred to. However, the largest part of the thesis comprises material not presented in the licentiate, but built upon it.

The work has incorporated several PhD courses and teaching, i.e. introducing students to environmental problems in the field of architecture. Both activities have been a welcome and fruitful complement to the normal research workday.

I would like to express my gratitude to all the people who have shown their support in different ways. First, my gratitude goes to my original supervision team, to my previous supervisor Prof em Anne Marie Wilhelmsen, who initiated the project and introduced me to the building stock research field, and to my previous co-supervisor Dr Åsa Jönsson, for helping me see the research problems more clearly. Second, my gratitude goes to my new supervision team that took over after my licentiate thesis and gave me the chance to modify my research project; Dr Henrikke Baumann, for giving me innumerous inputs to the project from new points of view, for never-ending encouragement and for being a great companion, and Dr Hans Lindgren, who guided me to the world of modelling building stocks. Thanks also to Jonas Tornberg, Department of Traffic and Mobility, who introduced me to the world of GIS and helped me in analysing and presenting data. Thanks for producing the images in Chapter 12 and good team-work. Also, many thanks to the readers of the first draft of the thesis, Raul Carlson and Prof em Anne Marie Wilhelmsen. Your comments and suggested improvements at the final seminar were much appreciated! Further, I would like to thank all the members of the Department of Built Environment & Sustainable Building (Besus) for stimulating discussions with never-ending flows of ideas in- and outside our seminars, the researchers from the MISTRA-Sustainable Building programme for networking and co-operation, in particular Catarina Thormark, and the Department of Environmental Systems Analysis for its hospitality. It was inspiring to do some guest research there, especially with Birgit Brunklaus. I also would like to thank researchers from two international research groups: The first with Professor Niklaus Kohler and Dr Bärbel Schwaiger at "Institut für Industrielle Bauproduktion", Karlsruhe, Germany, who introduced me to their building stock modelling work and the second group with Prof Phil Jones, Joanne Patterson, and Simon Lannon at Cardiff University, UK, who introduced me to their Energy and Environmental Prediction Model. Not least of all, thanks to property managers in Göteborg and Göteborg Energi AB for the supply of data and to the Environment Administration of Göteborg municipality for helpful discussions regarding the use of the building stock model.

A big thank you also goes to my parents and my parents-in-law for all their support and for taking care of me in the summer months. Finally, with all my love, I wish to thank my husband Mattias. Thank you for all your patience, advice, for reading parts of the manuscript, and for everything, everything, everything ...

Göteborg, Sweden
December 2002 Liane Thuvander [i]

[i] Liane Stendel and Liane Thuvander are the same person.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

AP	Associated Press
AGS	Alliance for Global Sustainability
AMA	Allmän Material- och Arbetsbeskrivning
BEQUEST	Building Environmental Quality Evaluation for Sustainability through Time
BR	Building Register
BSAB	Swedish Construction Industry Classification System
BYKR	Ecocycle Council for the Swedish Building Sector
CAD	Computer Aided Design
DB	Database
DBMS	Data Base Management System
DOME	Distributed Object-based Modelling Environment
$EBSIS^{SD}$	Environmental Building Stock Information System for Sustainable Development
EEP model	Energy and Environmental Prediction model
EI	Environmental Informatics
ES	Environmental System
EU	European Union
EWC	European Waste Catalogue
FoB	Population and Housing Census
FTR	Property Taxation Register
GE	Göteborgs Energi
GHG	Greenhouse Gas
GIS	Geographic Information System
IS	Information System
ISO	International Standard Organisation
LCA	Life-Cycle Assessment
LCI	Life-Cycle Inventory
$MAIN^{tetra}$	Mind Artefact Institution Nature
MFA	Material Flow Accounting
MISTRA	Foundation for Strategic Environmental Research

OPR	Optical Character Recognition
PCB	Polychlorinated Biphenyl
PSL	Prediction of Service Life
PV	Photovoltaic
REPAB	Rolf Eriksson Produktionsplanering AB
SCB	Sweden Statistics
SNI	Swedish Standard Industrial Classification
SNV	Swedish Environmental Protection Agency
SPINE	Sustainable Production Information Network for the Environment
SS	Social System
TS	Environmental System
VOC	Volatile Organic Compounds

VISION

The existing building stock can be looked upon as a composition of long-lasting, never finished products, and as long-term storage of resources, physical and cultural. What amounts of resources are available in the building stock and in what state do they exist? Where do these available resources come from and where do they go after the building has seen its best days and is demolished? …

After last week's asbestos scandal one really might ask how environmental issues are tackled in our town today as late as year 2011…

" We have recently bought a number of properties. Fortunately, for all properties EBSIS^{SD} files exist so that we can just add them to our other property data." - "Before buying, I checked some of the buildings' EBSIS^{SD} data; the environmental performance seemed to be quite good, low energy figures, but some problems might be expected regarding asbestos decontamination" - "Since we got EBSIS^{SD}, the internal control of the environmental performance of the building stock we own has much improved. Interestingly, the competition between property managers has increased by benchmarking." – "Benchmarking with the average stock of the region is an important indicator for our success."

"As an authority we function as a source of information to the public and we have to keep track of environmentally hazardous built-in and potentially released material from buildings. Thanks to EBSIS^{SD}, finally, we have access to all data in a co-ordinated way and we have a powerful tool for making up our asbestos plans for the reconstruction of buildings from the 1970s. EBSIS^{SD} helps us identify risk areas and to focus our future work on the environmental improvement of building stocks." – "Today we have quite a good picture of the environmental performance of the town's buildings and the co-operation with other actors in the building sector is improving. From time to time we ask property managers to send us some of their EBSIS^{SD} files, especially files on evaluated buildings. In turn, we provide information for benchmarking. Now and then, we mail over EBSIS^{SD} files to the National Board of Building, Planning and Housing for the compilation of statistics." (AP)

PART I

Point of departure

1. INTRODUCTION

1.1 Problem identification

The Swedish building sector uses approximately 40 percent of all materials and all energy used in Sweden (Energifakta 2000). A large amount of material is already built-in in the existing stock. Because of buildings' long lifetime, changes in the stock generally proceed slowly and the future building stock will largely consist of buildings already in existence today.[1] For substantial environmental improvement, immediate changes – first of all to the existing building stock – are necessary. Buildings affect the environment in different ways (use of resources and land, and emissions) and during different stages (the production of building materials, erection, use, and demolition of buildings). For example, the amount of energy used during the operation phase of a building is high compared to the production and demolition phases (Adalberth 1997, Elmberg et al. 1996). Unfortunately, knowledge about material flows generated by renovation, maintenance and demolition and the actual impact on the environment from the building stock is limited. Also, there is poor knowledge about quantities and locations of environmentally hazardous built-in materials. Thus, to identify the potential for improvement for the building sector, the actual status of the building stock and its impact on the environment must be better known.

In Sweden, environmental studies of individual buildings have been carried out (Adalberth 2000, Thormark 2000), however, neither statistics nor models exist which can describe changes in terms of flows and resources over time in the building stock. Both in Sweden and internationally, there is a need for information on the building stock

[1] Of course, in a more nuanced consideration, the pace of change varies. There are parts of the building stock that change faster, for example, some industrial buildings, unattractive residential buildings, or buildings with a particularly attractive location.

as a basis for taking future consequences into account and deciding on suitable measures in planning and management situations. The Swedish government, for example, has established 15 objectives for environmental quality to support the sustainable development of society, several that address the built environment (Government Bill 1997/98). Thus, for environmental improvement and to fulfil/follow up the environmental objectives, concrete knowledge and data on the building stock is needed.

Because of different administrative systems and available resources, countries have tackled this task in different ways. In Sweden, random sample surveys of various parts of the stock (housing stock, industrial building stock) and from different aspects (energy-saving potential, potential for reconstruction) have been carried out since the 1970s (Stendel 2000b). Apart from the high costs, one drawback connected to random sample surveys is that they give an on-the-spot picture of the stock and do not allow for a follow-up of continuous changes. Efforts have been made to describe the Swedish stock and its changes over time in a study called 'Material Flows in the Construction Sector' (SNV 1996, Tolstoy et al. 1998). However, the above study only includes material flows, based on rough estimations, not energy issues. In Germany, a prototype for a dynamic description of the stock's material and energy flows has been developed using a top-down and bottom-up approach (Klingele et al. 1997, Kohler et al. 1999). Although the structure of this model may be adapted to Swedish conditions, the German model cannot be used straight away because the data sources that are available and accessible are different.

In an earlier Swedish investigation, the need for a systematic follow-up of the stock and its changes was expressed and a system of descriptions was requested (Lindgren 1989). Maybe the time is ripe to establish such a system?

What is needed is an integrated building stock information system that provides a general and dynamic description of the Swedish building stock with a focus on environmental issues, such as use of resources including both deposits and flows. With the help of such a system, environmental information on building stocks could be structured, analysed, and made available to actors in the building sector and the research community. Nevertheless, before developing a prototype for a building stock information system the conditions for establishing such a system must be investigated.

1.2 Aim

The aim of the thesis is to carry out the modelling work necessary before prototyping a building stock information system with a focus on environmental issues. On a conceptual level, this comprises an analysis of the relevance of such a building stock information system, the identification of variables to be modelled, and the feasibility of the system. The modelling objective is to arrive at a specification for a prototype. The conditions for developing a prototype have been investigated by exploring the following questions:

Questions	as regards the following aspects
• What data needs to be stored to provide statements about buildings and building stocks? • Are there already systems, which can handle and manage building related environmental data?	Q1: Database modelling
• Is it possible to collect relevant data? How? Where?	Q2: Feasibility
• Is there any need for the information addressed? By whom? What for? • What kind of information do potential users need?	Q3: Relevance

1.3 Method and scope

The formulation of the research question and the research process as a whole can be described as an iterative process along a time axis and at the same time as explorative, starting from one place and discovering another one, Fig 1.1.

The initial goal description of the project was to develop an all-round model for the description of buildings and building stocks on the national level, to supply the building industry and the research community with information on the Swedish building stock pertaining to environmental issues, resource flows and deposits in the stock. No specific user was addressed. While addressing the national level, progressing research identified users and potential hosts of a database to be developed, such as governmental bodies (the National Board of Housing, Building and Planning[2]), public authorities, a branch organisation (the Ecocycle Council for the Building Sector[3]), and researchers. Still, it was difficult

[2] In Swedish: Boverket

[3] In Swedish: Byggsektorns kretsloppsråd. Abbreviation is BYKR.

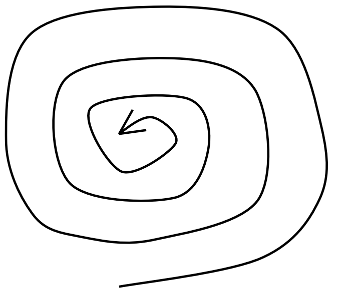


Figure 1.1. An iterative approach to the field and the research question. Scanning and mapping of a research field, narrowing the project and focusing the questions, outlining traces, follow-up of only some of them.

to extract what to focus on. In the licentiate thesis (Thuvander 2000), several possible ways to proceed were outlined.

The experience I gained from the licentiate thesis called for modifications of the project, such as a shift of the problem from being research-oriented to a project with practical implications. This shift resulted in work focused on data sources and use(r) aspects of a future building stock information system and a shift in focus from the national level to the regional level. Addressed users thus became local authorities, planners, property managers, etc. However, this does not mean that it is impossible to return and address the national level in the future. These changes are factors that contributed to a broad approach, many different parts of which I touched upon, but decided to go into depth with only a few.

Thus, the research comprises state-of-the-art and implementation studies, theoretic considerations, and conceptual modelling including some manual tests. Every part has been investigated in several sub-projects resulting in different kinds of publications (reports, conference papers, chapters in a licentiate thesis, and a thesis), Fig 1.2.

The methodologies used for knowledge generation range from interviews studies, literature studies, exploring the Internet, studies of other models (visits, personal contacts), data collection and test of several data sources.

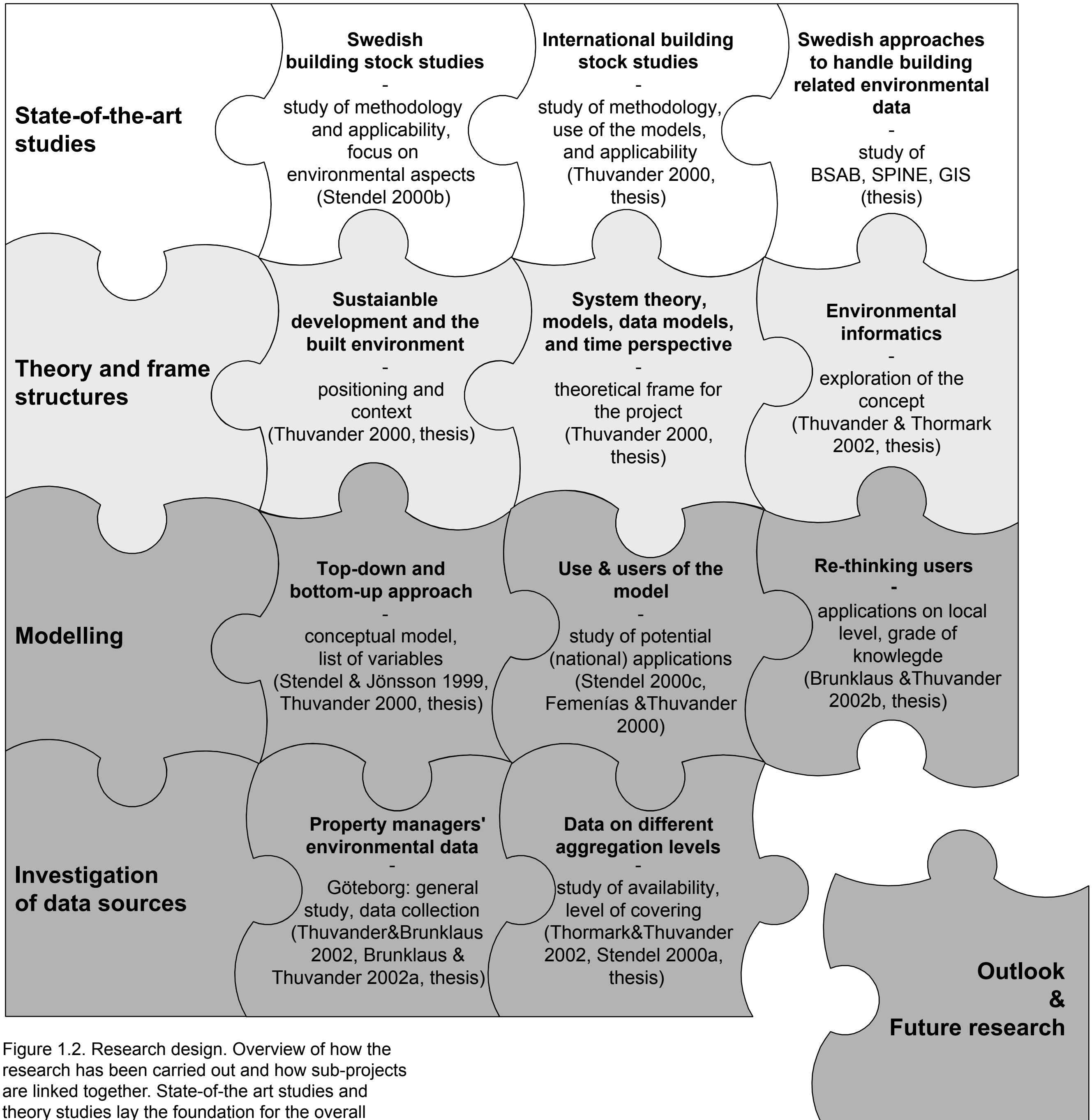


Figure 1.2. Research design. Overview of how the research has been carried out and how sub-projects are linked together. State-of-the art studies and theory studies lay the foundation for the overall modelling. Each part includes feasibility issues, database modelling issues, and relevance issues. The references are publications of the sub-projects, see separate reference list.

In my licentiate thesis, I extracted problems regarding building stock studies and the development of a system for description (Thuvander 2000). It is said that the problems are related to several aspects, such as the purpose of the study, the commissioner and user, the methodology used for the investigation, the choice of properties to be described (variables and data collection), the use of the database and the results, and the administration/management of the database. Departing from the above, a framework for the thesis has been developed, see Fig 1.2. If one considers the framework in the context of the aim-questions formulated above, feasibility aspects can be related to data sources, issues of database modelling can be related to questions concerning the building stock information system, and relevance issues to use(r) aspects. The research design supports the interconnection of the questions posed in Section 1.2 and the framework Fig 1.3.

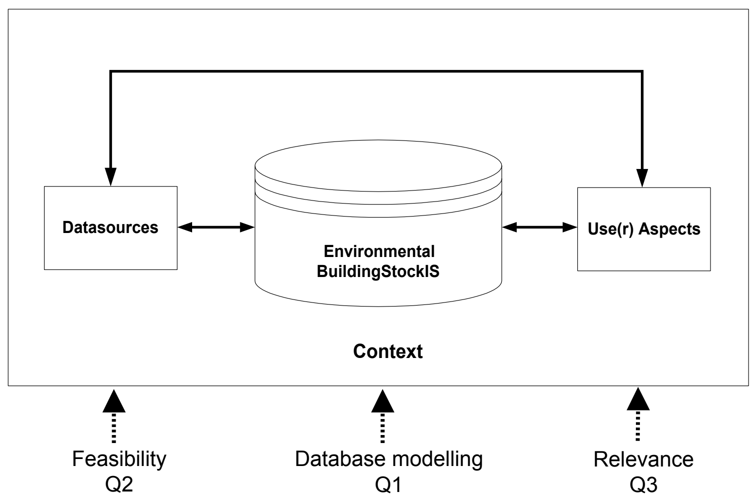


Figure 1.3. Framework for discussing the building stock information system. Not only database issues are important but also data sources and user aspects seen in an overall context. Data sources and user aspects have been the focus of the thesis.

The *modelling part concerning Q1 questions*, has been approached from the point of view of state-of-the-art studies of building stock modelling (Stendel 2000b, Thuvander 2000) and studies of existing prototypes potentially relevant to the project in focus here (Chapter 8). A conceptual model of the overall approach has been developed (Stendel & Jönsson 1999, Thuvander 2000), and a list of "desired" variables has been elaborated (Chapter 10). Thus, the modelling part studies methodological aspects, followed by a discussion of advantages and disadvantages of the models used and the potential for applicability to my purpose. Concepts, such as system and system theory, model, environmental informatics, and time related to building stock issues have been applied.

Feasibility studies, i.e. Q2 questions, cover an investigation of several bottom-up data sources, namely the Swedish building register (Stendel 2000a), property managers' data (Brunklaus & Thuvander 2002b), and demolition plans (Thormark & Thuvander 2002). Further, the level of coverage has been studied by a comparison of the variable list vs data available on several levels of aggregation (Thuvander & Brunklaus 2002) (Chapter 11).

Use(r) aspects, i.e. relevance issues concerning Q3 questions, include comprehensive studies on implementation, an investigation of potential applications in a broad sense (Stendel 2000c), and a more narrow one for exchange of windows (Femenías & Thuvander 2000), and the investigation of potential users of a fully developed computer-based prototype (Brunklaus & Thuvander 2002b, Brunklaus & Thuvander 2002a), (Chapter 9). Hereby, users on the regional and local levels, with property managers and local authorities have been addressed as a focus group.

Swedish conditions have been addressed and Sweden forms the overall spatial system boundary for the project as a whole. On the local level, the spatial system boundary has been defined as the municipality of Göteborg, Fig 1.4.

Figure 1.4. Swedish conditions have been addressed and Sweden forms the spatial boundary for the overall project. Case studies focus on Göteborg.

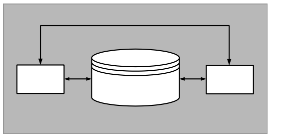
The modelling problems, consequently, concern environmental aspects with a focus on resource use in building stocks (material and energy use, to some extent water use), data aspects (examination of data sources, availability of relevant data, data coverage), and time aspects (flows, transformations).

Neither the building-user interaction, i.e. human activities (lifestyle, behaviour, different demands for thermal comfort) inside the buildings, nor interaction with other structures, such as transport structures, media-providing structures, or green structures have been taken into account. Buildings are, here, regarded as a system and the system boundaries are the outside of the building. The emphasis is on the outdoor environment, thus, indoor climate and its impact on humans is not taken into account.

A systems analytic approach, in which the system-in-focus is changing, has been chosen for modelling from a so-called top-down and bottom-up approach.

1.4 Report structure

The report comprises five parts. *Part I* introduces the research problem and the aims of the thesis and makes the reader familiar with the general research design, Chapter 1. It also presents the context of the research – sustainable development, Chapter 2. To approach the problems at hand, *Part II* defines central objects of the study which are identified and discussed in Chapter 3, which, then, lead into the modelling sphere. The theoretic framework, presented in Chapters 4-6, opens up for *Part III* and the investigation of existing database systems/structures and a discussion of how these might contribute to a solution to the problems defined, Chapter 7. Chapter 8 gives the reader an idea of how other researchers have tackled similar tasks. Building on experiences gained, *Part IV* guides us through the empirical part of the research. Chapter 9 investigates the relevance issues, Chapter 10 introduces the conceptual model and, subsequently, Chapters 10-11 deal with feasibility, i.e. a discussion of a number of data sources. Finally, *Part V* provides a summarising discussion of the research on the whole and outlines possibilities for future research.



2. SUSTAINABLE DEVELOPMENT & THE BUILT ENVIRONMENT – A SWEDISH CONTEXT

Chapter 2 introduces the concept of sustainable development as one of the external models that shape the content of the building stock model presented in the forthcoming chapters. The research problem is elucidated in a broader context by relating it to ongoing activities in the building sector.[4]

2.1 What is Sustainable Development?

The United Nations World Commission on Environment and Development adopted a global programme for changes to reach sustainable development in the years to come and introduced the notion *sustainable development* in the Brundtland Report *Our Common Future* in 1987 as follows:

> Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED 1987).

At the United Nations Conference on Environment and Development in Rio de Janeiro in 1992, an action plan, *Agenda 21*, was agreed upon internationally and adopted. In the Agenda 21 document, ecological aspects, among other aspects, are described explicitly, for example, the emissions to atmosphere, soil and water of harmful gases and substances that have to be reduced substantially and the efficiency of resource and material use that has to be increased (UNCED 1992).

The above vision of sustainable development is broad and can be used as a guiding principle. To make this ambitious and ambiguous policy target more operational, sustainable development today is

[4] The chapter is an extended and modified version of Chapter 4 in (Thuvander 2000).

often perceived as comprising three basic dimensions with equal importance, a social, an economic and an environmental dimension (three-circle diagram). In recent years, a fourth dimension of sustainable development has been introduced, the institutional dimension, which is being increasingly adopted (CSD 1996)[5]. A helpful model for discussing sustainable development is 'the prism of sustainability' developed by the Wuppertal Institute in Germany (Valentin & Spangenberg 1999), which has been further developed at the Department of Built Environment and Sustainable Development at Chalmers by Kain (2003) to a MAIN^{tetra}. MAIN stands for the domains Mind, Artefact, Institution, and Nature and is a conceptual knowledge model for urban sustainable development, see Fig 2.1. It must be emphasized, that MAIN^{tetra} is only a model for structuring thoughts with purpose of supporting discussion and communication. It is not a model that describes reality in geometric forms (Kain 2003).

MAIN^{tetra} illustrates the external model for my own model of the building stock and it shows how feasibility studies, relevance studies, and modelling the information system (Fig 1.3) are related to a broader context – sustainable development. The starting point for my study is that artefacts and their interaction with nature can be perceived as a problem (see also Sections 2.2 and 3.3).

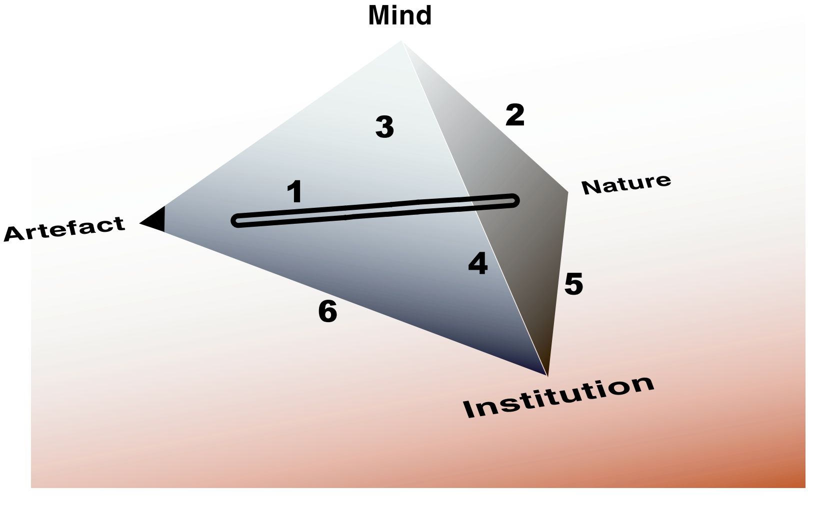


Figure 2.1. MAIN^{tetra} - a knowledge model for urban sustainable development (Kain 2003).

The content of an environmental building stock information system focuses on artefacts, i.e. buildings, and the interaction between artefact and nature (1). However, environmental improvement of the building stock also depends on the institutional and mind domains. For example, the perception of a problem (Mind) influences which actions are taken. The implementation of regulations or instruments, such as a building stock information system, depends on users (Institution), i.e. feasibility aspects and relevance aspects are represented here. The starting point for my study is that the interrelation artefact – nature is perceived as a problem.

Examples of understanding the domains:

(2) Mind – Nature: Perception/understanding of an environmental problem.
(3) Mind – Artefact – Nature: Understanding of the interrelation nature and artefact, influence on actions.
(4) Mind – Institution: feasibility, relevance – decisive for implementation of policies.
(5) Institution – Nature: policy, regulations (care of environment).
(6) Institution – Artefact: policy, market.

[5] United Nation's indicators for sustainable development (accessed summer 2002): http://www.un.org/esa/sustdev/indisd/english/english.htm

For a sustainable development of (existing) building stocks, as seen through the lenses of the model, one has to study and understand all four domains and the interactions between the domains:

- the *artefacts*, in our case buildings. They are man-made systems and the objects in focus.
- the *nature* around them (natural environment) including flora, fauna, landscape, ground, water, atmosphere, and the lithosphere (from where natural resources, such as oil, minerals, and metals are extracted). Thus, the domain nature deals with pressure on the physical environment, resource throughput and the preservation of the internal evolutionary processes of the ecosphere (Kain 2003, Valentin & Spangenberg 1999, CSD 1996). For further illustration of the interrelation of nature and artefact see also Section 3.3.
- the *institutional* aspects, incorporating participation, democracy and regulation. Institutions, here, are formal and informal organisations, companies, municipal institutions, universities, organisations, and also discussion groups, colleagues at work or entire families. Laws and regulations, and also formal and informal norms, which exist in society, have an impact on how these different institutions function (Kain 2003). In a building stock context, for example, the Ecocycle Council for the Building Sector, property managers, town planning offices, or environment departments are institutions of concern.
- the *mind* (often referred to as the social dimension), which steers all our understanding and actions, comprising knowledge of human thoughts and feeling. Mind also includes aspects, such as cohesion, human integrity, health, housing, discrimination, social security and unemployment (Kain 2003, Valentin & Spangenberg 1999). The knowledge of individual peoples' world-view, perception of problems, lifestyle, i.e. behaviour inside buildings influence efforts towards the sustainable development of a building stock. Researchers' and other actors' understanding of the problem and need for knowledge may differ.

Sustainable development is a complex task, and, generally, these domains should not be considered as separate domains of action (Edén et al. 2000). The MAIN^{tetra} of sustainable development provides a space where the four domains of sustainable development interact. The space allows for approaching questions concerning sustainable development from any of the domains, which is often necessary to handle such a complex notion without losing the links to the other domains. In MAIN[tetra], time is not explicitly addressed but the term development includes the notion of time and by that, time perspective.

Building stock issues have been approached by modelling Artefacts (buildings) and focusing on their interrelation with Nature (resource management). The links to the other domains are elucidated by studying relevance aspects (the different perceptions and needs of different users) and feasibility aspects. This knowledge, in turn, can be utilized for the implementation of a building stock information system (Fig 2.1).

Local situations differ from each other, as well as regional situations around the world. Accordingly, strategies for achieving sustainable development will differ in a global context (Edén et al. 2000). Efficient use of resources is an important target for sustainable development in rich countries like Sweden. Concepts of resource efficiency based on factor-thinking (Factor 4[6], Factor 10[7]) have been introduced. Weizsäcker et al. (1997) have stated that our use of resources should be reduced at least four times as much as is the case today. But progress by Factor 4 is not enough to meet criteria for sustainable development in western societies. An improvement by at least Factor 10 has been proposed as necessary. This target, however, becomes a barrier to sustainable development in poor countries. Here, on the contrary, an increased use of resources is necessary to fulfil basic needs for people and, thus, is compatible with sustainable development (Edén et al. 2000).

2.2 Environmental efforts on a national level

The principles of sustainable development are implemented in Swedish governmental work and there is a flora of ongoing activities at all levels, addressing the built environment more or less directly. Often, the focus is on environmental aspects which a short introduction to a number of actions will illustrate.

In agreement with the Brundtland definition of sustainable development, the Swedish government has stated that Sweden should be a driving force and a model for 'ecological' sustainability

[6] The concept of Factor 4 implies a decreased resource production by four times.

[7] The concept of Factor 10 focuses on the control of inflows (more effective by a factor of 10) - a reduction of material use by 90 percent.

(regeringsförklaring September 1996 in (Government Bill 1997/98)). Departing from this statement, the Swedish government's commission on ecologically sustainable development[8] has raised *three overall environmental objectives* as political goals, Fig 2.2. Based on these a Government Bill with *15 national objectives for environmental quality* has been proposed, Fig 2.3 (Government Bill 1997/98), and was adopted by the Swedish Parliament in spring 1999, to navigate the environmental work of Swedish society.[9]

The above environmental objectives point out a direction to follow and what to achieve within one generation (20-25 years), while the ways to achieve them are not described in detail. The building sector is affected by several objectives, but above all, by the objective: *A good urban environment*. Other objectives significant for the building sector are those, for example, that address groundwater, eutrophication or climate change (1, 2, 4, 6, 7, 8, 9, Fig 2.3).

Every objective has been broken down into a number of subgoals for making them operational (Government Bill 1997/98, SOU 2000)[10]. Generally, work on the environmental quality objectives is built upon five fundamental principles: promoting human health, safeguarding biological biodiversity, protecting cultural heritage, preserving the long-term productive capacity of the ecosystem, and ensuring that natural resources are properly managed (SOU 2000).

Boverket, the Swedish National Board of Housing, Building and Planning, has the main responsibility for the environmental quality objective *A good urban environment*. The objective is complex and regards a wide range of aspects in our surroundings, among others, a pleasant atmosphere, access to green areas, historically valuable buildings, waste management and economizing on energy, gravel and water. Boverket has proposed a number of subgoals and intermediate goals (Boverket 1999b) that have been concretised in the proposition SOU (2000), a proposal of 22 indicators for following up the objective *A good urban environment*. For 13 of the indicators, Fig 2.4, Statistics Sweden (SCB) has tried to gather available data. However, this was only possible to a limited extent and a need for further development of data, as well as of the indicators has been pointed out (SCB 2002).

Figure 2.2. The three overall environmental objectives of the Swedish government are (Government Bill 1997/98):

Environmental protection
To reduce environmental impact to a level that does not exceed the environment's natural capacity to deal with it.

Efficient utilisation
To use energy and other natural resources much more efficiently than we do today.

Sustainable supplies
To conserve the long-term productive capacity of forests, soils and water resources, and to use a higher proportion of renewable raw materials.

Figure 2.3. The 15 Swedish environmental objectives are (Government Bill 1997/98), restructured (http://miljomal.nu):

1 Reduced climate impact
2 Clean air
3 Natural acidification only
4 A non-toxic environment
5 A protective ozone layer
6 A safe radiation environment
7 Zero eutrophication
8 Flourishing lakes and streams
9 Good-quality groundwater
10 A balanced marine environment, flourishing coastal areas and archipelagos
11 Thriving wetlands
12 Sustainable forests
13 A varied agricultural landscape
14 A magnificent mountain landscape
15 A good urban environment

[8] In Swedish: Delegationen för en ekologiskt hållbar utveckling.
[9] On the homepage 'http://miljomal.nu' new information and information on the history of the environmental objects can be found as well as related publications.
[10] See also: www.miljo.regeringen.se.

Figure 2.4.[11] Thirteen indicators, relevant for the environmental objective 'A good urban environment' (investigated by SCB (2002)).

Energy use per person, per GNP and sector as per energy carrier category

Total water use divided into drinking water, industrial water and irrigation

Index for air quality in densely built-up areas

Amount of waste ending up in waste disposals and total amount of generated waste

Lifecycle analysis for amount of material and energy for some large volume products

Size of green areas in densely built-up areas in relation to built-up and hard surface areas

Travel time to work with public transport, number of travellers within different intervals of travel time

Share of population disturbed by noise at home and outdoors, respectively

Share of economic investments in public transport and bicycle paths of the total infrastructure investments

Natural gravel areas protected from exploitation according to the Environmental Code[12], and the amount of extracted natural gravel and share of reused material

Amount of recycled waste of different types (metals, glass etc.)

Energy use per floor area in newly constructed and older residential buildings and office buildings, respectively

Waste deposits that fulfil the EU directive on waste disposal

Besides the above-mentioned subgoals, specific goals that address the building sector, so-called *sector goals*, have been proposed (Boverket 1999a). Moreover, issues of building for sustainable development, including the existing building stock, have been addressed in several activities initiated by the government or sector specific organisations. The Swedish government appointed for the period 1998-2000 the *Committee for Ecologically Sustainable Procurement*[13] with the task of actively promoting public procurement as a means of achieving ecologically sustainable development. One of the twelve working groups explicitly addressed buildings. As a result, the importance of establishing factor goals (4/10) for a more efficient use of resources has been emphasized. It has also been concluded that, above all, the *existing building stock* has to be *adapted* to meet the national goal – a sustainable society within one generation – and the *management* of the property stock should be *prioritised* (EKU-Delegationen 1999).

The Environmental Advisory Council[14] was commissioned by the government to take part in the work of developing strategies for the development of 'ecologically' sustainable trade and industry. One of the two projects initiated was *Building/Living*[15], a dialogue between twenty companies, three municipalities and the Environmental Advisory Council, discussing future sustainable building and the property sector. The dialogue resulted in a vision, goals and strategy presented in the report *Think new, think sustainable – building and managing properties for the future* (Miljövårdsberedningen 2001). Based on the vision, three themes and seven goals have been prioritised (Fig 2.5). Also, seven strategic areas have been elaborated, comprising: sustainable community planning, new solutions and new technology, the lifecycle perspective and a holistic view, co-ordination of the building and property management processes, environmentally classified residential and commercial properties, investment in research and development and marketing environmental solutions (Miljövårdsberedningen 2001).

[11] The author's translation.

[12] In Swedish: Miljöbalken.

[13] In Swedish: Delegationen för ekologiskt hållbar upphandling. Appointed for the period 1998-2000.

[14] In Swedish: Miljövårdsberedningen.

[15] In Swedish: Bygga/Bo dialogen.

The Ecocycle Council of the Building Sector (BYKR)[16], a voluntary organisation of trade representatives (clients, property owners, architects and technical consulting enterprises, building material producers, building constructors), has carried out a survey of the building sector's most important environmental aspects on the national level, including both buildings and constructions. According to the study, there is a need for better statistics on material and energy flows in the building sector with a division into different categories of buildings, for different phases (construction, operation and maintenance), increased knowledge about material, technical and functional properties in the building stock, better statistics on waste from construction and demolition, and better statistics on the use of hazardous substances in the building sector (BYKR 2001).

In SOU (2001), the need for action to achieve greater efficiency in our use of natural resources has been reviewed and it has been stated that the composition of material use is essential to environmental impact (SOU 2001). It has also been stated that statistics for calculating potential energy savings and following up are insufficient. For example, within the housing and service sector, detailed information for an exact description of development is not available: households might use the same amount of energy despite additional façade insulation aimed at decreasing energy consumption for heating. The reason for this difference might be a higher indoor temperature, which makes more efficient energy use invisible in the statistics (SOU 2001).

The most recent action is that the Ministry of the Environment[17] has called for a commission to investigate questions regarding building declarations and a building register (report to the government in March 2004, (Miljödepartementet 2002)). The task is to analyse and to design a mandatory or voluntary building declaration containing information on radon, ventilation, and energy use. Further, the design of a national building register containing building-related information as a basis for following up relevant subgoals of the environmental objectives, in cases of municipal supervisory liability, to support environmental objectives.

On behalf of the Swedish Environmental Protection Agency[18], SCB investigated the possibilities of producing material flow statistics. The generation of waste material statistics from the building sector is one

Figure 2.5. Three themes and seven goals have been prioritised by the Building/Living dialogue (Miljövårdsberedningen 2001):

Energy
No fossil fuels are to be used for space or hot-water heating after 2025. By 2015, more than half of the annual energy need is to be met by renewable energy sources.

Use of purchased energy in the sector is to have decreased by at least 30 percent by 2025, compared with 2000.

Indoor environment
By 2005, sector specific information will be available that makes it possible to reject building materials and structures that contain or give rise to substances known to be hazardous to health or the environment.

By 2010, all new buildings and 30 percent of existing buildings will be declared and classified with respect to building-related health and environmental impacts.

Resources
By 2008, the building sector will have phased out all use of substances and metals covered by the Government's guidelines for chemical use.

By 2010, the quantity of waste from new construction and reconstruction that is landfilled, counted in tonnes, is not to exceed 25 percent of the 1994 level. No more than 10 percent is to be landfilled in 2025.

By 2005, extraction of natural gravel is to have been limited to a few specific purposes and is to amount to no more than 3 million tonnes per annum by 2020.

[16] In Swedish: Byggsektorns kretsloppsråd.
[17] In Swedish: Miljödepartementet.
[18] In Swedish: Naturvårdsverket.

important issue, but it is a problematical task because of difficulties in finding appropriate data sources (Szudy 2000).

On the EU level, implementation of energy declarations for buildings are being discussed (Faktapromemoria 2001) and investigated on the national level (CIT 2002). Further, the production of detailed waste material statistics coded according to the so-called European Waste Catalogue (EWC)[19] is being investigated (Szudy 2000). Activities on the EU level have a direct impact on Swedish environmental efforts, for example, demands for statistics not available today, are posed.

2.3 Sustainable development of the Swedish building stock?

Government, authorities, society in general, and the building sector in particular, request information needed for their efforts towards sustainable development, as the previous section has shown. The various target settings, such as the environmental objective *A good urban environment* and its subgoals or the goals elaborated in the Building/Living dialogue, point out the need for a considerable change concerning the use of material and energy in the building sector. All of the targeted settings have the goal of improving the environmental impact of building(s). If the goals are to be reached, immediate and wide spread activities will undoubtedly be called for.

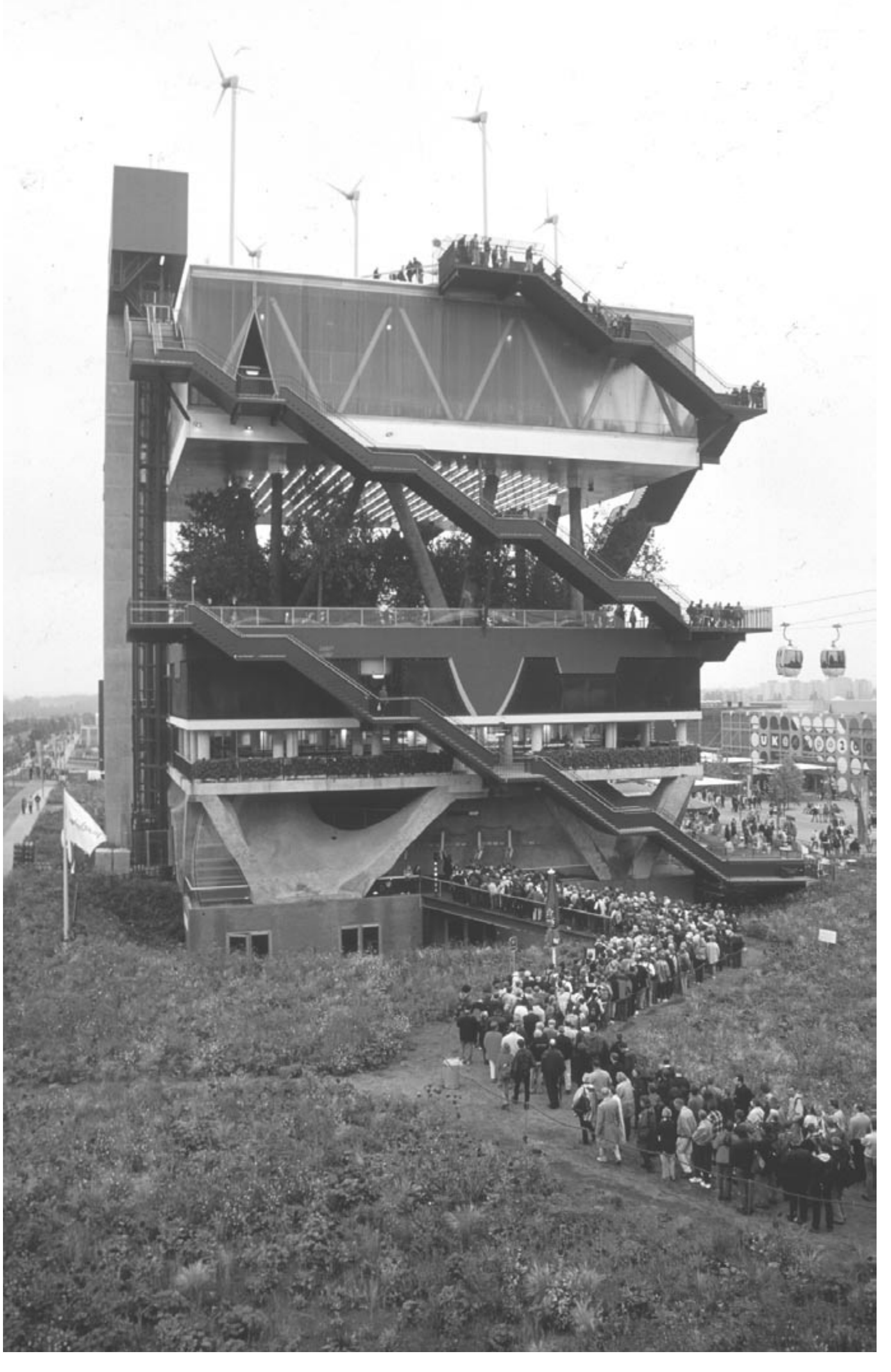
In order to pursue the targeted settings related to existing buildings, basic knowledge of the (starting) conditions is needed in a structured way. As illustrated above, the independent mappings that have been carried out indicate a lack of detailed data, indicators, statistics and a need for measurement of environmental impact (SOU 2001, BYKR 2001, SCB 2002). Material flows have been focused on (BYKR 2001, Szudy 2000), as well as energy flows (Faktapromemoria 2001), and time aspects have been evaluated as important, but still, data are non-existant or the available data are unsatisfactory. So far, no models or systems are available that can deliver a complete picture of the building stock from an environmental perspective.

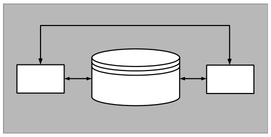
[19] The European Waste Catalogue is a classification system for waste materials. It categorises wastes based on a combination of what they are and the process or activity which produced them (http://www.environment-agency.gov.uk/business/wasteman/landfill/).

Thus, any improvement in environmental impact from buildings and any environmentally sustainable development of the building stock is only possible with better knowledge about the composition of the stock, the resource use of the stock and changes over time. An instrument is needed to gather necessary data and to provide this knowledge. The successful establishment of such an instrument relies on a balance of meeting present needs for knowledge and future needs.

PART II

Terms, Definitions & Theoretic Framework





3. BUILDINGS & BUILDING STOCKS – THEIR RELATION TO THE ENVIRONMENT

Modelling is a simplified representation of the real world and, as such, only includes variables relevant to the problem at hand. In a building stock model that addresses environmental issues, buildings and building stocks are the central objects for modelling. They need to be defined explicitly along with their interaction with the environment. Chapter 3 identifies the modelling aspects – environmental issues represented from a resource-use and time perspective in the context of building stocks.

3.1 What is a building and what is a building stock?

The original purpose of buildings is to protect humans from intruders and to provide an appropriate climatic condition for survival. Buildings serve as a place for different cultural activities; they serve as a home, a workplace, a place for contemplation, and a place for communication. They form spaces, villages, and towns and make up the building stock that has a cultural heritage. Hence, buildings are parts of the stock. They create a landscape of artefacts and give aesthetic experiences. The location of the artefacts initiates communication and transports. The building stock is also a composition of different building materials, which have been extracted from the earth and deposited in the buildings. Thus, a building stock can be considered to be a resource with several natures: natural, man-made, cultural, etc.

Buildings

The definition of buildings and building stocks, above, is more of a literal description. However, for modelling buildings and building stocks more exact definitions are needed. A *building* is defined according to the Swedish Dictionary (1997) as a free standing, covered, above ground raised, solid

A building is a kind of built facility and a produced object, which is permanently fixed to the ground and used for a special activity purpose. It is an artefact with load bearing, enclosing, and media-providing (energy, water) properties (BSAB 1998).

construction.[20] According to ISO/CD 12006-2, a construction entity is an independent material construction result of a significant scale serving at least one user activity or function. Construction entities are buildings, streets, canals, bridges, etc. Based on ISO, the classification system of the Swedish construction industry (called BSAB) defines a building as a kind of built facility and a produced object, which is permanently fixed to the ground and used for a special activity purpose. It is an artefact with load bearing, enclosing, and media-providing (energy, water) properties (BSAB 1998). Definitions of a building may vary depending with the purpose of the use of the definition and classification, which (Thuvander 2000) further discusses. As the BSAB definition is well established in the building sector and is sufficient for my purpose (not too delimited, and the location of a building is addressed), the term 'building' refers to the BSAB definition in the following text (with the reservation for a broader interpretation of "enclosure", see car decks below).

