# A SYSTEMIC APPROACH TO BUILDING MODELING
## - analysis of some object-oriented building product models

Tekn.dr, Arch. SAR Anders Ekholm
Lund Institute of Technology
School of Architecture
Dept of Computer Aided Architectural Design
Box 118
S-221 00 LUND
Tel: +46 46 10 72 46, Fax: +46 46 13 68 26
E-mail: anders.ekholm@caad.lth.se

## INTRODUCTION

### Summary

This paper introduces a systemic approach to the description and modeling of buildings. Basic properties of buildings are discussed. A critical analysis of some proposals for building product models based on object-oriented modeling is made. The analysis shows that ontology, including systemics, can contribute to the theoretical background of building modeling by clarifying concepts like property, system, part-whole, level and space. Some areas for future study are proposed.

### Architecture and building technology

Architecture as a field of inquiry can be seen as the study of the complex system man-building, considering both building technology and mans use and experience of buildings. Building technology deals specifically with the building as a technical system for which site-conditions, use and construction technology are the main deciding factors.

Like many other cross-disciplinary fields, architecture and building technology lacks scientific definitions of the basic concepts by which the concrete object of knowledge is described. Also in everyday speech, it causes obscurity when concepts with different meaning are used synonymously, like e.g. system and structure, or level order and hierarchy. In scientific research and in advanced multi-disciplinary applications it is necessary to use theoretically well-grounded concepts.

Basic concepts within any science should be based on, or connect to, a more general understanding of the world. In my doctoral thesis "Systemet människa-byggnadsverk" (The system man-building) I have developed a conceptual model of buildings and the system man-building, based on Mario Bunge's systems theory (Ekholm 1987). The purpose of this paper is to introduce the *systemic* approach to building modeling in the context of object-oriented modeling for computer software development. Basic concepts are clarified, and a very general systems model is presented and used as a basis for developing a basic building model. With this background object-oriented modeling and some proposals for building product models are discussed.

## Object-oriented modeling of buildings

In later years important efforts have been put into using the computer as a building modeling tool. Such computer based building product-models allow sofisticated analysis of building properties already in early design stages. A considerable amount of research has already been carried out within this area. Different modeling techniques have been tried and evaluated. Currently there seems to be an agreement that techniques based on object-oriented modeling seem the most promising (Björk 1993).

Object-oriented modeling is dependent on domain-specific knowledge and requires definitions of basic concepts emanating from the specific field of interest (Rumbaugh, et al 1991). The development of building models thus require building technology specific concepts. In building technology today there is no common agreement about basic concepts. The differences in terminology and scope of current building product models are an example of this.

# ONTOLOGY

This section of the paper is a short introduction to basic ontological concepts in systemics. The theoretical background is Mario Bunge's comprehensive "Treatise on Basic Philosophy", especially his two volumes on ontology (Bunge 1977 and 1979). Ontology is that branch of philosophy which accounts for the most general properties of things. The definitions here are from these two books, otherwise a reference is given.

## Properties of things

Bunge postulates that every *object* is either a thing or a construct. A *thing* is a concrete object with factual properties and part of the (physical) world. A *construct* is a conceptual (abstract) object with formal properties, also called attributes.

Factual properties can be divided into intrinsic and mutual, primary and secondary, see figure 1. *Intrinsic* properties are possessed by the thing itself, while *mutual* properties are relations between two or more things. The composition of the house with all its parts is an internal property while its function as a home is a mutual property of the house and its dewellers.

*Primary* properties are possessed by things independently of a subject's experience, while *secondary* properties are dependent on the subject's experience. Among the latter are properties like colour, intensity of light and sound, hardness and smell. The secondary properties can be more or less *objective* and *subjective*, i.e. they can have more respectively less correspondence to the primary properties.

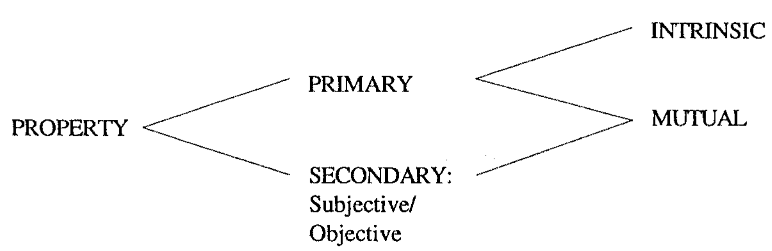


Figure 1. Classification of properties.

A 50-storey highrise building can be experienced as high by a person. This is an objective property since it corresponds to a primary property of the house. The house may also be experienced as threatening or beautiful. These are subjective properties since they are more founded in the feelings of a subject than in the primary nature of the house.

Secondary properties are dependent on the perceptions of an sentient organism. *Interpretation* is a way of ordering perceived facts and comparing them to hypotesized data (Bunge 1983). Man interprets the environment in different ways. It is possible to distinguish two main kinds of interpretation of things: *epistemic* and *semiotic* (Bunge 1974).The former is used as a means to understand the environment as a concrete system, to detect its composition, environment and structure. The latter is used to interpret the environment as a sign in a communication system.