Building stocks

According to the Swedish Dictionary (1997) a stock is a (larger) collection of similar phenomena.[21] In the Swedish National Encyclopaedia a stock is defined in a more limited sense as comprising the individuals of a species, sub-species, variety or forms, which exist together within a limited area (NE 1990).[22] A building stock, then, is complex. Each part of the building stock, i.e. every building, is individual in this sense, that the buildings are adapted to local conditions and have a clear spatial relation (they have only one specific location). In general, the composition of a building stock differs geographically, from country to country, from region to region, depending on the activities in the buildings, climate, building materials available, traditions, culture, historical events, regulations, politics, etc. Modelling the stock implies that aspects essential for the object in focus are taken into account. That which is considered as essential depends on the need for knowledge.

A building stock can be considered as consisting of several partial stocks. A partial building stock usually consists of individual buildings, alternatively it may also consist of building aggregates (Fig 3.1).

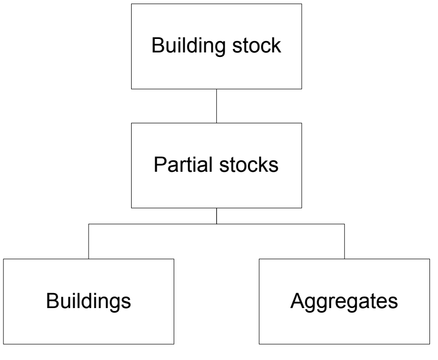


Figure 3.1. A building stock can be considered as consisting of several partial stocks. A partial building stock in general consists of entire buildings, but it may also consist of building aggregates.

[20] In Swedish: byggnad: … fristående, täckt, över marken upphöjd, fast konstruktion.
[21] In Swedish: (större) uppsättning av likartade företeelser inom ett visst område.
[22] In Swedish: i inskränkt mening de individer av en art, underart, varietet eller form som finns samlade inom ett begränsat område.

Aggregates are not necessarily complete buildings but they can be a part of them, for example, the building part 'roof', or average buildings/ building parts. Average buildings/building parts can be described as consisting of several materials; the average building part 'roof' may consist of 50% roofing tiles, 30% roofing felt and 20% metal sheets (SNV 1996). This type of partial stock can also be called 'virtual stock' (Barth & Schwaiger 1998). By partial building stocks composed of entire buildings I mean either all buildings with the same use (domestic buildings, non-domestic buildings, etc.), all buildings (blocks of flats, cottages, offices, warehouses, churches, barns, industrial buildings, etc.) within a geographically limited area (all buildings in Göteborg), or buildings with a special location (rural area/densely built-up area).

For the actual modelling, a building stock is considered as comprising all existing buildings, domestic and non-domestic buildings within a geographically limited area. For example, the total of all buildings in Sweden comprises the Swedish building stock. The Swedish building stock, then, can be divided into partial stocks as required, and, in this way it can be considered as consisting of several partial stocks. The same goes for the building stock of Göteborg.

When modelling building stocks, the system boundaries (that which is included or excluded) are not clearly given from the beginning but are chosen by the investigator to suit the question in focus. Here, for example, constructions, such as car decks, are included because these structures stand for a certain amount of built-in materials. However, materials, constructions and installations outside the building and products connecting buildings with the surroundings (block pavers, drainage systems, etc.) are excluded, as well as built constructions, such as roads, bridges, docks, channels, airfields, etc. They are beyond the scope of this study for practical reasons as their properties differ too much from buildings but not because they lack importance.

Building stock descriptions

The definition of buildings and stocks is not only essential for modelling but it is also important for how to model representations of the stocks and partial stocks. A main methodological problem when describing building stocks is the choice and description of the buildings entering an age-use class matrix – the most common way to represent building stocks, used by ref?. In many studies, a typological approach is chosen, i.e. one building represents one class of the stock (typical buildings or stereotypes), but even non-typological approaches have been used, where the building stock is described by a number of real existing buildings (reference buildings).

Briefly, a typological building has a real structure (geometrical type, structural type, construction type) which is supposed to give the appropriate image of the class from the desired point of view (Kohler & Schwaiger 1998). Only a few aspects can be reproduced idealistically when using typical buildings, for example all aspects necessary to describe energy use. Typological approaches are simple and efficient; however, some disadvantages can be identified. The fixed composition of the typical building doesn't allow for a description of aspects other than those representative for the chosen aspect. For example, a typology adapted to describe energy patterns does not necessarily include the relevant aspects needed to describe material flows. Determining relations between different aspects is difficult; like energy and material flows (Kohler & Schwaiger 1998).

In a non-typological approach, a general structural description of a building is given instead of a predefined building type and a building stock is described by a number of real existing buildings. For each view of the building stock, groups of buildings can be assembled according to desired attributes (Barth & Schwaiger 1998, Kohler et al. 1999). These buildings can be selected in different ways: random sample surveys (as in earlier Swedish building stock studies, for example (Hammarsten 1980, Tolstoy et al. 1984, Wilhelmsen 1987)) or an investigation of a number of buildings with good data available. In the latter case, the number of investigated buildings will increase gradually. If the number of buildings is large enough, the sample will be representative (Barth & Schwaiger 1998, Kohler et al. 1999).

Another approach to representing buildings and stocks is archetypes[23], which I see as quite similar to the concept of virtual stocks (aggregates) as described above. Archetypes can be defined as a statistical composite of the features found within a category in the stock. Archetypes are buildings which have no real existence but represent, in each basic component, the specific distribution of a specific class of buildings. Archetypes are always more complex than actual buildings since they include bits of many different materials, technological systems, and energy and water

[23] Archetype comes from Geek *archetypos* and means original pattern.

sources. Depending on the focus of an investigation, archetypes can be normalised as a building or household, or as one square meter of a typical floor area (Moffatt 1999).

3.2 Time perspective

The author, inventor and designer Stewart Brand[24] declares…

> Time is asymmetrical for us. We can see the past but not influence it. We can influence the future but not see it. Both the invisibility and potential malleability of the future draw us to learn into it, alert to threat or opportunity, empowered by the blankness of its page… (Brand 1999:119).

Buildings are in some way permanent, “permanently fixed to the ground” as the BSAB definition states, but they are not as permanent as it may appear. Changes occur through the entire life-time of a building for different reasons and these changes often generate flows of resources or are related to flows of resources. A building stock model, which addresses environmental issues should take these changes into account. Thus, a closer look at buildings and building stock from a wider time perspective is needed to understand the dynamics involved.

Buildings usually have a very long lifetime compared with most other products created by humans. Peuportier et al. (1997) describe them as unique one-of-a-kind products, some of them with a potential to exist for hundreds of years.

Typically, many actors (architects, constructors, property managers, etc.) are responsible for a building during different phases of its lifetime. They often have contradictory interests, different time perspectives, and varying concerns about long-term effects. The design and construction phase of a building is handled as a short-term project; in contrast, the management of a building is a long-lasting process. Project and process are fluent notions, hence, a building project consists of parts and several minor processes (design process, construction process).

The economic time perspective often concentrates on new construction only, even though maintenance during the use phase may amount to as much as three times the cost of the original building (Brand 1997, Kohler et al. 1999). Not only the costs are considerable during the

[24] Co-chair and founding member of the The Long Now Foundation, http://www.longnow.org.

use phase of a building but also the main impact of the building on the environment in terms of energy use arises during this phase. For example, about 85 percent of a building's lifecycle energy is used during this period in a modern Swedish dwelling (Adalberth 1997). The temporal phases of a building's lifecycle related processes, which generate energy and/or material flows, are illustrated in Fig 3.2. Material flows are large for construction as well as for operation, cleaning, maintenance and a frequent change of tenants (and possible change of use) and these create material flows. Consequently, buildings change over time.

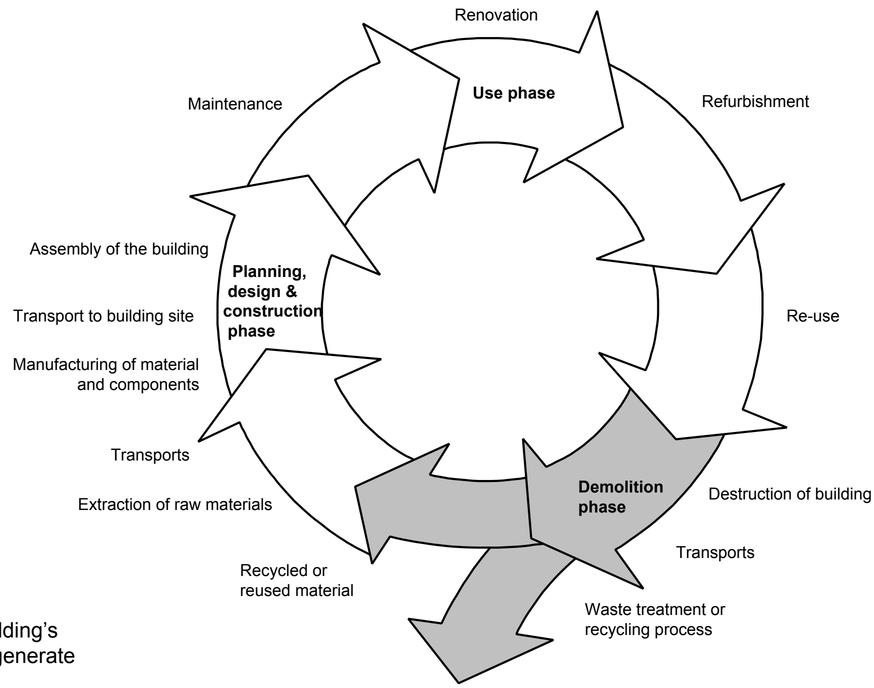


Figure 3.2. Temporal phases of a building's lifecycle and related processes that generate energy and/or material flows.

Should we adjust our time horizon thinking? In the book 'The Clock of the Long Now', Brand presents a special clock as an instrument for thinking about time in a different way: A clock very big and very slow; designed to last 10 000 years, to tick once a year, to bong once a century, and a cuckoo to come out every millennium (Brand 1999:2-3). This long time-scale thinking challenges technology, research, and design; robust and durable materials or the easy exchange of resources and maintainable material are needed. It provokes important policies and practical matters of design, construction and the operation of the built environment.

Instead of considering buildings exclusively as a whole and from a lifetime view, a time-layered perspective can be applied. The English architect and researcher Frank Duffy argues that such a perspective is fundamental for understanding how buildings behave. He distinguishes four layers of longevity of built components. Brand (1997:13) extends this model and defines six shearing layers of change, Fig 3.3:

This is the geographical setting, the urban location, and legally defined lot, whose boundaries and context outlast generations of ephemeral buildings. "Site is eternal". […]	Site	Society [25]
The foundation and load-bearing elements are perilous and expensive to change, so people don't. These are the building. Structural life ranges from 30-300 years (but few make it past 60, for other reason).	Structure	Building related, maintenance
Exterior surfaces now change every 20 years or so, to keep up with fashion or technology, or for wholesale repair. Recent focus on energy costs has led to re-engineered Skins that are air-tight and better-insulated.	Skin	
These are the working guts of a building: communications wiring, electrical wiring, plumbing, HVAC (heating, ventilating, and air conditioning), and moving parts like elevators and escalators. They wear out or obsolesce every 7 to 15 years. Many buildings are demolished early if their outdated systems are too deeply embedded to replace easily.	Services	
The interior layout – where walls, ceilings, floors and doors go. Turbulent commercial space can change every 3 year or so; exceptionally quite homes might wait 30 years.	Space plan	Activity related
Chairs, desks, phones, pictures; kitchen appliances, lamps, hair brushes; all the things that twitch around daily and monthly. Furniture is called 'mobilia' in Italian for good reason.	Stuff	

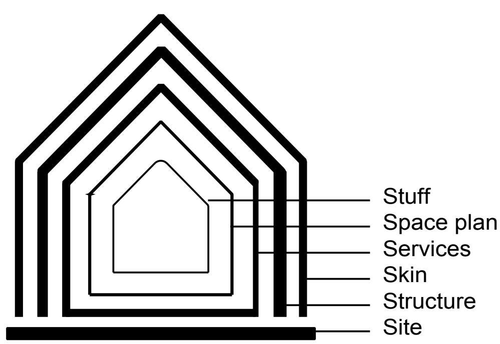


Figure 3.3. "Because of the different rates of change of its components, a building is always tearing itself apart." - The six shearing layers of change. Adapted after Brand (1997:13).

[25] Society, building related/maintenance, and activity related: the authors add-on.

The time-layered model is a general model not explicitly related to environmental issues. Cole & Lafreniere (1997) have enlarged the scope of the time-layered model and have developed a model to organise environmental information in three frames: time, scale and context.

A basic principle is that all the layers of different longevity interact. To understand the dynamics of how the layers of change interact, one can learn from nature how ecological systems manage change:

> The answer appears to lie in the relationship between components in a system that have different change rates and different scales of size. … The combination of fast and slow components makes the system resilient, along with the way the differently paced parts affect each other. Fast learns, slow remembers. Fast proposes, slow disposes. Fast is discontinuous, slow is continuous. Fast and small instructs slow and big by accrued innovation and occasional revolution. Slow and big controls small and fast by constraint and constancy. Fast gets all our attention, slow has all the power. All durable dynamic systems have this sort of structure; it is what makes them adaptable and robust. (Brand 1999:34)

The same applies to buildings: The dynamics of buildings is determined by the interaction of fast and slow layers. Slow, in buildings, is the load bearing structure. Fast, on different levels, is skin, service and stuff. The site dominates skin, which dominates services, which dominates the space plan (Brand 1997). These considerations may be extended and applied to building stocks. Slow, then, is the building stock structure, fast are the buildings. Buildings change, the infrastructure remains. The housing stock, for example, could be described as a framework that maintains more or less the same size for many years. But the buildings 'inside' the framework will be exchanged through new construction and/or demolition. Going even further, site is eternal, building stock is fast and changing. So, 'slow' is comparable with a longer life-time, and 'fast' with a shorter life-time, but everything is relative, as one can see.

In what way are the different time perspectives, changes, and transformations important for modelling the building stock from an environmental perspective? It is obvious that the understanding of time, the different time horizons (thinking and acting) play a vital role in how a building stock evolves over time. The understanding of the dynamics of both the stock and the parts of the stock is substantial. For that, the dynamics of the stock, nativity and mortality, i.e. the construction rates, survival and losses of buildings should be known. Also, an understanding of the time-scale, representing the duration of a building's different phases, is necessary because the impact of the building on the environment is considerably different over time. The speed of the stock's 'turnover', consequently, has importance for material flows and energy use:

> The speed of transformation is probably one of the key parameters of sustainable urban development. Towns, cities, urban context etc. have historically evolved with a certain speed. There have been faster and slower developments, but the overall relatively slow speed has allowed at the same time a conservation of resources and a cultural continuity, which could be understood by the inhabitants and which allowed an identification or created identification. There has always been a difference between the time constants of the basic infrastructure (decades and centuries) and their use (decades). The underlying physical transformation of the built environment (as expressed by different energy and massflow levels but also by the overall appearance) stays within certain limits. (Kohler 2002:134-135)

Observe that the life-time of buildings or building parts is closely interconnected with the activities inside the buildings and the cultural environment, the society and its valuations. Buildings are demolished or changed not only for maintenance reasons or because of poor constructional conditions but also because of aesthetic reasons or for practical reasons (a new activity in buildings 'demands' a new interior design).

To sum up, in order to describe a building stock from an environmental point of view, time aspects and the understanding of the dynamics of buildings and building stocks, are important as they are related to the use of resources. Thus, a building stock model will need to be time-integrative; it has to assume a life-time for buildings, exchange rates for the different time layers, and rates for maintenance/renovation, i.e. to work with figures which, for example, property managers apply. A time integrated (dynamic) model, is necessary to achieve the aims.

3.3 Interrelation between the built and the natural environment

From	To
local	global
distinct	diffuse
simple	complex
direct	delayed
predictable	unpredictable
reversible	irreversible
visible	invisible

Figure 3.4. Scale displacement of environmental problems (Holmberg 1995).

So far, buildings and building stocks have been defined in general and illuminated in a time perspective, in a way that is related to environmental issues. The research focus, aiming at understanding and minimising negative environmental impact of existing buildings and the entire building stock, however, requires a closer look at the environmental aspects of the built environment. Consequently, the environmental impact of buildings and building stocks is of prime interest, but also the mutual relation, the environment's impact on buildings is worth examining. The question is then, which are the relevant aspects to be modelled and how should they be described?

Environment and environmental problems

To begin with, the term 'environment' is often used in a broad sense: 'The circumstances, objects, or conditions by which somebody or something is surrounded' (Allen 2001), for example, as in the expression 'built environment'. A more narrowed definition of environment is: 'The natural surroundings of or the complex of external factors that acts upon an organism, an ecological community, or plant and animal life in general' (Allen 2001) - to this I would like to add buildings. The latter definition is the one of concern when discussing building related environmental aspects.

In general, there is no consensus about when effects on the environment turn into an environmental problem and even what an environmental problem actually is. An *environmental problem* may be defined as a change in the environment caused by anthropogenic factors and experienced as a problem (Andersson & Molander 1995). The changes can obviously be assessed, but the definition of a change as an environmental problem depends on the value given to it. The interpretations depend, for example, on how nature is perceived: as robust, fragile, friendly, robust within limits, or unpredictable (Sundqvist 1990).

Also, humans' perception of the scale of environmental problems has successively changed from a local character with concentrated impact from specific point sources into problems of a regional (e.g. acidification) and global character (e.g. global warming and ozone depletion), Fig 3.4.

All end-effects are local, but there are differences in their spread, i.e. the cause-effect chain contains several steps in-between. There is

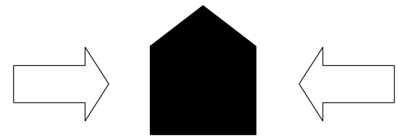
Environment: surroundings in which an organization operates, including air, water, land, natural resources, flora, fauna, humans, and their interrelation.
Note: - surroundings in this context extend from within an organization to the global system (ISO 14001 1996:8).

Environmental aspect: element of an organization's activities, products or services that can interact with the environment.
Note: - a significant environmental aspect is an aspect that has or can have a significant environmental impact
(ISO 14001 1996:8).

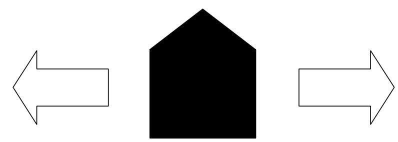
Environmental impact: any change to the environment, whether adverse or beneficial, wholly or partially resulting from an organization's activities, products or services (ISO 14001 1996:8).

obviously a need for environmental understanding, both from long-term and short-term perspectives. The short-term perspective is more about immediate and visible problems like health aspects or waste management. Large-scale problems have to be removed in the long-term and they are important for the well-being of following generations. Any improvements we make today will perhaps not give any visible results in our own time.

Figure 3.5. A mutual relation: impact of buildings on the environment vs. the environment's impact on buildings (leading to different effects on the environment).



The natural environment has an impact on the buildings (for example, the climate). This is not the focus of the modelling but is being handled by external models.



Buildings have impact on the environment (modelling focus, environmental aspects).

The built environment

Buildings and building stocks[26] affect the environment and they are affected by the environment (Fig 3.5) throughout their lifecycle in different ways, directly/indirectly and locally/globally. Directly and locally a building affects the ground, the flora and fauna; land is used and the biodiversity of the local area may change; or erosion of land may possibly be intensified. Indirectly and in addition to the actual place, buildings can have an impact on other places, for example, where building material is extracted from the earth or where building materials are produced, where energy is generated, water is cleaned and supplied, and waste is handled.

The environmental aspects and resulting environmental impact of buildings are closely related to the use of resources and can be described in a flow model (input, accumulation, and output) as Fig 3.6 illustrates. Airflow and issues related to matters of indoor climate, however, are excluded here. Airflow is not measurable in the same way as other resources.

Flow perspective

The main elements of material flow studies are accounting for and monitoring input and output to and from a system.[27] Input, in this case would be *inflows* of material, energy and water. Material flows are generated for different reasons and in different phases of a building's lifecycle (Fig 3.2). Raw materials are extracted from the lithosphere and are deposited in the building as built-in materials. Parts of the extracted resources eventually return to the natural eco-cycle. Flows are not only generated for sustaining the building and its functions, but extensive

[26] In the following text I will only refer to buildings, being aware that they are a part of the building stock.
[27] An extended discussion of this issue can be found in Thuvander (2000:17-21).

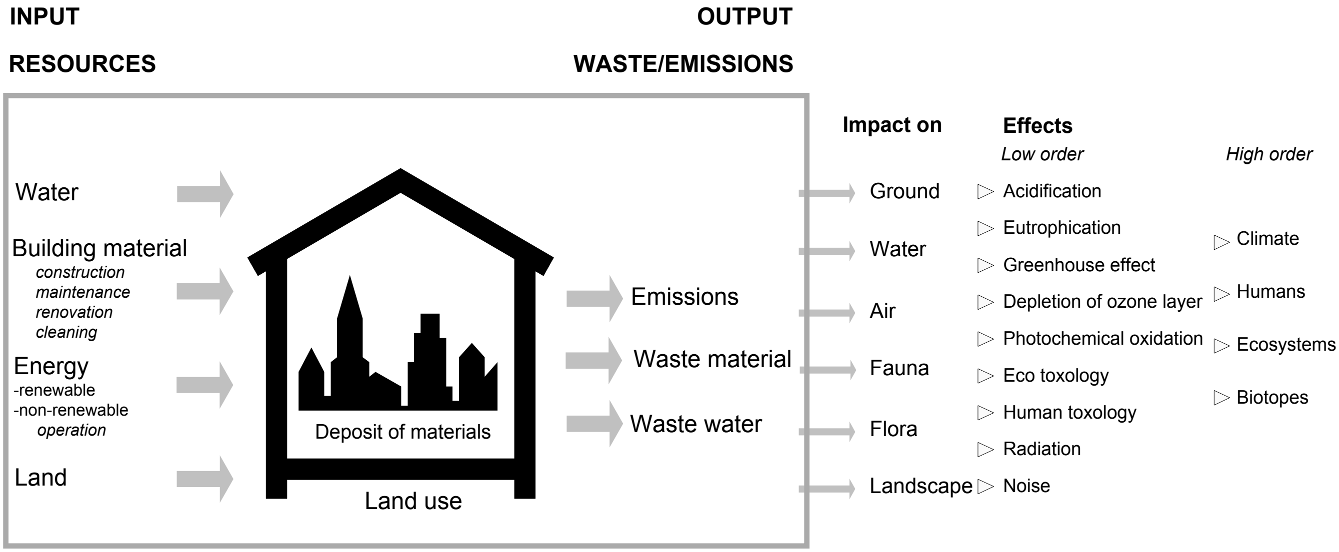


Figure 3.6. Buildings' and building stocks' interaction with the environment, adapted after (Kohler 1999:25). The grey box illustrates the proposed system boundaries for modelling, applicable to all phases of a building's life-time.

flows also arise when the use of buildings changes (as is common for office buildings, for example) or tenants change (domestic and non-domestic buildings).

Over a particular time period, natural resources are used for the construction maintenance, renovation, and refurbishment of buildings and so natural resources are added to the stock, as well as being eliminated and spread. Energy is used for extracting, producing, and transporting building materials. However, most of the input energy today is used for operation and to provide thermal comfort inside the building, i.e. for heating, cooling, electrical appliances and for lighting.

Moreover, water use is a matter of interest. Water flows are mainly connected to activities inside the building, i.e. related to the use of buildings. However, even rainwater comes into contact with the building (and may change its content depending on the building's surface material).

The *outgoing flows* are, in principle, waste materials from demolition, as well as from new construction, maintenance, renovation, and refurbishment. Energy leaves the stock in the form of transmissions (leakage, warm water). During operation, emissions occur from the use of energy, from leaching and corrosion-solvents. Depending on which energy source is used (renewable – bio fuel, solar energy, water power, or non-renewable – coal, oil, gas, nuclear power), the building stock has a significant impact on the environment during this phase. In this way, it contributes to global effects on the environment like global warming, depletion of the ozone layer and depletion of resources.

Wastewater from buildings is a result of activities related to water use (bathing, dish water, washing clothes, toilet use) and surface water. Usually, all kinds of wastewater are mixed and led to the sewage system.

In terms of the modelling problem, so far, it can be concluded that inflows and outflows of resources, specifically for material, energy and water should be included in a building stock model. However, it is not necessary to include the whole cause-effect chain in the model. The proposed system boundaries are illustrated in Fig 3.6 by the grey frame. Additional tools may serve the purpose, too, for example, impact assessment (evaluation of the effects).

Deposit perspective and perception issues

Flow studies say little about already built-in materials, hence, deposits needs to be examined from an environmental perspective, in particular.

Today, buildings are usually planned for a lifetime of 30-50 years. This long period, compared with most other products, has its consequences. For example, environmentally toxic materials, built in today, are hidden for many years in the building stock. They are likely to cause problems that we will be confronted with in a relatively distant future when the buildings are demolished. Some built-in materials like PCB and asbestos have serious impact on human health. Perhaps other materials, already built-in but not considered as risky, might be found to be harmful in the future. Buildings "just standing there" with a certain building material, for example a copper or metal sheet roof exposed to the environment, can have a significant impact on the environment and even more so because of changes in climate and the environment. Acid rain is one reason for the dissipation of hazardous substances from the surface of building materials, e.g. heavy metals in the case of a copper roof. Metals get into the ground water via rainwater and enter into an unwanted circulation in the eco-cycle. In this way, changes in the environment can turn building materials which formerly were considered "safe" into environmentally harmful substances.

Other materials may not have a direct impact on human health but belong to a limited natural resource and may be scarce in the future, such as gravel. Neither do we know which natural resources will become an article in short supply in the future. Nevertheless, this is less an environmental problem of the kind described above but important. Resource use can be influenced by the society and its valuations (re-use, recycling).

The deposit perspective is related to the environment's impact on buildings. The environment around buildings and building stocks can be called the exposure environment (the environment a building is exposed to), characterised by degradation agents (mechanical, electromagnetic, thermal, chemical, biological agents), which affect components and materials of the buildings. The exposure environment can be described with help of data on different geographical scales: macro, meso, local, and micro scales according to Westberg et al. (2001), Fig 3.7. There is no common definition, but normally the macro climate is the gross climate (described in terms like polar climate, subtropical climate and tropical climate). The meso climate takes into account the effects of the terrain and of the built environment and the local climate represents the local conditions close to the object, for example, in streets around a building. The microclimate, then, describes the meteorological variables close to the building material surface. The microclimate is strongly dependent on factors such as design, characteristics of the material surfaces, orientation, terrain, topography, or local sheltering (see also external environmental data Section 6.2).

From the above, we can conclude that a building stock model should also model deposits of resources (built-in materials) and should take into account related aspects such as land use. The location of a building or building stock plays a vital role when discussing them from an environmental perspective. A deposit perspective mainly includes material aspects. Water is not stored and energy is only stored as so-called embodied energy, which is not in focus here. The exposure environment is important for modelling. Data related to the exposure environment will not be included in a building stock model but of external models or databases, potentially connected to a building stock model.

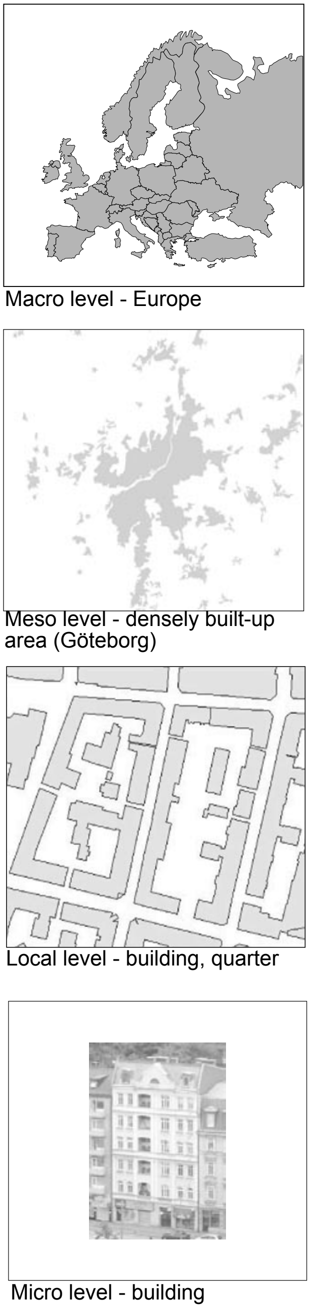


Figure 3.7 The exposure environment can be described with help of data on different geographical scales: macro, meso, local, and micro scales according to Westberg et al. (2001:431/432).

3.4 The modelling aspects at hand

Up to this point, definitions for the key issues have been given and aspects to be included in a model have been discussed broadly and a context has been described. Now it is time to extract and summarise the basic ideas.

The central objects for modelling are buildings and building stocks (defined in Section 3.1) and their environmental aspects. Buildings and building stocks can be considered as complex systems with a low speed of transformation, and which are influenced by a number of factors, as Section 3.2 has shown. The perception of time and time frames (Fig 3.3) are not only key issues for the understanding of buildings and building stocks dynamics but also for the understanding of environmental aspects of the built environment, for example, environmental problems and the way they are tackled are closely related to space and time (Section 3.3). The environmental aspects of buildings and building stocks are delimited to comprise the description of a number of natural resources used and the output flows (see flow model, Fig 3.6).

Buildings have an impact on the environment (land use, resource use, emissions, biodiversity) and the environment has an impact on buildings (degradation, forced due to climate changes, air, soil, pollution, acidification, etc.). The kind and grade of impact differ during a building's lifetime. The three key phases on a time scale are the construction phase, the use phase, and the demolition phase, of which the user phase makes the greatest 'contribution' to the environmental impact of buildings (energy use, material use for maintenance, and cleaning).

Thus, in order to describe building stocks from an environmental point of view, time aspects and the understanding of the dynamics of buildings and building stocks are important factors as they are related to the use of resources. A building stock model will need to be time-integrative; it has to assume a life-time for buildings, exchange rates for the different time layers, and rates for maintenance/renovation.

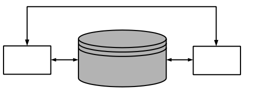
Because of a building's long life-time both material deposits and material in- and outflows should be modelled (not only flows) and all phases of a building's lifecycle should be included. However, only flows in and out from the building's place are included, not flows related to extraction of rawmaterials or production of materials. Modelling should incorporate all building materials, both structures exposed to the climate and structures inside the buildings. Appliances and fixtures like equipment in bathrooms and kitchens should be included as well as, for example, wallpaper and wall-to-wall carpeting. These boundaries have been chosen because all structures are essential parts of the building, and thus contribute to material flows during the lifetime of a building (see also Fig 3.3, the time layered model).

Buildings have a location, which is usually the same for their entire life-time. This makes it possible to consider buildings and some of their environmental aspects/impacts in different spatial contexts.

Table 3.1. Basic demands on the model and the modelling criteria.

From the ideas above we can extract some basic demands on a building stock model and aspects to be modelled:

Basic demands	**Criteria**
Built environment	Buildings and building stocks
Environmental issues	Use of material, energy, water: input - output flows and deposits
Time aspects, follow changes	Time-integrative, dynamic model, including all phases of a building's lifetime
Spatial aspects	Include location of buildings, support local, regional, global (national) levels



4. A SYSTEMS APPROACH

On a general level, different approaches to scientific studies can be identified: the analytical approach, the systems approach and the phenomenological approach (Arbnor & Bjerke 1994). The approaches are based on different ways of understanding the nature of reality. As systemic thinking has already been established for the general description of buildings, Chapter 4 presents and discusses some of the peculiarities of a systems approach and widens the discussion to building stocks and environmental issues.

4.1 Basic notions

The term system comes from the Greek *systema* and means a whole composed of several parts, hence the concept of system is very general. A system representation is…"an assembly of elements related in an organised whole" (Flood & Carson 1993:7). Thus, a systemic approach accounts for both the parts and their mutual relationship, and the emerging properties of the whole. It deals with concepts like 'part', 'whole', 'emergence', and 'level'. Generally, one separates real systems and representations of real systems, the system model (Arbnor & Bjerke 1994).

Ekholm (1987) has developed a theoretical framework and applied the notion 'system' to the physical built environment for the description of construction works and social systems (context man-building) as well as their mutual relations. Ekholm's field is relevant but wider than ours, which comprises only buildings and building stocks. The principles developed by Ekholm have been applied to obtain a general classification of buildings (BSAB 1998), see Chapter 7. However, I find it necessary to make the reader more familiar with the concept. The following considerations of systems applied to buildings are mainly based on Ekholm (1987), Ekholm (1994), Ekholm & Fridqvist (1995), Ekholm & Fridqvist (1996), which I expand to include the perspective

The whole is greater than the sum of its parts….

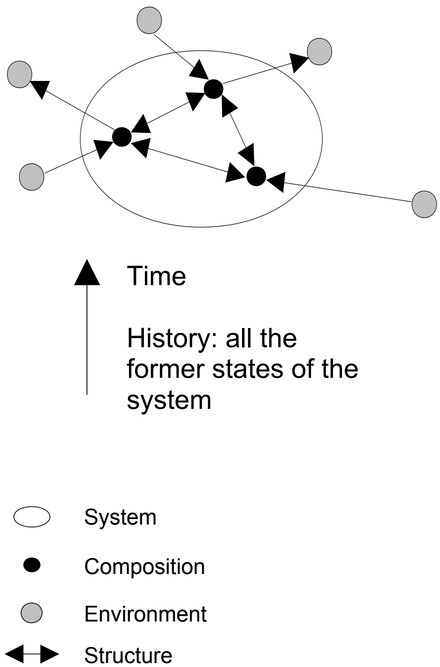


Figure 4.1. A system with composition, environment and structure. Adapted after Ekholm (1994).

of building stocks to provide the foundation for the overall modelling of building stocks.

A system is a complex thing with composition, environment, structure, law, and history (Fig 4.1). A comprehensive description of a system's properties should include all these aspects. The *composition*, then, is the set of different kinds of parts of the system. Different levels of order can be identified (supersystems and subsystems).

Between a part in the composition and the system as a whole there is a part-whole relation. If the parts of a system are systems themselves, they are called subsystems. If the total environment of a system is a system, it is called a supersystem. Together these systems make up a level order with subsystems on a lower level and supersystems on a higher level. A level order is a set of levels, where lower levels precede higher levels. The whole has other laws than its parts, however, its properties are based on the properties of the parts. The composition of a building stock, for example, has a level structure with a lowest level of building (or its aggregates), whereas the composition of a building has a level structure with building materials as the lowest level. Building materials combine into higher levels like building components, building elements, the principal subsystems of a building (load bearing, enclosing, media-providing). Buildings continue into building stocks, which might be a property manager's stock, all single family houses, all buildings or parts of buildings having specific properties. A building stock, in turn, can be a part of an urban system, a part of the society, or a part of the global building stock.

The *environment* is the set of things that interact with the system, without being a part of it. In the case of a building, the environment contains the natural environment (including the site, the ground the building is situated on, climate factors such as precipitation, air conditions with wind-forces, pollution, temperature, and humidity), artificial infrastructure, the building production systems and the users of the building. In this study, our focus is on the natural environment.

The *structure* is the set of relations between the parts of the system and its environment (internal and external relations). Relations can be bonding or non-bonding. Bonding relations of the internal structure between the parts of a building, for example, can be caused by gravitation or fixing devices. An external bonding relation is, for example, the transformation-relations to the site (change of the site). Among the non-bonding relations are spatial relations, including the configuration of

Super- and subsystems. A subsystem is a system which is a part of a larger system. A supersystem is a system which contains smaller system (Arbnor & Bjerke 1994:137).

buildings, and the interpretation-relations to those, who experience the building and appreciate its architecture and history. If the relations are non-bonding, it is an aggregate.

A system's *laws* are the relations among its properties (for example how heating transmissions are calculated) and the system's state mirrors its properties at a given moment of time. Laws regarding functional and composition aspects belong to the system 'a building'. Laws are often the preferred aspects when studying the system.

The *history* of the system comprises all the former states of the system. The history of a building or building stock, then, includes all of its former states and changes of the state.

The properties of a building are partly determined with respect to the supersystem of which the building is a part, and partly by the systems, which make up the building. The natural environment is one of the supersystems of a building and here a supersystem of prime interest.

The properties of a system can be resultant or emergent. For example, the mass of a building is a resultant property and a mere addition of the masses of the parts. A resultant property exists already among the parts of a system, while an emergent property is new, and characterises the system as a whole. The building's climatic properties or energy transmission values are properties of the parts but emerge with their enclosure of an air volume (energy demand for heating, climate protection). Building stocks form structures, streets, blocks or squares.

In principle, there are two kinds of systems: closed systems[28], which do not have any relationship or communication external to the system (they have no environment), and open systems, which have an exchange of material, information or energy with the environment across a boundary (Flood & Carson 1993). Buildings and building stock systems belong to the latter kind in a life-time perspective (flow model). The main target of a building stock model is to understand and decrease the environmental impact of buildings and building stocks, i.e. to understand the relationships and decrease the exchange of material and energy external to the system – which also means approaching a closed system.

System boundaries should partly be drawn with respect to the partial subsystems included in the system, and partly with respect to the supersystem the system is a part of. The partial systems included are

[28] More or less only possible in theory.

those which are most fundamental for the properties of the system. The system, which is studied, is the one whose properties are fundamental to the properties of the supersystem (Ekholm 1987). System boundaries may be temporal (the life-time of the building) or spatial (extraction of resources from nature and returning emissions to nature).

One of the fundamental concepts of system science is the so-called homeostasis. An example from ecology explains the term:

> The fact is,..., that an organism exchanges materials, information, and energy with its environment in order to survive. So at [time + a certain time period] the identity of the organism may appear to be unchanged, but the actual materials that make up the organism at time [t] will partially or totally be replaced by time (time + a period). This idea of dynamic equilibrium, with fluxes in and out, is termed homeostasis. (Flood & Carson 1993:12)

Certain mechanisms in a system make it possible to maintain the basic function of the system despite (external) disturbances. This concept can also be applied to buildings and building stocks. Buildings appear to be unchanged after, say 20 years, but in fact parts of a building have been replaced, and many kWh of energy have flowed through the building to secure the function of the building and the comfort of the inhabitants. Buildings, then, are homeostatic systems that require an exchange of material, information, and energy in order to maintain their identity. The building stock of Göteborg may have approximately the same size (number of buildings) for several years but some of the components, buildings, may have been demolished or new buildings may have been constructed.

4.2 Complex systems

System science deals with the analysis of complex systems. Complexity covers an enormous area, somewhere between order and chaos (Nørretranders 1999). Complex systems can be defined as systems in which fine details are linked to large outcomes (Ahl & Allen 1996).

The perception of the complexity of a system depends also on the interest of the observer of the system (Flood & Carson 1993). To a materials researcher, the building material concrete, as a composition of several substances and a "soup" of chemical reactions, is certainly complex; and a detailed description of it would require much effort. To an architect, the building material concrete is simple, because the architect has only to distinguish it from a limited number of other building materials. The same is valid for buildings and building stocks. These systems are not a priori complex systems. A town planner is interested in that a building fits in the overall plan of an area, that it fulfils its main tasks (specific function or use of a building), that the façade is optically suitable. But a researcher, modelling the building stock and the material and energy flows, or a property manager, is interested in much more detailed information. The size and use of the building is of importance, what kind of materials and energy are used, "when" and "where" need to be known. Consequently, the researcher has to handle buildings and building stocks as complex systems. Ahl & Allen (1996) stress that several levels of detail need to be addressed simultaneously in order to adequately describe a complex system. Hence:

> To be an effective systems scientist we must at the same time be both a holist, looking at the system as a whole, and a reductionist, understanding the system in more detailed forms. (Flood & Carson 1993:17)

Characteristic for system thinking is that a system always has to be considered as a part in a bigger whole before one can start to describe the parts of the system. A system can never be understood as it is on its own because its properties are always dependent on a context. This is the cognitive and methodological "moral" of system thinking (Ekholm 1987:34).

4.3 System modelling

Methodological aspects of a systems approach concentrate on the whole mapping of the components in the real system and their relationships, the motivation to understand the interrelations of the components and the whole, the preparedness to revise the system model and to accept that different analysts may devise different system models. Analysis in a system sense thus means that the whole is not divided into parts, but the components' interrelations must be understood. The analysis of a real system is usually explorative, and techniques are modified during the course of the study. It is an iterative procedure (Arbnor & Bjerke 1994).

The different approaches to scientific studies also have an impact on the models used for representing the real world. Generally, a model is a simplified representation of the real world and, as such, includes only those variables relevant to the problem at hand. A model may not include all relevant variables because a small percentage of them may account for most of the phenomena to be explained (EB 1994). Models are social constructions (Wallén 1996) and they are used heuristically (from Greek *heuriskein* – to find, to discover), i.e. serving as aids leading to discovery or problem-solving by experimental and especially trial-and-error methods (Allen 2001).

The notions 'model' and 'system' belong together (Lundequist 1995a), where *system* stands for the part of reality to be investigated and the *model* stands for a representation of this part. Hence a model is a system, which represents another system. There are concrete models and abstract models. Concrete models are things, which, in some way, are very similar to the modelled thing, and abstract models are conceptual representations of a thing. An abstract model precedes a concrete model.

As our focus is on systemic models, the characteristics of these models are of interest, which can be summarised as follows (based on Arbnor & Bjerke (1994)):

- The emphasis is on the *whole* in a complicated world. The parts are more or less dependent on each other.
- The presence of *complex* systems. Every system model is only one of many possible representations of the real world system. There are no absolute system boundaries; they are only more or less adequate for a certain purpose.
- A search for *purposive (teleological)*[29] characteristics of the system and goal orientation applies.
- The principle of *recursiveness*[30]. A system always contains and is contained by another system or many systems. Every system is a potential component of a larger system (sub- and supersystems) and every component within a system can be developed and made into a new system (compare: a series of Chinese boxes). There are different levels of resolution for the systems (grade of detail).
- The importance of a frame of reference (*relevance*). The simplification of the real world underlies subjective decisions. Depending on different persons, situations and subjects, a system may be transferred into differing models.
- Modelling is a matter of *interdisciplinarity.*

The systems modelling approach seems to be a fruitful way for modelling building stocks from an environmental perspective. Buildings and building stocks are considered as real systems, more or less complex depending on the observer's view. Complex systems need to be modelled on different levels of detail, and this applies to building stocks as well. Therefore, a building stock model should be based on recursive modelling, so that the stock can be explored on different levels, switching from a holistic description of the stock with only a few indicators to a very detailed description of certain parts of the stock, so-called top-down and bottom-up approaches.

The objective of the building stock model in focus here is to understand and support environmental improvement of the building stock. A model is not a complete representation of reality, but a number of properties are chosen because of the purpose of the model. Such properties are often interrelated and can be called aspects. Relevant aspects to be modelled are, in our case, buildings and the interrelation of buildings and the environment, particularly flows and deposits of resources (Section 3.3 and 3.4). Aspects of a building can be, for example, the façade, material, energy balance, location or space. Other researchers, for example those interested in buildings' impact on peoples' behaviour, may possibly choose other variables for the description of buildings and building stocks.

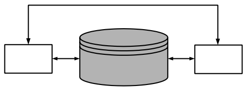
Building stock modelling requires knowledge from several disciplines: knowledge to describe the artefacts (building and building stocks), knowledge to describe the interrelation between buildings and the environment (focus on the impact caused by the artefacts), social knowledge and institutional knowledge for evaluation and implementation.

Briefly, as buildings are usually described as systems and a flow model can be applied, then even a building stock model focusing on interrelation with the environment would be well suited for a systems approach. Further, established systems are based on systemic thinking, which is important for the future dissemination and implementation of an environmental building stock model.

---

[29] Teleology – a doctrine explaining phenomena by reference to goals or purposes, the character attributed to nature or natural processes of being directed towards an end or designed according to a purpose (Allen 2001).

[30] Recursive: of, relating to, or involving recursion (a return).



5. INFORMATION SYSTEMS

The research problem of this thesis deals with pre-modelling an information system that addresses the environmental aspects of building stocks. Chapter 5 gives the context – a short introduction to theory and background on databases, information systems and the development of databases and information systems, respectively. Different modelling phases are presented and the importance of the pre-modelling phase is emphasised.

5.1 Data and information

I would like to begin with a short discussion of data[31] and information as these terms are frequently used in various contexts. Very basicly, 'data' is the plural of 'datum'. Datum can – without taking science theoretical aspects into consideration – be defined as any fact, what has really happened or is the case, truth, reality, assumed to be a matter of direct observation. Thus, data are a set of discrete, objective facts about events, terms, or instructions in the form of characters, figures, facts or numbers appropriate for transfer, processing, and interpretation. There is little or no inherent meaning in data, it provides no judgement or interpretation, and data by itself has little relevance or purpose (Davenport & Prusak 2000, Eklundh 2000, Törnqvist et al. 2000). Examples of data are; single family house, 1954, 1 kg PCB, 120 kWh/m^2 x year.

Information, on the other hand, is a higher level representation of data, it is where data have been given a form of character and meaning (Michener & Brunt 2000). 'Inform' originally means "give shape to"; information shapes the person who gets it and it has shape, i.e. information is organised for some purpose. Information is interpreted data and data functions as essential raw material for information (Davenport &

[31] The word data is used both as singular and plural, as is common in database literature; the context will determine whether it is singular or plural. In standard English data is plural.

Prusak 2000, Eklundh 2000, Törnqvist et al. 2000). Because information communicates knowledge from a sender to a receiver, information has to be represented and structured in such a way that it can be communicated via a medium of choice (paper, database, etc.) and interpreted by the receiver (Lundequist 1995b), i.e. the idea to be communicated has to be extracted. Building upon the data from the example above, information may be (Fig 5.1):

Type of building	Year of construction	Energy use for heating	Environmentally hazardous material
Single-family house	1954	120 kWh/m² x year	1 kg Asbestos

Figure 5.1. Information which can be extracted from the data: A single-family house is a house inhabited by one or two families. The energy use for heating includes energy use for domestic hot water. The average heating energy use for a single-family house constructed in 1954 is about 150-200 kWh/m² x year and floor area. Thus, the house of interest is below this level. Asbestos is used as an insulation material (pipes). It is injurious to human health, classified as environmentally hazardous when existing in loose fibres, and it has been prohibited in new construction in Sweden since 1976. Hence, the data is used to give information on the building's environmental state.

Knowledge is the understanding gained through the discovery, perception and erudition of information (Michener & Brunt 2000). Data, information, and knowledge are not interchangeable concepts and their interconnection may be represented as follows (Fig 5.2):

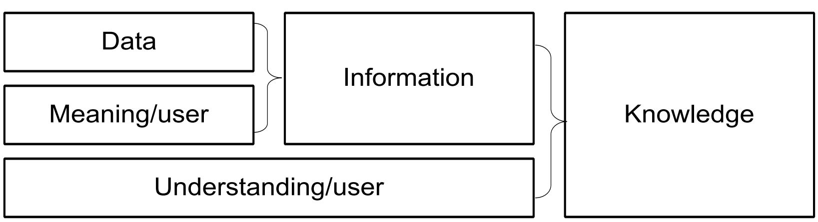


Figure 5.2. Data, information, knowledge and their interconnection.

Data collection, organisation, and maintenance are costly tasks, and usually one is reluctant to perform them for only one data analysis. A possible solution is to construct a database where data can be accessed and analysed several times by several users. However, to avoid designing a data-cemetery, the purpose of the database should be clear.

5.2 Databases and information systems

What is a database and how do other systems, such as information systems, relate to databases? Generally, these systems are important bricks of informatics. Informatics, basically, can be defined as the science of fundamental methodology of information and knowledge processing, its applications and implications (Avouris & Page 1995), thus, informatics studies the use of information technology and how such technology can be designed and applied in an appropriate way.

A database is a set of in some way interconnected data (recorded facts), stored in a structured way in a computer and accessible for processing, retrieval, and sorting. Some implicit properties are that a database represents some aspects of the real world, and it is designed, built, and populated with data for a specific purpose (Elmasri & Navathe 2000). A database system is, on a conceptual level, made up of three different parts: the *actual data*, a *structure* in which data must be organised (logical data modelling), and a collection of software programs called *database management systems* (DBMS), which manages both data and structures in a standard format and provides tools for data input, verification, storage, retrieval, query and manipulation. In short, a DBMS is needed to organise a database and the user interface (Elmasri & Navathe 2000), Fig 5.3.

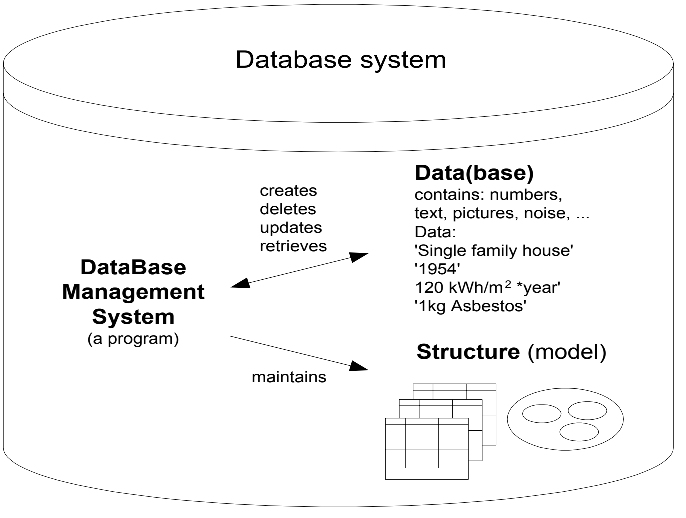


Figure 5.3. Principal parts of a database system and their interconnection.

An *integrated* database contains the data for many users and potentially it can be linked and matched with other databases. The heart of any database system is the data model (Date 1979, Eklundh 2000). Databases provide the user with pre-structured data and tools to access and explore the information content. Databases containing a collection of spatial data and related descriptive data are called geographic databases (ESRI 2002).

Different database technologies based on different modelling paradigms (methods) for structuring data are available: hierarchical, networks, relational and object-oriented structures (refers to logical data modelling). The two last structures are the most commonly applied ones and therefore the fundamental principles of them are described here. On a basic level, a relational database structure is organised in tables. Each table is made up of a number of columns (each describing one attribute) and a number of records, where attribute data is stored for a number of objects. The relation between data is given and data is stored in only one place in the database but can be used by several modules. However, data related to one object, for example one building, may be stored in different tables. In an object-oriented approach a direct correspondence between the real world and the database objects is maintained, an object-oriented approach can represent complex objects (product modelling for buildings, for example). An object-oriented database has the power to specify both the structure of complex objects and the operations that can be applied to these objects. An object typically has two components; state (value) and behaviour (operations) (Elmasri & Navathe 2000). As the modelling in this thesis does not construct or explicitly suggest a model for data structuring, no in depth examination of the technologies will be carried out here, but can be found elsewhere (Elmasri & Navathe 2000, Date 1979).

What, then, is an information system? Information systems may be defined as:

> …constructs that collect, organize, store, process, and display information in all its forms (raw data, interpreted data, knowledge, and expertise) and formats (text, video, and voice). In principle, any record-keeping system – e.g., an address book or a train schedule – may be regarded as an information system. (EB 1994)

An information system, moreover, is to admit, process, store and distribute information that is relevant for an organisation or for society, in such a way that information is accessible and useful for the users. Thus, an *information system is a user-oriented system*, which can, but does not necessarily have to, include the use of computers (Buckingham et al. 1987 in: Svensson et al. 2001).

The terms database system and information system are not used consistently in literature. According to my interpretation (and the use of the terms in the text below) a database and an information system can be distinguished as follows: A database is the data content of an information system and an information system can contain one or more databases. More figuratively speaking, databases represent the "archives" of information systems. A database system exists in electronic form and consists of hardware, software (DBMS), structure and data, while an information system additionally includes the user as a part of the system as well as information processors necessary for linking and co-ordination. My understanding, then, is that a database system in use with possibilities for interaction with the user (for searching, processing, analyzing, and generating extracted information), is an information system. Information systems that mainly store environmental data can be called environmental information systems.

Special types of information systems are Geographic Information Systems (GIS), computerised *information systems* for describing physical properties of the geographical world. A GIS may be defined as an organised collection of computer hardware, software, geographic data and personnel, designed to efficiently capture, store, update, manipulate, analyse and display all forms of geographically referenced information (ESRI 2002). GIS software programmes, such as ArcInfo[32], integrate a special type of DBMS, combining spatial mapping and analytical capabilities with database functions (Michener & Brunt 2000, Elmasri & Navathe 2000). An operational GIS usually includes one or more databases (Eklundh 2000).[33]

A GIS database includes data about the spatial location and shape of geographic features recorded as points, lines, areas, pixels, grid cells, or tins, as well as their attributes (ESRI 2002, Elmasri & Navathe 2000). Thus, geographic data are represented as vector data and/or raster data and include *spatial data* and non-spatial data, *descriptive or attribute* data. Spatial data deal with location, shape, and extension (geometry) and relationships (topology), among geographical features. Attribute data describe the non-spatial properties of objects. For the object 'building' attribute data could be the type of building, the year of construction, the material, or energy use. In addition, data that describe the object in the form of descriptive text, photos, films, drawings and sound, belong to this category (Haagenrud et al. 2000, Eklundh 2000, Elmasri & Navathe 2000, Korhonen 2001). Objects handled in a GIS always have spatial data (geometry) but not necessarily any attribute data other than 'object type' and 'identity'. A data record, which is not assigned to a specific location,

[32] Software developed by ESRI.

[33] A database system, which can only be used for presentations on a map without any possibilities for processing of data or searching of individual objects, is not a GIS (Ott & Swiaczny 2001:127).

can become geographic by adding location, called geo-coding (matching with co-ordinates or addresses).

In a GIS, today, data modelling is often based on relational structured data models (Castle 1998, Ott & Swiaczny 2001). In literature, the reader can find an ongoing discussion regarding advantages and disadvantages of relational data structures in the context of time compared to object-oriented approaches (Ott & Swiaczny 2001, Korhonen 2001). An object-oriented modelling approach, for example, could support flexible classifications for entire objects.

5.3 From reality to a database

The development of an information system involves work in two areas: the infological problem[34] area (dealing with the external properties of an information system, i.e. the 'what' and 'why') and the datalogical area (dealing with information systems' internal properties, the 'how') (Sundgren 1992 in: Svensson et al. 2001). The infological part deals with the properties relevant for applications of the information system and the user of the system. It includes the purpose of the system, functionality and content. The datalogical part deals with the question how to realise the information system (technical, economic, human or personnel, and time related resources) with a focus on technical issues and the construction and implementation of the system (Svensson et al. 2001).

The infological part addresses the extraction of the 'idea'. This important part is also the part I have focused on in my research and which takes up most of the forthcoming pages. However, to get a broader context and to focus more clearly on the "target" (vision), all principal modelling steps towards an information system will be presented.

Our understanding of the real world, and therefore our conceptualising of the real world, depends on our "world-view", our experience, our theoretical knowledge, and last but not least our interest and objective (compare relevance aspect of system modelling Section 4.3). The influences on our world-view are commonly addressed as external models, but often they are undeclared assumptions (Ott & Swiaczny 2001). The research problem handled here in the thesis is naturally influenced by a number of external models, one of them is sustainable development (Chapter 2).

[34] Infology: studies of different ways to represent and transmit information to reach an optimal communication.

Several models for describing the modelling phases exist, more or less detailed, depending on what they focus on. Generally, the modelling stages leading to an applicable physical data model (database) comprise a conceptual model (that captures the idea), a conceptual data model, a logical data model, and finally, the physical data model, i.e. a translation from an infological to a datalogical model. The process is characterised by a decreasing grade of abstraction and an increasing grade of reduction (Fig 5.4).

Conceptualisation aims at giving a formalised description of the real world system. The formalisation should be as clear and unmistakable as possible and should not rely on a specific way of modelling (Ott & Swiaczny 2001). This means that objects, variables, and relations chosen for modelling should be defined as precisely as possible (definition of the components of the model system, the interrelation of the components, and the system boundaries).

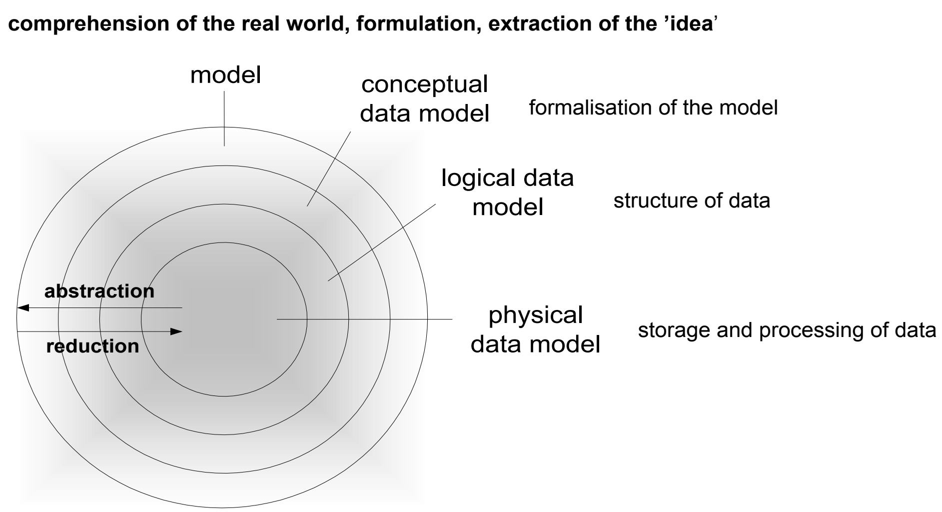


Figure 5.4. Stages of data modelling. Decreasing grade of abstraction and increasing grade of reduction. Modified from (Ott & Swiaczny 2001:24/26).

The initial *conceptual model* defines the objects and the variables to be modelled. Conceptualisation tackles the separation of the level of content and the level of modelling. It deals with modelling meaning, notions, and terms, and it can be addressed as semantic modelling of reality (infological part). A conceptual model can rarely be applied directly in order to store data (Ott & Swiaczny 2001). A conceptual model for the building stock from an environmental perspective, for example, would state that a building, its year of construction, type of use and owner are objects to be included, as well as variables, such as energy use and material use. Consequently, a conceptual model is an abstract representation of the concrete building and its interrelation with the environment. As during this stage of modelling the most important issue is to capture the 'idea', the initial process of conceptualisation should not be started by choosing, for example, a special modelling language, but by extracting the essential features to be modelled. This first stage is crucial for the successful development of a database and an information system (Ott & Swiaczny 2001, Svensson et al. 2001, Elmasri & Navathe 2000).

The *conceptual data model* defines exactly the properties and relations between the objects to be studied. A building has only one location (geographic reference), it may have one or many owners, one or many uses. It may consist of many building elements, which in turn consist of several materials, or, a building element may be a part of the façade. For conceptual data models, formalised modelling languages exist, i.e. a common language, understood by different users and software developers. For the building stock model in focus here, no specific language is suggested, (which is a modification from Thuvander (2000) where the modelling language EXPRESS has been proposed). This disclaimer is based on the fact that there are other modelling languages possibly more appropriate, even though EXPRESS would be a reasonable alternative. The final choice will be made by the experts carrying out this part of the modelling.

The *logical data model* deals with structuring data and is dependent on the modelling paradigm and database technology being used (relational, object oriented, etc.). The choice of database technology depends, among other things, on the applications of the database/ information system.

The *physical data model* (often referred to as a data model) is a conceptual model translated to a form, that can handle electronic or paper-based data. The physical data model describes the data storage in a storage media and includes a database structure, i.e. the logical data model (data types, relationships and data constraints) (Ott & Swiaczny 2001, Elmasri & Navathe 2000).

The way from the real system via the conceptual model to an operational physical data model, the database, should be accompanied by mixed expertise. For conceptualisation, good knowledge about the content of the modelling issues is needed, in the case at hand this would be building stocks and their environmental interrelation. For successful data base construction, competent persons familiar with database modelling are usually involved.

Central notions of a modelling process are object, class, properties and relations. Objects are concrete or abstract entities, in our case, buildings, which can be described by attributes that represent the properties of the object. The properties of an object, which are defined as relevant in a specific context, are called aspects. Of interest here are the environmental aspects of building stocks. An aspect is a specific number of properties and, therefore, it can be considered to be a class of properties (Engdahl 2001).

Attributes can be defined by other attributes, for example 'energy source' can be defined by the attribute 'non-renewable'. Attributes have different orders; 'energy source' is superior in relation to 'non-renewable'. The subordinate attribute 'non-renewable' is the value of the superior attribute 'energy source'. In principal, 'attribute' is a synonym of 'variable'. Because attribute is an established term for formalised modelling, while the focus here is on pre-design and requirement collection, the notion 'variable' is preferred in the subsequent text and for the conceptual model.

A classification system is a system in which objects are grouped into classes based on the properties of an object relevant for a specific purpose. A classification system has no value of its own but is created to be a part of a larger system (for example information systems), which with the help of such a classification system will be more effective (Engdahl 2001).

5.4 Tools for database applications

Databases can be explored using different application tools. The following might be of interest in considering the environmental aspects of building stocks.

Time is important for the modelling problem at hand as described in Chapter 3. In addition, user access with the potential to explore and analyse specific questions is important, as well as the visualisation of results (for better understanding and communication of results - pedagogic value). Thus, databases need to be completed with suitable tools for different applications and analyses. Tools of interest are, for example, *simulation tools, visualisation tools* (maps, graphics, tables, flow charts, etc.), *analysis tools* to answer specific questions, and also *linking* *and matching several databases*, such as other environmental databases (climate data, environmental state data, such as acidification).

Simulation, a classic sequence of system analysis, is, basically, the process of designing a model of the real world system and conducting experiments with the model for the purpose of describing, explaining and predicting the operation of the system (Lundequist 1995a). Basic types of simulation models are conceptual models (flow diagrams on paper or the computer screen for the purpose of organising ideas), or mathematical models (key features of a system are translated into the symbolic logic of mathematical formulas). In general, computer simulation models are mathematical models in which the relevant features of a particular pattern or process are represented by a set of variables (Ott & Swiaczny 2001).

Simulation allows the temporal dimension of a process to be compressed or extended, so that long-term processes or short-term processes can be investigated (Ott & Swiaczny 2001). Models can be used for simulating a course of events and to represent different conditions (Lundequist 1995a). By simulating, i.e. experimenting with the model, one can understand what is happening. Simulation is important for applications of the building stock information system, for example, when carrying out scenarios or describing a building stock from different premises (composition, structure or environmental impact). If a number of buildings in northern Göteborg are demolished x tonnes of concrete and y meters of PCB will have to be taken care of . How should this be handled? Or, a certain amount of energy will be used annually for heating blocks of flats. How much? What happens if I change the initial conditions? (see questions, Chapter 9).

Further, a user wants to get easy access to the data content and the information in a database. Visualisation of data is one approach. Data can be visualised in the shape of maps, graphics, tables, flow charts, etc. Hereby, a building's spatial connection (a building can be allocated to a specific place) and some of the environmental data's spatial connection will be of special interest. Thus, besides a pure illustration of attributes, a spatial distribution can be included in the visualisation process. The basic purposes of visualisation can be summarised as follows: to *present* (spatial) information (Where is …? What belongs together?), to *analyse* a set of data, for example, by overlays to understand interrelations (What is the best site?), or just to *explore* huge amounts of raw data.

6. TOWARDS ENVIRONMENTAL INFORMATICS FOR BUILDING STOCKS

Departing from the previous chapters, Chapter 6 illustrates concepts specifically related to environmental issues, such as environmental informatics and environmental data. At the end of the chapter, the puzzle becomes complete: criteria on and elements of an Environmental Building Stock Information System for Sustainable Development model - EBSIS^{SD} are formulated.

6.1 What is Environmental Informatics?

Environmental Informatics is a branch of Applied Informatics (Avouris & Page 1995, Le Duc 1996). Applied Informatics, in turn, is the branch of Informatics which bridges the gap between information technology and its various application fields. E*nvironmental informatics* (EI) may be defined as a branch of Applied Informatics concerning the study and development of adequate techniques for effective collection, storage, retrieval and processing of complex *environmental data* (Avouris & Page 1995:ix). EI combines informatics topics, such as database systems, geographic information systems, modelling and simulation, computer

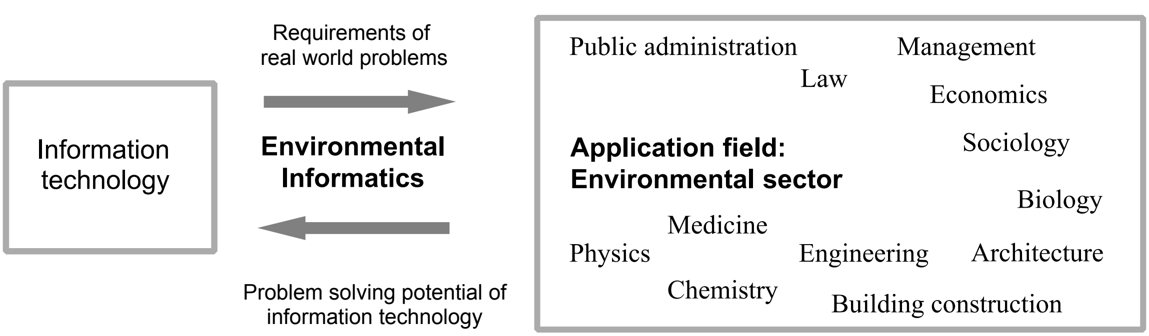


Figure 6.1. Environmental Informatics supports an interdisciplinary field of Information Technology applications. Adapted after (Hilty et al. 1995:3).

graphics, user interface design, etc., with respect to their *application to environmental problems* (Hilty et al. 1995). Briefly, EI involves information technology development and its adaptation to environmental work.

A major concern of EI, besides ordinary processing of environmental measurement data, is *handling vague, uncertain and often incomplete data and knowledge* (Avouris & Page 1995). My understanding is that this vagueness, in a broad sense, is a matter of context and character, where and how environmental problems are handled. I see the contextual vagueness as a result of the heterogeneity of the environmental sector as an application field, or better, a combination of several application fields (Fig 6.1). The different users within different fields (scientific and non-scientific) have different needs for environmental information, which unavoidably will result in different interpretations.

Vagueness in terms of the type of character of environmental problems is a result of the multi-dimensionality of different effects on the environment (see for example Fig 3.6, high order, respectively, low order effects and perception issues) and a heterogeneous focus (parts of the cause – impact – effect chain, or scale – substance, artefact, or global issues) within the environmental sector.

Further, the environmental problems to be handled are often ill-defined, or issues of interest are still relatively new and, therefore, neither adequate knowledge is available nor relevant data are collected to address the aspects of interest (see, for example, Chapter 2). To tackle the problems, knowledge, methods and data from different disciplines have to be put together, so a wide flora of different data sources must be used. These sources are usually non-homogenous sources, containing, for example, text data, measurement data, statistical data, or research-result data. Even the scale of data collection may differ as data is often collected by a large number of scientists, from different disciplines under the auspices of projects that have diverse objectives (Michener et al. 1994). This often results in a number of problems, as data may have a 'wrong' or incomplete level of aggregation (property instead of building, data not linked to activities such as refurbishment, demolition, etc.), a 'wrong' focus point (kWh instead of energy source or CO_2, no material issues), 'wrong' kind of description (static instead of time referencing descriptions). It may also be difficult to interpret existing data if no information on the data itself is available (what exactly is addressed by the data, how has it been collected, and when it is/was valid).

In this sense, EI functions as a catalyst for integrating data and information (Avouris & Page 1995); *data*, i.e. overcoming heterogeneity caused by a variety of operating database systems, data formats, documentation, program interfaces, software tools, and *information*, i.e. enabling data to be interpreted meaningfully in different disciplinary contexts (architecture, building material science, geography, chemistry, etc.).

For a better understanding of how data and information can be integrated, it is necessary to be aware of the characteristics of environmental data and metadata.

6.2 Environmental data

Environmental data, here, are defined as data used to describe the natural environment and its interaction with artefacts. Environmental data often have a spatial dimension and are possibly geographically coded, so that data can be attached to a particular point or region in space.

As follows from the discussion in the previous section, environmental data are complex and heterogeneous and, consequently, can be divided into several types, such as according to different data sources used (text data on environmental laws, or compilation of research project data, measurement data from, for example, monitoring networks, or structural data on chemical substances) or the different data formats to be integrated. The focus here is on a more general level, to describe environmental data as a type of relation to the environment and environmental facts. From this point of view, environmental data can be divided into:

- Resource use data,
- Emission data,
- Environmental state data.

Resource use data comprise all data that describe inflows, outflows and deposits of the resources material, water and energy, or data in some way related to these. Material flow data, for example, show the amount of virgin resources used, how much material is recycled or re-used, how much material is accumulated in society or buildings, and how much is given back to nature. Problems caused by large, unwanted, or wrongly handled flows of substances and materials, can be described, see also Section 3.5 for building and building stock related examples. Resource use data are the kinds of data an information system that describes the environmental aspects of building stock should focus on, as summarised in Table 3.1.

Emission data are data that describe the release of particles, pollutants, gases, etc. to air, water and land, as well as noise, heat, vibration, light and radiation from a specific source. They belong to the outflows. Emission data for the built environment describe emissions that can be related in some way to buildings and building stocks.

Environmental state data are data which describe, for example, air quality data (air pollution measurements) or meteorological data for a geographically limited region, and, in turn, describe the background pollution levels. Environmental state data, then, are data regarding attributes, which have an impact on the built environment (see also Section 3.3). These data do not necessarily need to be a part of a building stock database but can be linked to a building stock database as external databases. For example, there are databases with geographic data for VOC (Volatile Organic Compounds)[35], SO_x (Sulphur oxides)[36]; NO_x (Nitrogen oxides)[37], CO (Carbon monoxide)[38], Fig 6.2.[39]

Thus, to obtain an overall picture of a building stock's interrelation with the environment, many kinds of the environmental data, resource use data, emission data and environmental state data should be used for the description, although not necessarily in one database. Environmental state data are not specifically connected to buildings, as resource use data and emission data are indeed.

[35] The environmental impact of VOCs is principally related to their contribution to global warming and to the production of ground level or lower atmosphere ozone (emissions from petrol-fuelled vehicles, evaporation of solvents used in paints).
[36] Sulphur dioxide emissions are the most important reason for acidification (combustion of fossil fuels for heating and electricity, conversion of wood pulp to paper).
[37] Nitrogen dioxide is a strong oxidizing agent that reacts in the air to form corrosive nitric acid. It also plays a major role in the atmospheric reactions that produce ground-level ozone or smog (traffic-related pollutant produced during burning of fuel).
[38] CO is produced when fuels containing carbon are burnt where there is a deficiency of oxygen. In the presence of an adequate supply of O_2 most carbon monoxide produced during combustion is immediately oxidised to CO_2. The major source of atmospheric carbon monoxide is road transports. Minor contributions come from processes involving the combustion of organic matter, for example, waste incineration.
http://www.doc.mmu.ac.uk/aric/eae/Air_Quality/Older/Carbon_Monoxide.html
[39] Homepage of SMED (co-operation of SCB, SMHI, IVL):
http://www.smed.miljodata.nu.

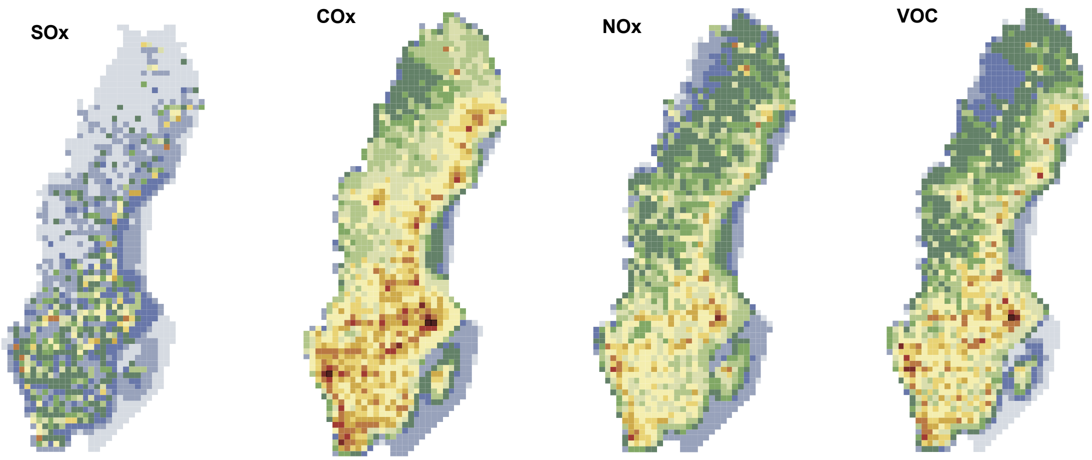


Figure 6.2. External environmental state data are available for Sweden, for example, for CO, VOC, SOx, and NOx in the co-ordinate system RT90 (see also footnotes 36-39).

For modelling building stocks I have chosen the approach *environmental data, i.e. data that* describe flows and deposits of resources, such as energy, water and material. Material includes both natural resources and products – processed, recycled, reused or raw material – used for construction and maintenance, built-in material, waste material, wastewater, etc., the generation of emissions to air, water, ground/land. Note that emissions related to energy generation are not always generated at the same place where energy is used. Noise, heat, vibrations, light, and radiation are not included. Further, data of land-use are of interest in relation to buildings and in a broader sense in relation to green structures and traffic structures. Figure 6.3 illustrates some building and building stock relevant environmental data for different aggregations.

6.3 Metadata

Few data sets, whether written in a notebook or stored in a database, are perfect or self-explanatory. Thus, when using data, one has to rely on documentation to understand a specific data set. This is where the concept 'metadata' comes in, which is significant in the context of EI. The concept has not explicitly been developed for EI, however, but within informatics. Nevertheless, as metadata play an important role in EI, I will discuss metadata below.

What exactly are metadata? *Metadata* are commonly defined as "data about data", i.e. it is a kind of dictionary containing data descriptors that define the scope of the data. Metadata, essentially, give the information

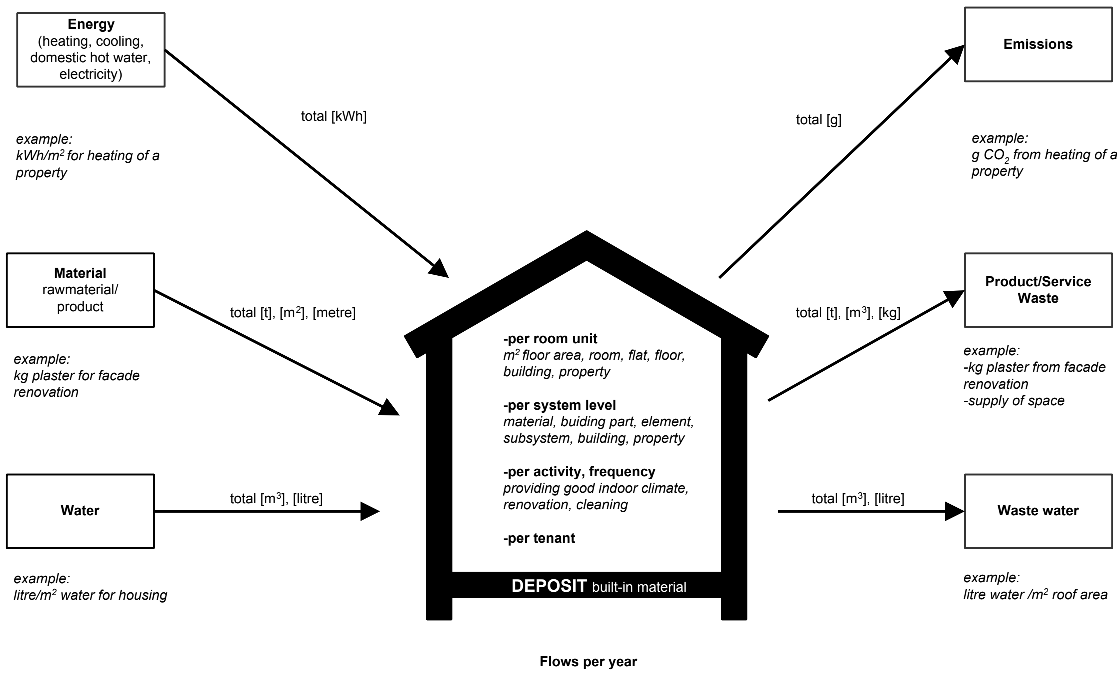


Figure 6.3. Example of environmental data for building stocks (Thuvander & Brunklaus 2002).

necessary to understand and use a particular data set, including documentation of the data set contents, context, quality, structure and accessibility. According to Michener (2000), metadata descriptors attempt to answer five basic questions when a specific data set is used (Fig 6.4). Accordingly, metadata do not describe environmental facts, but give a description of the contents of information sources, what information is available where, how data are technically accessible, and which access methods are available (Page 1995). Metadata are usually a part of an information system. Standards have been developed or are under development for several kinds of data.

Metadata for all geographic data (as many of environmental data are) include, for example, thematic connections (buildings or environmental state data), names of the different data (building/quarter, VOC), geographical region (Sweden, Göteborg) and extension (latitude, longitude), details about the co-ordinate system, reference system, comprehensive descriptions of the thematic content, origin of data, meaning of attributes, and so on (Eklundh 2000).

Benefits of metadata are that data entropy, i.e. the degradation of

Figure 6.4. Metadata descriptors attempt to answer five basic questions when a person wants to use a specific data set (Michener 2000:101):

1. What relevant data exist?
2. Why were those data collected and are they suitable for a particular use?
3. How can these data be obtained?
4. How are the data organised and structured?
5. What additional information is available that would facilitate data use and interpretation?

the information content associated with data, is delayed, and a data set's longevity is increased (Michener 2000). Metadata also help to make statements about data quality and suitability to purpose (Thuvander & Thormark 2002).

As for the investigation of environmental problems, sharing data across agencies, regions and scales is necessary and data from various sources and disciplines should be possible to integrate, the reuse of data is a significant issue. Maintaining metadata archives is a premise for this to be done effectively.

Examples of aspects a metadata archive for an environmental building stock database should include are (based on Thuvander & Brunklaus (2002)):

Metadata

- time perspective on available data (measurement period)
- kind of measurement and access of data (direct or indirect, requency)
- documentation system (data capture possibilities)
- type of data: qualitative or quantitative data (occurrence or amounts)
- periods for use of certain materials
- system boundaries
- environmental state data
- comments

Another example of metadata for a building stock database is a metadata archive concerning the use of materials. Such metadata could, for example, contain information on the use and non-use of a number of materials and substances, such as 'asbestos forbidden in Sweden since 1976'. For an environmental building stock database, environmental state data should not only be regarded as an external database and an additional tool, but also as a metadata database (buildings are recipients of emissions).

All together, in environmental informatics better data documentation is needed than in traditional informatics, including more comprehensive metadata archives, which increase the accessibility and sharing of high-quality, well-maintained and understandable data (Michener et al. 1994, Michener & Brunt 2000). Metadata are important for the judgement of data quality and the relevance to purpose (data capture), and are necessary when comparing data, as system boundaries may differ (Thuvander & Thormark 2002).

Metadata also increase the transparency of a system, which fulfils communicative interests. The availability of metadata is also an indicator of data control. Metadata put demands on the documentation and the reporting format of the data to be collected.

6.4 Environmental Building Stock Information System^{SD}

The theoretic elements of environmental informatics seem to be highly relevant to modelling building stocks from an environmental point of view and these elements can provide guidance for future modelling.

From the discussion so far, we can state, that a database containing environmental data on buildings as the part of an information system is asked for. Such an information system (model system) might be used to support environmental improvements of building stocks (real system) towards sustainable development. Therefore, I have named the model ENVIRONMENTAL BUILDING STOCK INFORMATION SYSTEM FOR SUSTAINABLE DEVELOPMENT, in short, EBSIS^{SD}. The next step is to extract and summarise demands and criteria for development of an EBSIS^{SD}.[40]

Such a model has to emphasise building-related *environmental issues*. Here, the use of resources, material and energy-use, have been chosen as primary aspects. Even water use is included. Materials should be considered in terms of amounts and types of material deposited in the stock and in terms of flows. Energy use is to be considered in terms of energy used during the operation time of the building (Chapter 3).

Modelling a building's environmental aspects demands a model that takes into account *changes* in the stock *over time* (see Chapter 3); i.e. a dynamic model is needed. Longer time series of data are needed to identify changes (improvements, deterioration) and the speed of transformation. For this reason, it can be advantageous to develop a system of descriptions. By a system of descriptions, I mean that a basic building stock information system structure exists, which can be expanded with more data and detailed descriptions time after time in line with actual needs for knowledge.

Dynamic modelling may be interpreted in different ways: the questions to be answered change, the content of the model change, the

[40] Some of the demands have already been explained in Chaptet 3 and are summarised in Table 3.1. These aspects are briefly explained in the text but re-occur in Table 6.1 to give a complete picture of all demands and criteria on an EBSIS^{SD}.

model can be revised and extended, a dynamic course of events can be modelled or the whole lifecycle of buildings is included.

The *spatial aspects* of buildings should be included as they make it possible to consider buildings and their environmental aspects/impacts in different spatial contexts on different spatial levels.

A *basic data set* of information should be established to describe the Swedish building stock as a whole and in a general way, including the number of buildings, the year of construction, the year of refurbishment, the use of the building, the gross floor area, etc. It should be *possible to update* this data set after a certain time period.

A further demand on the model is that it should have an *open structure*, which allows *extensions* to be made according to needs, to add up-to-date knowledge or modified regulations. Extensions should also be possible by means of the addition of other data modules that model other parts of reality than the built environment (green structure, traffic structure and water structure). Thus, it should be an *integrated* data model. External databases should be possible to link and match to EBSIS^{SD} (environmental state data, population statistics, energy statistics, etc.) and different kinds of tools (for analysing, visualisation and simulation) should be feasible to add.

Different users should be addressed (nation-wide) for an efficient utilisation of the database content and communicative interests. Distribution of EBSIS^{SD} via networks could support this, as well as easy data delivery. Many users require the possibility of different views of the database content and easy, but possibly restricted, access. Also, an information system with nation-wide coverage should be based on an established format (use a 'language' established among many actors).

An additional basic demand is that the model should possess a *pedagogic value* not primary as a teaching media but as a foundation for knowledge generation. A *transparent structure* is desirable as it supports efficient use and straightforward interpretation of results. A transparent structure is important in order to make underlying assumptions clear and, in that way, enable a clear understanding of how the results have been gained and to facilitate control of the uncertainties. As many researchers emphasise the importance of metadata, the need for data management, and the involvement of different types of scientists in the data management process (Avouris & Page 1995, Michener et al. 1994, Michener & Brunt 2000, Thuvander & Thormark 2002, Ott & Swiaczny

2001, Eklundh 2000). These aspects will be an important ingredient when constructing the $EBSIS^{SD}$.

As buildings are considered to be systems, a systems approach to modelling would be advantageous (see Chapter 4), including recursive modelling and a top-down and bottom-up approach.

Chapter 5 explains structures of a database system, i.e. the logical data model (with a focus on relational structures and object-oriented structures). However, as I work on the conceptual level, it is not necessary (and not recommended) to get locked for one specific database structure. Nevertheless, for further development of the $EBSIS^{SD}$ it would be advantageous to investigate possibilities for object-oriented modelling which is an established way of studying buildings in the building sector.

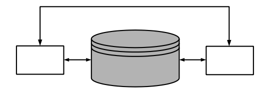
Basic demands on and criteria for the $EBSIS^{SD}$ are summarised and listed in Table 6.1.

Table 6.1. Basic demands on the data model.

Basic demands	**Criteria**
Built environment	Buildings and building stocks
Environmental issues	Use of material, energy, water: input-output flows and deposits
Time aspect, follow changes	Time-integrative, dynamic model, including all phases of a building's life-cycle
Spatial aspects	Include location of buildings (support local, regional, global (national) level)
Different users, pedagogic value, communicative	Transparent structure, easy data delivery and use
Transparent structure	Metadata
Systems approach, recursive modelling	Top-down – bottom-up approach
Extensions are possible (tools, modules)	Open structure, integrated model
Possible to update (additional tools)	Basic data set

PART III

Exposition of Existing Approaches and their Relevance



7. EXISTING APPROACHES TO HANDLING BUILDING-RELATED ENVIRONMENTAL DATA

After having defined a number of basic demands on the EBSIS^{SD}, a look at established "skeletons" for handling building-related and/or environmental data is called for. Do approaches already exist that fulfil the demands and criteria outlined in the previous chapter? Guided by this thought, Chapter 7 discusses their suitability for modelling buildings, environmental aspects, for handling time, data structures and spatial issues.

7.1 BSAB

What is BSAB?

BSAB is a common classification system for buildings established by the Swedish construction industry. It is relevant to building stock descriptions from an environmental point of view as it offers a basic frame for structuring building-related information.

The BSAB 96 system (BSAB stands for the Swedish construction industry classification system[41], 96 – the most recent one) addresses both the building and management process and supports effective communication throughout the sector. As described in Section 5.3, a classification system has no value of its own but is designed for being a part of a larger system (for example, an information system), which with the help of such a classification system will be more effective.

BSAB 96 supports IT use and is intended to be built into different applications. The Swedish Building Centre[42], which maintains the

[41] In Swedish: Byggandets Samordning AB. Nowadays, only the acronym is used.
[42] In Swedish: Svensk Byggtjänst. Construction and Real Estate Sector's Company for Information and "Know-how".

BSAB system, therefore, supplies the system in electronic form (BSAB 1998). Several other national systems, such as the AMA[43] system (general material and implementation descriptions), Sektionsfakta (supports the calculation of costs), or REPAB[44] (a company that has developed computer software for property management) use the BSAB system as a common structure.

Modelling and applications of the classification system

The BSAB system builds upon a systemic view and has a hierarchic structure. The system consists of co-operating tables, each expressing a special aspect of a building, Fig 7.1 shows an example. The system organises the different parts of buildings and constructions in a way suitable for different applications, such as, building product models, CAD, descriptions, drawings, cost estimates, etc. In addition, the system is neutral in order to suit different projects and companies.

Figure 7.1. Example of a classification table from the BSAB system.

- 0 SAMMANSATTA BYGGDELAR OCH INSTALLATIONSSYSTEM
  - 01 SAMMANSATTA BYGGDELAR
    - 01.S Sammansatta byggdelar i hus
      - 01.SB Innerväggar, sammansatta
      - 01.SC Ytterväggar, sammansatta
      - 01.SF Bjälklag, sammansatta
      - …
- 1 UNDERGRUND, UNDERBYGGNAD, SKYDDANDE LAGER I MARK, GRUNDKONSTRUKTIONER OCH STÖDKONSTRUKTIONER
  - 13 LAGER I MARK FÖR SKYDD AV BYGGNADSVERK
  - 15 GRUNDKONSTRUKTIONER
- 2 BÄRVERK
  - 20 SAMMANSATTA BÄRVERK
  - 27 BÄRVERK I HUSSTOMME
    - 27.A Sammansatta bärverk i husstomme
    - 27.B Stominnerväggar
    - 27.C Stomytterväggar
    - …
- 4 RUMSBILDANDE BYGGDELAR, HUSKOMPLETTERINGAR, YTSKIKT OCH RUMSKOMPLETTERINGAR
  - 40 SAMMANSATTA RUMSBILDANDE BYGGDELAR, HUSKOMPLETTERINGAR, YTSKIKT OCH RUMSKOMPLETTERINGAR
  - 41 KLIMATSKILJANDE DELAR OCH KOMPLETTERINGAR I YTTERTAK OCH YTTERBJÄLKLAG
    - 41.C Ytterklimatskärmar i yttertak och ytterbjälklag
  - 42 KLIMATSKILJANDE DELAR OCH KOMPLETTERINGAR I YTTERVÄGG

[43] AMA stands for 'Allmän Material- och Arbetsbeskrivning'.

[44] REPAB stands for 'Rolf Eriksson Produktionsplanering AB', http://www.repab.se/.

In Sweden, research in improved classification systems in the building sector is being conducted with a branch programme for implementing IT in building construction and management, called IT Construction & Real Estate 2002[5]. It aims to further develop BSAB, especially by creating better information co-operation in the construction and management processes with a focus on the user phase. The real world is described using process models, activity models[6], and product models (object-oriented models) – all of these models are under development. One of the projects specifically deals with the classification of buildings and spaces based on a system theoretic foundation (Häggström et al. 2000). Additional research projects concern property management information (FI 2002)[7]. Additional reading to obtain an overall picture is found in (Bergenudd et al. 2000, Sandström et al. 2000, Svensson et al. 2001, Svensson et al. 2000a, Svensson et al. 2000b, Yngve et al. 2000a, Yngve et al. 2000b, Törnqvist et al. 2000).

Relevance for EBSIS^{SD}

The BSAB classification system is an established and standardised 'language' for structuring building-related data. BSAB offers all prerequisites for nation-wide coverage by EBSIS^{SD}. The needs of different users can be supported (BSAB is adaptable).

BSAB and the above mentioned research programmes deal with building informatics, i.e. structuring and processing building-related information. Environmental issues are not in focus, but are indirectly addressed via energy issues, maintenance, etc. Location factors are included in the models developed within the research programme. The BSAB system is advantageous for bottom-up modelling. However, it remains to be investigated in what way its structures function in modelling larger building stocks (appropriate level of detail, co-ordination). EBSIS^{SD} might be seen as complementary to the models developed in the research programme presented in Svensson et al. (2001).

Time is not an aspect explicitly addressed in the classification system but time can be taken into account for different phases of a building's lifetime. BSAB is based on a systemic view and the classification structure offers different levels of detail (resolution).

---

[45] In Swedish: IT Bygg & Fastighet 2002. Homepage: http://www.itbof.com/.

[46] In Swedish: Verksamhetsmodeller.

[47] Swedish project title: Förvaltningsinformation 2002.

All together, the BSAB classification system seems to be a natural part of EBSIS^{SD} for structuring building-related data.

7.2 SPINE

What is SPINE?

There are information systems specifically developed to handle environmental data as opposed to the BSAB system, which structures building-related data. One example of such an environmental information system is SPINE (Sustainable Production Information Network for the Environment)[48], a computer-based integrated environmental information model that facilitates the collection and review of LCA (Life Cycle Assessment) related environmental data in order to support environmental management (Steen et al. 1995).

LCA methodology focuses on three systems: the technical system (TS), the environmental system (ES), and the social system (SS). As the systems are not hierarchically ordered but on the same level, SPINE models the information needs for analysing the three systems and their mutual relations (Fig 7.2). TS contains information about operation units, process units and aggregated systems. Typical TS issues are allocation[49], system boundary settings, data quality aspects and other inventory-related metadata. ES concerns information about the environmental state and environmental changes caused by environmental loads. Typical ES issues are environmental categorisation, environmental sensitivity and cause-effect chains. SS concerns information about weighting different environmental changes (to each other) and the control/evaluation of technical systems. Typical SS issues are valuation methods, value choices expressed in terms of numerical weights and other background data on how different value choices have been interpreted (Carlson & Pålsson 1998).