Similarly the interpretation of a building has these double facets. On the one hand we see it as structure and material, with a certain use, and on the other hand it is interpreted as having beuty, an architectural style and perhaps a powerful owner.

A *law* is a relation between concrete properties, and thus a property itself. Laws are relations which are constant or varies in a constant manner. For example the relations between energy consumption of the house, the heated air volume, and the area and heat transmission of enclosing materials, are lawful.

A thing is, at a given time and relative to some reference frame, in a certain *state*. The state of a thing is a *fact,* and can be represented by a state function that can take certain values, *data*. The total set of states of a thing is its *state space*. The states of a thing may be restricted by its laws. An adequate representation of a thing should account for the *lawful state space* of the ting. For example a door has different states of openness that can be represented by a state function for the angle between the wall and the door. The function can take values from 0-180°, other values are not possible because of the lawful relation between the properties of the door and the wall.

The concept of state can be further elucidated by introducing the concept of change. If a thing changes within the space of a given state function the change can be considered quantitative. To equip the loft of a house of flats with some additional apartments may be considered a quantitative change. If the change requires a representation by a new state function, then it may be considered qualitative. An example of the latter is the change of a single storey factory building into a multistorey office-structure by inserting extra floor structures.

An *event* can be defined as a change of a thing from one state to another. A *process* is the composition of two or more events of a thing.

The scope of a property is the set of things possessing it, such a set is called a *class*. A thing is a member of the class if it has the property which defines the class. The property that defines the class is generic to the class. A set of properties determines a kind. The Stockholm Town Hall is a member of the class of "brick buildings". It also belongs to the kind "massive brick structures".

Classification should be based on a theory of the lawful properties of the thing, not by its idiosyncratic properties. The principle underlying the classification of things in species, genera, order etc. is to group things in equivalence-classes with different degrees of fineness, see figure 2.

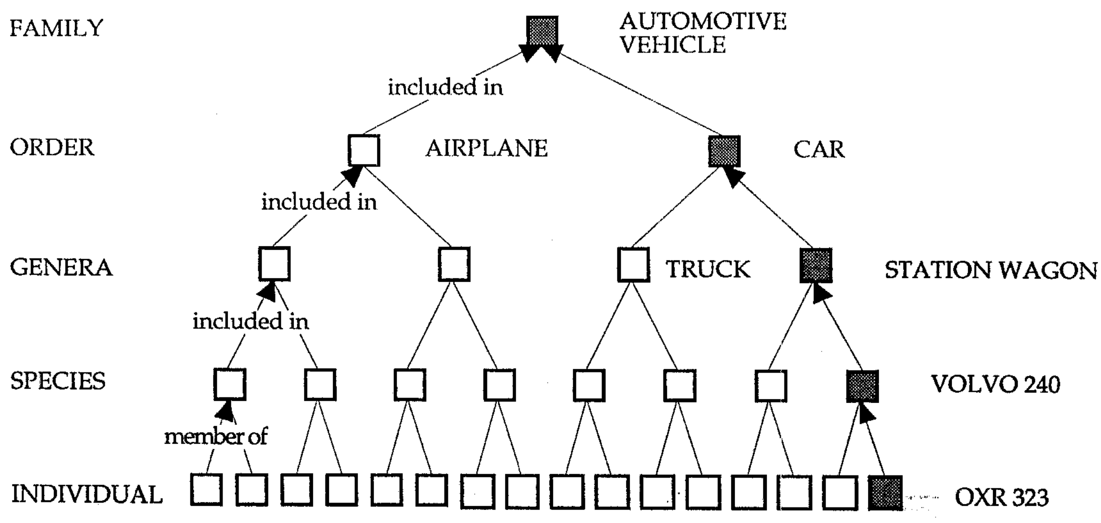


Figure 2. The "tree of properties" from general to specific, separated into equivalence classes of inreasing fineness.

In classification only two relations are involved, the set-membership relation ∈ that relates individuals to sets and the set-inclusion relation ⊂ that relates sets to subsets. It should be observed that the individual member (instance, occurrence) of a class is not a class but an object, in this case a thing.

## Systemics

The properties of a thing as a whole are called *global* properties. These are of two kinds, *resultant* and *emergent.* The resultant properties are possessed already by the parts, while the emergent properties are new. The mass of a building is a resultant property and a mere addition of the masses of the parts. The buildings' climatic properties are mutual properties of the parts and emerge with their enclosure of an air volume.

The observation that the whole possesses new properties is expressed already by Aristotele as "the whole is more than the sum of its parts". The whole has other laws than its parts, however its properties are based on the properties of the parts. Systems Theory or *systemics* also recognizes that the parts and internal relations of a system are dependent on the environment. This implies that a system can never be studied in itself only, but must be seen in relation to its environment. This cognitive and methodological "moral" of systemics has been recognized by Ackoff who concludes that: "ultimate understanding of anything is an ideal that can never be attained but can be continuously approached" (Ackoff 1979).