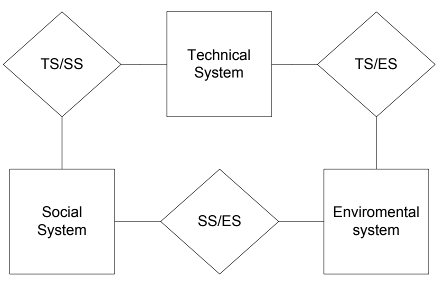


Figure 7.2. SPINE's major concerns are the technical system, the environmental system, the social system and their mutual relations. After Carlson & Pålsson (1998).

[48] Released in 1996. SPINE is managed at the Department of industrial environmental informatics at Chalmers University of Technology. Check also http://www.globalspine.com (accessed August 2002).
[49] Allocation: to assign something to somebody/something or to designate something.

About SPINE modelling

SPINE is a data model of an information system that includes a relational database structure (logical data model), where data is stored as text. Central concepts of SPINE are *activity* and *flow*, Fig 7.3. Activities are, for example, the production of building materials, construction and the erection of a building, transports, or management of buildings. An activity has inputs and outputs (flows of material and energy). In SPINE, any TS is an activity, even if they are aggregates of other activities in the database.

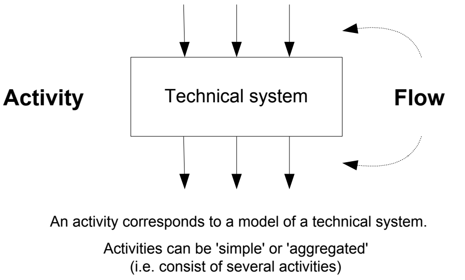


Figure 7.3. Activities and flows are basic concepts in SPINE (Steen et al. 1995, Pålsson 1999).

SPINE is built on a systemic view. Each TS is considered as a system (machine, transportation system, cradle-to-gate production system, etc.). SPINE allows for the recursive storage of TS, which means that aggregated data can be stored with full transparency and with no loss of information. The activity on the higher level has the role of a system and the other the role of a subsystem. A data set in the database is free, which means that it is not related to any specific study. Any data set stored in SPINE can be used and re-used in many different studies, Fig 7.4 (Steen et al. 1995).

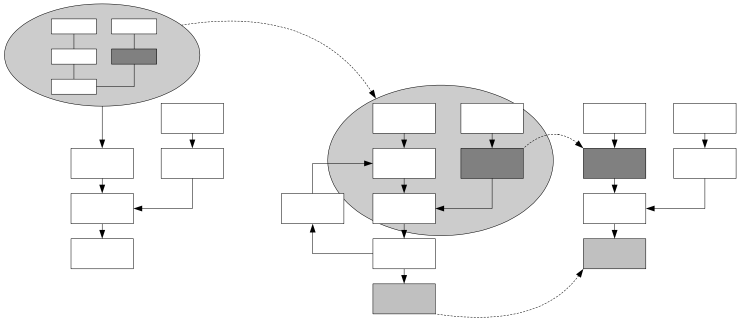


Figure 7.4. Re-use of technical systems. Specific inventories that make use of general data vs old inventory of general interest (CPM 2001).

The SPINE model also hosts an efficient metadata base for producing analyses and assessments of good quality. Data quality is based on reliability, accessibility and relevance (Fig 7.5). Thus, SPINE is based on a flexible and fully transparent documentation structure and modularity. It facilitates communication between different systems (exchange of data) and is open towards other systems and disciplines.

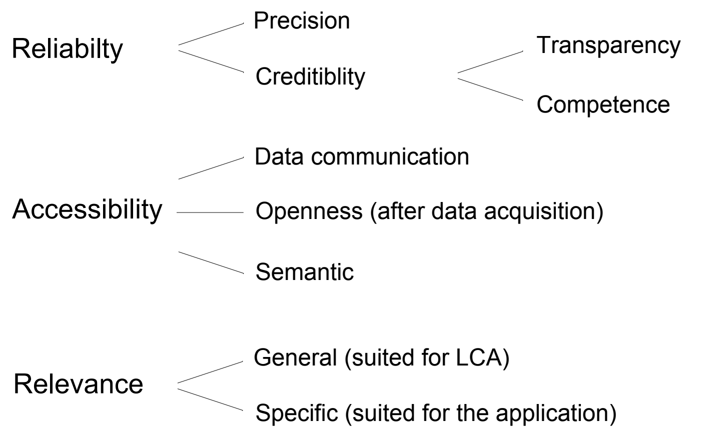


Figure 7.5. Dimensions on data quality, metadata. After Pålsson (1999)

SPINE has been developed in an interdisciplinary manner. Stable management (maintenance, administration, quality control) of a database is an important issue. Meanwhile, new data sets are added, mainly supplied by users of the data. For example, companies supply data in return for other favours, such as education.

Relevance for EBSIS^{SD}

Some lessons learnt are that there are gaps between SPINE and EBSIS^{SD} but also similarities. SPINE has been developed to handle large amounts of environmental data, it is an established database structure in industry, flows are included, and modifications and extensions of the data model are possible. It is/has an effective high-quality metadata archive. Some disadvantages are that deposits are not handled, only a little data on building-related materials and processes are stored so far, and data are not specifically structured according to building-related processes. In SPINE, activities are in focus, and in the building stock information system even objects (buildings) are important. Thus, SPINE meets some of the demands on a building stock model (Section 6.4) and seems to function for modelling building-related processes, such as property management, construction and demolition processes.

As mentioned, SPINE manages flows of resources, but not deposits. A matter of interest here is when deposits become a flow, as this will differ depending on the time perspective that is adopted. Building stock studies need to apply long-term perspectives due to a building's comparably long lifetime and a description of both resource flows and resource deposits (built-in materials) is essential (Section 3.2). However, according to CPM (2000), SPINE also contains a structure that can be developed to store the composition or content of a product or material. Thus, SPINE could possibly be modified to include resource deposits (storage).

SPINE is prepared for handling spatial data, but, to date, geographical information is handled as complementary information and regards flows on a very general level. SPINE is based on a systems approach and is recursive upwards.

7.3 GIS

Environmental GIS for buildings

GIS has already been defined as an information system capable of handling geographically referenced information (Section 5.2), with software programs including a DBMS able to manage geographical data. The question is in what way a GIS could contribute to modelling buildings' environmental aspects (basic demands Table 6.1).

Usually, GIS is used for the presentation, documentation and analysis of spatial data. Applications are for cartography, digital terrain modelling, geographic objects applications, for planning issues, technical distribution systems, properties, environmental care, etc. (Andersson 2001). However, the use of GIS in the building sector, including property management, is so far modest (Andersson 2001, Brunklaus & Thuvander 2002b), despite buildings' unique geographic identity (which is constant over time) and that they have a spatial extension, geometry, form and height. For example, it is possible to handle building data, such as floor space and building-related environmental data, such as energy use.

In addition, external environmental data, such as sensitivity to acidification, background concentrations are attribute data[50] that have a spatial connection.

GIS is advantageous for the visualisation and analysis of spatial data and it allows for the combination of different data sets (Decker 2000). The visualisation of the spatial distribution of a phenomenon may not only give answers to specific questions but may also provide further aids for identifying new questions and may help transfer knowledge (Le Duc & Sivertun 1994). Thus, GIS can also be defined as an analytical

[50] See Section 5.2 for an explanation of attribute data.

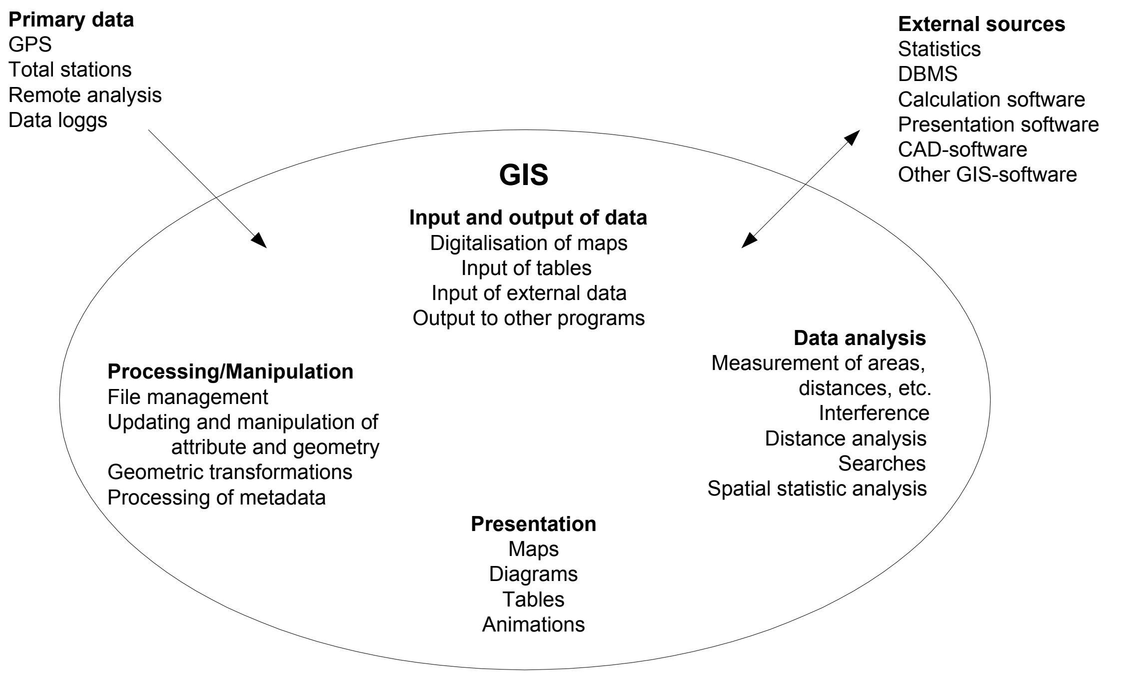


Figure 7.6. The most common functions of a GIS, modified figure (Eklundh 2000:24).

and visualisation tool that supports communication, understanding and seeing relationships otherwise hard to see. The most common functions of GIS are presented in Fig 7.6.

Time in GIS

As I'm interested in time, I've also examined GIS from the time perspective. Time adds process to pattern and a time-integrative (dynamic) GIS, in turn, may be defined as an attempt to store and analyse spatial objects and changes in their attributes over time. Three kinds of data must be processed in a temporal GIS: spatial, temporal and attribute data. Together these data represent the attributes of an object located at a certain position at a certain time (Ott & Swiaczny 2001). The main purpose of a time-integrative GIS is to reproduce temporal processes or sequences of events of the real world in a model, to make them accessible for spatial query, analysis and visualisation.

The information processed in the GIS may exhibit zero, one, two, or three spatial dimensions, either zero or one temporal dimension (data may or may not have a temporal component), and dimensions of measurements of attributes may be numerical (I/R)[51] or categorical (N/O)[52], Fig 7.7. Temporal information may also be a part of attribute data (Ott & Swiaczny 2001) as:

- a point in time of an event occurring (year of construction),
- a period of time related to events (validity of a building code),
- an attribute value at a single time section (energy use for year 2000),
- an attribute value at consecutive time sections (time slices/time series: built in material or energy use for heating 1990, 1995 and 2000),
- changes during a period of time or between two time sections.

A frequently used approach for conceptualising time is to incorporate time information by time-stamping single layers, attributes and spatial objects (Ott & Swiaczny 2001).

Relevance for EBSIS^{SD}

GIS is advantageous for data analysis, data generation, documentation, and visualisation, and, thus, it could function as an additional tool to EBSIS^{SD}. In accordance with Section 5.2, an operational GIS can link and match databases, i.e. it has the potential to serve as a 'meeting place' for several databases, for example, environmental state databases, statistical databases, and an EBSIS^{SD} database.

GIS manages a geographic connection between spatial, attribute, and, to some extent, temporal data. As buildings and building stocks have a geographic connection (for example, the building co-ordinates for a centric point in the Swedish building register) and environmental data can be related to a building, it seems reasonable to establish a building stock information system linkable to GIS.

In GIS (as in SPINE), large amounts of data can be handled and analysed, which is essential for building stock modelling that addresses environmental issues (a large number of objects and attributes). It is

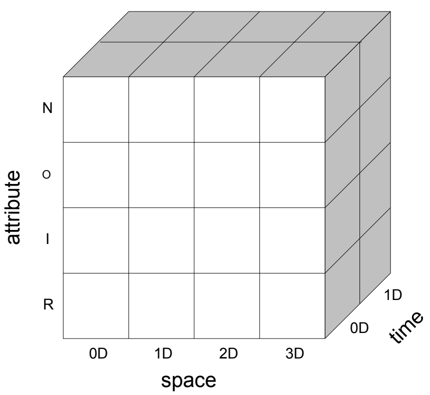


Figure 7.7. A multidimensional cube of space, time and attribute (adopted from (Ott & Swiaczny 2001:4).

[51] Interval/Ratio. *Interval*: a set of real numbers between two numbers, values of numbers give a rank, differences between different values can be measured. *Ratio:* same as interval, but an absolute zero point is added.

[52] Nominal/Ordinal. *Nominal:* (measurement) values are possible to allocate to categories. *Ordinal:* (measurement) values have a specified order or rank in a series.

easiest to carry out applications of resource deposits for a certain time layer or time-stamped attributes. It should be possible to address a time perspective (resource flows for the maintenance and operation of buildings and transformation of stocks). However, the lack of consistent and accurate graphic and attribute data with geographic reference may discourage the use of GIS.

In general, GIS applications deal with bottom-up data, i.e. individual objects that have certain attributes allocated to a specific place. From these objects, statistics can be generated and the objects can be analysed in GIS. The other way round, applying statistical data is not that easy as statistics do not have any spatial reference. Nevertheless, if statistical data is available divided into classes (use of building, year of construction, owner), those data can be related to data similarly classified in GIS. It is easy to classify data and visualise patterns in GIS for classes of objects. By utilizing these properties it should also be possible to allocate top-down data.

As an additional tool for EBSIS^{SD} the analytic capacities of GIS can be used for input data generation in an EBSIS^{SD} database.

7.4 Application-potentials to an EBSIS^{SD}

The three systems presented (BSAB, SPINE, and GIS) are quite different in their character (classification system for buildings, computer based environmental information model, geographic information system) but in some way each could be suitable for a building stock information system, complementing each other, having advantages and disadvantages in relation to an EBSIS^{SD} (Table 7.1).

Table 7.1. Comparison of BSAB, SPINE, and GIS and evaluation of their relevance and suitability for an EBSIS^{SD}.

	BSAB	**SPINE**	**GIS**
Buildings	ok	possible	possible
Environmental data	implicit	ok	possible
Time	add lifetimes	flows	possible
Spatial aspects	To some extent	Possible on an aggregated level (not always relevant)	ok
IS, DB, Tool, …	Classification system for buildings, possible structure for an information system	Operational datamodel of an information system, including DBMS	Information system, DBMS, data generation tool, analysis tool, visualisation tool

BSAB is an established classification system for buildings within the Swedish building sector and it is actually developed and modified to suit international standards. SPINE is a database structure, containing/possible to store sufficiently documented environmental data and metadata. GIS are geographic information systems, with software programs including a special type of DBMS that combines spatial mapping and analytical capabilities with database functions.

BSAB can structure all building related information. SPINE has been developed within the field of environmental informatics to specifically handle environmental data. Its strength is that it can handle flows, data for activities such as construction of a building or parts of a building, cleaning of floor space, etc. GIS' speciality is to handle all kind of data with a geographic relation, i.e. a supplementary dimension of environmental data. A combination of all three structures could meet many of the demands of $EBSIS^{SD}$.

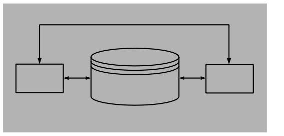
For $EBSIS^{SD}$ the most important aspects are to address building related environmental issues (BSAB, SPINE). Including spatial aspects gives an added value with a potential for data generation for an $EBSIS^{SD}$ and additional analyses (GIS). SPINE can be linked to a GIS if spatial connections of the flows is given and/or it can be linked to a specific type of building (point, region).

Time aspects can be addressed in the BSAB by adding, for example, time spans or lifetimes for elements (as in REPABs software). SPINE handles flows. GIS can handle time in different ways and time series can be carried out.

BSAB has a hierarchic structure and is applied in building product models, where all information about one building is stored from the very beginning (object oriented modelling). SPINE is built on a relational logical database structure and GIS software programs normally handle relational structures, some of the programs can be modified to handle a kind of object-oriented structure. Thus, when combining these structures, a data modelling problem may occur. To solve this potential problem is not the scope of the thesis but it is worth mentioning.

Data in the database structures will be complex and one cannot overview the data content or the analysis results easily. Additional tools for visualisation, especially of a spatial resolution, may help to see relations. Therefore a GIS implementation is advantageous.

In conclusion, building related information should be structured according to BSAB. Also SPINE and GIS seem to have potentials to be applied for EBSIS^{SD}, and, EBSIS^{SD} seem to offer a possibility to enlarge the scope of existing structures such as the addition of a further dimension to SPINE and extending applications of GIS.



8. THE BUILDING STOCK RESEARCH FIELD

So far, no database structure or information system has been found that 'perfectly' suits the demands of EBSIS^{SD}. As a complement to the previous Chapter, this Chapter takes a look at modelling efforts outside Sweden that examine how similar issues regarding building stocks have been handled. Chapter 8 presents and discusses a number of chosen projects relative to the modelling demands listed in Table 6.1. In what way do the projects solve relevant problems, what are the advantages/ shortcomings and what can we learn from them?

> One of the unique challenges of building large system simulations, such as the model of an urban region, is that their boundaries, scope, or definition are ill-defined and, undoubtedly, will evolve considerably over time. (Kraines et al. 2001:37)

8.1 Introduction

All over the world projects are underway to increase the knowledge about existing building stocks in terms of environmental issues and towards sustainable development. The approaches for doing so differ and the following examples have been chosen to illustrate a span of ongoing research regarding:

- Complexity (simple models, more complex models)
- Area of study (resource use, energy/emission calculations, material flows, social aspects, etc.)
- Scale (type and scope of building stocks, i.e. a limited number of buildings, urban building stock, national building stock, as well as system boundaries and spatial limits)
- Classification and representation of buildings.

Data collection is an important part of the modelling process, thus, an even closer look at that issue is included. Further, user aspects are considered as well as descriptions of environmental impact, tools, database systems, modelling approaches and time. The focus and scope of the projects differ, and therefore my reflections on each project will treat different aspects.

A compilation of a number of studies regarding larger building stocks and environmental issues (mainly on the national level) can be found in Thuvander (2000). These studies are not further discussed in the text here, except for the German study, but they are included in the summary in Table 8.2. Kohler & Hassler (2002) give a general exposition of approaches to study building stocks in their article the building stock as a research object.

Before going into detail, I would like to begin by mentioning a general approach of interest, namely urban metabolism studies, which are sometimes referred to as environmental rating approaches not based on an explicit physical model of the development of urban artefacts. In these studies, all flows in and out of a geographically limited area are included, not only those specific to the built environment. However, the building stock related flows are usually a distinguishable part of the overall flows.

> Energy and material flows through human settlements are conceived as urban metabolism, in which material inputs are transformed into useful energy, physical structure, and waste. Decker in (Kohler 2002:135)

Attempts to study the urban development from transdisciplinary approaches can be found in Baccini & Oswald (1999) and Baccini (1997) and operational tools for such urban metabolism studies have been developed. Examples are given in Kohler (2002). An example of a limited model of that kind is the *Quantifiable City model*, a transport model developed in the UK, that addresses the issues of transport, land use, and population (May et al. 1997)[53]. The project is a part of the BEQUEST[54] network.

[53] http://www.its.leeds.ac.uk/tec/appraisal.html.

[54] BEQUEST is a pan-European network. The acronym stands for Building Environmental Quality Evaluation for Sustainability through time. Further reading in Deakin et al.(2002), Hamilton et al. (2002) and Kohler (2002).

8.2 Mass, energy and monetary flows in the German building stock

On behalf of a committee of the German parliament, a study of mass, energy and monetary flows in the German building stock was carried out (Schwaiger et al. 1997, Kohler et al. 1999) at *Institut für Industrielle Bauproduktion*, Karlsruhe. The objective of the study was to quantify the development, to identify steering variables and to identify instruments that can be applied to achieve desired changes. The following aspects were considered:

- annual material input and amounts of waste material
- annual energy use
- emissions to air
- material deposits in the stock
- composition, areas and development of the building stock
- costs for new construction, maintenance and use of the buildings.

Because of the long lifetime of buildings and the complexity and interference of flows, the long-term dynamics of the stock had to be demonstrated. As a result, an integrated and dynamic building stock model (including the whole building stock) was developed. The dynamic model is capable of demonstrating historic changes, and it can be used to simulate foreseeable and possible future developments as regards mass flows, emissions, energy use and costs (Schwaiger et al. 1997, Kohler et al. 1999).

The investigation is built upon two approaches: a macro-economic approach (top-down) for calculating the overall flows and a process-oriented approach (bottom-up) for detailed flows created by new construction, refurbishment, demolition and utilisation of buildings (Schwaiger et al. 1997, Kohler et al. 1999). The top-down approach records the material and energy flows and the related emissions to air for a reference year (1991). Buildings, but not other constructions, are considered. Material flows, energy use and emissions are taken from public statistics. Even indirect emissions, material and energy use (so-called Rucksack) are included. From the bottom-up approach, material flows, energy flows, emissions and costs are calculated on the building level. In principle, this approach incorporates a *static model and a dynamic model*. The static part models the composition of the stock. The dynamic model is a combination of stochastic modelling of the lifetime

Figure 8.1. Age-use matrix applied in the German study of mass, energy and monetary flows in the building stock (Kohler et al. 1999).

Age classes
- Pre 1870
- 1871-1918
- 1919-1948
- 1949-1965
- 1966-1978
- 1979-1990

Use classes
- Single family houses
- Terrace houses
- Small multi-family houses
- Large multi-family houses
- High-rise buildings
- Offices & administrative buildings
- Institutional buildings
- Hotels & restaurants
- Commercial buildings & storehouses
- Factories & workshops
- Agricultural buildings
- Other non-domestic buildings

of building elements (periodic replacement) and a maintenance and refurbishment strategy (replacement of buildings) (Klingele et al. 1997). From this approach, flows initiated by different measures are calculated, for example, from detailed process chain analysis of buildings, via building elements, building material construction, etc. Besides quantitative results, also qualitative statements are formulated about when and which measures initiate flows (new construction, renovation and demolition). In the bottom-up model, about 160 reference buildings, 2 250 building elements and 700 building materials are described in such a detailed way (Kohler et al. 1999). Mainly drawings and building-related documents were used for the description.

Top-down and bottom-up approaches were combined. Building stock data were aggregated on a national level and have been represented by m^2 floor space in an age-use matrix (6 age and 12 use classes), Fig 8.1. Top-down data were allocated proportionally to the floor space in the age-use matrix and bottom-up data were scaled to fit the matrix. The combination of the two approaches has many advantages but also some limitations. From the top-down approach it is difficult to define limits between buildings and other built constructions, and therefore uncertainties occur about the amount of mineral building materials used. From the bottom-up approach it is difficult to model the whole stock beginning with the reference objects. A principal methodological problem was to define limits between the private and the public sector. Despite this, the combination of the two approaches is valued as a forthcoming method (Kohler et al. 1999).

Reflections: The study focuses on environmental issues related to building stocks on the national level. As environmental aspects include the resources material and energy from a flow and deposit perspective, the model addresses aspects that should be included in EBSIS^{SD}. Beyond this, emissions are included and allocated to impact categories. Even emissions and energy-use related to the production of materials are included (Rucksack) in the model. This will not be the case in an EBSIS^{SD}, at least not for the description of the composition of the stock. A time perspective is addressed in several ways in the German model, i.e. a life-cycle perspective of buildings and the transformation of building stocks over time, simulations of future scenarios and flows. Thus, most of the issues of interest for an EBSIS^{SD} are in fact addressed.

Modelling the stock from a top-down and bottom-up approach and the combination of these approaches via a matrix is an appealing approach, as intervals indicating where the resource-use figures can probably be identified. Data for the bottom-up approach are mainly collected from documents and less from surveys or site visits. For an EBSIS^{SD} a combination of several sources is appealing. The German study concerns the national building stock and does not use GIS. Thus, a spatial dimension, beyond the national one, is not included.

8.3 Energy and Environmental Prediction model, UK

The Energy and Environmental Prediction model (EEP model), under development at Cardiff University[55] since 1994, is a computer-based information system that is capable of quantifying energy use and associated emissions for different activity sectors and spatial areas within cities. It establishes a baseline for energy consumption and helps in predicting future levels of energy use (Jones et al. 2000)[56]. Thus, the EEP model is mainly used as a prediction tool, but it also acts as a database for environmental survey data. It includes calculation and visualisation tools and it is implemented in a PC environment with a GIS (software program MapInfo). The model is functional within local authorities, and co-operation between local authorities and industry is aimed at (Jones et al. 2000).

The EEP model incorporates a number of submodels: *Domestic energy use*, *Non-domestic energy use*, *Industrial energy use*, and *Traffic flow energy use*, Fig 8.2. A Health submodel is currently under development. Every submodel includes a procedure for predicting energy use, based on existing energy calculation procedures accepted by the UK government. The procedure for domestic buildings is the most advanced one, where calculations are based on information about construction, surfaces, installations, etc. The procedure for non-domestic buildings uses activity-related energy ratings. The road network is represented and analysed with the spatial analysis procedures[57] method for the calculation of traffic-related emissions (Jones et al. 2000).

---

[55] Cardiff University, Department of City and Regional Planning, research is being carried out in four large research groups, Environment, Spatial Analysis, Housing and the Built Environment, Urban and Regional Governance.

[56] See also http://www.cf.ac.uk/archi/research/eep/index.html (accessed May 2002).

[57] Spatial analysis is a collective name given to a set of computer-based spatial modelling techniques used to represent, quantify, and analyse space on several levels within the built environment. The model includes the concept of integration (Jones et al. 2000:866).

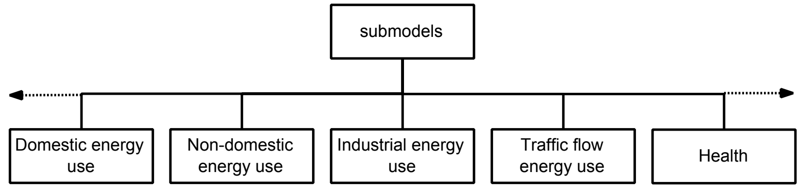


Figure 8.2. Principal components of the EEP model framework: a number of submodels to be used independently (Jones et al. 2000).

Buildings are classified in different ways. The domestic submodel classification is based on construction type and age resulting in 100 types (Fig 8.3), which the surveyed buildings are assigned to. The age-classes are based on changes that have taken place in building regulations and changes in material use. Non-domestic buildings (buildings providing a service to the public but do not use energy to manufacture a product) are surveyed individually and they are divided into 48 categories (Fig 8.4). For industrial buildings (buildings using energy for the production of goods), 16 processes were identified, as for example, iron and steel, brick, glass and glassware, chemicals, vehicle manufacture (Jones et al. 2000).

Cluster analysis of built form based on
- heated ground area
- façade area
- window to wall ratio
- exposed end area

=20 clusters

Divided into five age classes
- Pre-1919
- 1919-44
- 1945-64
- 1965-80
- post-1980

= 100 clusters

Figure 8.3. Examples of clusters for domestic buildings (Jones et al. 2000).

Data for the EEP model were collected from a variety of sources including maps, historical records, local authorities' information, and site visits (external inspections), but not from drawings. For the domestic submodel, data were collected for more than 25 000 buildings mainly by site visits (estimations of number and height of storeys, window area, and number of chimneys) and from a digital ordnance survey map (built form, exposed end area, storey area, and façade type). Variables, such as window areas, height, number of rooms, or year of construction were based upon estimations. Moreover, energy calculations were also based upon a number of estimations (installation systems, such as heating systems, fans, etc. and constructions). For the collection of process energy data, industry was contacted. Rating and energy calculation procedures had to be translated into a computer model. No digital (attribute) data were available for properties.

Catering
Entertainment
Factories and warehouses
Higher education
Health care
Hotels
Museums, libraries and churches
Post offices, banks and agencies
Prisons and emergency buildings
Schools
Shops and stores
Sport and recreation
Offices

Figure 8.4. Example of classes of the non-domestic submodel (Jones et al. 2000).

GIS is used for visualisation, calculation, and analysis. In MapInfo, heated ground floor area is calculated by measuring the extension of the building on the map. In the same manner, façade areas (exposed end area) are calculated. The roof area is estimated as being equivalent to the floor area. Further, built forms are identified on the maps (detached, semidetached). The results are presented spatially on a city-wide scale. Additionally, pinpointing 'hotspots' in smaller areas is possible as data are collected and calculated on a building level. Representations are possible on a property level, a postcode level, for a certain type of property, a selected property cluster or an entire region. Results are produced graphically in the form of thematic maps (total energy use, energy ratings, CO_2 emissions from all buildings or one/several submodel/s, etc.).

Reflections: Energy issues, as handled in the EEP model, are of interest for EBSIS^{SD} modelling. However, the energy calculation tools used are based on specific UK procedures, which cannot simply be transferred to Swedish conditions. Material aspects are considered indirectly (assumptions of constructions) but not explicitly from a resource or an environmental perspective (no material accounting). Location is included, thus, a spatial dimension is included.

GIS is used for analysis, data generation, data storage (database), linking sub-models, and visualisation. Data generation from GIS-based maps seems principally to be an effective approach for automated data collection, which is even better than in the EEP model if appropriate attribute data for properties or buildings are available. The postcode level as a representation level is possible also elsewhere, but it is not advantageous when including a time perspective as postcode areas are not really constant over time, changes may occur due to postal areas merging or splitting. Time aspects in the EEP are addressed in the sense of planning and prediction, i.e. simulations can be carried out for potential energy and emission reductions.

Even if the model is built on several assumptions, it seems to be better to start with a simplified model, which can be improved, rather than having no information at all. The EEP model has been elaborated and is used in co-operation with local authorities.

8.4 Tokyo Greenhouse Gas Half, Japan

The Tokyo Greenhouse Gas Half Project, carried out within the Alliance for Global Sustainability (AGS)[58], seeks technological measures to reduce greenhouse gas emissions (GHG) from Tokyo by half. These measures include reduction technologies, as well as a structural modification of urban settings in Tokyo. Topics dealt with are urban heat island effects, energy efficient building design, district heating and cooling,

[58] AGS is a co-operative venture involving research teams from four universities: the Swiss Federal Institute of Technology Zürich, the Massachusetts Institute of Technology, the University of Tokyo and Chalmers University of Technology. Check also http://www.global-alliance.org/.

car performance and emissions, traffic flow models, and demand site management.

A software prototype called DOME (Distributed Object-based Modelling Environment)[59] is used as a platform for relating and integrating heterogeneous computational models that use a wide variety of application tools, databases and process simulation tools over the Internet. In a broader sense, DOME is applied in order to co-ordinate research from different fields and to evaluate alternative options for a more sustainable urban development (Kraines et al. 2001).

Additionally, two types of tools are used, regional definition tools and process simulation tools. The *regional definition tools* provide services based on databases that characterise the urban region under consideration, in this case Tokyo. Models for the representation of the characteristics are, among others, spatial distribution of land use, circulation of airborne pollutants and heat, electric power utility structure, information on travelling habits for traffic flow generation, and industrial material flows expressed in an input-output table. *Process simulation tools* are calculation tools that make use of the services of the regional definition tools to simulate the behaviour of technology and the consequences of policy alternatives.

1 Public offices
2 Education and culture
3 Health service facilities
4 Utilities
5 Office buildings
6 Commercial buildings
7 Combined shops and residence
8 Hotels and amusement
9 Sports and recreation
10 Houses
11 Apartments
12 Factories and workshops
13 Combined workshops and residence
14 Warehouses and transport facilities
15 Outdoor facilities and planned buildings
16 Parks
17 Unused residential land
18 Roads
19 Railroads and harbours
20 Agriculture and fisheries
21 Rice fields
22 Agricultural fields
23 Orchards
24 Grazing pastures
25 Rivers and channels
26 Fields
27 Forests
28 Other

Figure 8.5. Land use types in the GIS-based land use aggregator database for Tokyo (Kraines et al. 2001). Fifteen of the land-use type are building types, such as public offices, health service facilities, hotels, apartments. Other types include roads, railroads, parks, outdoor facilities.

A working example of the prototype is a feasibility study of using rooftop photovoltaic (PV) modules for electric power generation. The prototype involves tools for calculating irradiation profiles, assessment of the rooftop area available for mounting PV modules, Life Cycle Inventory (LCI) and input-output tables of the material requirements for manufacturing the modules, and other positive effects of generating power using PV modules.

The land use aggregator (one of the regional definition tools) compiles data on different types of land use from a GIS-based Tokyo database, maintained by the Bureau of Urban Planning, Tokyo Metropolitan Government. The database contains geographic data on the total ground area occupied by a given type of land use (all together 28 types, Fig 8.5), the total area of all building floors, and the number of units for each of the land use types (Kraines et al. 2001). Data are analysed and presented graphically on a map in a raster GIS comprising grids of about 250 m.

The rooftop area available for PV installations is calculated from the ground floor area multiplied by a coefficient depending on roof type

[59] Initially developed as a platform for the car industry.

(inclination). The floor area is also used for estimating energy use and for determining the densities of different building types.

For calculating total CO_2 emissions, an input-output based analysis is applied. This permits the inclusion of emissions from sectors inside and outside of the city of Tokyo. Data represent 250 sectors (out of 500), that have been aggregated to 27 sectors, among them agriculture and fishery, textiles, construction, real estate, and transports (Kraines et al. 2001), Table 8.1.

Object	Inputs	Outputs
Land use generator	Region of Tokyo	Total planar ground area
	Building types used	Total building floor area
	Fraction-of-use coefficients	Total number of buildings
Input-output analysis model	Material consumption	Change in industrial outputs
	Unit material costs	Change in total CO_2 emissions

Table 8.1. Example of tools, input data and generated output data (data generation) in the Tokyo Greenhouse Gas Half project (Kraines et al. 2001).

Two scenarios (simulations) have been carried out within the project, a partial installation scenario of PV modules and a full installation scenario on all the rooftops of all types of buildings in Tokyo.

Reflections: Environmental issues, such as emissions of GHG on an urban level are addressed, with the built environment as part of the overall modelling. In the feasibility study, energy aspects are elucidated from several points of views (LCI, structural and economical aspects) but few material issues (the PV study includes materials used for manufacture and, consequently, potential built-in material from PV modules).

In the rooftop study, data are to a large extent taken from existing (spatial) databases and to some extent from industry (LCI). The benefits of GIS-based databases have been utilised for the generation of basic data sets, such as floor and rooftop area or number of units. Energy use figures for buildings are based on rough estimates only (with floor area as the starting point). Time is included in the form of simulations of scenarios as well as in the input-output analyses (flows).

A spatial dimension is included. Results are represented on geographic grids as totals and building-related figures are distinguished by land use types without further classification (age). This geographic matrix is probably not detailed enough for a building stock information system but it is an interesting complement to the matrices that include age, use, or built form classes.

The Tokyo project is quite complex. Several databases, process simulations and calculation tools communicate via the DOME platform, which is attractive as many users can utilise the same data and application tools for different purposes. The implementation of EBSIS^{SD} in such a platform is appealing but it would be a later step in the development process.

8.5 Urban-architectonic design and energy use, Argentina

In Argentina, case studies have been carried out aimed at qualifying and quantifying factors related to the urban-architectonic design, that influence the energy use of the residential sector associated with location and geographical distribution. The variables studied are related to family structure, living habits[60] in the dwellings, use of lighting and electric devices, inhabitants' perception (greater or less comfort), building characteristics and energy sources, as well as income levels. The methods for data collection range from random sample survey (site visits at about 162 dwellings out of 1 500), and energy calculations (5 types of dwellings represent about 5 000 dwellings).

GIS is used in the studies for the representation of localisation and spatial distribution of aspects that have an impact on the energy use in residential buildings and are related to urban-architectonic design. A geo-referenced database has been constructed that contains relational tables for energy use, measurements, surveys, parcelling, etc. The results are presented per property in an AutoCAD Map and in GIS (software ArcView) that address the annual range of energy use (kWh), the number of dwellings (different colours representing different energy intervals) and spatial distribution (Blasco Lucas et al. 2000). The knowledge gained from the studies is used for the improvement of resource efficiency.

Reflections: In this study, energy issues in connection with activities inside the buildings are in focus. Material issues are of interest for the calculation of energy use but not for resource economic reasons. The way living habits and buildings' performance is tied together is interesting.

[60] Similar studies including living habits are carried out in Switzerland, however, I have chosen to describe the Argentina case to show that research is carried out at many places all over the world.

Even though this is not my focus it may still be a potential aspect to keep in mind for future development. A time perspective is not included. On the other hand, a spatial dimension is included.

8.6 Degradation studies of the built environment, Norway

To widen the perspective a bit more, a project describing environmental aspects, such as climate and air pollution and the resulting impact on building materials exposed to the climate, is presented. In relation to $EBSIS^{SD}$ it should be interpreted as an example of an external, complementary model.

The modelling issues deal with the degradation of the building stock and conducting cost-benefit analyses (costs from/without pollution). A module (tool) for material and cost calculations has been developed and implemented in PC and GIS (software program ArcView) environment. Various geographical scales have been modelled based on dose-response functions, lifetime equations, and resulting costs for maintenance, repair and replacement. For regions with existing air pollution information in a geographical grid system, calculations of the corrosion rates and the lifetime of materials can be obtained from these grids. If knowledge about the amount of materials exists as well, the total material loss can be calculated and translated into capital terms (Haagenrud et al. 2000).

Oslo has been used as a test example. There, the corrosion and cost assessment has been mapped on two levels representing the years 1985 and 1993. On level 1, environmental degradation factors (NO_2, SO_2, O_3, etc.) have been modelled and corrosion maps have been produced for weathering steel, zinc, aluminium, copper and bronze. The maps show the exposure environment and the stock of materials and buildings at risk by integrating an information layer from the Norwegian building register (location, number of different building types, such as single family houses, hotels, and offices), with the environmental characteristics of the grid. Level 2 mapping deals with the assessment of corrosion costs for each grid. The cost assessment is based on a material distribution factor, environmental dependent service life, and maintenance intervals. This part also includes information on building type and statistical amounts of materials (not real buildings) linked to the building type (Haagenrud et al. 2000).

The knowledge about materials' exposure to climate and their degradation helps improve methods, such as the prediction of service life.

Reflections: The project gives inspiration for how an external environmental database could be applied, for example, by showing how acid rain causes corrosion and degradation of a building stock. In these studies, built-in materials exposed to the environment are dealt with, but not materials inside buildings and not energy issues.

A time perspective is addressed, as two different slices of time have been investigated. Also, the term 'degradation' in itself embodies a time perspective, as well as the prediction of service life of materials. Both a description of the state of materials exposed to the environment and simulation of changes, i.e. degradation, are covered.

A spatial dimension is included, and GIS is used for analysis, visualisation, and data storage. For example, the exposure environment is visualised on corrosion maps within the grids. The buildings (location and type of building) have been obtained from the Norwegian building register.

8.7 Lessons learnt

Table 8.2 compiles *examples* of building stock studies carried out in Sweden and internationally, highlighting some of the modelling problems of the thesis. The studies represent different approaches in the context of building stock descriptions. Even studies discussed in Thuvander (2000) are included.

The first observation is the diversity of ongoing activities to increase knowledge about the existing building stock – world-wide. Studies cover a wide range of aspects and models differ in terms of their complexity, because they serve different purposes, covering almost everything from comprehensive building stock studies to degradation studies of a few buildings. The spatial levels and the part of the stock addressed, as well as the quality of input data, and aspects taken into consideration differ, as shown in Table 8.2.

Table 8.2. Examples of building stock studies carried out in Sweden and internationally that focus in some way on the modelling problem of this thesis: environment, data handling, and time aspects. Extended and modified table from (Thuvander 2000:50).

Study/ country	Investigated stock/spatial dimension	Aspects considered	Methods for data collection, analysis	Time
Several building stock studies/Sweden (summarising description in Stendel (2000b))	Whole Swedish building stock/parts of the stock	Mostly energy use, to a limited extent material flows, built-in materials, economic aspects	Mostly random sample surveys, site visits, conglomerates	Material flows
Degradation studies/ Norway (Haagenrud et al. 2000)	Different geographical levels (grids)	Degradation and corrosion of building materials (focus wood) due to climate exposure, costs	Inspection and condition assessment of buildings	Prediction of service life of building materials
Mass, energy and monetary flows/ Germany (Schwaiger et al. 1997, Klingele et al. 1997, Kohler et al. 1999)	Whole German building stock	Mass and energy deposits and flows, costs, emissions (LCA)	Investigation of reference buildings, allocated to building elements and materials	Dynamic model of the behaviour of stocks, resource flows, scenarios/ simulations
Mortality and resource flows/New Zealand (Johnstone 1994, Johnstone 2000a, Johnstone 2000b)	Domestic stock in New Zealand	Mortality, economy, mass and energy flows	Population dynamics	Resource flows
NDBS database/ UK (Steadman 1997, Bruhns 2000, Brown et al. 2000, Holtier et al. 2000, Mortimer et al. 2000, Penman 2000, Steadman & Bruhns 2000)	Non-domestic stock, a certain sector in four towns	Energy use and emissions, built forms	Site visits and survey of buildings, visualisation and analyses in a GIS	
EEP model/UK (Jones, et al. 2000, Jones et al. 1997)	Whole building stock on an urban level	Energy use and emissions (extension to health aspects and surroundings)	Site visits, digital ordnance survey map, visualisation and some analysis in a GIS	Prediction and planning, up-dating of energy rating possible
Tokyo half/Japan (Kraines et al. 2001)	Urban level, all kinds of buildings	Energy use and emissions	Calculations in GIS	Scenarios (structural changes, technical solutions)
Design and energy/ Argentina (Blasco Lucas et al. 2000)	Domestic buildings on an urban level	Energy use in an urban-architectonic context, activities (family structure, habits, income level)	Survey, site visits of a number of buildings, questionnaire	-

Environmental aspects

Models that handle both energy and material data are interesting for the development of EBSIS^{SD}, as these models potentially have database structures to 'borrow'. Moreover, the scope of the environmental aspects addressed is of interest for comparison with the intention of EBSIS^{SD}, i.e. the description of kind and amount of resources used, with the addition of related emissions (which means energy sources must be known), including impact assessment, etc.

In most of the studies (German study, EEP model, Tokyo half, Argentina, see also Table 8.2), energy flows, energy related emissions, and potential for change are addressed for the use phase of buildings. The German study includes energy used for the production of materials and an assessment of emissions. Material issues not related to energy issues are scarce both as regards flows and deposits: Tokyo half adapts a material flow perspective for PV module production and the degradation study includes building material from a deposit perspective and the impact side (only façade materials). A comprehensive material flow perspective for existing buildings is only addressed in the Germany study and the New Zealand study, Table 8.2 and Thuvander (2000).

Modelling issues

Concepts are not bound to a specific country or an integrating platform, such as DOME, or additional tools for calculations, analysis, and presentation. However, national models differ because of different data sources and structures available in the different countries.

One such concept is the top-down and bottom-up approach, used in the German study, which seems to be suitable for EBSIS^{SD} as it supports a systems view and has good control of the system (intervals). However, the German database structure is not directly applicable to Swedish conditions for the reasons mentioned above. Furthermore, a spatial dimension is not included

The survey of the different projects has shown that GIS databases have several advantages. An operational GIS handles spatial information, and is, if appropriate data (base) are available, a very powerful tool for analysing data, not only for visualisations or data storage, but also for statistics or calculations (Tokyo half, Degradation model, to some degree EEP model). Also, basic data for building stock descriptions, such as floor areas, building volumes, etc., can be generated in GIS. The material resource side has not been explored very much in GIS, but it should be possible to demonstrate the spatial distribution of environmentally hazardous materials built into the stock and to deal with other material issues.

Finally, some comments on the research "environments" of the examples studied and on user aspects: All of the above are interdisciplinary projects in that integrated models are elaborated, the researchers involved in the development of the models come from different disciplines, and data is collected from many sources. Further, not only researchers, as in the EEP case, but also the commissioners/users are involved, as the models have been elaborated in close co-operation with local authorities.

Data and data collection

Data collection issues of the projects presented above, including their problems, may support the data collection issues of $EBSIS^{SD}$, which would prevent mistakes and give ideas about where to find data.

Since the studies vary in level of detail and starting conditions, data collection and data storage problems vary considerably. In some of the studies above, a number of databases already existed (Tokyo half, Degradation studies), which can be linked and matched together. Others (the EEP model, the German study) had to start with comprehensive data collection for individual buildings from a number of sources and develop database structures and/or additional tools for calculations (EEP). This will also be the case for $EBSIS^{SD}$. The challenge is to obtain measured data (or estimated/calculated data of good quality) and data for a large number of buildings in an efficient way. The German top-down and bottom-up approach seems to be a useful method for approaching data capture and getting initial results. Consequently, a considerable number of buildings will have to be surveyed in detail to obtain bottom-up data.

Matrix

Age, use, and built form are the most common aspects used for the classification of buildings. To some extent, use-classes indirectly address the built form (high-rise buildings and large multi-family houses). In the Toyo half project as well as in the Degradation study, another division has been chosen, namely geographic grids that contain land use types and building types for use, respectively. This division is interesting as it adds a spatial dimension to the first mentioned classifications. The EEP model offers more classes (based on cluster analysis) than the German age-use matrix. However, cluster classifications are based on calculations of collected data, the age-use matrix, on the contrary, can be made up before data are gathered, which facilitates getting started.

For EBSIS^{SD}, it would be suitable to apply an age-use matrix (which has a certain tradition in Sweden, see (Stendel 2000b)) combined with a geographic grid representation, as this method provides a clear spatial connection.

Time

Time issues are included in several ways in the studies presented. A lifecycle perspective of buildings (the German study) or part of buildings (the energy system PV modules) is addressed, and thus make it possible to model the long-term dynamics of the stock. Another time perspective is the planning horizon and simulations of several development scenarios (more or less all studies), changes in the building stock between time slices (Degradation study), or, short-term perspective of resource flows over a limited time period. The German approach, in particular, is inspiring for EBSIS^{SD}, as it includes a description of the long-term dynamics of building stocks in addition to resource flows.

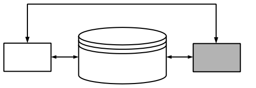
Conclusion

From the studies presented above, I have learnt the following:

- A variety of applicable models exists.
- Data collection is crucial and access to good quality data might be limited.
- A model with adaptations to regional and local conditions for maximal benefit (space-place) is possible.
- The German model may serve as a basis and a complement to the Swedish tradition of building stock descriptions.
- A combination of top-down and bottom-up approaches is advantageous.
- An age-use matrix combined with a geographic matrix (preferably grids) adds a further dimension.
- Investigations of individual (reference) buildings are needed.
- Static and dynamic descriptions of reference buildings are important.
- A long-term perspective includes a lifecycle horizon.
- GIS is a powerful tool and it should be used for analysis and visualisation, implying that all data must have a spatial reference in the database.
- An interdisciplinary approach is necessary.

PART IV

Proposal of a Conceptual Model



9. USE(R) ASPECTS

Use(r) aspects have been a crucial part of my work, but they have also meant a lot of trouble. As for all projects that deal with modelling the real world and developing information systems, use(r) aspects are important, among others, for implementation reasons. The project was initiated with no specific client in mind, but with a general intention of supplying the building industry and the research community with information on environmental issues of building stocks. Influence from outside the research world was limited, and an analysis of earlier building stock studies carried out in Sweden has shown that the use of the results in a broader context greatly depends on the client and the user (Stendel 2000b). When a building stock study addressed a specific task the results were often narrow (a description of energy saving potential (Hammarsten 1980) or an investigation of damages and costs for measures (Tolstoy & Svennerstedt 1984)), or when no specific user was addressed the results were broad and not deep enough to answer detailed questions (a survey of building stocks for knowledge generation (Wilhelmsen 1987, Lindgren 1991)). Learning from that, the needs of the potential users have to influence the construction of EBSIS^{SD}, specifically to guide the choice of variables. Also, it is important to identify potential users and institutions, which can possibly take over EBSIS^{SD} after a prototype has been developed.

The chapter 'Use(r) aspects' is based on literature studies, interviews, and discussions with several actors in the building sector, both on the national level and on a more regional level, actors in Göteborg municipality, and researchers. Questions explored are:

- Is there a (future) need for a building stock information system that addresses environmental aspects? By whom?
- What exactly are the needs and is it possible to meet them?

9.1 Potential users

National level

On the *national level* I found several actors of interest, such as the Swedish National Board of Housing and Planning[61], the Swedish Environmental Protection Agency[62], and branch organisations, such as the Ecocycle Council for the Swedish Building Sector[63] (BYKR).

BYKR, a network of representatives from the whole building sector (building proprietors, property managers, architects, technical consulting companies, the building industry, and the building material industry), acts to co-ordinate the growing environmental interests of the sector and is a strong driving force behind the development of a sustainable eco-cycle society. BYKR's primary task is to function as the building sector's contact organisation with authorities, primarily with the Swedish Ministry of the Environment. Among others, BYKR has carried out a survey to identify environmental problems related to the building sector and, based on this, developed a plan of action (BYKR 2001). Thus, BYKR needs supporting knowledge to strengthen its environmental work.

Boverket is a national authority for housing and planning and urban development. It works on behalf of the Swedish government with the commission to support good everyday life in a sustainable society. Boverket is generally interested in amounts of resources used, such as volumes of built-in material and material passing in and out of the existing stock that have an environmental impact to varying extents. Also, Boverket is interested in floor space areas, technical solutions for energy supply, and indicators, such as, for energy use, wastewater and waste material. As an authority, Boverket has an interest in the distribution of environmentally hazardous materials. Such knowledge is valuable, for example when estimating amounts of released environmentally hazardous materials from demolition. Besides dividing the stock into domestic and non-domestic buildings, it would be interesting for Boverket to divide the building stock into time periods during which different building regulation/codes were valid. These age-use classes, then, would represent changes in regulations related to material use or other aspects (energy use). Another concern of Boverket is the possibility

[61] In Swedish: Boverket. In the following text the Swedish name will be used.
[62] In Swedish: Naturvårdsverket.
[63] In Swedish: Byggsektorns kretsloppsråd.

of assigning a number of statistical values to indicators from property management and the operation of buildings, and thus, obtaining some kind of "normflows", which could be connected to specific time periods. (Boverket 2000)

The *Swedish Environmental Protection Agency* is a governmental authority that co-ordinates and promotes environmental work. The Agency is interested in material flows since the agency is responsible for compiling national statistics and for supplying statistics to the EU. Hereby, waste material is one of the areas of focus and the Swedish Environmental Protection Agency is interested in national figures regarding material flows in the building sector (Sundqvist et al 2002). The agency commissioned an investigation into the use of demolition plans as a source for generating waste flow statistics (Thormark & Thuvander 2002). Waste flows are a focus of the agency's work because of environmental legislation.

Regional and local levels

On the regional and local levels, I have focused on Göteborg. Here, I have identified *several actors* interested more directly in the questions I address in my research: the Environment Administration of Göteborg Municipality[64] and the Ecocycle Department[65], energy suppliers, such as Göteborg Energi (GE), and locally, property managers, and Chalmers University of Technology.

The *Ecocycle Department of Göteborg Municipality* functions as an information source to the public about the progress of ecocycle adaptation in the City of Göteborg. One of the Ecocycle Department's tasks is to keep track of waste flows in Göteborg. One approach to fulfil the commission is to establish statistics on flows. Today, the input data are not satisfactory, according to the Ecocycle Department. The extent of coverage is poor, along with reports on waste from activities[66], which include building material (RVF 2001, Ecocycle Department 2002).

The *Environment Administration of Göteborg Municipality* has a broad responsibility including outdoor climate and housing environment. Among others, the town's Environment Administration monitors the environmental situation in Göteborg, makes sure that

[64] In Swedish: Miljöförvaltningen.

[65] In Swedish: Kretsloppskontoret.

[66] In Swedish it is defined as 'verksamhetsavfall'.

laws are obeyed, and contributes knowledge to the development of a sustainable Göteborg from a long term perspective. Even matters of energy (energy plans), traffic and land use are addressed. More concretely, the local Environment Administration controls handling of environmental hazardous materials in buildings. For example, a survey of PCB in buildings has been carried out, as well as investigations into the occurrence of mercury and radon in domestic buildings. Data from these different studies are stored in various ways. PCB data are stored in a specific database; mercury related data are collected in paper documents with limited access; radon data can be found in a somewhat different database than the PCB database. Thus, information is not stored systematically (Environment Administration 2002a, 2002b).

Now and then consultants, responsible for environmental quality issues, call the Environment Administration and request information about buildings, for example, material built into a specific piece of real estate property.

Generally, the Environment Administration emphasises the importance of surveying built-in material and material to be released in the future. Thus, material flows are of interest in the context of demolition. The Environmental Administration would like to have more comprehensive and detailed demolition plans than they have today. At present, the responsibility for demolition plans is spread among several authorities: the city planning office, the Environment Administration, and indirectly, the Ecocylce Department. There is no sufficient documentation of demolition plans. Documents are stored (if at all) in two places in an uncoordinated way, and access is problematical (Thormark & Thuvander 2002).

The Environment Administration has also mentioned a project carried out in Stockholm in which copper roofs were surveyed, i.e. the location and the horizontally projected size of the roofs (a part of a project on metal flows in Stockholm). The Environment Administration is interested in gathering similar knowledge about buildings in Göteborg. Other issues of interest to the Environment Administration are wastewater pollution and contaminated land connected to buildings. Knowledge about building materials, foremost exposed to the environment, could help identify risk areas. The Environment Administration is also interested in my research and after presenting my project one of the comments I received was, “I wonder why we don’t have such a data base yet…” (Environment Administration 2002a).

Göteborg Energi (GE), an incorporated company owned by the City of Göteborg, is a major energy supplier (district heating, gas, electricity) in the Göteborg area. GE uses GIS as a tool for identifying future customers. GIS applications are used as a starting point for diagnosis, resulting in proposals for measures to be offered to customers. For this purpose, GE uses a data masterfile containing energy use data and energy system data from the last Population and Housing Census (FoB), which is about ten years old[67]. GE does not use measured values (delivered energy) for these calculations, see also Fig 9.1. Measured energy data are not available per property. Generally, GE is interested in everything that improves their model and in particular, the connection between energy use, building volumes and the construction of buildings. GE would also like to be able to identify specific buildings on a piece of property. GE finds it difficult to obtain good data related to properties/buildings (GE 2002).

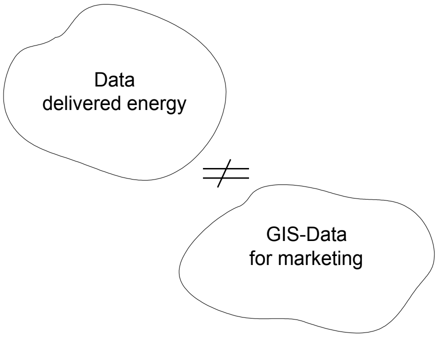


Figure 9.1. Data on delivered energy to subscriptions (number of stations in Göteborg) vs GIS data for marketing, based on Population and Housing Census, about ten years old.

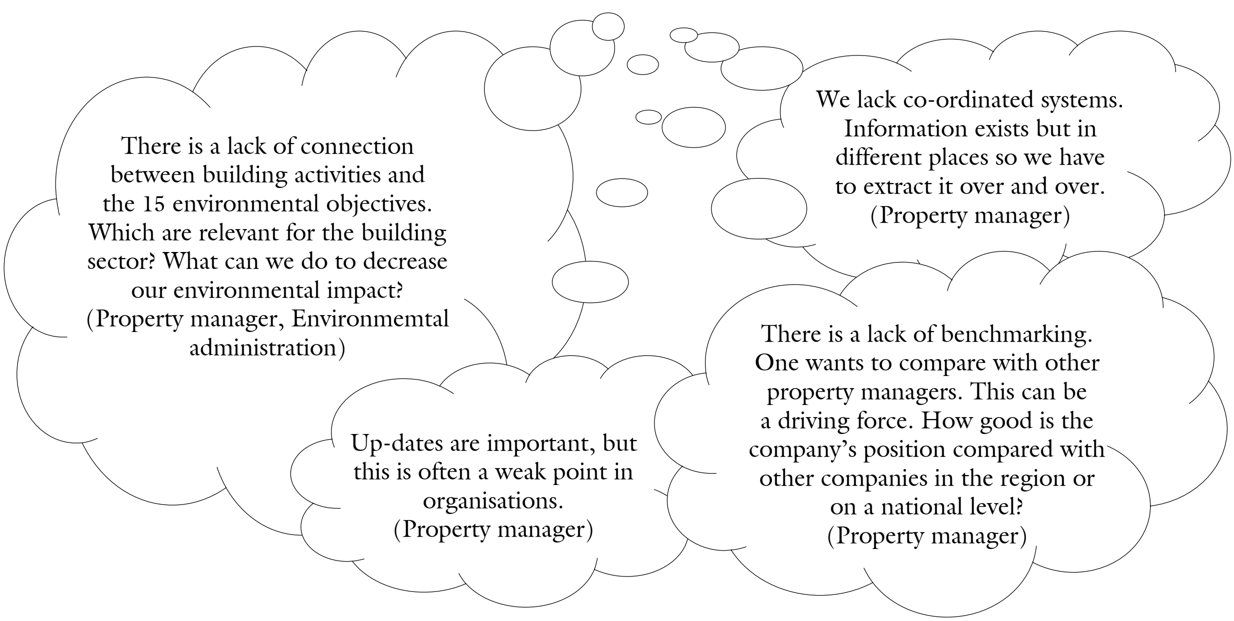
Additional actors of interest are *property managers*. The main field of action of property managers is to take care of buildings and place spaces at disposal for certain uses, and the maintenance and operation of buildings. Naturally, there are very different approaches to doing the above, in general, and integrating environmental issues, in particular, see, e.g. Brunklaus (2002). Operation usually deals with energy-related issues, whereas maintenance deals with long-term and short-term issues, such as cleaning stairwells, papering walls, or repainting façades. In addition, buying and selling properties is a significant part of property management. Today, environmental issues have entered and influenced many tasks of property management. Property managers both generate (see Chapter 11 and Thuvander & Brunklaus (2002)) and need data for carrying out relevant measures from an environmental point of view, such as controlling the use of resources and the environmental impact of buildings during the use-phase. Indicators are used, environmental policies are established, and to a limited extent environmental assessment methods are applied (Thuvander & Brunklaus 2002, Brunklaus & Thuvander 2002b). Property managers in Göteborg pointed out the following fields of interest for their environmental work (Brunklaus &

[67] The latest Population and Housing Census was made in 1990. The next will be carried out in 2005 by Statistics Sweden and will be totally register based.

Thuvander 2000b):

- better benchmarking of environmental activities
- better co-ordinated information structures
- links to environmental work on the national level
- inclusion of a time perspective.

Better environmental benchmarking and co-ordinated information structures would support a company's more efficient internal work and would lead to better control of a building's resource use and information flows. Benchmarking is interesting for comparing the environmental performance of buildings between different property managers, both locally and nationally, and for comparing a property manager's stock to an average stock, for example, Göteborg's building stock. Co-ordinated information structures would help avoid taking out the same data or information several times from different sources, which is labour intensive. Co-ordinated information structures also could support data input by single property managers as well as support their access to data input from others (to a limited extent). Better control of the environmental performance of buildings may assist marketing and buying and selling properties. EBSIS^{SD} users could easily exchange data files.



Last but not least, an EBSIS^{SD} database could support *learning* and *research*. Environmental researchers work on different levels of detail in many different fields. Some of the researchers need very detailed input data for modelling, which often addresses one specific aspect, for example, the optimisation of energy use in a specific region (Department of Energy Conservation, Chalmers University of Technology). Waste management modelling is a similar application. Thus, knowledge about amounts and types of material is often important. Research projects of this type could directly use data from EBSIS^{SD}. Other researchers may have a more complementary relation to this thesis project (environmental assessment of property management, a project carried out at the Department of Environmental Systems Analysis, Chalmers). Another important area of research, very relevant to the issues in focus here, is the study of urban structures (systems) and sustainable development of them. There is significant research underway regarding green structures and traffic structures (Architecture, Chalmers). A deeper study of the building structure would contribute to more complete modelling of the urban environment.

As the field of architecture is strongly related to buildings, the education of architectural students (and other construction-related fields) has to be discussed as well. New construction and reconstruction of buildings are activities which need an awareness of the existing environment (urban or natural) and an analysis of the location: What is specific for this place? Knowledge about existing built structures is important, as well as all kinds of infrastructures, possible contamination, and cultural aspects. EBSIS^{SD} could help architects to understand environmental relations and provide a knowledge base for decision-making, as well as support a systems view. This knowledge could be used in the initial design process, during which programmes for future building activities are determined. EBSIS^{SD} could support a more appropriate writing building programmes. One possible synergy effect could be that students, when working on specific projects, fill EBSIS^{SD} with data.

9.2 Potential applications

"With the help of such a database, information on the Swedish building stock and its current properties regarding environmental issues could be structured, analysed, and made available" is the overall description of this thesis project. This is a broad framework for possible applications, and it is in fact too broad to reach an operational level. Below, I will give a more concrete picture of possible applications. These are combinations of ideas and needs expressed by the above-mentioned potential users and aspects I find important to focus on as a result of my research. Generally, I will discuss two kinds of uses, one foregoing the other: descriptions of building stocks and scenarios (simulations from a time perspective) of developing building stocks.

Descriptions of building stocks

The basic purpose of EBSIS^{SD} is to describe the *composition* of building stocks on different levels of detail, with different spatial distributions, and using different aspects (compare list of variables Appendix A). Descriptions may include:

- Composition of the stock in general (age, use, and owner, of buildings and building stocks)
- Geometry and location
- Resource deposits in general (kinds and amount of, for example, built-in materials)
- Resource deposits related to position in the building (wall, roof)
- Resource deposits related to the position in the building and the geographical location (roofs in Göteborg)

Besides general questions, such as number of buildings and floor area (m^2) in a geographic limited region, questions of the following type will be possible to answer when the model has been finalized:

> What kind and amount of material is built into typical blocks of flats from 1955 in Sweden?
>
> How much PCB do blocks of flats built between 1961-75 in Göteborg contain?
>
> How much copper roofing (m^2) exists in the non-domestic stock in urban areas? Where?
>
> How many roofs are suited for solar energy technologies, for example, with an inclination of 45º? What point of the compass do the roofs face?
>
> What system prerequisites (heating system/roof areas) exist for mounting solar collectors?

Not only the composition of buildings and building stocks, but also *flows* of resources (related to a single time slice or a specific unit, for example, year) are of interest under the heading 'Descriptions'. Aspects related to new construction and demolition are also of interest. Examples of flow related questions are:

> What do building related material flows (inflows and outflows), including operation and maintenance, look like in shops and office buildings?
>
> Have we reduced material flows and energy use, respectively, to target levels?
>
> What amounts of material from demolition and reconstruction are generated over a specific period of time, preferably one year?
>
> What is the grade/amount of re-use of materials, recycling, combustion, or deposition?
>
> What are the expected transport needs generated in connection with handling building waste material.

Environmental descriptions are useful in a number of situations, such as planning and benchmarking, Table 9.1, below, summarises potential users of EBSIS^{SD} on the national and regional levels and gives some examples of applications, which in turn have to be considered in relation to the above posed questions in Fig 9.2 and Fig 9.3.

As I see the local level as more fruitful for further development of the EBSIS^{SD}, this level is discussed further.

Planning issues related to the EBSIS^{SD} range from land use to waste management and are possibly of foremost interest to local authorities, but to a limited extent, also to property managers. For example, in the case of municipal waste management, amounts from the demolition of buildings in relation to recycling issues are of interest. In this case, planning needs knowledge about the amount of material released from demolition, the composition of the material, and the potential for recycling. – This type of knowledge can support decisions, such as location, size, and kind of recycling stations, as well as calculations of transports (local authorities). Also, economic issues may be addressed, for example, as waste handling will become more expensive. – How much money can be saved if we decrease material flows or recycle materials?

Local authorities working with environmental adaptation and support of a sustainable development of society need information,

<table>
<tr><th>Aspect</th><th colspan="2">Supposed users</th><th>Examples of applications</th></tr>
<tr><td rowspan="2">Composition</td><td>National level</td><td>Boverket
BYKR</td><td rowspan="4">Planning issues (waste management, hotspots - areas for action)

Benchmarking
Development of indicators (use of resources, application of environmental assessment methods, energy declarations, turnover of tenants, …)

Demolition plans

Statistics
Control of the system (qualitative and quantitative)</td></tr>
<tr><td>Local level</td><td>Local BYKR
Environment Administration
Town planning office
Property managers
Consultants (environment and quality management)
Demolition companies
GE
Researchers
Students (School of Architecture/planning)</td></tr>
<tr><td rowspan="2">Flows</td><td>National level</td><td>Swedish Environmental Protection Agency
Boverket
BYKR</td></tr>
<tr><td>Local level</td><td>Environment Administration
Eco-cycle Department
Property managers
GE</td></tr>
</table>

Table 9.1. Examples of users and applications of a future EBSIS^{SD} on national and local levels.

which supports the development of means of control. In the case of waste handling, knowledge can be used as a base for expansion and development of more effective recycling of building materials, and by that bring about environmental gains.

EBSIS^{SD} should be able to show hotspots of energy use, the concentration of environmentally hazardous material, and the distribution of "normal" materials and type of buildings. Consequently, EBSIS^{SD} will bring about saving potential for resources or potential for change, of interest to both local authorities and property managers.

As a tool for generating statistics and taking out indicators, EBSIS^{SD} could be used for benchmarking. Material flow statistics for waste can be considered as a part of the reporting system up to the national (and EU) level. Benchmarking and indicators are of interest to property managers.

An EBSIS^{SD} that contains information about the location and distribution of built-in material (and of environmentally hazardous material) can also be used as a basis for demolition plans. EBSIS^{SD} can support inspections and inventorying in connection with demolition. Interest groups are property managers, the local Environment

Administration, the Ecocycle Department, building contractors, (environmental) quality managers, consultants, and demolition companies.

Generally, descriptions of the composition of building stocks and flows through building stocks can generate new knowledge and contribute to an improvement of already existing knowledge. This knowledge can be applied:

- for planning issues → resource management
- for identification of problems and potential → hotspots, identify important areas for action
- to support local authorities' work → design of means of control
- to support companies' environmental work → control of the system
  → as a basis for statistics (local, national)
  → for marketing, buying/selling
  → as a basis for demolition plans
- for generation/development of indicators → benchmarking
- for communication
- having a preparedness for knowledge

All these applications aim at *tracking*, which in turn leads to better control of a system (which is what EBSIS^{SD} is all about). For the local Environment Administration, the system in focus for better control is the building stock in Göteborg, for property managers the system in focus is their owned and managed stock.

Preparedness is another aspect to be mentioned here (probably the primary interest for authorities). From a historic perspective, data, which were of no interest several years ago, have gained in importance today. Examples are PCB in joints or amounts and composition of waste material generated by the building sector, in general, and released in connection with demolition, in particular. In the future, other aspects may become important (waste management is one aspect of growing interest). Thus, EBSIS^{SD} may support such issues – potentially having information in readiness, or alternatively the possibility to add the information of concern. A prerequisite in this context is that even "uninteresting" data are collected.

In summary, with help of EBSIS^{SD} the control of the systems building stock and building will be improved, both qualitatively and quantitatively. More knowledge about the general composition of the stock and the long-term effects resulting from building will be gained.

Scenarios

When a (longer) time perspective is added to the descriptions of building stocks we can extend the discussion to future development of existing building stocks. Scenarios, then, are simulations of the future, or in other words, experiments with $EBSIS^{SD}$ with help of a simulation tool. Thus, a fully developed $EBSIS^{SD}$ is meant to be a basis for carrying out different scenarios, exploratory[68] and anticipatory[69] (Thuvander 2000, Stendel 2000c):

- to illustrate development and changes in a building stock.

> How much can the emissions of CO_2 be reduced if we change the heating systems/energy source in single family houses or all blocks of flats? In Sweden, in Göteborg?
>
> How will the building stock develop if we continue building as we do today?

- to indicate future problems in the stock.

> What kinds and what amounts of hazardous waste do we have to expect in the next five years from blocks of flats constructed between1961-75?

- to discover potential for improvements in the existing stock.

> What is the potential for applying solar energy systems to the façade or roof of existing buildings in "public buildings" in Göteborg?
>
> What is the potential for improvement of energy use in blocks of flats by exchanging windows?
>
> What is the potential for reducing ”landfill” and amounts of waste from the building sector or amounts of waste released from construction/demolition?

- to assess several ways of achieving a defined goal or a desirable future.
- to make improvements or arising problems visible (trend identification).
- to support communication between different actors.

[68] Exploratory scenarios: start in the present time and project several trends into the future. Analysis of trends in order to evaluate their consequences.
[69] Anticipatory scenarios: start with a defined goal or image of "desired" future and investigate possible ways of getting there and the consequences involved.

Analogies with medical research can be drawn: identification of long-term illness and spatial patterns.

The scenario issues above are very simplified. In a wider and more real context, for example, in an urban context, building related scenarios should examine additional issues, such as social, cultural, historic, and architectural. The development of building stock (backward and forward in time) is also interesting for investigations of the interplay between various structures, such as building structures and green structures, or building structures and traffic structures.

9.3 "I wonder why we don't have such a database yet..." [70]

Going back to the initial question of this chapter, I can conclude that there is a need for an EBSIS^{SD} that addresses environmental aspects. There are several users, and there are several applications. Potential users are found at the local, regional and national levels. Some of the potential users have direct interests (Boverket, Environment administration, GE) regarding different aspects and others have more indirect, not explicitly defined, interests.

One important conclusion is that it would be advantageous to develop an EBSIS^{SD} prototype on a regional/local level in close contact with potential users, namely, the Environment Administration and the Ecocycle Department of Göteborg municipality, property managers in Göteborg, possibly GE, and last but not least research groups at Chalmers. Data available from there would influence the progress of the research work. When companies are addressed, efficiency aspects of companies' real estate management will become important, for example, simulations of material and energy flows have to pay off in some way. Thus, financial interests or cost savings have to be overcome.

A property manager might be aware that knowledge about material is necessary for environmental work, but that it is not profitable to collect data to gain that knowledge and it is even less attractive to construct large databases for the purpose. Necessary information is just not collected. Incentives are important; maybe incentives could be handled as in SPINE, where delivery of data gives access to the database. Municipal conditions differ a bit because local authorities are commissioned to have certain

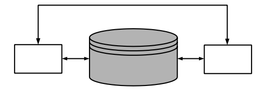
[70] Environment Administration in Göteborg

information in readiness for the public (environmental performance, indicators, or statistics).

From a long-term perspective, it is possible to turn back to EBSIS^{SD} applications on a national level. Depending on which spatial system level and user is addressed, the demands for complexity in EBSIS^{SD} will change. Property managers have asked for simple system solutions, containing only data really needed. Authorities with the task of preparedness may need a more complex systems solution as do researchers, a user group not to be forgotten. Thus, a general structure, which can be filled with data to fit local, regional and national conditions, is needed.

Moreover, maybe the EBSIS^{SD} can obtain the status of an "optional" or de facto standard.

The demands for information "outside" research seem to be in relative harmony with the basic ideas of EBSIS^{SD}. Both have interests in built-in materials and future release of materials, potential for energy savings, as well as statistics, benchmarking and development scenarios, which demand integrating a time perspective. Aspects, such as structuring information, use of existing solutions, and benchmarking are important. Finally, I wonder why *they* don't have an EBSIS^{SD} yet…



10. EBSIS^{SD}

What would an EBSIS^{SD} that meets the deamands raised in the use(r) study look like? Chapter 10 outlines a conceptual model for such an Environmental Building Stock Information System for Sustainable Development - EBSIS^{SD}. The fundamental methodological principles are illustrated and an initial list of variables is suggested. The conceptual model will be the starting point for later development of a physical data model, a prototype based on the BSAB structure complemented with SPINE, to be implemented into a GIS-based environment. However, the conceptual model is not intended to be implemented directly, but rather as a basis for discussion and a point of departure for data modelling and prototyping.

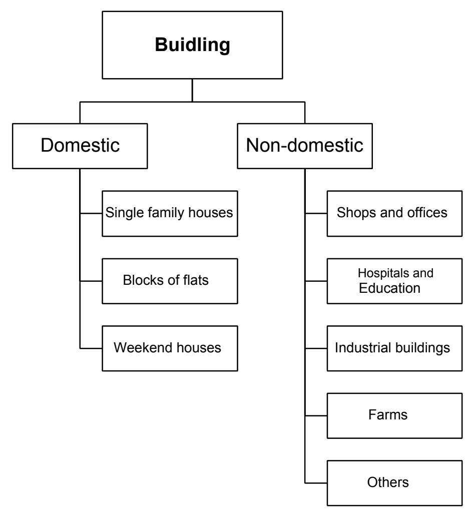


Figure 10.1. The object building has either the attribute domestic or non-domestic. A domestic building can have the attribute single family house, blocks of flats, or weekend houses. A non-domestic building can have the attribute shops and offices, hospitals and education, industrial buildings, farms, or others.

10.1 The framework

Matrix

A matrix containing the number of buildings, gross floor area, and building volume (Table 10.1) has been developed. The frame of the matrix is based on similar frames used in earlier studies of the Swedish building stock, see compilation in Stendel (2000b); this is advantageous for reasons of comparison. Comparisons will be possible with official statistics, above all with statistics regarding the domestic building stock, but only to a limited extent will it be possible to compare new data with previous investigations of the Swedish stock.

An age-use matrix has been chosen for several reasons. Building stock studies are often based on buildings categorised in age-use classes (previous Swedish building stock studies, the German building stock study or the EEP model described in Chapter 8). The attributes ‘age’ (year of construction) and ‘use’ (building category) are relatively common and the class ‘building’ in official statistics and previous Swedish building stock studies is based on buildings categorised according to these attributes. Buildings with the same use often have similar performance in many respects (construction, size, space, use of energy, intervals for maintenance, costs or installations). Similarly, buildings constructed within a certain time period often have similar properties (construction, use of material).

A building class is either a subclass 'domestic building' or 'non-domestic building'. A 'domestic building', in turn, is a superclass of a single family house, a block of flats or a weekend house. A 'non-domestic building', then, may have further subclasses, Fig 10.1.

Table 10.1. Age-use matrix of the Swedish building stock. For example, number of buildings, properties, gross floor area or gross volume can be entered into the table. See also Chapter 12, where the matrix is applied to the Göteborg level. Essential is the information for which time slice the matrix is valid.

m^2, m^3,
number of buildings, …

Building stock	Use of buildings	Year of construction				
		-1940	1941-1960	1961-1975	1976-1990	1991-2000
Domestic	Single family houses					
	Blocks of flats					
	Weekend houses					
Non-Domestic	Shops and Offices					
	Hospitals and education					
	Industrial buildings					
	Farms					
	Others					

In previous Swedish studies, the stock was mostly divided into periods of 20 years (starting from before 1920 or 1940) up to the actual year of the investigation (Stendel 2000b). In investigations of exclusively the Swedish domestic stock, the periods instead have been 15 years (starting from before 1930 and up to 1975), as these breakpoints approximately coincide with changes in Swedish building codes (Stendel 2000b). Industrial buildings have only been divided into before and after 1960 (Stendel 2000b). In the proposed matrix for EBSIS^{SD}, a more flexible frame is aimed at. The matrix will be adaptable to most of the previous studies and to different user needs (SCB statistics, 5-10 year periods, building codes and regulations). Thus, the matrix will be a kind of filter and a measurement of "coarseness", which can be adapted according to needs.

The Swedish Building Register (BR) together with the Swedish Property Taxation Register (FTR) (Stendel 2000a) and additional sources will be used to fill the matrix in a GIS application (Chapter 12). In addition, information about the location of the buildings (densely built-up area/sparsely-populated area) will also be taken from the BR. This matrix, then, will be used to study the building stock from two approaches; a top-down and a bottom-up.

A second matrix, a geographic one, will be added to the age-use matrix. The geographic matrix will consist of grids that correspond to the map sheet division of Göteborg. Thus, two coupled matrixes will be used.

Top-down & bottom-up approach

Two approaches for studying the building stock, a so-called top-down & bottom-up approach are suggested. The two approaches will be combined via an age-use matrix.[71] The concept is inspired by the German approach presented in Chapter 8.

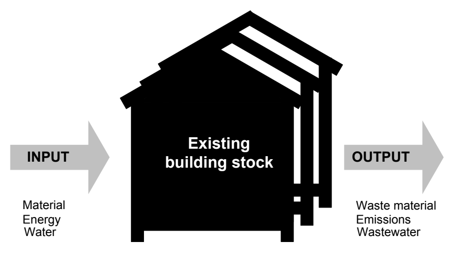


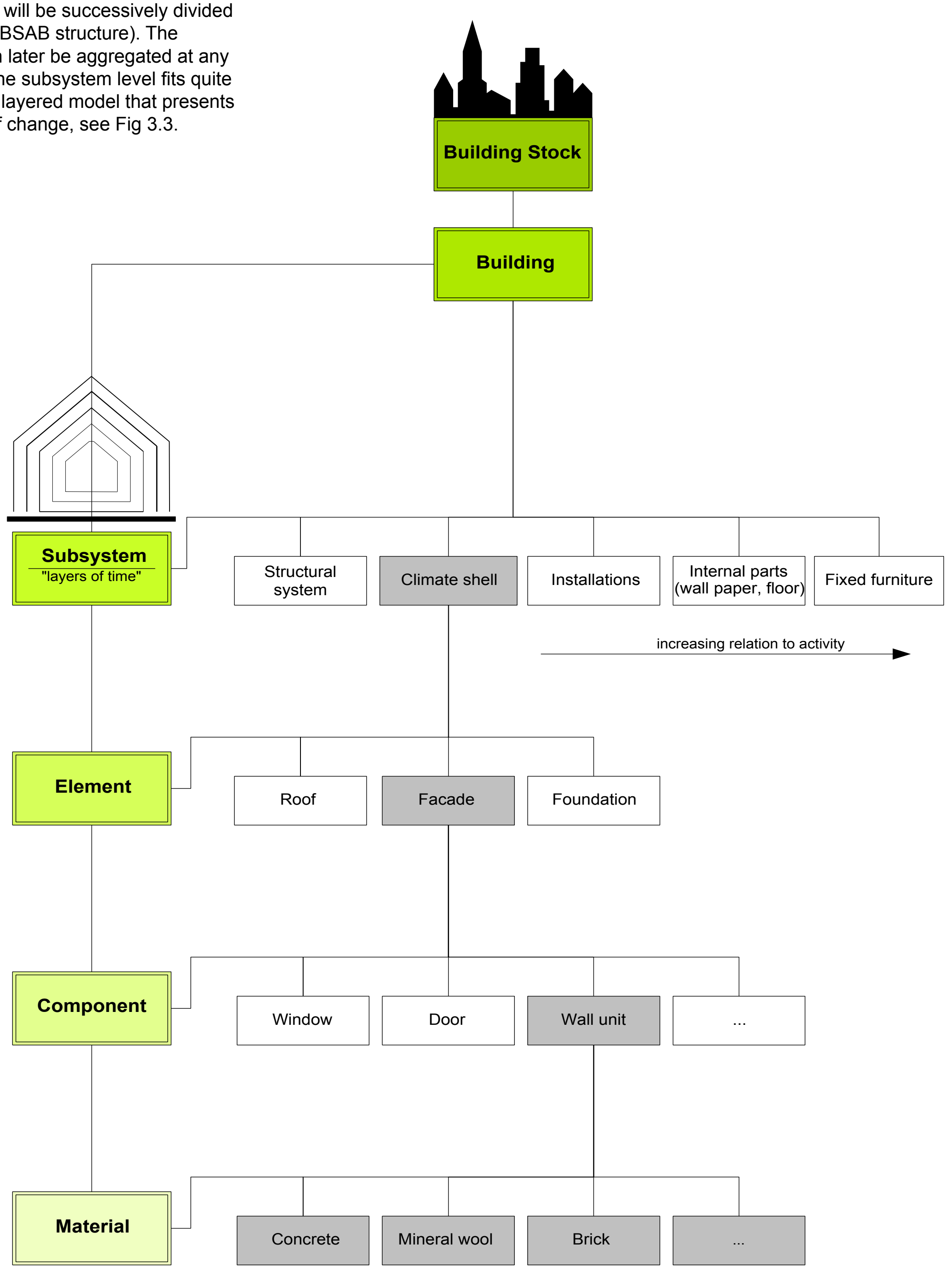
Figure 10.2. From the top-down approach, the existing stock is considered as a "black box". Resource flows in the building stock: input of materials, energy, and water and output of waste materials, emissions, and waste water are considered.

From the *top-down approach*, the existing stock is considered as a "black box", in which a certain amount of resources have already been deposited. The "black box" will consist of a certain number of buildings. The overall flows of resources, such as material, energy and water, into and out of the stock will be investigated as a whole (Fig 10.2). The total amounts will be described using general statistic data, data from the building industry, producers and trade organisations. The top-down approach has been further described in Jönsson (2000), in which data sources for material flows on the national level have been presented. Examples of data sources are also given in Table 11.1.

From the *bottom-up approach*, individual buildings are of interest. The building stock will be successively divided into subsystems, i.e. individual buildings, parts, elements and materials (Fig 10.3). These divisions into subsystems correspond to BSAB's hierarchy. Building elements include the foundation, façade/outer wall constructions, inner walls, floor structures and roof constructions. Building components include stairs, windows, bathroom and kitchen fixtures. The stock can later be aggregated at any of these levels. With this exposition, it seems that not only the building level is a bottom-up approach but the material level is

[71] The framework of the model is partly outlined in Stendel & Jönsson (1999) and Thuvander (2000).

Figure 10.3. From the bottom-up approach, the building stock will be successively divided into subsystems (BSAB structure). The building stock can later be aggregated at any of these levels. The subsystem level fits quite well with the time layered model that presents shearing layers of change, see Fig 3.3.



at the 'most' bottom-up level. However, from a systems view, there are always subsystems and the chain never ends. Thus, on a conceptual level, I have chosen the building level to be the bottom-up level. A number of buildings need to be investigated in detail and recorded in EBSIS^{SD}. These buildings will be chosen in different ways. For example, buildings for which data of good quality are available will be studied, all buildings or a number of buildings within a limited geographic area will be surveyed, all buildings of a number of property managers will be investigated, data might be delivered from property managers who 'join' the EBSIS^{SD}. With an increasing number of thoroughly investigated buildings, the results will become more and more accurate. Data emerging from both approaches will be compiled in an age-use matrix, as presented in Table 10.1, to check the reliability of the results. All data obtained from the top-down approach will be allocated in proportion to the number of buildings and to the gross floor areas in each age-use class, respectively. The allocation may regard weights, volumes, areas, economic values, emissions or kWh, etc. Bottom-up data of entire buildings will then be scaled to fit and represent the entire building stock or a fraction of the stock, i.e. individual buildings or building parts as multiplied by the number of buildings and/or by the gross floor areas in each age-use class of the matrix (Fig 10.4 and 10.5).

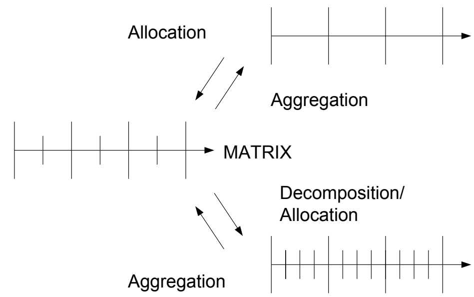


Figure 10.4. Top-down is all data allocated to the matrix. Bottom-up data is all data aggregated to the matrix.

Great efforts are needed to use two approaches instead of one. However, it is not possible to gather all data by using one approach only. By using two approaches, a lack of data can be compensated because in some cases, only top-down or bottom-up data will be available. Here, the matrix will facilitate results either way (allocated or aggregated data). Furthermore, the differences between the results of the two approaches will give an indication of the reliability of the figures.

The bottom-up approach is advantageous for describing built-in materials, whereas the top-down approach is advantageous for describing changes, i.e. of the in- and outflows of resources. From the top-down approach, it is sometimes difficult to distinguish between buildings and other built constructions, and, therefore, uncertainties may occur about the amounts of mineral building materials used. From the bottom-up approach it is difficult to model the entire stock starting from a limited number of reference objects. However, the more buildings that are investigated from the bottom-up approach, the less the discrepancy should be between the approaches and the more reliable the results should become. Bottom-up data are very detailed, and from

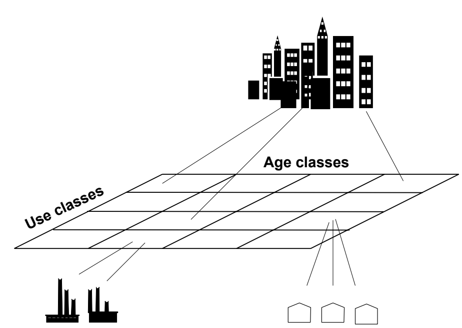


Figure 10.5. Top-down data will be allocated proportionally. Bottom-up data will be scaled to fit.

this approach, data are rather transparent and the control of the system is good. It will be well known which data are included or excluded. The weakness of the bottom-up approach is that one does not really know how well the system has been modelled, i.e. how representative the buildings are. If a limited number of buildings are investigated in detail, and if those happen to be exceptional, the average building obtained will not be representative of the stock (Stendel & Jönsson 1999).

In a conceptual sense, only two levels exist, a top-down and a bottom-up. In the operational sense, several levels exist because of data sources that address levels in-between (presented in the section below, 'The data universe').

The top-down & bottom-up approach, as presented, fulfils the EBSIS^{SD} criteria for addressing resource flows and deposits in buildings and building stocks as well as for a systems approach. The concept illustrated, so far, is similar to the German approach, despite that the Swedish classification system is suggested. What also differs from the German approach to the Swedish one is the inclusion of a spatial dimension. In EBSIS^{SD}, the location of buildings matters and not only will the national stock be addressed but also more geographically limited stocks (see Fig 10.6).

10.2 The "data universe"

By adding a spatial perspective and a data source perspective to the matrix and the top-down & bottom-up approach, a further framework is established, which I call the *data universe* (Fig 10.6). In the following text, Göteborg functions as an example for the urban level.

The spatial perspective comprises several spatial system levels with increasing resolution, namely the national level, the regional level, the urban level, the quarter and property level, and the building level. Data sources are, for example, statistics on different levels (Sweden, Göteborg), archives at the town planning office, suppliers, property managers, or the buildings themselves. For some of the data sources, it may be difficult to distinguish between property and building (suppliers', property managers') data. Data sources can serve several spatial system levels and function as bottom-up or top-down data depending on the level to which the matrix is adapted. For example, Göteborg statistics will be top-down data if the matrix is adapted to property managers' needs that address the urban level. At the same time, Göteborg statistics can be bottom-up data for a matrix adapted to the national level. Operationally, the age-use matrix will interconnect data sources and spatial system levels.

For switching between the levels, the coarseness of the age-use matrix can be the same, but it does not necessarily have to. This means that only the value of the age-use matrix cell has to be adapted to the actual level. A less detailed presentation would be sufficient on a higher system level.

This perspective meets the EBSIS^{SD} criteria for spatial aspects, besides the location of buildings, to support a local, regional and national level. This part will also be based on a systems approach.

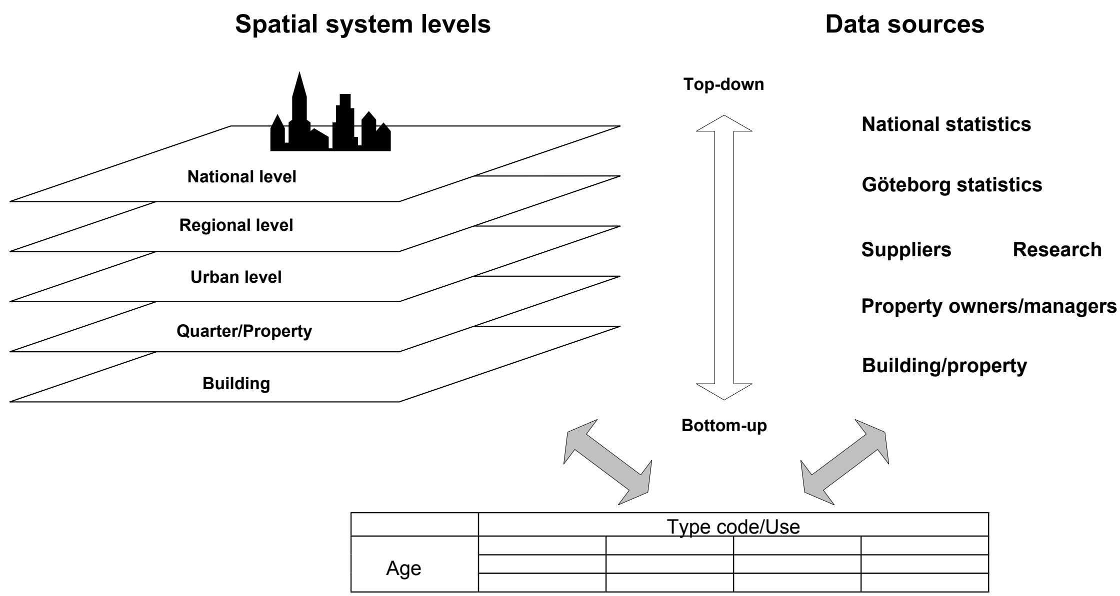


Figure 10.6. Spatial system levels (subsystems) and data sources of interest will be related to each other by the age-use matrix (see Table 10.1).

10.3 Aspects to be considered for a dynamic description

When including a time perspective, both the *composition* of the stock and the *changes* in the stock must be known. The bottom-up approach, then, will comprise a *static* (object) and a *dynamic* (flows of resources and changes in the stock) description of buildings.

The stock consists of buildings in different 'states', with different age, determined by climate, use, maintenance and renovation. Consequently, one problem will be to find the 'is state' of the stock (static description, composition today, at a certain time). It is possible to make a sample survey (random sample surveys, as carried out in former Swedish studies) or to conduct artificial ageing of buildings (and the stock) as performed in the German study. This means that old 'new construction data' exist and to update them, they will be aged, i.e. data was collected for buildings as they were built. The buildings have then been aged artificially (simulation of development), i.e. undergone different stages, such as partial renewal of buildings, total renewal of buildings, important changes in regulations and standards, up to today. The two approaches (ageing and random sample survey) may be combined. For the Swedish stock it may be possible to use previous studies as a starting point where the buildings are described as they were at a certain time. To this, artificial ageing may be added describing the changes up to a desired time data (year of interest, future).

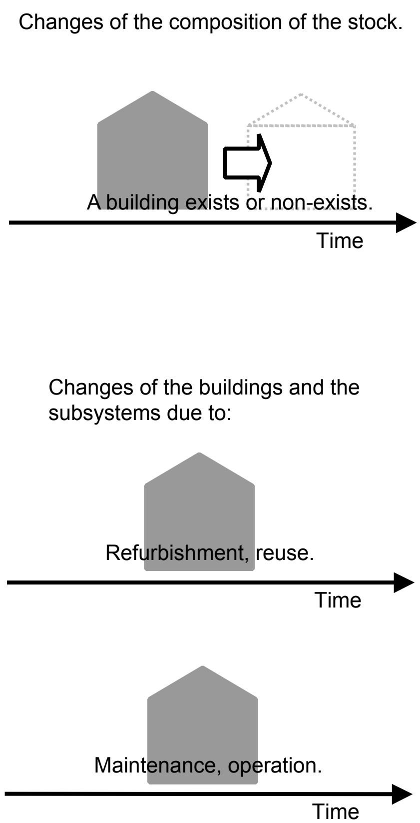


Figure 10.7. Two kinds of changes in the building stock can be identified: changes in buildings and subsystems during their lifetime, and changes in the composition of the stock.

In principle, two kinds of changes can be identified in the stock: *changes in buildings and subsystems during their lifetime*, and *changes in the composition* of the building stock, Fig 10.7. Changes in the composition of the building stock occur due to new construction and demolition of buildings. In building stock studies, this has been handled similarly to population development. Somewhat simplified it works as follows: The population at a certain time comprises all people living at that time. Through rates of birth and mortality, the development of the population can be calculated. For every point in time the population comprises all people living at this point of time. The building stock can be considered in an analogous way. Birth corresponds to new construction and mortality corresponds to demolition. A lifetime corresponds to the duration of time that a building exists. Thus, a building either exists or non-exists. When the new construction rate/demolition rate are known, the dynamics of the stock can be calculated. (In addition, renewal/not renewal might be added in a more complex model.) In this way, the development of building stock can be considered in terms of the entire stock or partial stocks. A building stock can grow, be constant, or diminish.

Changes in buildings and building parts occur due to use, operation, ordinary maintenance and extraordinary maintenance, rebuilding of parts of the building or the whole building. Depending on the year of construction and the use of the building, the pace of maintenance and rebuilding will differ and will occur with a certain periodicity in every age-use class. Domestic buildings have other maintenance cycles than commercial buildings (e.g. owing to higher turnover of tenants or change in activities inside the buildings, new use). Building elements and building parts also have different lifetimes. The surface material has a certain life span, the inner wall has a certain life span, and the core has a certain life span, possibly the same as the entire building element (as the time-layered model Fig 3.3 illustrates).

Building elements and parts need to be provided with a time index that describes their lifetimes, which is necessary for simulating future changes and flows. Another time index is needed for storing historic events in time in the database which is necessary for describing past developments in time.

For maintenance and operation, there is a computer-based program, namely 'Summarum' from REPAB (see also Section 7.1). Its suitability should be investigated (for the description of buildings and building subsystems with a time index for lifetime). Summarum has, for example, a module for technical property management that contains functions for planned maintenance (maintenance data can be added to a building façade, to a room,…), cleaning routines, and media providing issues.

10.4 List of "desired" variables

A list of variables gives an idea of what kind of variables that are of interest and what kind of data that needs to be stored in a future database. Fig 10.8 gives an overview of the variables included and in Appendix A a number of the variables are further outlined. The decisive factor for the choice of variables, and the objective of the model, is based on the potential users' indicated needs and aspects evaluated as important for research.

In the process towards a physical database system, the variable list functions as a point of departure for data modelling and prototyping.

A building is described by means of several variables, some that give a more general description of the building and its context, and others related to environmental issues. For example, the 'location' of a building is of interest. Location can be described in different ways: point of compass (north, south, east, west), location within an administrative area (municipality), an administrative key (building key, property key, property name, address), density (densely built-up, sparsely built-up areas), spatial connection (building co-ordinates), climate zone, etc.

Moreover, variables that describe owner conditions, type of use (code of type in the property taxation system, SNI code[72]), use-intensity (the

[72] SNI code stands for Swedish Standard Industrial Classification. In Swedish: Svensk Näringsgrens Indelning.

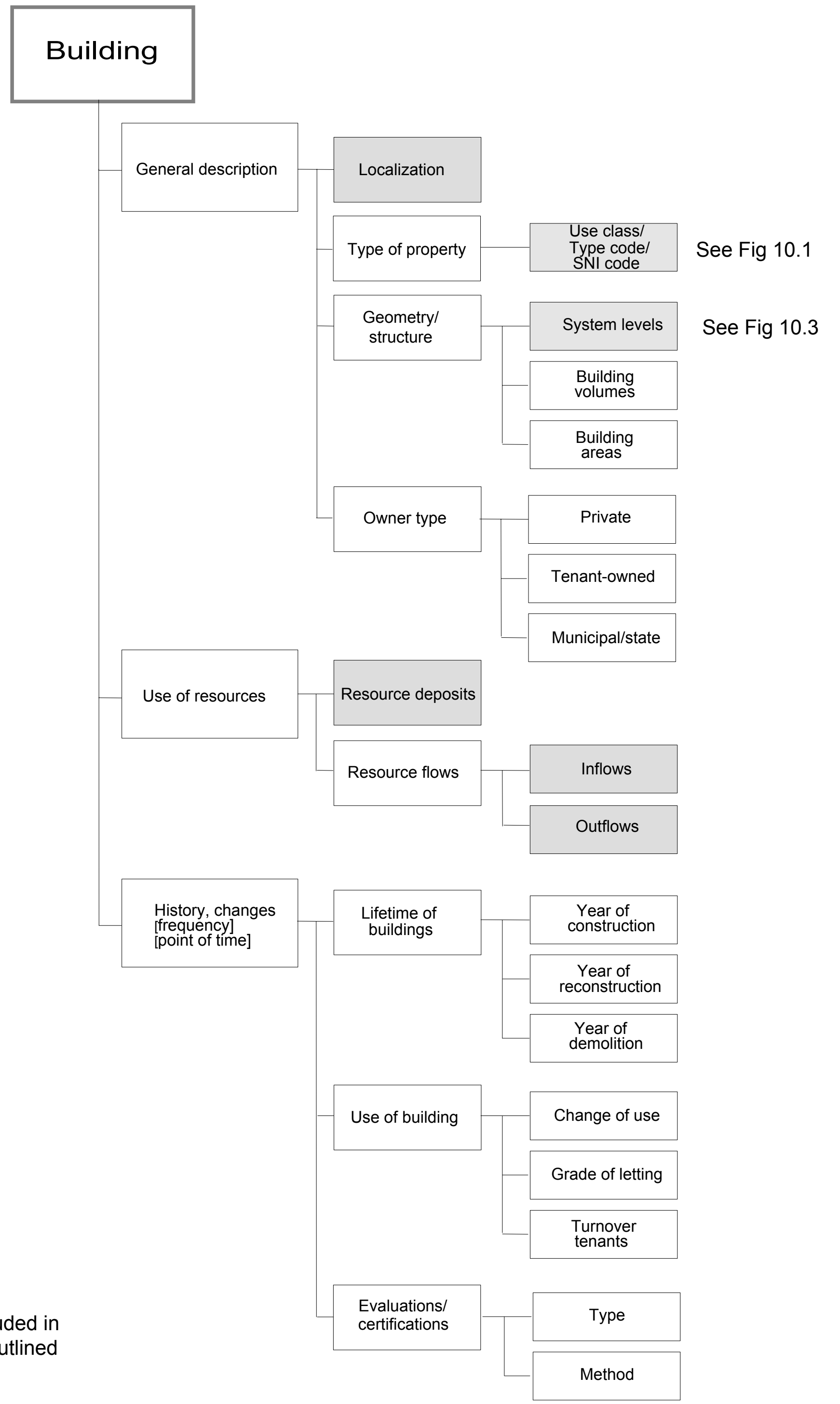


Figure 10.8. Overview of variables included in the model. The grey fields are further outlined in Appendix A.

effective use of a building, e.g. how many hours a building is empty per day), and year of construction are of interest, as well as variables that describe size/geometry (number of floors, gross floor area, volume, window surface area, façade surface area, roof inclination and surface area). Buildings will be considered for the duration of their life-cycle, as time and changes over time are important (time index for a change).

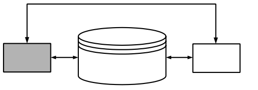
Individual buildings will be further described by means of resource related variables (media-providing of energy and water, and material use) in relation to the entire building and its subsystems. Media-providing variables only concern flows. Energy-related inflow data to be collected will consider both the amount of energy used and energy source (sources, such as oil, gas, district heating, wind power, etc. will be allocated to classes of non-renewable or renewable energy sources). This is important for a more nuanced discussion of environmental impact from energy use in buildings. Outflows will take in consideration emissions and transmission losses. Emissions are not necessarily connected to buildings' location but buildings themselves contribute to certain emissions. Presentation units will be, e.g. [kWh/year] within a specific area, [kWh/year x m^2 gross floor area], [CO_2/year x m^2 gross floor area], [t] emissions.

For water, the amount of inflows is of interest, as well as the total amount of outflows, the sum of surface water and water used inside the building that leave the system boundary (are led to the wastewater sewage system).

For material related variables, a distinction between flows and deposits is to be made. Material deposits (built-in material) can be described in terms of total amounts of the building, weight, volume or length ([t] , [m^3], [m]). The amount of material can also be described in relation to geometry [t building material/m^2 gross floor area] and/or in relation to the subsystems of the building [amount/m^2 of the subsystem in focus]. Material flows are to be described (as amounts) in relation to activities (new construction, maintenance, operation, renovation, refurbishment, and demolition), thus, including the exchange of building elements during their service life. Material flows can also be described in relation to the use of the building and changes in use or tenants. The timeframe can, e.g. be flow/year (overall flows or flows related to a specific activity) including the dynamics of the stock (new construction or demolition of buildings). It will be necessary to generate, for example, 'norm flows' for the different types of uses (domestic, non-domestic).

Further, variables regarding building evaluations such as environmental assessment, building declarations and energy certifications are also to be included. Variables will describe if a building has been evaluated or not and in what way. The evaluation method will be noted, if the building has a building declaration and/or an energy certification.

The list of variables also should open up for the inclusion of other constructions than buildings (roads and bridges) as well as the description of environmental impact on buildings.



11. FEASIBILITY - DATA SOURCES

Obviously, an EBSIS^{SD} needs to be filled with data. What environmental data are available on the different levels in Sweden? Where and in what form? Are there sufficient data? These are guiding questions for the feasibility study presented in this chapter. Departing from the list of variables (Appendix A) and the 'data universe' (Fig 10.6), a number of data sources have been studied, and the level of coverage of data compared with the variable list has been evaluated.

11.1 Data sources and available data

A survey of a number of data sources has been carried out, comprising national and local statistics, local authorities' registers and statistics, and data from suppliers of energy and water, waste material managers, property managers and research studies. Data sources on the local level, including suppliers, concern conditions in Göteborg. None of the surveyed sources addresses the regional level, as I could not find any appropriate regional data source. However, such sources might exist, such as the study on energy supply systems for southern Sweden (DESS 2000a, DESS 2000b). Some data sources have been examined in more detail in case studies, namely, the Swedish Building Register and the Property Taxation Register (see Stendel (2000) and Chapter 12), property managers (Brunklaus & Thuvander 2002), demolition plans and the Environmental Administration's registers (Thormark & Thuvander 2002), as well as top-down data for material flows (Jönsson 2000).[73]

In order to evaluate the level of coverage of existing and required data, data sources have been entered into Table 11.1 according to their data content. In the table, one can see which data are contained in each data source in terms of flows and deposits on one hand and energy, material, water and age-use matrix/geometry on the other. Data concerning the

[73] How to find environmental data in general is discussed in Thuvander & Thormark (2002).

	Data sources for environmental data and the matrix			
	Energy	**Material**	**Water**	**Matrix/ Geometry/other**
National statistics, registers and similar				
Deposit	Not included.	SNV, Research reports, Consulting companies (Mängda) RAÄ	Not relevant.	SCB (FTR, FoB, SNI, land use figures) National Land Survey (BR), RAÄ, Previous building stock investigations/
Input	SCB (FoB Masterfile), Energifakta, STEM, Research reports, Specific investigations Previous building stock, investigations	SNV, SCB, Research reports, Trade organisations	SCB, Swedish Water & Wastewater Association	SCB
Output	SNV, Research reports	SCB, SNV, Research reports, Trade organisations	Swedish Water & Wastewater Association	SCB
Local statistics and authorities in Göteborg				
Deposit	Not included.	Environmental Administration (database/ investigations)	Not relevant.	Town planning office (building permit archive, drawings, property administration system)
Input	Research reports	Environmental Administration (annual reports)	Environmental Administration (annual reports)	Town planning office (building permits)
Output	Environmental Administration (reports/ statistics)	Town planning office (demolition plans), Environmental Administration (reports, annual reports, demolition plans), Eco-cycle office	Environmental Administration (annual reports)	Town planning office (demolitions)
Suppliers in Göteborg				
Deposit	Not included.	-	Not relevant.	Research Chalmers
Input	GE Other energy suppliers	Trade organisations (?)	VA-verket (annual reports, internal statistics)	
Output	Emissions GRAAB (annual reports, internal statistics)	Renova, Reci, Återbruket (annual reports, internal statistics)	GRYYAB (annual reports, internal statistics)	

Property managers in Göteborg[2]				
Deposit	Not included.	Drawings (reconstruction), Environmental assessment tools, Survey (environmentally hazardous materials)	Not relevant.	Annual reports (adress, floor area, type)
Input	Annual internal statistics, annual (environmental) reports, economic data	Economic data, Environmental assessment tools,	Annual reports, Economic data, Internal statistics	Internal data, property administration system, economic system
Output	(Annual environmental reports)	Sorting of waste material, demolition plans (annual reports)	Not measured.	Internal data, property administration system, economic system
Buildings in Göteborg				

Table 11.1. Compilation of a number of data sources related to different spatial system levels and the environmental data of interest.

BR: Building Register
FTR: Property Taxation Register
FoB: Population and Housing Census
GE: Göteborg Energy
GRAAB: Waste Incineration Plant in Göteborg
GRYYAB: Wastewater Treatment Plant
RAÄ: Cultural Heritage Management
SCB: Statistics Sweden
SNI: Swedish Standard Industrial Classification
SNV: SwedishEnvironmental Protection Agency
STEM: Swedish Energy Agency

matrix and geometry function as indirect or secondary data sources for other aspects, especially for material deposits and flows.

From Table 11.1 we can extract that the available data sources are:

- statistical data, register data (national level, local level)
- companies that compile and sell data (energy data, material data)
- research data and reports (can consist of measured data, statistical data, compiled data from several sources including literature)
- annual reports of companies (suppliers, property managers)
- internal data from companies gathered by auditing systems

On the national level, SCB compiles and provides statistical data of total amounts of energy used for heating and domestic hot water. These statistics are available for domestic and non-domestic buildings. For industrial buildings, SCB provides other data that cover the amount of electricity or fuel bought by the companies. Industrial production is included in these energy figures. From SCB and the Swedish Census of Population and Homes supplementary statistics are available, in particular, for the domestic building stock. For example, data on the demolition and modernisation of blocks of flats are provided.

Good quality statistics on the total amounts of materials used or waste material generated from building-related activities are neither available from SCB nor from any other single source (yet). Therefore, they must be obtained from different trade organisations, manufacturing companies, other companies, surveys and investigations or case studies. There are consultant companies, that extract and compile data professionally from several sources, such as their own investigations, telephone interviews and compilation of other existing data. For instance, 'Energidata' compiles all kinds of energy data, 'Industrifakta' collects data regarding turnover of building materials in monetary terms, and 'Mängda' captures the amount of built-in material on a detailed level (structured according to BSAB).[74]

On behalf of Boverket, SCB has extracted figures for indicators on the national level for following up the environmental objective *A good urban environment,* Fig 2.4. The sources are described and evaluated in (SCB 2002). The indicators pertain to the overall resource use in the building sector, but they are hardly related to buildings, except in indicating energy use per floor area of domestic and non-domestic buildings.

FTR, BR, and even SNI codes deliver basic data for the age-use matrix including location of buildings (co-ordinates), see also Chapter 12.

On the local level, some statistics and reports, on material use in particular, can be obtained from local authorities, such as the Environmental Administration and in the future also from the Ecocycle Council (see also Thormark & Thuvander (2002)). The Environmental Administration collects data on built-in PCB per property and the Ecocycle Council has the task of providing statistics on waste materials (which is unfortunately not satisfactory today because of lacking data).

In addition, the Town Planning Office of Göteborg collects data on buildings. One source is the administrative register where information on building permits and demolition permits are stored. The register is connected to an archive that contains, among others, drawings and demolition plans. From this register the frequency of changes can be obtained, and, to a limited extent, the amount of released material. By frequency of changes, I mean both changes in a specific building and

[74] 'Industrifakta' and 'Mängda' have been engaged by BYKR for calculating material flows on the national level. Industrifakta data have been calculated from manufacturing prices, then converted into sold units with the help of SCB's industrial production statistics, and further converted into amounts of material with the help of weight/unit, etc. The black market is included in the total figures.

changes in the building stock in Göteborg. However, these data are stored in a quite un-accessible way, i.e. as a number of paper documents. Conversely, overall figures for the number of given demolition permits or building permits can be accessed quite easily (Thormark & Thuvander 2002).

The Town Planning Office also provides digital maps with property keys, suitable for GIS applications.

The next source is suppliers, by which I mean companies that both deliver resources to buildings and take care of outputs from buildings. Suppliers often provide information to local authorities and research; they produce annual reports and have internal monitoring. An example of data obtained from a waste handling company based on the company's monitoring system is presented in Table 11.2. To date, only aggregated numbers for building waste can be obtained, but nothing about how much material is released from what kinds of buildings. Examples of energy-use data are presented in Chapter 12.

Property managers produce annual reports and in some cases also environmental reports that show the average figures of energy use, emissions and water use in the owned building stock. Often, general figures about the managed stock are presented, such as type of building, size, number of flats, age and address. Property managers' monitoring systems for energy and maintenance planning (if existing) can generate detailed environmental data for building stocks, especially for energy use (Brunklaus & Thuvander 2002).

Generally, top-down data are allocative and bottom-up data aggregative. A data set becomes top-down or bottom-up depending on at what level the matrix is applied, Table 11.3.

Table 11.2. Example of material data of building waste (outflow) in Göteborg year 2001. Special data processing by Renova (2002).

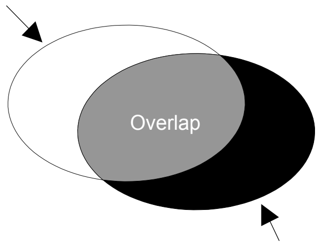
Waste	Amount [t]
Combustible demolition materials	1 900
Non-combustible demolition materials	910
Mixed demolition materials	12 330
Recyclable wood	720
Recyclable metal scrap	740
Gipsum	540
Clean filling material	490
Pure stone material	2 700
Mixed stone material	4 450
Concrete scrap	80
Σ	24 860

Table 11.3. Examples of top-down and bottom-up data on a general level. A data set becomes top-down or bottom up depending on at what level the matrix is applied.

Top-down	Bottom-up
Statistics (SCB)	BR
Research results	FTR
Previous building stock studies	Data stored in a GIS
Annual reports	Masterfile FoB
Suppliers' data	Research rawdata
	Annual reports of property managers
	Suppliers' data

11.2 Level of coverage - evaluation of data sources

Figure 11.1. The level of coverage is determined by the agreement of data needs and available (accessible) data.



To give an idea of how feasible the above described data sources are for EBSIS^{SD}, the level of coverage of data needs and data available will be discussed below (Fig 11.1).

National statistics are aggregated, especially material data and water data, which makes it difficult to allocate data to the age-use matrix. It is difficult to obtain figures on a more detailed level than ‘building sector’. Energy statistics are quite good on a general level: data either represent the type of energy source (carrier) or the amount of kWh for heating and domestic hot water, which can be related to buildings. However, data is not always good enough for detailed descriptions, in compliance with the matrix for all cases, or for a description of all phases of a building’s lifecycle. There is a need for improvement of the material and energy flow statistics in the building sector, with divisions into categories of buildings and constructions, for production, operation & maintenance, waste from construction and demolition, and use of hazardous substances in the building sector. This has also been pointed out in BYKR (2001).

Material statistics are unsatisfactory. However, some improvement of material flow statistics will be seen in the near future, as SNV and SCB have been commissioned to extract flow statistics regarding released materials, with the building sector as one of the sectors.[75] Methods for data capture and documentation of material flow statistics are still under development, and, thus, can still be influenced. One recommendation would be to include specifications from what type of building and from which location materials have been released, in addition to amounts and kinds of material, in the new documentation system. This has also been suggested in Thormark & Thuvander (2002).

A combination of the Swedish Building Register and Property Taxation Register can be used for filling the age-use matrix with data that have a spatial connection. Nevertheless, it is still difficult to obtain building related attribute data, as in the Property Taxation Register properties, and not buildings, are recorded.[76] Today, properties are 2D, but in the near future 3D properties will be introduced. Thus, data collected in the Property Taxation Register will not be easier to allocate to a specific building than it is today (unless building keys are introduced, which correspond to building keys of the building register). However, the

[75] At the end of year 1998, because of EU’s requirement for statistics.

[76] A property can have none, one, or several buildings.

Swedish government, namely the Environmental Department, seems to be interested in an improvement and extension of the building register. For example, it is being investigated whether or not data on energy-use related to buildings can be registered (Miljödepartementet 2002).

On the Göteborg level, it is difficult to find building-related data. Generally, there is better control of the existence of environmentally hazardous materials compared to other materials (PCB inventories). Suppliers' data are valuable, but it is somewhat difficult to allocate the data to a specific kind of building (domestic, non-domestic) or activity (demolition or maintenance). Energy suppliers have control over emissions related to the energy source used. Flow schemes established on the Göteborg level for energy use, waste material and water flows, help to identify all relevant actors.

The figures of the Environmental Administration are often aggregated data, based on data from suppliers, and, as already mentioned in Section 9.1, it is difficult to identify the buildings behind the figures. Municipalities, in turn, report these data as statistics to the national level.

The register for building permits and demolition permits at the Town Planning Office in Göteborg is a valuable source for quick generation of general figures. For information about the age of a building and scope of the demolition (demolition of small parts of a building or demolition of an entire building), special processing is necessary, both automated and manual, which is quite labour intensive.

On the property management level, the level of coverage of energy data is good, but not of material data. The material data, if available at all, is mainly qualitative and not quantitative. However, property managers use checklists and, increasingly, environmental assessment methods, that hopefully will lead to better data availability in the near future, Table 11.4.

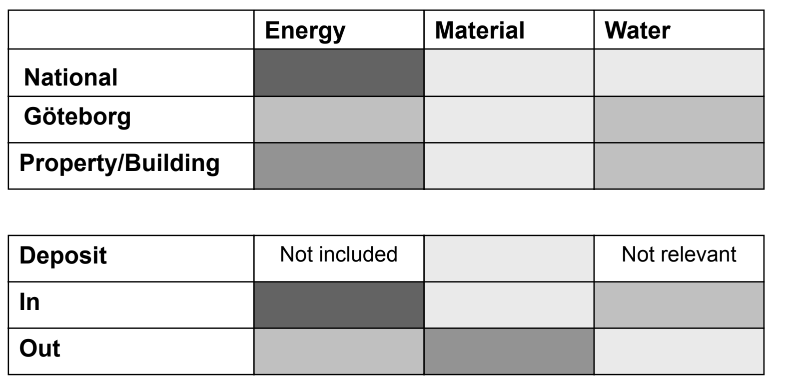
+	-
Good coverage of energy data in different units	Little knowledge about materials and chemicals (more qualitative than quantitative data)
Possible to translate economic data into environmental data (both into quantitative and qualitative data)	No comprehensive data on wastewater from specific properties
Knowledge about tenant change as an indicator for environmental effects	Not much data available for carrying out time series

Table 11.4. Evaluation of property managers' data on a property/building level (Thuvander & Brunklaus 2002).

Generally, companies' annual reports, environmental accounts, and internal monitoring data are useful data sources. Obtaining access to monitored data, which can be the amount of delivered resources and/or billed resources, is advantageous as models built on these figures; a) will be closer to the real resource use, and b) do not explicitly need to rely on calculations based on rough estimates. Also, research data are valuable if existent.

Fig 11.2 summarises the above discussion by giving a coarse evaluation of environmental data's level of coverage on the different spatial levels related to input, output, and deposit of resources. The evaluation is graded from poor to excellent. Environmental data are judged regarding availability and suitability in relation to the age-use matrix and the description of buildings. For a more nuanced evaluation, all data sources presented in Table 11.1 should be investigated in more detail.

Figure 11.2. Coarse evaluation of coverage level.



Energy data have the best level of coverage. The level of coverage for material data and water data, on the contrary, is not satisfactory. Data exist but are not stored in an easily accessible way and are not co-ordinated. Thus, data cannot be gathered efficiently from sources that exist today and therefore case studies are necessary for data generation. Moreover, the data time perspective needs to be further investigated.

11.3 Availability is not always accessibility

So far, I have discussed availability of different data. When discussing data and potential data capture (data capture for EBSIS^{SD}), we are faced not only with a matter of data existence or non-existence, but also in what form data are available, i.e. if data can be used directly or if data have to be translated (e.g. costs into amounts). Last but not least, it is of crucial importance whether or not data are accessible, Fig 11.3.

Availability means that data exist but it might be difficult to gain access to it. Accessibility, then, can be restricted because data might be confidential or because of financial reasons.[77] Confidentiality restriction is often a concern for companies that do not want to deliver data because it is regarded as sensitive for the company's operations (marketing, competition). Data may also be available for one study but not for others (secrecy aspects allow access to data only for a certain purpose). This may be contrary to local authorities' commission to meet public needs following principles of openness. Additionally, secrecy aspects may have an impact on the applicability of EBSIS^{SD} when data allowed to be used for research purposes only, is also used for education.

Financial aspects are other restrictions on data access, as costs for data are considerable, especially when large amounts of data are handled. Special data processing with a limited number of variables is less expensive. However, these data are often of limited use as they are compiled for a certain purpose and thereby possibly not suitable for other purposes. High data costs are also an obstacle to implementing GIS-based analysis. Data can be bought from, among others, SCB, National Land Survey, or companies dealing with data collection.

In general, environmental data capture is difficult, since often data are simply missing, such as amounts of various built-in materials, or are measured in different ways by different actors. For example, an energy supplier measures total kWh delivered to a certain subscription, a property manager/owner may measure kWh or kWh/m^2 per subscription and/or building. Data may not be stored and if data is stored, the data format can differ from paper documents (tables, diagrams, text, or bills) to databases. Hopefully, the situation will improve in the near future as environmental issues become more important.

For efficient data capture, it is crucial that EBSIS^{SD} overcomes the above mentioned obstacles by offering incitement to data providers.

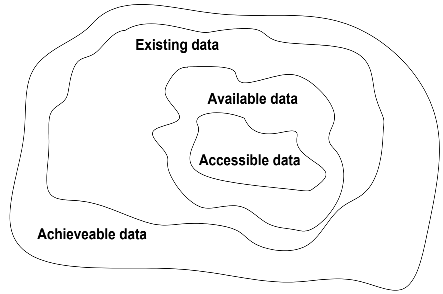
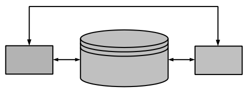


Figure 11.3. According to my interpretation, accessible data are a subset of the available data set, which in turn is a subset of existing and achievable data sets. Existing data (but non-available) are measured/captured data stored in such a way that they are difficult to get hold of (unreadable data format, unpublished research results, data compiled in a binder of a former employee, etc.). Achievable data are all data, which could be captured if desired (unlimited amount of money, time, persons, etc.).

[77] For a broader discussion regarding data access within environmental research regarding building and construction, see also Thuvander & Thormark (2002).



12. GÖTEBORG AS AN EXAMPLE

After outlining EBSIS^{SD}, elucidating the use(r) aspects, and presenting a number of data sources on different levels, it became time for the initial tests of the conceptual model. An age-use matrix with a spatial dimension was constructed, and a number of data sources to support EBSIS^{SD} were explored, addressing conditions in Göteborg. Chapter 12 illustrates some of the "experiments" carried out with data from SCB, the Town Planning Office, from property managers in Göteborg, and data from Göteborg Energi AB. The test gives an idea of how these data can be applied to building stock descriptions and for filling the matrix that uses GIS applications. The test is also a kind of data accessibility analysis.

12.1 Data sources

The main data and data sources for the Göteborg study are:

- the Swedish Building Register (BR) managed by the National Land Survey[78] combined with data from the Property Taxation Register (FTR), SNI codes, population statistics and road net with addresses delivered from SCB. All data have a spatial reference.
- digital maps of Göteborg with associated property keys provided by the Town Planning Office.
- (three) property managers in Göteborg that delivered environmental data (heating and operation energy, water use) and addresses of the properties.
- energy data for 96 sections in Göteborg (covering all of Göteborg) provided by Göteborg Energi AB (GE).

Thus, data from different sources are merged together. The BR data comprise all existing buildings in Göteborg in the year 2000, about 68200 records. The FTR data contain data on properties, evaluation units of properties and of taxation units. In many cases, a property contains only one building, however, a property can be made up of several buildings and a building may also have several evaluation units. This entails some problems when combining BR data and FTR data. BR and FTR data (and to some extent SNI code data) have been used for constructing the age-use matrix with a spatial dimension. In the BR and FTR every building and property has been provided with a specific key (Fig 12.1).

Figure 12.1. Example of property keys and building keys. There are three buildings on the property in the example.

Property key	Building key
140000053	14800023035
140000053	14800023036
140000053	14800035495

Besides several attribute data, such as 'year of construction', 'year of reconstruction' or 'floor space', each building has a spatial definition via a co-ordinate allocated to the centre of gravity of the building. The same applies to properties. Co-ordinates for buildings and properties are available from both the national co-ordinate system called RT90 and Göteborg's local co-ordinate system. Mainly the national system has been used in the study because more data are available.

The Town Planning Office provides a GIS-based map of Göteborg where properties, buildings, and streets can be identified. Properties are provided with property keys[79] corresponding to the property keys of the BR and FTR. The map is used to illustrate linked attribute data, which

[78] In Swedish: Lantmäteriet. Homepage http://www.lantmateriet.se/.

[79] However, 1828 property records are without a property key.

in the example, are mainly 'type of building', 'year of construction', and 'energy use' data. Further, it has been determined whether or not the map can be used for data generation, such as building area on ground level and the relation of this built-up area in proportion to the total size of the property.

Data from property managers comprise data from three property managers in Göteborg. Two of them are municipal owners that manage blocks of flats and the third property manager is a private one that manages both blocks of flats and non-domestic buildings. The delimited number of data from property managers has several reasons. For the property managers, it takes time to compile data (data are stored in different systems and data has to be compiled to suit our purpose), some property managers were not positive to deliver data on that level of detail, some did not have data. Additionally, as this study is a test, full coverage is not necessary to draw initial conclusions, and minor problems with data can become insurmountable problems with data sets that are too large. Also, because data were delivered in paper documents (contrary to my expectations to obtain data in digital format) extra work had to be conducted to digitalise the data. Only energy data for heating was obtained from all three managers, two managers had electricity data and only one had data on water use. Data cover the years 2000-2001. A total of about 600 records for properties with heating energy data were obtained.

Property managers provided addresses and property designations for the properties owned. A property designation consists of 'name of quarter and a number', for example, 'OLIVEDAL 14:1'. Property keys, as used in the BR or by the Town Planning Office, are not used by property managers. A spatial connection is indicated by the address.

Data from GE, the main energy supplier in Göteborg, were for the annual energy use of district heating, gas, and electricity for the year 2001. Data comprise both private and industrial[80] customers within GE net's distribution region and are for delivered energy in (kWh). Data are represented in different sections, which in turn consist of subsections, which then result in a number of 'meter districts'[81]. In each district, there are several measuring points[5] at which the meter is read. In total, the town is divided into 96 sections, which geographically correspond

[80] Delivery of electricity for production.

[81] In Swedish: avläsningsdistrikt.

to the city districts of Göteborg, comprising 590 districts and 260 000 measuring points. The data obtained from GE were aggregated on the district level corresponding to geographic areas of subsections. GE had no map representations, but data files that described the street addresses were included in the area (addresses for measuring points for the meter reader).

The geographic coding of the obtained energy statistics has been based on a geographic database on Göteborg's road net with addresses. Coding problems occurred due to incomplete address data from GE (no street numbers). Statistics of this type from GE were unfortunately not possible to extract for two or more years back. Interesting for our study, is that data for delivered energy have been obtained, i.e. 'real' data, and not modelled energy-use data. However, data are not related to buildings or properties but to 'meter' districts or measuring points at which the meter is read and that can comprise several buildings or parts of buildings, such as flats.

BR's general data issues and data content, such as compulsory basic information (property and building key, administrative affiliation, geographic location, assessment information, owner, and status), completing information (location within a statistical area, information from building permits, building area), and voluntary information is discussed in Thuvander (2000) and Stendel (2000). Property managers' data (kind and system limits for data) are discussed in Brunklaus & Thuvander (2002), Thuvander & Brunklaus (2002).

Tests and analysis of the above-described data were carried out with the GIS software program ArcView. Data from the National Land Survey, obtained in digital form on a CD containing a number of tables, were pre-processed in Microsoft Access before linking the tables to ArcView. Data from property managers were obtained on paper, i.e. print outs of the energy data program where data are presented in tables and diagrams. The paper documents were scanned in an OCR[82] mode directly to an editable table in Microsoft Excel. The tables, then, were exported as dbase files into ArcView. Data from GE were obtained in an Excel file, which was exported into ArchView.

Time is handled as one time slice for the reference years 2000-2001.

[82] Optical Character Recognition. Paper documents and images were scanned into editable formats.

12.2 Matrix and visualisation

The fundamentals of the age-use matrix have been presented in Chapter 10. The matrix is also intended to be the basic structure for visualisation of data sets. Visualisation of the matrix on a map is only possible if a spatial connection of the objects in every cell is given, meaning that every building, and the related aspects of interest, has a reference to a map. This reference point is given in the BR for every building and indirectly by addresses. Property managers' data, as well as GE data, include addresses (addresses for subscriptions/position of meters).

As pointed out before, the level of detail is an important but difficult matter. The same goes for the choice of appropriate spatial resolution. The level of data presentation differs from the level of data content and depends, of course, on the use of the results, i.e. national comparisons or reporting; regional benchmarking; information on a specific partial building stock in relation to another partial stock.

Resolutions for spatial presentations found in other studies, besides representation of the urban level, are the postal code level (Section 8.3) or grids (Section 8.4 and 8.6). The spatial age-use matrix for Göteborg has been extracted both for the urban level and for one grid. Visualisations on the urban level provide an overall view, see Fig 12.2, Fig 12.3 and grid representations provide a more nuanced picture of the building stock, Fig 12.7. Table 12.1 presents the number of buildings in a non-spatial age-use matrix.

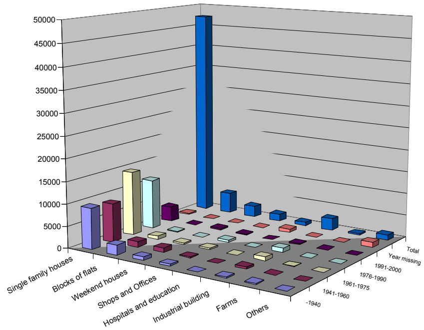
In this study, grids corresponding to map sheet divisions have been suggested. The grids are 1 600 m x 1 200 m. Similar grids should be possible to extract for other Swedish towns. Changes of these grids (size, position, boundaries) over time are unlikely as long as new regulations are not established.

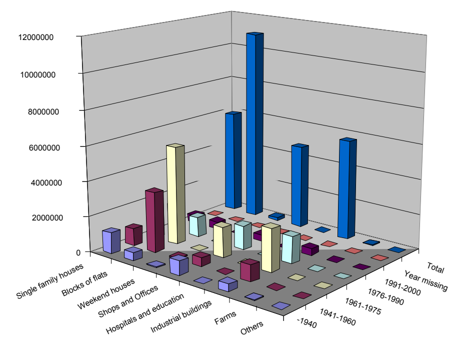
For closer considerations of partial stocks, or parts of the town, individual properties and/or buildings are distinguishable. Spatial limits are defined by the boundaries of the municipality of Göteborg, also defined as densely built-up area (Fig 12.2), and the chosen grids.

Table 12.1. Example of age-use matrix for Göteborg (number of buildings and floor area year 2000), special processing of FTR data by SCB.

Number of Buildings

Building stock	Use of buildings	Year of construction					
		-1940	1941-1960	1961-1975	1976-1990	1991-2000	Year missing
Domestic	Single family houses	9324	8719	14516	11188	3389	270
	Blocks of flats	2232	1276	807	233	141	16
	Weekend houses	789	1007	356	0	404	17
Non-Domestic	Shops and Offices	434	200	422	436	114	7
	Hospitals and education	-	-	-	-	-	763
	Industrial buildings	222	466	856	958	225	7
	Farms	234	21	9	5	11	-
	Others	-	-	-	-	-	1183





Building floor area

Building stock	Use of buildings	Year of construction					
		-1940	1941-1960	1961-1975	1976-1990	1991-2000	Year missing
Domestic	Single family houses	1196053	971166	1882645	1466169	443528	1185
	Blocks of flats	443528	3422890	5618325	1120277	392886	-
	Weekend houses	57570	55703	21361	0	40057	-
Non-Domestic	Shops and Offices	831932	498142	1758016	1371498	352178	-
	Hospitals and education	-	-	-	-	-	-
	Industrial buildings	414938	943346	2445052	1539726	381936	-
	Farms	27734	2081	1124	888	1373	-
	Others	-	-	-	-	-	-

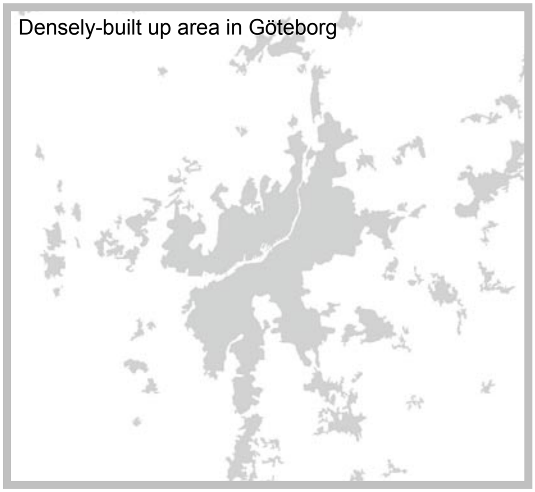
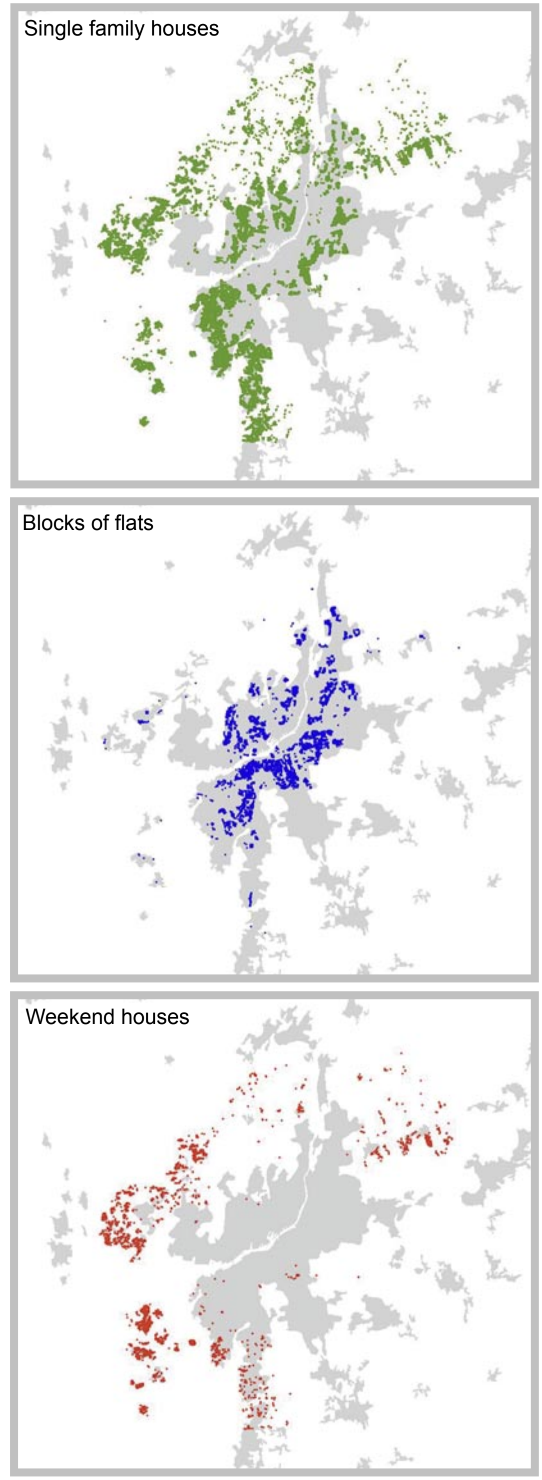
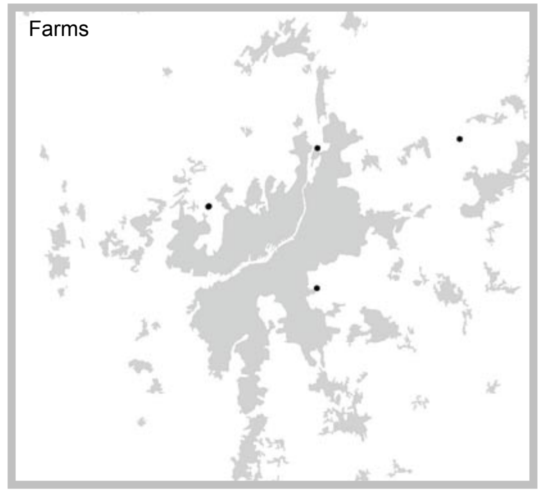
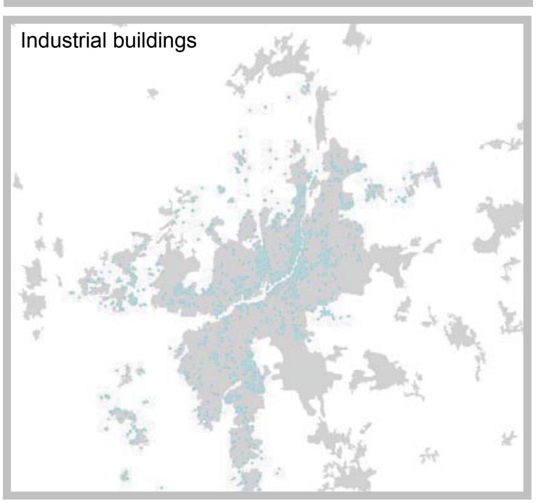


Figure 12.2. Spatial age-use matrix on the Göteborg level. The use classes represent all buildings existing in the year 2000. No further division into age-classes. Data sources: BR and FTR



Domestic buildings





Non-domestic buildings

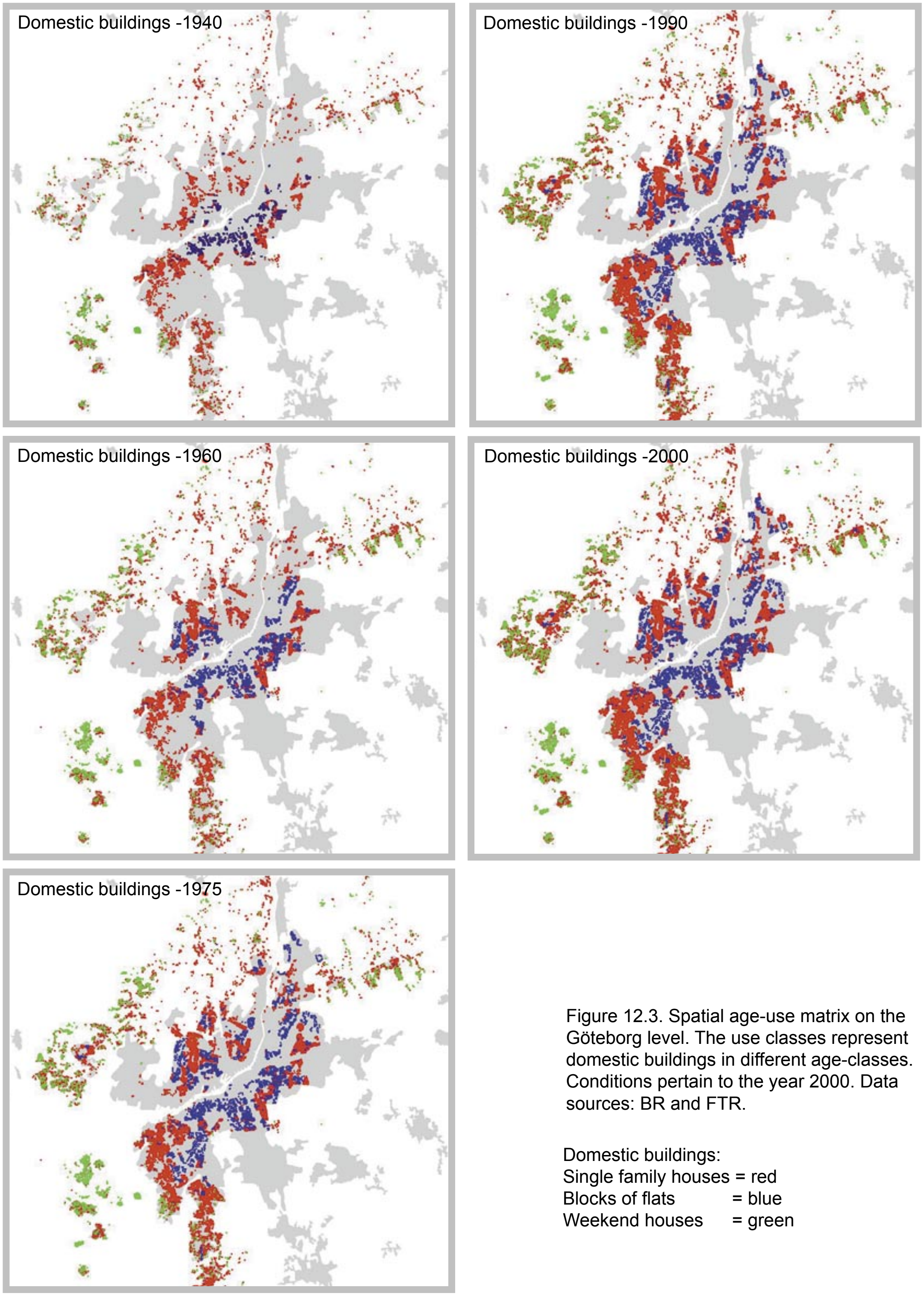


Figure 12.3. Spatial age-use matrix on the Göteborg level. The use classes represent domestic buildings in different age-classes. Conditions pertain to the year 2000. Data sources: BR and FTR.

Domestic buildings:
Single family houses = red
Blocks of flats = blue
Weekend houses = green

12.3 Digital map from the Town Planning Office

The digital map of Göteborg, containing property areas and building areas, is used for representations of buildings in 2D and 3D, and for the illustration of property boundaries and land-use. The map has also been tested for data generation, in cases such as calculation of built-up area on a property or the ratio of built-up area and property area. The built-up area, in turn, was intended to be used for calculating roof areas. Property areas and building areas, then, were intersected in ArcInfo, however, with limited success as too many interfering lines made it impossible to generate reliable data, see Fig 12.4

Figure 12.4. Cut-out from the Göteborg map. Too many interfering lines made it difficult to generate reliable data on built-up areas on a property and carry out other analyses of related issues.

12.4 Data from property managers

Environmental data obtained from property managers have been ‘geocoded’ via the addresses and connected to BR and FTR data. Between 50 and 75 percent of the addresses gave matching results. Thus, even property managers’ data can be visualised on a map. In this Chapter, however, I only present some general figures for energy and water use so that the reader can get an idea about the amount of resource use that is related to buildings, Table 12.2.

Table 12.2. Example figures of environmental data obtained from property managers in Göteborg.

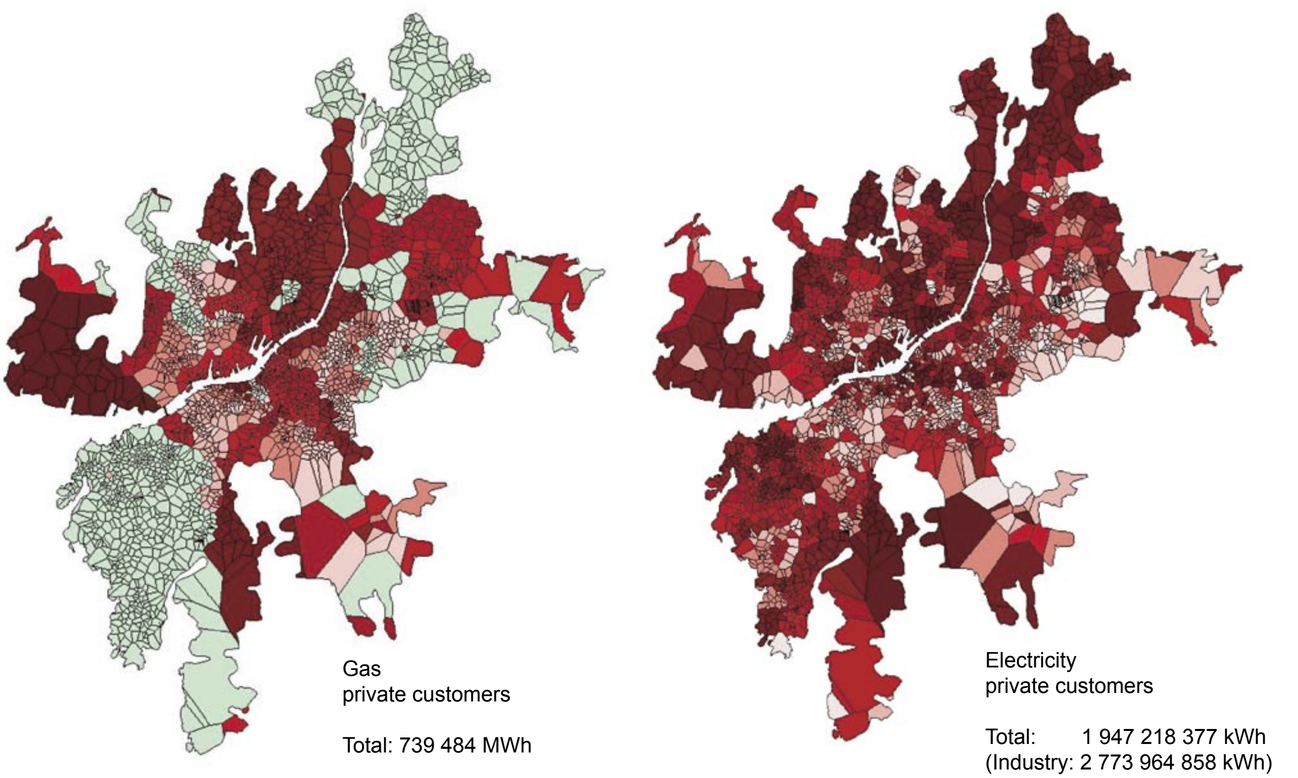
Environmental data obtained from property managers (per property or group of property)		**Property manager**				
		1 – private domestic & non-domestic buildings		**2 - municipal domestic buildings**		**3 - municipal domestic buildings**
		2000	**2001**	**1999**	**2000**	**2001**
Floor space	Average [m^2]	3 540				7 610
Heating energy	kWh/ m^2 year	105 (max 205)	227 (max123)	170 (max 331)	175 (332)	175 (max 298)
Electricity appliances	kWh/m^2 year	28 (max180)	29 (max 175)	-		-
Water use	m^3 / year	2 284 (max 19 643)	2 196 (13 457)	-		-
	l/m^2 year	1 106 (max 7 564)	1 063 (5182)	1 759 (4372)	1 762 (4807)	-

Maximum figures are valid for “worst case” property.

12.5 Energy data from suppliers

From the energy data provided by GE, an energy model for Göteborg has been created for three energy sources: natural gas, district heating energy, and electricity. The amount of energy use is presented in districts corresponding to the distribution area of energy/utility plant, which Fig 12.5 illustrates. Thus, energy figures are allocated to streets and addresses. The next step is to couple energy use to individual buildings. Fig 12.6 gives a 3D illustration of the district heating energy use in Göteborg. The figures for electricity tell us nothing about what the energy is used for, i.e. if electricity is used for heating or electrical appliances. The reference year is the year 2001.

Figure 12.5. Energy model for energy distribution in Göteborg for different energy carriers for the reference year 2001. Classifications on the maps illustrate the energy use within subsections. The darker the red the higher the energy use.



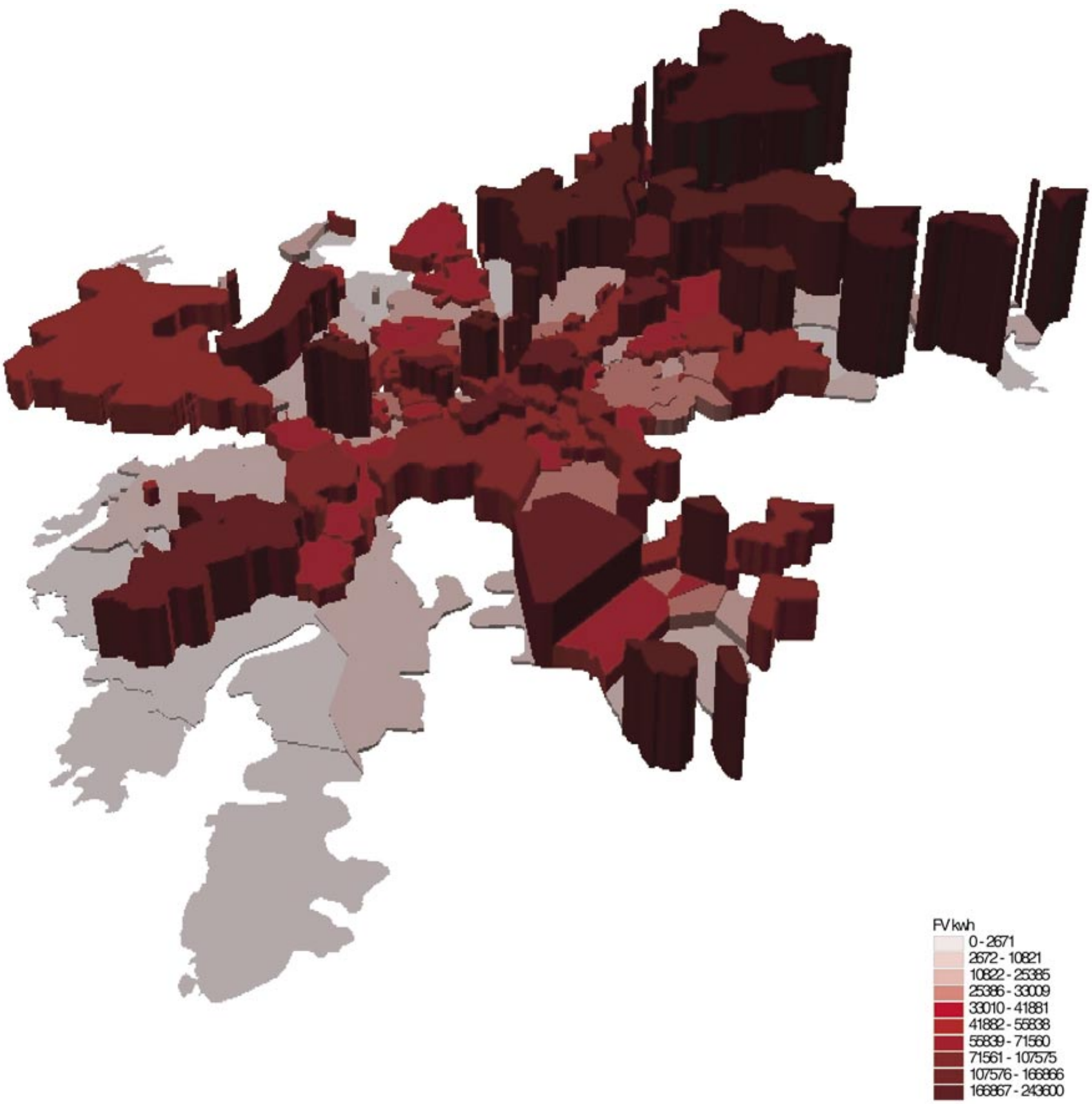


Figure 12.6. 3D energy model for the district heating energy delivered by GE in the year 2001. Total: 3 926 861 MWh.

Figure 12.7. Göteborg divided into grids according to map sheet divisions. The grid marked in grey has been studied further, see Fig 12.9 and 12.10. A grid has an extension of 1 600 m x 1 200 m.

12.6 Data sources for description of building stocks

After establishing a geographic-coupled, age-use matrix and an energy model with top-down figures for three different energy sources for Göteborg on an urban level, data sources were tested on a smaller geographic area – one grid as illustrated in Fig 12.7. A layer model was constructed and Fig 12.8 visualises the geographic context of the model. In addition, Fig 12.9 illustrates the information layers available for constructing the matrix and a top-down energy model. For the matrix, the number of buildings was calculated and energy values were calculated for different energy sources, although not explicitly related to the matrix. Even additional variables, such as population data and three dimensional representations of buildings are presented and calculated for the grid. These information layers can be extended, for example, with information layers containing data on material use and further data on geometric extensions and points of the compass of buildings.

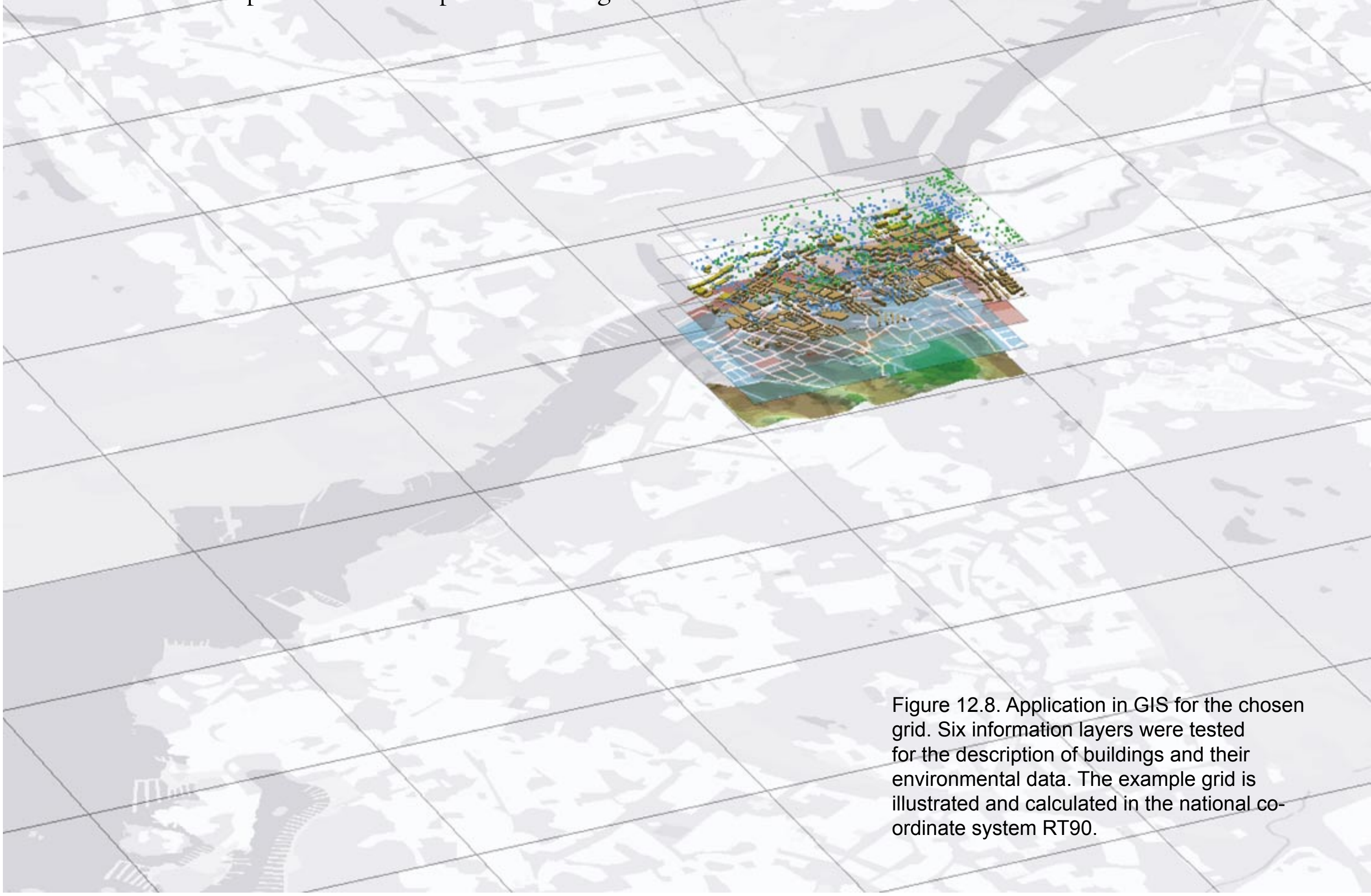
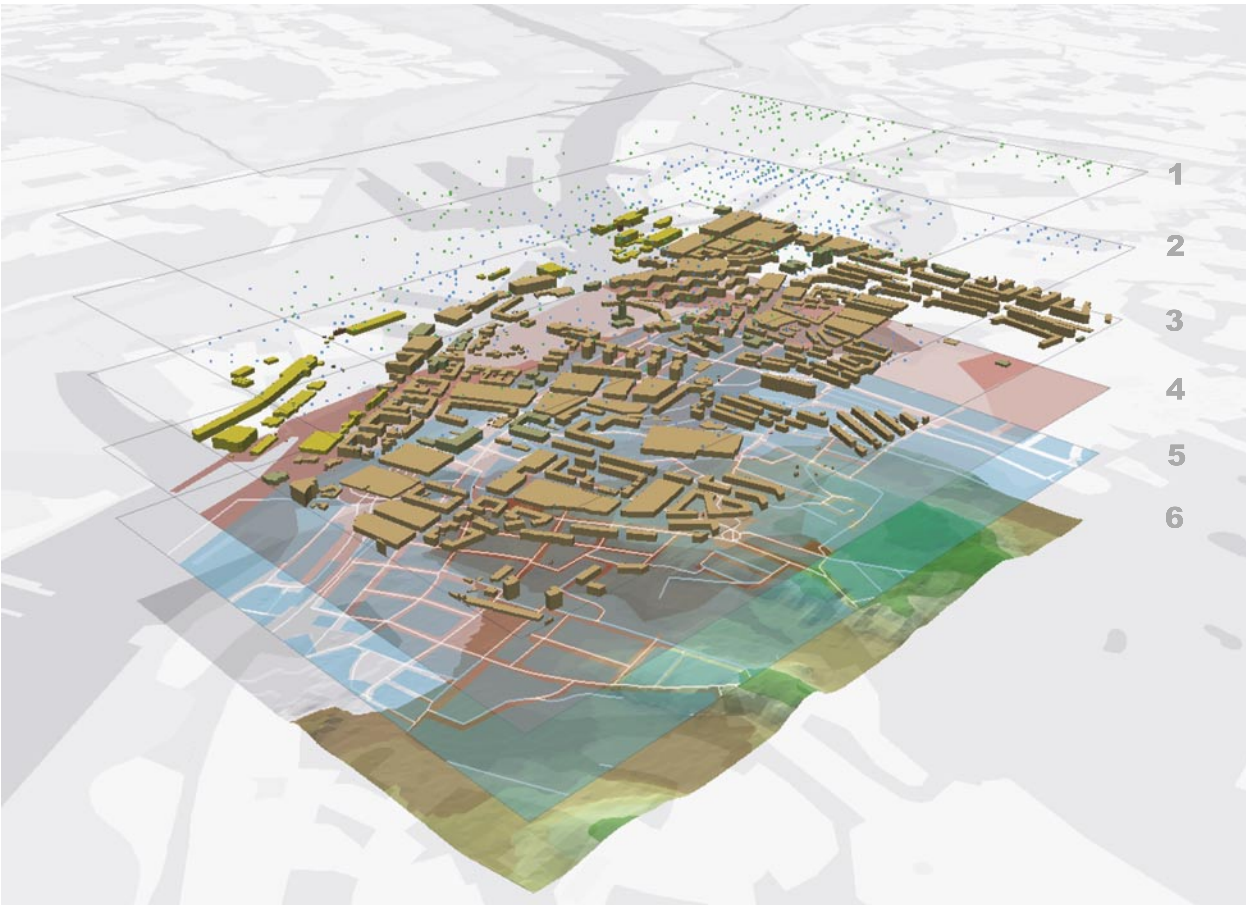
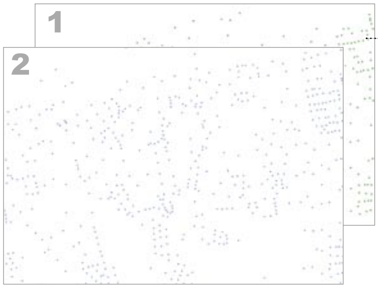


Figure 12.8. Application in GIS for the chosen grid. Six information layers were tested for the description of buildings and their environmental data. The example grid is illustrated and calculated in the national co-ordinate system RT90.

Figure 12.9. Geographic information layer model for a grid for building stocks and energy use.





Information layers

Information layer **1**: Population co-ordinates:

(green points)	23 090	persons live in the actual grid
	612	working places (15 different branches)
	7 601	employees

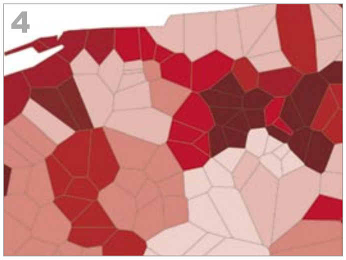
Information layer **2**: Building co-ordinates
(blue points, same co-ordinates as population)

Information layer **3**: Buildings and their 3D presentation

Buildings:	352	329	Blocks of flats
		23	industrial buildings (no year of construction)

Average year of construction: 1938

-1940	234
1941-1960	18
1961-1975	41
1976-1990	24
1991-2000	11



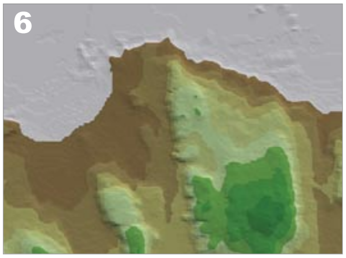
Information layer **4**: Energy model (map illustration for electricity use - private customers)

Energy use in the grid for the reference year 2001

Natural gas	22 133 MWh (11 sections)
District heating energy	567 270 kWh (11 sections)
Electricity private customers	99 660 372 kWh (28 section parts)
Electricity industry	60 396 764 kWh (11 sections)

Information layer **5**: Property area

Information layer **5-6**: Land-use and road net



Information layer **6**: Terrain model

12.7 Evaluation of the sources

Most of the data and data sources discussed in this Chapter pertain to the matrix and visualisation of the matrix with different spatial extensions. An example of environmental data that is to be included in $EBSIS^{SD}$, is the energy-use data from GE and from property managers. The energy-use data from GE comprise top-down data and the energy-use data from property managers comprise bottom-up data.

An age-use matrix filled with the number of buildings (or properties), year of construction, and floor space area can be established for different years and as GIS-based applications on different spatial system levels, i.e. urban level and grid level. This concept works best for domestic buildings and, within that category, for single family houses. Also, it is easier to distinguish the number of buildings than it is to obtain good quality results for floor space and year of construction. The most complicated properties to obtain good quality results on are properties that are not taxed (hospitals, schools) or properties taxed according to other methods than building value (industrial buildings).

In general, it is possible to establish additional age-use matrixes for earlier years than the chosen reference year. However, this is an expensive procedure, as special processing is necessary and older data are stored in other data formats in the SCB archives.

Worth mentioning are the differences between data analysed in GIS applications (a combination of BR and FTR data) and the special processing without geographic reference as conducted by SCB (Appendix B). The largest differences in the domestic stock occur in blocks of flats. One reason may be that blocks of flats with mixed activities are taxed both as dwellings and shops/offices. Another reason may be difficulty in assigning values to buildings on a property, which can lead to double accounting. Today, an indication of the size of the stock can be obtained. In the future, it is desirable to improve data sources in order to make better analyses of the building stock possible. Foremost, improvement in BR data would be beneficial along with coupling it to FTR data. This will become even more important when properties are introduced in 3D divisions. I suggest an extension of BR data because some of the environmental data are more closely connected to the buildings than to the properties, as for example energy issues.

It seems reasonable to use map sheet division for the resolution level of grids. The grids are large enough for the application of the matrix but small enough for inventories of all buildings inside a grid. With help of the grids, it will be possible to identify differences between the building stock in different parts of the town, i.e. the city centre or edge. In addition, the grids make it possible to process the large amount of data necessary for a grid-layered model with reasonable efforts.

The grid layer model (Fig 12.10), is a starting point for integrating information layers for different kinds of environmental data and other building related data. So far, only top-down data for energy use are included, thus, the model needs to be extended with layers containing other environmental data. The grid-based layers may also be advantageous for representing indicators.

Property managers' environmental data are principally of interest as total amounts of annual energy use can be obtained for various aggregations, such as (kWh) or (kWh/m^2), for different types of buildings and different uses, such as heating, electrical appliances or use of water. However, a lot of manual processing of data is needed for obtaining input data.

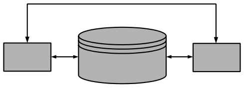
An additional thought concerns the inconsequent use of existing keys. If there are building keys and property keys, why not use them? - At least by all people and all systems within one and the same organisation. Today, property designations or addresses are referred to in communication concerning properties: for building permits, demolition plans, in property managers' registers, and when buying and selling properties. For example, neither building keys nor property keys are used in the administration register for building permits or demolition permits (but at least property designations are used). For any improvement, the building key, or at least the property key, should be better implemented in practise among property managers and municipal authorities. Using existing building keys would support the recognition of buildings on a property and the addition of other attributes, for example, EBSIS^{SD} data.

The quality of the existing digital map of Göteborg is good enough for the visualisation of buildings and properties on a map, but not satisfactory for analysis in GIS as long as data can only be related to the property layer and not to the building layer (Fig 12.10, layers 3 and 5). With a better map even the volumes of buildings could be calculated.

In conclusion, the study has shown that a geographic-coupled, age-use matrix can be established for the urban level, as well as the grid level. Suppliers' data and property managers' data are valuable sources for EBSIS^{SD}. Worth emphasising is that measured energy data have been used for modelling, instead of calculated data, as in the models presented in Chapter 8. Still, more data processing is needed for obtaining more comprehensive and integrated results. Visualisation of the results gives an additional dimension for interpreting data sets and increases the transparency of data/results. Finally, it is still necessary to carry out in-depth case studies of a number of buildings in order to add further information layers for material and water use, and to improve the integration of the information layers. Thus, the study forms a solid foundation for further development of EBSIS^{SD}. A survey of a limited number of buildings within a few chosen grids may be a good starting point for further data collection.

PART V

Final Comments



13. REFLECTIONS AND CONCLUSIONS

A conceptual model for an environmental building stock information system, called EBSIS^{SD}, has been developed and the conditions for establishing such a system have been examined. The relevance and feasibility of EBSIS^{SD} have been investigated through interview studies and literature studies, and modelling aspects of EBSIS^{SD} have also been elaborated through studies of state-of-the-art, field trips and test runs of data sets with the City of Göteborg as a case in particular. To tie all the aspects together, we will re-examine the research questions posed in Chapter 1.

13.1 Relevance

The first issues of interest, and the most crucial to the existence of EBSIS^{SD}, are issues of relevance. Is there any need for environmental information that addresses building stocks? By whom? – My studies have shown that there is actually a need for better knowledge on the environmental conditions of building stocks, both on a national level and on a more regional/local level. The regional and local level is deemed as more fruitful for the development of EBSIS^{SD} than the national level (Chapter 9). Actors on the local level have more outspoken and concrete interests, and, consequently, are valuable sources when choosing variables and testing EBSIS^{SD}. Interested actors are to be found among property managers, the Environmental Administration of the City of Göteborg (a municipality) and the Ecocycle Department, and suppliers, such as Göteborg Energy. Also, EBSIS^{SD} is of interest to environmental researchers and researchers within the field of sustainable building, as well as students.

What kind of applications do potential users need? – Applications should help to keep better track of the environmental performance of building stocks and increase knowledge about them. Applications may range from 'simple' descriptions of the built environment, over benchmarking, to planning issues. In a long run, applications should support simulations of different scenarios. Benchmarking is of interest for comparisons between actors or for comparisons between the average performance of a specific type of building stock or the whole building stock. Applications that include the location of buildings would help to better understand the starting point for sustainable development of specific places.

The resource perspective can be expanded and associated with design issues. The shape of the building, the organisation of space inside the building and even the combination of materials are vital to the scope of the impact of buildings on the environment. Here, the architect can play a vital role by creating inspiring surroundings and at the same time promote recycled materials and the "re-use" of buildings. With this in mind, the architect may strive for creating buildings (new and reconstructed) with high aesthetic, environmental and functional values and with low impact and energy use.

Thus, $EBSIS^{SD}$ users may be found among most actors that deal with a building during different phases of the building's lifecycle (design phase, use and management phase and demolition phase). Nevertheless, the applications will differ for each actor.

A fundamental observation is that knowledge about built-in material is often of interest for handling environmentally hazardous materials and issues concerning re-use and recycling. In the long run, building without the use of "new" resources could be interesting as a vision for the future (discussion in Hassler (1999), Thuvander (2000)), i.e. the existing building stock could be considered to be a material resource.

13.2 Modelling

The next issue in terms of the scope of the model is: What data needs to be stored to provide statements about buildings and building stocks from an environmental perspective? Environmental data that describe inflows, outflows and deposits of material, energy and water are requested. But, also information about the lifetime of buildings and parts of buildings, property management aspects, climate issues and exposure environment are of interest as buildings should be considered in a temporal and spatial context. The temporal aspects concern year of construction, re-construction and demolition, as well as change of use and change of tenants. As buildings have a unique location, $EBSIS^{SD}$ should include spatial aspects, i.e. the location of buildings. Further, general aspects, such as type of building/property, geometry and structure, owner type and localisation should be included in the model. Examples of variables to be included are given in Chapter 10 and Appendix A.

Are there already systems (database systems, structures or tools), that can handle and manage building related environmental data? – Yes, there are. In my studies I have identified existing structures, such as BSAB, SPINE and GIS as the bricks for constructing the EBSIS^{SD} database structure (Chapter 7). These structures are advantageous for particular issues and should be applicable to the proposed EBSIS^{SD} with a few modifications. BSAB, an established classification system within the Swedish building sector, should be implemented as the basic system for structuring building related data, accomplished with time indexes for building parts and elements. SPINE, an information system for handling environmental data, is useful for handling resource flow data and, thus, could be applied to EBSIS^{SD}, representing the different phases of a building's lifecycle. GIS can handle all data with a spatial connection, allowing visualisation of spatial distributions, generation of data, and linking and matching with other databases (a kind of platform).

Moreover, other environmental building stock modelling efforts outside Sweden have inspired modelling EBSIS^{SD} from the conceptual perspective, such as using a top-down and bottom-up approach and an age-use matrix in combination with a spatial matrix (Chapter 8, and applied in Chapter 12). The City of Göteborg case study gives the first indications of the potential of such a model.

13.3 Feasibility

The final issues to be tackled are the ones that address feasibility. Is it possible to collect relevant data? How? Where? – My studies of an EBSIS^{SD} structure for many users with a focus on the regional and local level have shown that suitable data for direct input into a database is scarce. Energy data have the best level of coverage in relation to the variable list developed for EBSIS^{SD}, whereas the level of coverage for material flow data is not satisfactory. Data are not stored in an easily accessible way and are not co-ordinated, and, thus, cannot be gathered efficiently from the sources that exist today. Therefore, case studies are necessary for data generation. Also, time-related data must be further investigated. Nevertheless, there are several data sources that contain relevant data, such as statistics and register data on the national and local levels, companies that compile and sell energy-related or material-related data, research data and reports, annual reports of companies and internal data from companies gathered by auditing systems (Chapters 11-12).

If EBSIS^{SD} is to function as an 'institution', i.e. in demand by many actors in the building sector and not a once-and-only phenomena, it will be necessary to develop data collection and storage routines. Examples are the improvement of the Swedish building register or a more consequent use of existing keys for the identification of buildings on all levels (national and local). Further, when establishing new statistics, as is underway for material flow statistics in the building sector in Sweden, it would be valuable to add to such a reporting system variables that describe, among others, the type of building the material comes from. Other sources that could be improved are demolition plans (more unified) and better implementation of building product models in all phases of a building's lifetime. Stricter environmental legislation and regulations is one approach the Swedish building sector believes in (Baumann et al. 2002).

Re-thinking in terms of established variables could be called for. The amount of energy use has been of interest for a long time, as well as energy source. However, it would be interesting to compile these figures together and translate them into emission figures. From an environmental point of view, figures for the CO_2-equivalent instead of kWh (or both) would be valuable.

What incentives will be available for data providers? Again, regulations and laws can be one incentive. Another incentive is that data providers themselves will be users of the EBSIS^{SD} services and pay for the services with data sets. The users, preferably, will collect relevant data in connection with their ordinary activity. However, this doesn't mean that the scope of their data collection should not be expanded to meet future demands.

Generally it is difficult to find consistent data on a building level because many of the data sources address properties instead of buildings. The future 3D division of properties (today 2D) will not solve this problem. The identification of the location of a building as part of a property, rather than by property only, and consistent and standardised keys should be adopted by all actors in the building sector. This would support data and information transfer between actors, which is not the case today (Chapter 12).

In the Göteborg study, the conceptual model has been tested with energy-use data from suppliers representing the top-down approach and, to a limited extent, with property managers' environmental data for energy and water use representing the bottom-up approach. The spatial age-use matrix has been filled with the number of buildings (properties), year of construction, and floor space area from the BR and FTR. These sources have been evaluated as useful to the EBSIS^{SD} purpose. Data capture may also be improved if 'building declarations' and 'energy declarations' are introduced.

In summary, it is possible to collect relevant data but with varying grades of exactness and difficulty in the act of collection. Even if data are available, it can be difficult to gain access to them because of company secrecy or for financial reasons.

Finally, the relevance, feasibility and database modelling aspects are strongly interconnected. The users' needs will shape the content of EBSIS^{SD} and the existence of EBSIS^{SD} greatly depends on users and likewise data sources.

13.4 Future research/work

Even future work will deal with relevance, feasibility and modelling. Concluding from the above, it is obvious that the most urgent task for the nearest future is to attract the interest of 'real' users. It is not the researcher who decides if EBSIS^{SD} exists or doesn't, but needs and demands that do so. Also, needs and demands are decisive for for EBSIS^{SD} possibilities to live a life of its own and to become an institution.

The next step will be prototyping. Hereby, the compatibility with the BSAB-based models, that have already been developed, SPINE and GIS will be a crucial part of modelling. Generally, for the development of an EBSIS^{SD} prototype, there are *several ways* to go:

1. To develop a relatively simple, indicator-oriented prototype
2. To develop a complex, research-oriented prototype
3. To develop a hybrid prototype (research- and practitioner-oriented)

All ways have a certain realism; however, the results may differ quite a lot. An indicator-oriented prototype may more or less correspond to an administrative information system containing information on, for

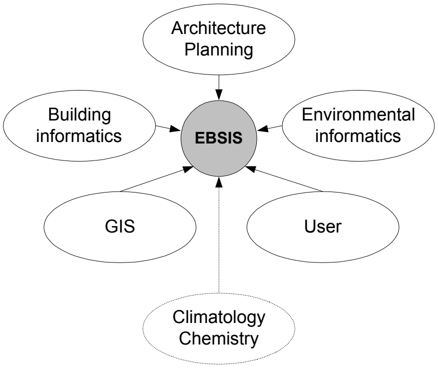


Figure 13.1. Suggested competence fields to be involved in the development of EBSIS^{SD}.

example, all buildings evaluated with an environmental assessment tool or managed in a specific way. It will not function well for the analysis of synthesising relations. It will likely be developed and managed by interested parties of the sector, and data most likely will be collected mainly from actors in the sector.

A research-oriented prototype would be developed, managed, and applied by researchers. Probably most data would be collected through case studies and surveys, but it would be difficult to collect data from actors in the building sector if the actors cannot utilise the data themselves.

A prototype that addresses both research and practitioners may be handled at different places but with a common interface and will function as a meeting point for users with simple questions and more advanced users such as researchers. Consequently, EBSIS^{SD} could support research, actors in the building sector, such as property managers, it could support policy and setting environmental objectives, and function as a pedagogic tool for teaching. This is the version I prefer, because it supports efficient data utilisation as several users will be addressed and potentially more data providers will be reached. To make this happen, co-operation between practitioners and the research community is necessary.

An interdisciplinary approach is recommended and competence from several experts is needed. Based on experience from pre-modelling, I suggest a mixture of the following competences (Fig 13.1):

- Architecture, planning, or similar expertise familiar with issues of building. Knowledge about sustainable development and environmental issues is essential.
- Building informatics, i.e. expertise familiar with modelling languages, product modelling of buildings, and structuring building-related information.
- Environmental informatics, i.e. expertise familiar with the problems related to environmental data,
- GIS, i.e. expertise familiar with handling spatial information
- Explicit users (at least one) for more precise definitions and test running. I propose municipal authorities and/or property managers.
- Possibly the perspective and knowledge of a building historian.

Data have to be collected in specific case studies to build-up a database(s) and evaluate EBSIS^{SD}. A large part of future research (time) will need to be allocated to this purpose. For detailed studies, the selection of a case area with a limited number of buildings is advantageous. According to the results from the test study, I suggest that a survey of all buildings in a limited number of grids corresponding to the map sheet division, as illustrated in Chapter 12, be conducted. An additional case study would be the investigation of all buildings on the Chalmers University of Technology Campus, which would add a pedagogic dimension for students and staff. Data from existing material, energy and water flow studies for Göteborg should be re-gathered with a shift in focus – to building-related flows.

Another field for action is the improvement of existing sources, such as the digital map of Göteborg and its related attribute data. This would lead to more effective data capture and support data generation in GIS applications, 3D presentations and calculations of built volume or surface areas.

Thus far, property managers and local environmental authorities are the main users addressed. From an architect's perspective, it could be interesting to study whether or not EBSIS^{SD} could benefit the pre-design phase in the architectural process, or 'formulation of building programme'. Will EBSIS^{SD}-supported building programmes lead to a more sustainable building?

The focus of the research presented has been on building stocks. In the long-term, there is potential interest in linking to 'modules' that model green structures, transport structure, other parts of the infrastructure, or social structures. If all these structures include a spatial dimension, a synthesis of the structures and effects might be possible via a GIS platform. From this broader perspective, EBSIS^{SD} could contribute to the refinement of Swedish urban metabolism studies. An operational EBSIS^{SD} could also deliver information on the resource use 'footprint' of an area, information for improved environmental target setting, and could be used for comparisons between other locations including those outside Sweden.

13.5 Conclusion

The thesis has provided insight into the problems related to building stock modelling. The Swedish building stock research field has been mapped broadly, a conceptual model for building stock descriptions from an environmental point of view, including a list of variables, has been developed, the availability of relevant data has been investigated, and the level of coverage of those data and the data needed has been studied. Several potential users have been identified, both on the regional and local level, such as property managers, municipal authorities and researchers. Potential applications comprise benchmarking, planning issues and scenario studies.

One of my conclusions is that when developing the database structure for EBSIS^{SD} one should not start on the national level but improvement of data sources on the national level could increase the dissemination of the model and it, thereby, would become useful for different actors with different purposes. However, purely commissioned work by only one user will possibly result in a narrow use for EBSIS^{SD}. Thus, a general description of buildings and building stocks is needed as a foundation that is attractive to many different users. A task for the nearest future is, literally speaking, to 'find' the potential users.

It is possible to build EBSIS^{SD} from a technical point of view. However, the co-ordination of existing systems and, foremost of all, data collection, will be quite time-consuming as most environmental data are not easily accessible or have to be translated from economic figures into resource use figures. Changes in existing data collection routines by national data holders, municipalities and possibly property mangers could facilitate data collection to a certain extent.

EBSIS^{SD} should be based on the Swedish BSAB system, which can be adapted to international standards, a top-down and bottom-up approach connected via a spatial age-use matrix should be used and implemented in a GIS for visualisation and analysis, which works well for EBSIS^{SD} purposes, as initial tests of the age-use matrix and energy data have shown. The environmental information system SPINE should be tested in EBSIS^{SD} for resource flow descriptions.

The conceptual model, as a result of the pre-modelling phase, is not intended to be directly implemented, but rather to function as a basis for discussion and a point of departure when developing data models and prototyping (in close co-operation with potential users).

Another conclusion is that we should not focus on one-time-only data collection and a specific study, but rather concentrate on building an 'institution', here in the meaning of long-term use, for many groups of users. Additionally, maybe EBSIS^{SD} could become an optional standard.

Last but not least, there is a certain interest in different kinds of applications by different users. The users above, have expressed a certain interest in EBSIS^{SD}, but it must be kept in mind that they have not placed an order yet. Thus far, there is no client with personal interest or offering financial support. In my opinion, an EBSIS^{SD} prototype should only be constructed if there is 'real' demand, otherwise a ship will be built that will not be able to float. Without users there can be no EBSIS^{SD}.

"… Could you mail over some of your EBSIS^{SD} files, please?"

EBSIS^{SD} is still a dream and it is not me, or any other researcher, who will determine the future for EBSIS^{SD}, but the actors who will need it.

The road to the EBSIS^{SD} concept was not straight.

Environmental data – what do I need all this for?

EBSIS^{SD} is not as self-evident as it may appear now. It took almost five years to understand what such a database should consist of. A crucial step for the advancement of the project and for fresh ideas was contact with potential users. Moreover, the visualisation of data has made the concept of EBSIS^{SD} more meaningful even if no prototype has been developed. However, …

"…a start small is better than none at all."

AFTERTHOUGHTS

REFERENCES

Adalberth, Karin (1997). Energy use during the life cycle of single-unit dwellings. Examples. *Building and Environment,* Vol 32, No 4, pp 321-329.

Adalberth, Karin (2000). *Energy use and environmental impact of new residential buildings.* Dissertation, Report TVBH-1012, Department of Building Physics, Lund Institute of Technology, Lund.

Ahl, Valerie & Allen, T.F.H. (1996). *Hierarchy theory. A vision, vocabulary, and epistemology.* Columbia University Press, New York.

Allen, Robert (ed) (2001). *The new penguin English dictionary.* Penguin books ltd.

Andersson, Karin & Molander, Sverker (1995). *Kompendium i miljösystemanalys. Miljö och miljöproblem. Definitioner och allmänna begrepp.* Kompendium, Teknisk miljöplanering, Chalmers tekniska högskola, Göteborg.

Andersson, Mia (2001). *GI i Sverige 2000. Redovisning och analys av ULIs enkät avseende användandet av geografisk information.* Rapport, ULI-RS-01/3--SE, Utvecklingsrådet för landskapsinformation, Gävle.

Arbnor, Ingeman & Bjerke, Björn (1994). *Företagsekonomisk metodlära.* Studentlitteratur, Lund.

Avouris, Nicholas M & Page, Bernd (eds) (1995). *Environmental informatics. Methodology and applications of environmental information processing.* Kluwer Academic Publishers for the Commission of the European Communities, Dordrecht.

Baccini, Peter (1997). A city's metabolism. Towards the sustainable development of urban systems. *Journal of Urban Technology,* Vol 4, No 2, pp 27-39.

Baccini, Peter & Oswald, Franz (eds) (1999). *Netzstadt. Transdisciplinäre Methoden zum Umbau urbaner Systeme: Ergebnisse aus dem Forschungsprojekt "SYNOIKOS - Nachhaltigkeit und urbane Gestaltung im Raum Kreuzung Schweizer Mittelland".* Hochschulverlag AG an der ETH, Zürich.

Barth, Bertram & Schwaiger, Bärbel (1998). *Abschlussbericht des DFG-Projekts Dynamisches Gebäudebestandsmodell zur Berechnung von Energiehaushalt, Stofffluessen und Finanzbedarf fuer Investitionen und Betrieb.* Institut fuer Industrielle Bauproduktion, Karlsruhe.

Baumann, Henrikke; Brunklaus, Birgit; Gluch, Pernilla; Kadefors, Anna; Stenberg, Ann-Charlotte & Thuvander, Liane (2002). *Miljöbarometern för byggsektorn.* ESA rapport 2002:x, Miljösystemanalys, Chalmers tekniska högskola, Göteborg.

Bergenudd, Christer; Svensson, Kjell; Sandström, Erik & Yngve, Håkan (2000). *Förvaltningsinformation 2002. Etapp 2 - Preliminära rekommendationer. 5 - Programarbete och erfarenhetsöverföring.* Rapport, Byggstandardiseringen, Stockholm.

Blasco Lucas, I; Rosés, R; Carestia, C & de La Torre, M (2000). GIS application for energy studies at residential sector. Proceedings of the *World Renewable Energy Congress VI,* Part III, pp 1866-1870, July 1st-7th, Brighton.

Boverket (1999a). *Byggsektorns miljömål.* Rapport, DNR: B6080-1668/99, Boverket, Karlskrona.

Boverket (1999b). *God bebyggd miljö.* Rapport, 91-7147-570-2, Boverket, Karlskrona.

Brand, Stewart (1997). *How buildings learn. What happens after they're built.* Phoenix Illustrated, London.

Brand, Stewart (1999). *The clock of the long now. Time and responsibility.* Basic Books, New York.

Brown, Frank E; Rickaby, Peter A; Bruhns, Harry R & Steadman, Philip (2000). Surveys of non-domestic buildings in four English towns. *Environment and Planning B: Planning and design,* Vol 27, pp 11-24.

Bruhns, Harry (2000). Property taxation data for nondomestic buildings in England and Wales. *Environment and Planning B: Planning and Design,* Vol 27, pp 33-49.

Brunklaus, Birgit & Thuvander, Liane (2002a). Do Swedish property management companies have necessary conditions for environmental management? An interview study on environmental data availability. *Corporate Social Responsibility - governance for sustainability*, pp 22-23, Proceedings of the 10th International Conference of the Greening of Industry Network June 23-26, GIN, Göteborg.

Brunklaus, Birgit & Thuvander, Liane (2002b). *Fastighetsförvaltarnas datauniversum. En intervjustudie av fastighetsförvaltare i Göteborg och Västra Sverige.* Rapport, Byggd miljö och Hållbar utveckling, Miljösystemanalys, Göteborg. In print.

BSAB (1998). *BSAB 96. System och tillämpningar.* AB Svensk Byggtjänst, Stockholm.

BYKR (2001). *Byggsektorns betydande miljöaspekter. Miljöutredning för byggsektorn.* Slutrapport, Byggsektorns kretsloppsråd. http://www.kretsloppsradet.com/miljoprogramMiljoutredning.shtml (December 2002).

Carlson, Raul & Pålsson, Ann-Christin (1998). *Establishment of CPM's LCA database.* CPM Report 1998:3, Center for Environmental Assessment of Product and Material System, Göteborg.

Castle, Gilbert H. (ed) (1998). *Geographic information systems. GIS in real estate: integrating, analyzing, and presenting locational information,* Appraisal Institute, Chicago.

CIT (2002). *Energicertifiering av byggnader.* Rapport, CIT Energy Management AB, Göteborg.

Cole, Raymond & Lafreniere, Julie (1997). Environmental information framworks - linking research with building design. *Buildings and the Environment*, Vol 2, pp 33-40, Proceedings of the CIB Second International Conference June 9-12th, CSTB, Paris.

CPM (2000). *Facilitating data exchange between LCA software involving the data documentation system SPINE.* CPM Report 2000:2, Center for Environmental Assessment of Product and Material System, Technical Environmental Planning, Göteborg.

CSD (1996). Indicators of sustainable development. Framework and methodologies. Commission on Sustainable Development, United Nations. http://www.un.org/esa/sustdev/isd.htm (December 2002).

Date, C J (1979). *An introduction to database systems.* Addison-Wesley, Reading, Massachusetts.

Davenport, Thomas H & Prusak, Laurence (2000). *Working knowledge. How organizations manage what they know.* Harvard Buisness School Press, Boston, Massachusetts.

Deakin, Mark; Huovila, Pekka; Rao, Susheel; Sunikka, Minna & Vreeker, Ron (2002). The assessment of sustainable urban development. *Building Research & Information,* Vol 30, No 2, pp 95-108.

Decker, Drew (2000). *GIS data sources.* Wiley, New York, Chichester.

DESS (2000a). *Energirapport Sydsverige.* Rapport, Delegationen för energiförsörjning i Sydsverige, Kristianstad.

DESS (2000b). *Energirapport Sydsverige. Faktabilaga.* Delegationen för energiförsörjning i Sydsverige, Kristianstad.

Edén, Michael; Falkheden, Lena & Malbert, Björn (eds) (2000). Built environment and sustainabledevelopment. Research meets practice in a Scandinavian context. *Planning Theory & Practice,* Vol 1, No 2, pp 259-284.

Ekholm, Anders (1987). *Systemet människa - byggnadsverk.* Akademisk avhandling, R22:1987, Statens råd för byggnadsforskning, Stockholm.

Ekholm, Anders (1994). A systemic approach to building modelling. Paper presented at *CIB W78 Workshop on computer integrated construction*, Esbo.

Ekholm, Anders & Fridqvist, Sverker (1995). Object-oriented CAAD - Design object structure, and models for buildings, user organisation and site. Paper presented at *CIB W78/TG 10 workshop*, Stanford University.

Ekholm, Anders & Fridqvist, Sverker (1996). Modelling of user organisations, buildings and spaces for the design process. Paper presented at *CIB W78 Workshop "Construction on the information highway*, Bled, Slovenia.

Eklundh, Lars (ed) (2000). *Geografisk informationsbehandling. Metoder och tillämpningar.* T12:1999, Byggforskningsrådet, Stockholm.

EKU-Delegationen (1999). *Ekologisk hållbar upphandling inom området fastigheter och anläggningar.* Skrivelse till Miljödepartementet från EKU-delegationens arbetsgrupp I.

Elmasri, Ramez & Navathe, Shamkant B (2000). *Fundamentals of database systems.* Addison-Wesley, Reading, Massachusetts.

Elmberg, Alf; Elmroth, Arne & Wannheden, Christer (1996). *Hus i Sverige - perspektiv på energianvändningen.* Byggforskningsrådet, Stockholm.

Energifakta (2000). Statistk, Flik 2.2-2.3, AB Svensk Energiförsörjning.

Engdahl, Stefan (2001). *Byggvaruinformation med IT. Analys av systematik och informationshantering.* Akademisk avhandling, ISRN LUTADL/TAPM--01/1001--SE, Avdelningen för Projekteringsmetodik, Institutionen för Byggande och Arkitektur, Lunds Tekniska Högskola, Lund.

ESRI (2002). http://www.esri.com/ (December 2002).

Faktapromemoria (2001). Förslag till Europaparlamentets och rådets direktiv om byggnaders energiprestanda. KOM (2001) 226, Regeringens promemoria 2000/01:163, Faktapromemoria EUN2001/1503, EUM2001/1239, Näringsdepartementet, Miljödepartementet.

Femenías, Paula & Thuvander, Liane (2000). Framtidsstudier av fönsterbyten i miljonprogrammets flerbostadshus. *Bygg och teknik 2000*, No 8, pp 37-40.

Flood, Robert L. & Carson, Ewart R. (1993). *Dealing with complexity. An introduction to the theory and application of system science.* Plenum Press, New York and London.

Government Bill (1997/98:145). *Swedish Environmental Quality Objectives.*

Haagenrud, Svein E; Rystedt, Bengt & Sjöström, Christer (eds) (2000). *GIS and the built environment.* CIB Report Publication 256, compiled by CIB/TG20.

Hamilton, Andy; Mitchell, Gordon & Yli-Karjanmaa, Sami (2002). The BEQUEST toolkit: a decision support system for urban sustainability. *Building Research & Information,* Vol 30, No 2, pp 109-115.

Hammarsten, Stig (1980). *Undersökning av husbeståndet från energisynpunkt, delrapport 10: En sammanfattning.* meddelande/bulletin, M80:7, Statens institut för byggnadsforskning (SIB), Gävle.

Hassler, Uta (1999). Umbau, Sterblichkeit und langfristige Dynamik. In *Umbau. Über die Zukunft des Bestandes* (Eds U. Hassler, N. Kohler and W. Wang), Ernst Wasmuth Verlag, Tübingen, Berlin, pp 39-59.

Hilty, L.M.; Page, Bernd; Radermacher, F.J. & Riekert, W.-F. (1995). Environmental informatics as a new discipline of applied computer science. In *Environmental informatics. Methodology and applications of environmental information processing* (Eds N. M. Avouris and B. E. Page), Kluwer Academic Publishers for the Commission of the European Communities, Dordrecht, pp 1-11.

Holtier, S; Steadman, J P & Smith, M G (2000). Three-dimensional representation of urban built form in a GIS. *Environment and Planning B: Planning and Design,* Vol 27, pp 51-72.

Häggström, Lars; Ekholm, Anders; Johansson, Bo; Lönn, Ragnar; Yngve, Håkan & Cuba-Gamarra, Salustio (2000). *Klassifikation av Byggnadsverk och Utrymmen - förstudie.* Slutrapport IT Bygg och Fastighet 2002, AB Svensk Byggtjänst.

Johnstone, Ivan M (1994). The Mortality of New Zealand Housing Stock. *Architectural Science Review,* Vol 37, pp 181-188.

Johnstone, Ivan M (2000a). Energy and mass flows of housing. A model and example. *Building and Environment,* Vol 36, No 1, pp 27-41.

Johnstone, Ivan M (2000b). Energy and mass flows of housing. Estiamting mortality. *Building and Environment,* Vol 36, No 1, pp 43-51.

Jones, Phil; Williams, Joanne & Lannon, Simon (2000). Planning for a sustainable City. An Energy and Environmental Prediction Model. *Journal of Environmental Planning and Management,* Vol 43, No 6, pp 855-872.

Jones, Phil; Vaughan, Nigel; Cooke, P & Sutcliffe, A (1997). An energy and environmental prediction model for cities. In *Evaluation of the built environment for sustainability* (Eds, P. S. Brandon, P. L. Lombardi and V. E. Bentivegna), E & FN Spon, London, pp 53-66.

Jönsson, Åsa (2000). *Industrial data on the material flows of the Swedish building stock. Using a top-down approach.* Rapport, Built Environment and Sustinable Development, Chalmers tekniska högskola, Göteborg.

Kain, Jaan-Henrik (2003). *Sociotechnical Knowledge: An Operationalised Approach to Localised Infrastructure Planning and Sustainable Urban Development.* Dissertation, Department of Built Environment and Sustainable Development, Chalmers University of Technology, Göteborg.

Klingele, M; Heitz S ; Hermann, M; Koch M & Kohler, N (1997). Simulation of energy and massflows of buildings during their life cycle. *Buildings and the Environment*, Vol 1, pp 41-48, Proceedings of the CIB Second international conference June 9-12, CSTB, Paris.

Kohler, Niklaus (2002). The relevance of BEQUEST. An observer's perspective. *Building Research & Information,* Vol 30, No 2, pp 130-138.

Kohler, Niklaus & Hassler, Uta (2002). The building stock as a research object. *Building Research & Information,* Vol 30, No 4, pp 226-236.

Kohler, Niklaus; Hassler, Uta & Paschen, Herbert (eds) (1999). *Stoffströme und Kosten in den Bereichen Bauen und Wohnen. Konzept Nachhaltigkeit,* Enquete-Kommission "Schutz des Menschen und der Umwelt" des 13. Deutschen Bundestages, Springer, Berlin, Heidelberg.

Kohler, Niklaus & Schwaiger, Bärbel (1998). Sustainable management of buildings and building stocks. *Green Building Challenge '98*, pp 197-204, Proceedings of the October 26-28, Vancouver.

Korhonen, Pernilla J (2001). *Stadsmiljöns förändringar i GIS. Om geografiska informationssystem som verktyg för hantering av stadshistorisk information.* http://www.design.chalmers.se/projects/histgis/projekt.html#stadshist kart (December 2002).

Kraines, Steven B; Wallace, David R; YIwafune, Yumiko; Yoshida, Yoshikuni; Aramaki, Toshiya; Kato, Kazuhiko; Hanaki, Keisuke; Ishitani, Hisashi; Matsuao, Tomonori; Takahashi, Hiroshi; Yamada, Koichi; Yamaji, Kenji; Yanagisawa, Yukio & Komiyama, Hiroshi (2001). An Integrated Computational Infrastructure for a Virtual Tokyo. *Journal of Industrial Ecology,* Vol 5, No 1, pp 35-54.

Le Duc, Michael (1996). *Constructivist Systemics. Theoretical Elements and Applications in Environmental Informatics.* Dissertation, School of Business, Stockholm University, Stockholm.

Le Duc, Michaël & Sivertun, Åke (1994). *A systems analysis of pollutants flow in an area and their environmental impact modelled by a Geographic Information Systems (GIS).* AFR-report 59, Avfallsforskningsrådet, Stockholm.

Lindgren, Hans (1991). Sveriges industribyggnader-en kartläggning. Tidskrift för *Arkitekturforskning*, Vo 4, Nr 3, pp 9-29.

Lindgren, Hans (1989). *Att beskriva byggnadsbestånd. Systematiska beskrivningars användning och objekt.* Akademisk avhandling, HACTH 1989:3, Avdelningen för husbyggnad, Chalmers tekniska högskola, Göteborg.

Lundequist, Jerker (1995a). *Design och produktutveckling. Metoder och begrepp.* Studentlitteratur, Lund.

Lundequist, Jerker (1995b). *Informationsöverföring och kunskapsintegration i projektering, byggande och förvaltning.* Forskningsrapport, TRITA-ARK-1995:9, Institutionen för Arkitektur och stadsbyggnad, Kungliga Tekniska Högskolan, Stockholm.

May, A.D.; Mitchell, G. & Kupiszewska, D. (1997). The development of the Leeds Quantifiable City model. In *Evaluation of the built environment for sustainability* (Eds P. S. Brandon, P. L. Lombardi and V. E. Bentivegna), E & FN Spon, London, pp 39-52.

Michener, William K (2000). Metadata. In *Ecological Data. Design, Management and Processing* (Eds W. K. Michener and J. W. E. Brunt), Blackwell Science, Oxford, pp 92-116.

Michener, William K & Brunt, James W (eds) (2000). *Ecological Data. Design, Management and Processing,* J. H. Lawton and G. E. Likens, Methods in Ecology, Blackwell Science, Oxford.

Michener, William K; Brunt, James W & Stafford, Susan G (eds.) (1994). *Environmental information management and analysis. Ecosystem to global scales,* Technical issues in geographic information systems, Taylor & Francis, London.

Miljödepartementet (2002). *Frågor om byggnadsdeklarationer, byggnadsregister och byggfelsförsäkringar.* Kommittédirektiv, Miljödepartementet, http://miljo.regeringen.se/loparkiv.htm (December 2002).

Miljövårdsberedningen (2001). *Tänk nytt, tänk hållbart! Dialog och samverkan för hållbar utveckling. Betänkande av Miljövårdsberedningen.* Fritzes offentliga publikationer, Stockholm.

Moffatt, Sebastian (1999). *Stock aggregation. Methods for evaluation the environmental performance of building stocks.* A contrubution to IEA ANNEX 31.

Mortimer, Nigel D; Ashley, Andrea & Rix, Jeremy H R (2000). Detailed energy surveys of nondomestic buildings. *Environment and Planning B: Planning and Design,* Vol 27, pp 25-32.

NE (1990). *Nationalencyklopedin.* Andra Bandet, Bra böcker, Höganäs.

Nørretranders, Tor (1999). *Märk världen. En bok om vetenskap och intuition.* Bonnierpocket, Nørhaven a/s Viborg.

Ott, Thomas & Swiaczny, Frank (2001). *Time-Integrative Geographic Information Systems. Management and Analysis of Spatio-Temporal Data.* Springer, Berlin.

Page, Bernd (1995). Database technologies for environmental data management. In *Environmental informatics. Methodology and applications of environmental information processing* (Eds N. M. Avouris and B. E. Page), Kluwer Academic Publishers for the Commission of the European Communities, Dordrecht, pp 39-52.

Penman, Jim M (2000). A database and model of energy use on the nondomestic building stock of England and Wales. *Environment and Planning B: Planning and Design,* Vol 27, No, pp 1-2.

Peuportier, Bruno; Kohler, Niklaus & Boonstra, Chiel (1997). European Project Regener. Life cycle analysis of buildings. *Buildings and the Environment*, Vol 1, pp 33-40, Proceedings of the CIB Second International Conference June 9-12th, CSTB, Paris.

Pålsson, Ann-Christin (1999). *Introduction and guide to LCA data documentation.* CPM Report 1999:1, Center for Environmental Assessment of Product and Material System, Technical Environmental Planning, Göteborg.

RVF (2001). Material- och avfallsflöden i Göteborg. Framtagande av ett statistikdatasystem - Etapp 1. Rapport, 01:8 Svenska renhållningsverksföreningen, RVF, Utveckling, Malmö.

Sandström, Erik; Yngve, Håkan; Svensson, Kjell & Bergenudd, Christer (2000). *Förvaltningsinformation 2002. Etapp 2 - Preliminära rekommendationer. 6. Drift- och underhållsinformation.* Rapport, Byggstandardiseringen, Stockholm.

SCB (2002). *Underlag för första uppföljning och utvärdering av miljömålet God bebyggd miljö. Förstudie.* Rapport, www.boverket.se (December 2002).

Schwaiger, Bärbel; Barth, Bertram; Koch, Markus & Kohler, Niklaus (1997). Mass Flow, Energy Flow and Costs of the German Building Stock. *Buildings and the Environment*, Vol 2, pp 11-18, Proceedings of the CIB Second International Conference June 9-12, CSTB, Paris.

SNV (1996). *Kartläggning av materialflöden inom bygg- och anläggningssektorn/AB Jacobson & Widemark.* Rapport 4659, Naturvårdsverket, Stockholm.

SOU (2000). *The future environment. Our common responsibility.* SOU 2000:52, Committee on Environmental Objectives, Stockholm.

SOU (2001). *Effektiv hushållning med naturresurser.* SOU 2001:2, Stockholm.

Steadman, Philip (1997). The non-domestic building stock of England and Wales. In *Structure and Style. Conserving 20th Century Buildings* (Ed M. Stratton), E&FN Spon, London, pp 49-72.

Steadman, Philip & Bruhns, Harry R (2000). An introduction to the national Non-Domestic Building Stock database. *Environment and Planning B: Planning and Design,* Vol 27, pp 3-10.

Steen, Bengt; Carlson, Raul & Löfgren, Göran (1995). *SPINE. A relation database structure for life cycle assessments.* IVL-report B 1227, Göteborg.

Stendel, Liane (2000a). A model for describing the Swedish building stock. The Swedish building register as a data source. *Sustainable Building 2000*, Proceedings of the International Conference Sustainable Building October 22-25th, Maastricht.

Stendel, Liane (2000b). *Studier av det svenska byggnadsbeståndet. En forskningsöversikt.* Form och teknik, Rapport 2000:02, Arkitektur, Byggd miljö och hållbar utveckling, Göteborg.

Stendel, Liane (2000c). Sustainable Building. What can we learn from the building stock? *TIA 2000. Sustainable buildings for 21st century, teaching issues, tools and methodologies for sustainability*, Section index 6.06, Proceedings of the TIA Third International Conference July 10-12th, Oxford.

Stendel, Liane & Jönsson, Åsa (1999). The Building Stock-Resource Deposits and Resource Flows. *Sustainable Use of Natural Resources - Cooperative Planning and Actions, ENTREE 99*, pp 89-98, Proceedings of the ENTREE 99 conference November 10-13rd, Tampere.

Sundqvist, Göran (1990). *Varför är miljöforskarna oense? : En vetenskapssociologisk rapport från Centrum för tvärvetenskap.* Göteborgs Universitet, Göteborg.

Sundqvist, Jan-Olov; Kock, Elisabet; Jakobsson, Åsa & Szudy, Mikael (2002). Administrativt system för avfallsstatistik. Slutrapport. SMED, IVL Svenska miljöinstitutet AB, Stockholm.

Swedish Dictionary (1997). *Svensk ordbok.* Nordstedts Plus, Språkdata och Nordstedts Förlag AB.

Svensson, Kjell; Tyrefors, Bo; Sandström, Erik & Bergenudd, Christer (2001). *Förvaltningsinformation 2002. Redovisning av etapp 3. Rekommendationer och krav avseende strukture och arkitektur för central förvaltningsinformation - grunddatabas. Modell- och textdel.* Rapport Etapp 3, IT Bygg och Fastighet 2002, Byggstandardiseringen, Stockholm.

Svensson, Kjell; Yngve, Håkan; Bergenudd, Christer & Sandström, Erik (2000a). *Förvaltningsinformation 2002. Etapp 2 - Preliminära rekommendationer. 1. Processhandbok.* Rapport, Byggstandardiseringen, Stockholm.

Svensson, Kjell; Yngve, Håkan; Bergenudd, Christer & Sandström, Erik (2000b). *Förvaltningsinformation 2002. Etapp 2 - Preliminära rekommendationer. 2. Informationshandbok.* Rapport, Byggstandardiseringen, Stockholm.

Szudy, Mikael (2000). *Byggsektorns avfall. Metoder och förutsättningar för produktion av nationell byggavfallsstatistik.* Rapport, PM MR/MI 2000:1, SCB, Stockholm.

Thormark, Catarina (2000). Including recycling potential in energy use into the life-cycle of buildings. *Building Research & Information,* Vol 28, No 3, pp 176-183.

Thormark, Catarina & Thuvander, Liane (2002). *Avfallsströmmar från rivning och ombyggnad. Möjligheter att beräkna mängderna. Förstudie.* Uppdrag av Naturvårdsverket.

Thuvander, Liane (2000). *The building stock. A complex system changing over time. Towards a model for description and analysis.* Licentiate thesis, Report 2000:2, Department of Built environment and Sustainable development, Chalmers University of Technology, Göteborg.

Thuvander, Liane & Brunklaus, Birgit (2002). What Environmental Data do Property Managers have on Buildings and their Management? *Sustainable Building 2002*, Document No 356, Proceedings of the International Conference Sustainable Building September 23-25th, Oslo.

Thuvander, Liane & Thormark, Catarina (2002). Experiences related to data in building research. In *MISTRA Sustainable building. Experiences from a cross-disciplinary research programme* (Eds M. Edén and Å. Jönsson), Department of Building Economics and Management and Department of Built Environment and Sustainable Development, Göteborg, Bollebygd, pp 91-104.

Tolstoy, Nikolaj; Björklund, Christer & Carlson, Per Olof (1998). Material flows in the construction and heavy engineering sector. *Construction and the Environment*, Symposium A, Vol 2, pp 857-864, Proceedings of the CIB World Building Congress, Gävle.

Tolstoy, Nikolaj; Sjöström, Christer & Waller, Tommy (1984). *Bostäder och lokaler från energisynpunkt.* meddelande, M84: 8, Statens institut för byggnadsforskning (SIB), Gävle.

Törnqvist, Lars; Svensson, Kjell; Yngve, Håkan; Bergenudd, Christer & Sandström, Erik (2000). *Förvaltningsinformation 2002. Etapp 2 - Preliminära rekommendationer. 4. Ordlista.* Rapport, Byggstandardiseringen, Stockholm.

UNCED (1992). *Agenda 21.* Proceedings of theUnited Nations Conference on Environment and Development, Rio de Janeiro.

Valentin, Anke & Spangenberg, Joachim H. (1999). *Indicators for sustainable communities.* Assessment methodologies for urban infrastructures, International workshop, September 20-21st, Stockholm.

Wallén, Göran (1996). *Vetenskapsteori och forskningsmetodik.* Studentlitteratur, Lund.

WCED (1987). *Our common future.* Oxford University Press, Oxford.

Weizsäcker, Ernst von; Lovins, Amory B & Lovins, L Hunter (1997). *Factor four. Doubling Wealth - Halving resource use.* Earthscan Publications Ltd, London.

Westberg, Kjell; Norén, Johan & Kus, Hülya (2001). On using available environmental data in service life estimations. *Building Research & Information,* Vol 29, No 6, pp 428-439.

Wilhelmsen, Anne Marie (1987). *Sveriges industribyggnader - en kartläggning. Industrihusprojektets uppläggning och metoder.* Rapport HACTH 1987:1, Avdelningen för husbyggnad Chalmers tekniska högskola, Göteborg.

Yngve, Håkan; Svensson, Kjell; Bergenudd, Christer & Sandström, Erik (2000a). *Förvaltningsinformation 2002. Etapp 2 - Preliminära rekommendationer. 7. Kvalitetssäkrad upplåtelse.* Rapport, Byggstandardiseringen, Stockholm.

Yngve, Håkan; Svensson, Kjell; Sandström, Erik & Bergenudd, Christer (2000b). *Förvaltningsinformation 2002. Etapp 2 - Preliminära rekommendationer. 3. Produktmodeller och klassifikation.* Rapport, Byggstandardiseringen, Stockholm.

Publications which are a part of the thesis work

Brunklaus, Birgit & Thuvander, Liane (2002b). *Fastighetsförvaltarnas datauniversum. En intervjustudie av fastighetsförvaltare i Göteborg och Västra Sverige.* Rapport, Byggd miljö och Hållbar utveckling, Miljösystemanalys, Göteborg. In print.

Femenías, Paula & Thuvander, Liane (2000). Framtidsstudier av fönsterbyten i miljonprogrammets flerbostadshus. *Bygg och teknik 2000*, No 8, pp 37-40.

Stendel, Liane & Jönsson, Åsa (1999). The Building Stock-Resource Deposits and Resource Flows. *Sustainable Use of Natural Resources - Cooperative Planning and Actions*, pp 89-98, Proceedings of the ENTREE 99 conference November 10-13rd, Tampere.

Stendel, Liane (2000a). A model for describing the Swedish building stock. The Swedish building register as a data source. *Sustainable Building 2000*, Proceedings of the International Conference Sustainable Building October 22-25th, Maastricht.

Stendel, Liane (2000b). *Studier av det svenska byggnadsbeståndet. En forskningsöversikt.* Form och teknik, Rapport 2000:02, Arkitektur, Byggd miljö och hållbar utveckling, Göteborg.

Stendel, Liane (2000c). Sustainable Building. What can we learn from the building stock? *TIA 2000. Sustainable buildings for 21st century, teaching issues, tools and methodologies for sustainability*, Section index 6.06, Proceedings of the TIA Third International Conference July 10-12th, Oxford.

Thormark, Catarina & Thuvander, Liane (2002). *Avfallsströmmar från rivning och ombyggnad. Möjligheter att beräkna mängderna. Förstudie.* Uppdrag av Naturvårdsverket.

Thuvander, Liane (2000). *The building stock. A complex system changing over time. Towards a model for description and analysis.* Licentiate thesis, Report 2000:2, Department of Built environment and Sustainable development, Chalmers University of Technology, Göteborg.

Thuvander, Liane & Brunklaus, Birgit (2002). What Environmental Data do Property Managers have on Buildings and their Management? *Sustainable Building 2002*, Document No 356, Proceedings of the International Conference Sustainable Building September 23-25th, Oslo.

Thuvander, Liane & Thormark, Catarina (2002). Experiences related to data in building research. In *MISTRA Sustainable building. Experiences from a cross-disciplinary research programme* (Eds M. Edén and Å. Jönsson), Department of Building Economics and Management and Department of Built Environment and Sustainable Development, Göteborg, Bollebygd, pp 91-104.

Personal communications

Boverket (2000). Hedén, S., Division of construction and management, Boverket, Karslkrona.

GE (2002). Ingulf, O., Planning and marketing, Göteborg Energi AB.

Ecocycle Department (2002). Granath J., responsible for material flow statistics, Göteborg.

Environment Administration (2002a). Andreasson, U., Environment Officer, Carlsson, P. E.,Housing and Local Environment Division, Svärd, B., Inquiries and analyses, City Planning and Traffic Division, Göteborg.

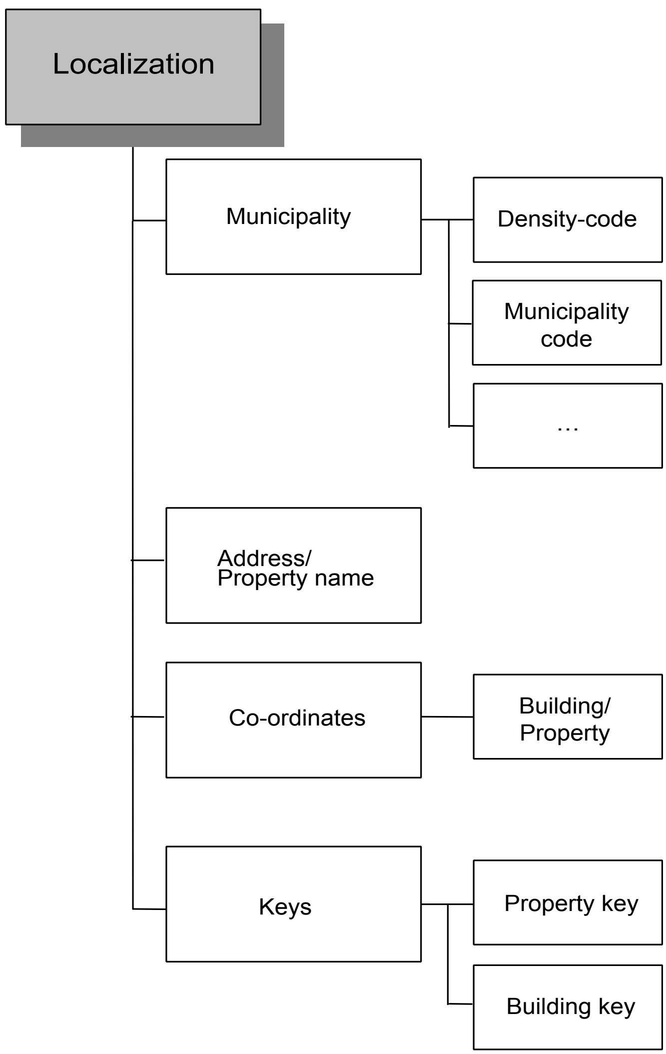
Environment Administration (2002b). Svensson, A., Environment Officer, Housing and Local Environment Division, Göteborg.

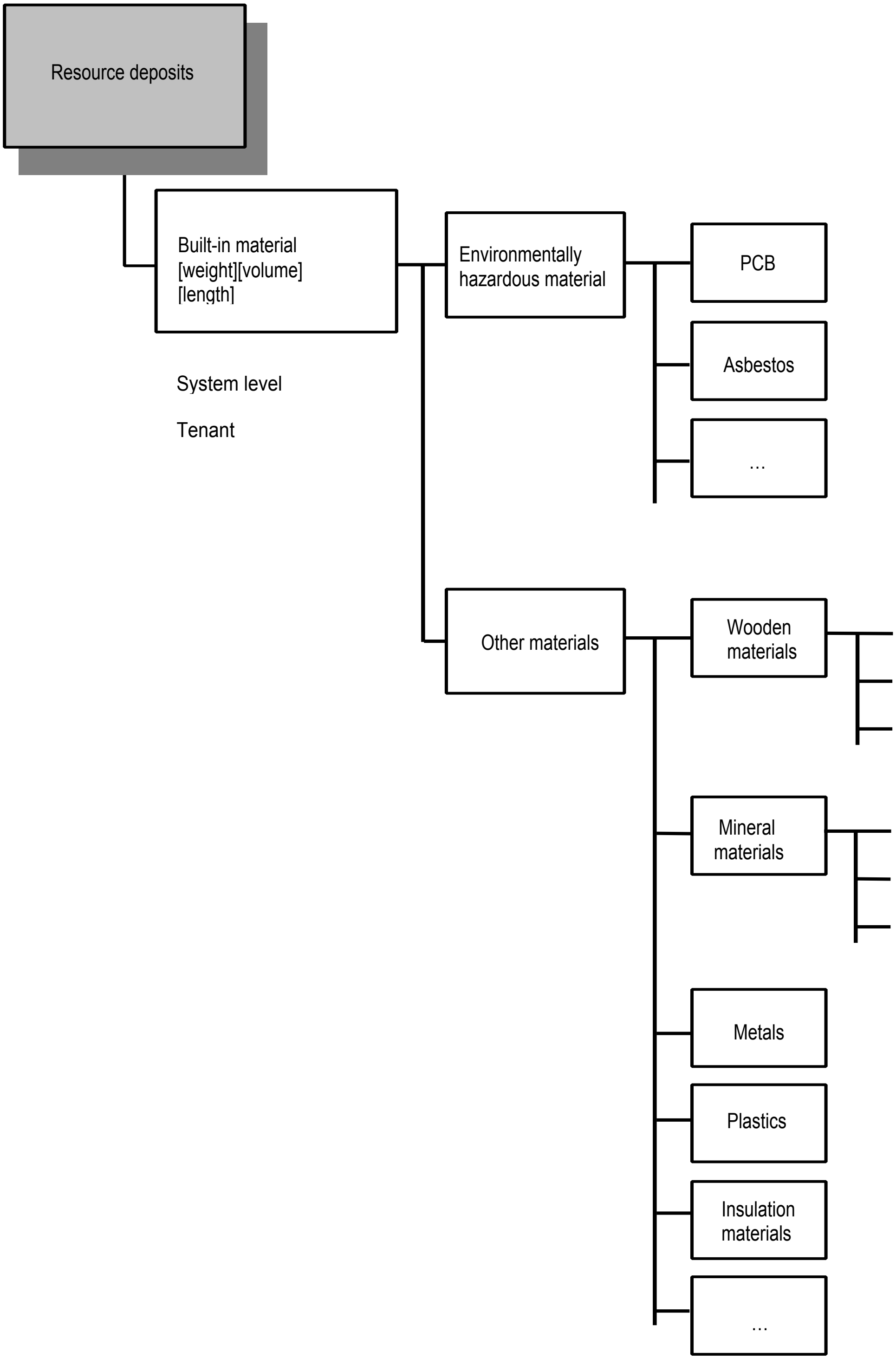
Other

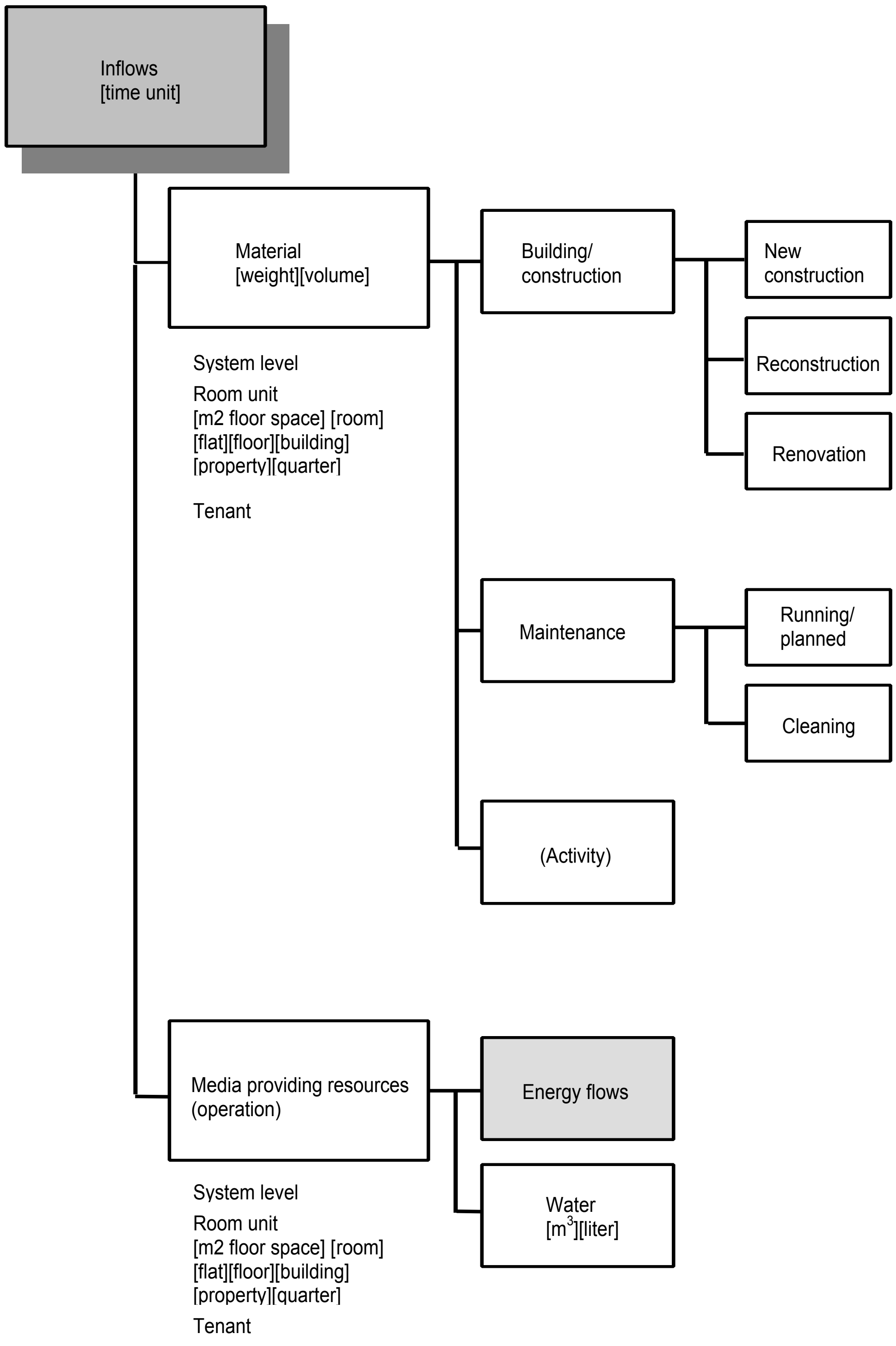
Renova (2002). *Compilation of internal material flow statistics.* Marketing division, Renova, Göteborg.

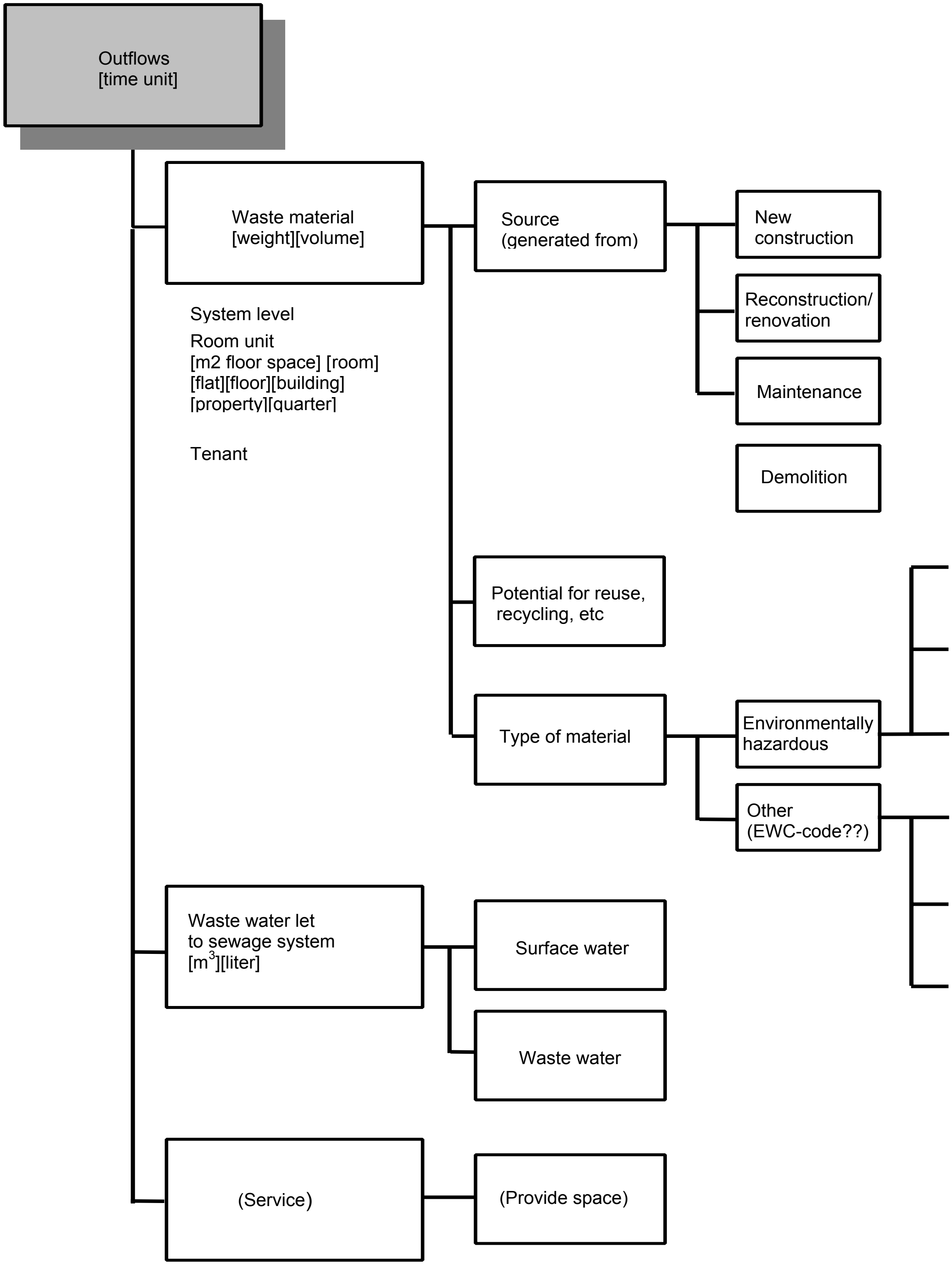
APPENDIX A

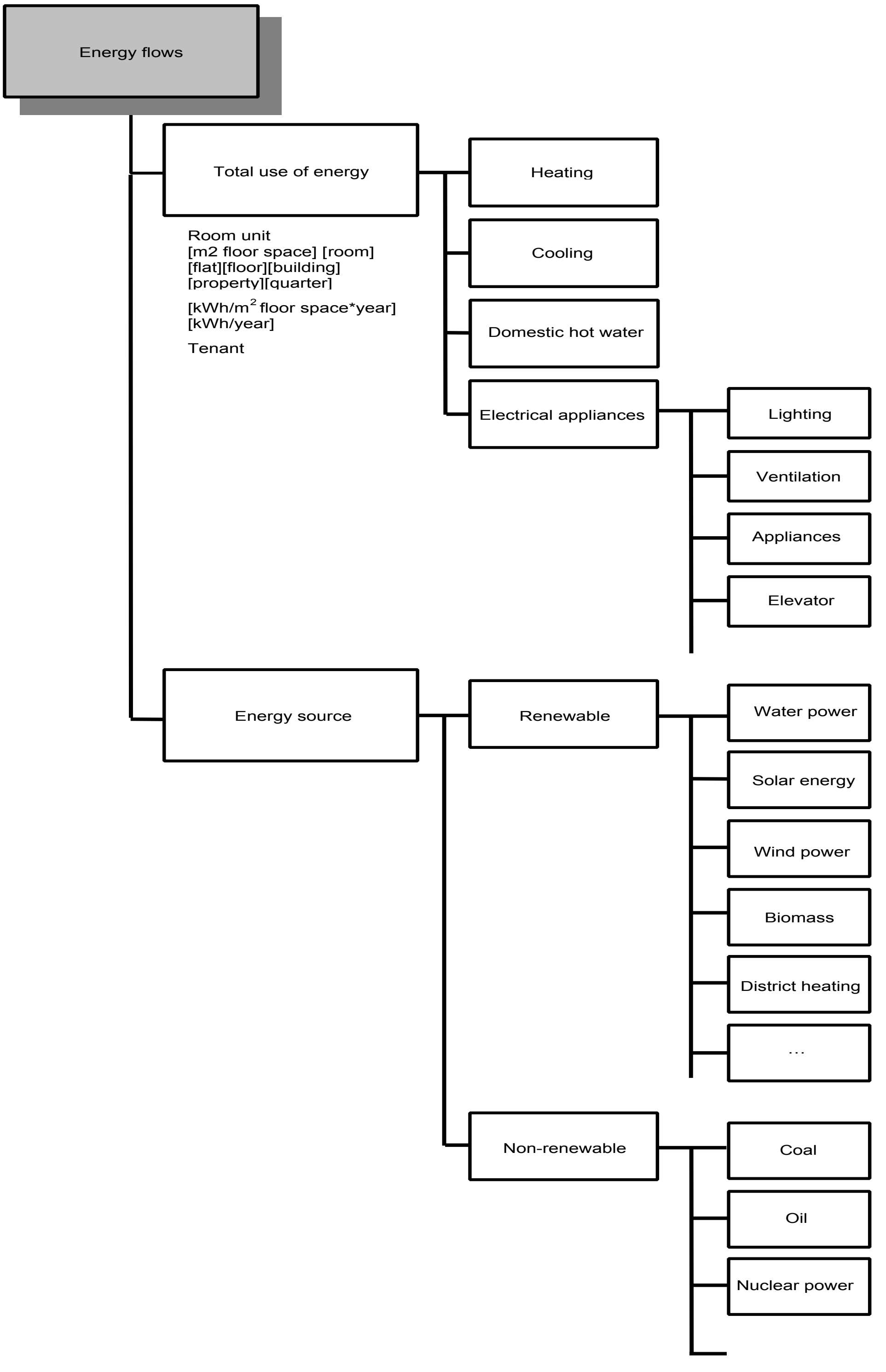
List of variables




Resource deposits
Built-in material [weight][volume] [length]
System level
Tenant
Environmentally hazardous material
PCB
Asbestos
...
Other materials
Wooden materials
Mineral materials
Metals
Plastics
Insulation materials
...


Inflows
[time unit]
Material
[weight][volume]
System level
Room unit
[m2 floor space] [room]
[flat][floor][building]
[property][quarter]
Tenant
Building/
construction
New
construction
Reconstruction
Renovation
Maintenance
Running/
planned
Cleaning
(Activity)
Media providing resources
(operation)
System level
Room unit
[m2 floor space] [room]
[flat][floor][building]
[property][quarter]
Tenant
Energy flows
Water
[m3][liter]


Outflows
[time unit]
Waste material
[weight][volume]
System level
Room unit
[m2 floor space] [room]
[flat][floor][building]
[property][quarter]
Tenant
Source
(generated from)
New
construction
Reconstruction/
renovation
Maintenance
Demolition
Potential for reuse,
recycling, etc
Type of material
Environmentally
hazardous
Other
(EWC-code??)
Waste water let
to sewage system
[m3][liter]
Surface water
Waste water
(Service)
(Provide space)


Energy flows
Total use of energy
Room unit
[m2 floor space] [room]
[flat][floor][building]
[property][quarter]
[kWh/m2 floor space*year]
[kWh/year]
Tenant
Heating
Cooling
Domestic hot water
Electrical appliances
Lighting
Ventilation
Appliances
Elevator
Energy source
Renewable
Water power
Solar energy
Wind power
Biomass
District heating
...
Non-renewable
Coal
Oil
Nuclear power

APPENDIX B

Internet addresses and homepages of interest, all of them accessed summer 2002.

AGS .... http://www.global-alliance.org/
BYKR .... http://www.kretsloppsradet.com/
Byggtjänst .... http://www.byggtjanst.se/
EEP-model .... http://www.cf.ac.uk/archi/research/eep/index.html
ESRI .... http://www.esri.com/
Government SD .... http://miljo.regeringen.se/hut/index.htm
IfiB .... www.ifib.uni-karlsruhe.de/
Industrifakta .... www.industrifakta.se/
International Society for the Systems Science (ISSS) .... http://www.isss.org
IT Bygg & Fastighet .... http://www.itbof.com/
Mängda .... www.mangda.se/
Swedish environmental objecties council .... http://www.miljomal.nu/index.php
SNV .... http://www.internat.environ.se/
SCB .... http://www.scb.se/
SPINE .... http://www.glObalSPINE.com
Svenska miljönätet .... http://www.smn.environ.se/
Lantmäteriet .... http://www.lantmateriet.se/
The Long Now Foundation .... http://www.longnow.org

APPENDIX D

Swedish glossary

Committee for Ecologically Sustainable Procurement.......... Delegationen för ekologiskt hållbar utveckling
Environmental Advisory Council.. Miljövårdsberedningen
Ecocycle Council for the Building Sector (BYKR) .... Byggsektorns kretsloppsråd
Environmental Code... Miljöbalken
Ministry of the Environment.. Miljödepartementet
Map sheet division .... Kartbladindelning
National Board of Housing, Building and Planning... Boverket
Population and Housing Census .... Folk- och Bostadsräkning
Statistics Sweden... Statistiska Centralbyrån
Swedish Environmental Protection Agency .... Naturvårdsverket

CHALMERS UNIVERSITY OF TECHNOLOGY
SE – 412 96 Göteborg Sweden
Telephone: + 46 31 772 1000
www.chalmers.se