Although systems thinking has been prevalent during the second part of this century it is not until the latest decades that the theory of systems has been incorporated into philosophy and the theory of science (Mattessich 1982). Bunge has shown that systems theories are ontological, i.e. they describe extremely general properties of things. Systemics deals with concepts like 'part', 'whole', 'emergence' and 'level'. The systemic view accounts for both the parts and their mutual interaction, and the emergent properties of the whole.

A concrete *system* is a complex thing with composition, environment and structure. The *composition* is the set of parts of the system. The *environment* is the set of things that act on or are acted on by the system. And the *structure* is the set of relations between the parts of the system and between the system and its

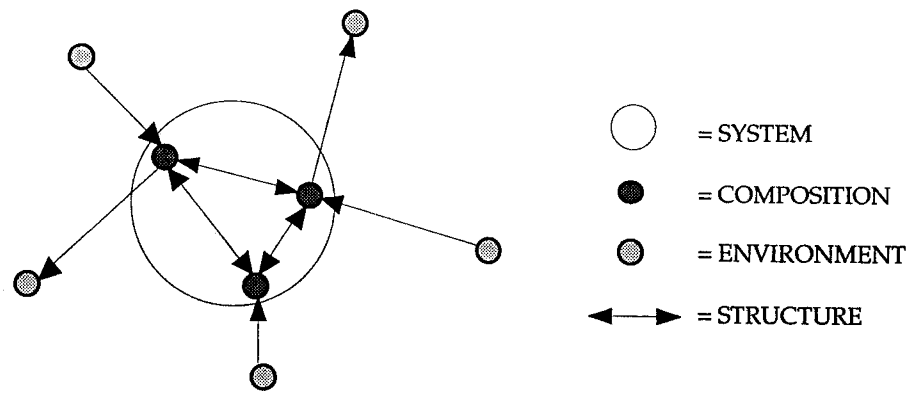


Figure 3. A system with composition, environment and structure.

environment. A complete account of a system also includes its laws and history (former states). See figure 3.

The *composition* of a system is the set of its parts. The relation between a part and a whole is the *part-whole* relation "$\sqsubset$". The existence of a part precedes the existence of the whole, the part is here named *precedent* to the whole. Bunge draws attention to the difference between the part-whole relation, which is defined for things only, and the set inclusion relation $\subset$ as well as the set membership relation $\in$, that are relations among constructs.

The parts of a system can be systems in their turn. Such a part is a *subsystem.* Also the total environment of a system can be a system, this is called a *supersystem.* So a system can be composed of subsystems in different levels and it can be part of supersystems, see figure 4.

A *level* is a set and the relation between levels is conceptual. The relation between a lower level and a higher level is a *precedence* relation, which means that things in a higher level are composed of things in lower levels. The properties of things in lower levels are basic to the emergent properties of things in higher levels.

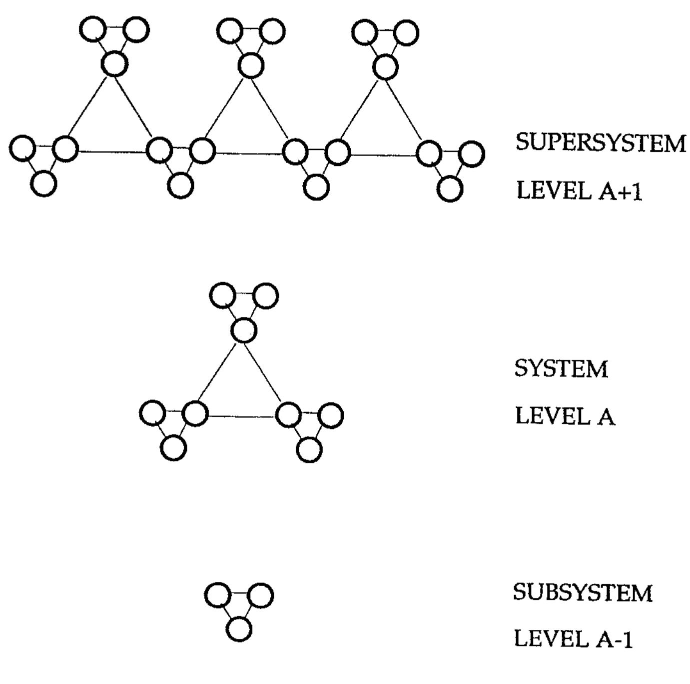


Figure 4. Level order in systems.

There is no action among levels so a level order must be distinguished from a hierarchy. In a hierarchy there is a one-sided action among parts that are ordered in agents and patients. By definition a whole is a new thing that emerges from the interaction of its parts. Consequently a whole does not act on its parts. The house as a whole with for example its climate properties, does not act on the walls or ventilation ducts.

A system is assembled from *precedents* to the system. From the assembly point of view, precedents in all levels are parts of the system. Once being assembled it is not a necessary condition for a part to be able to disassemble from the system. Using the same names as in figure 4, it is possible to distinguish the parts in level A-1 whose immediate interaction give rise to a whole in level A. These A-1 level parts are also called *atomic* parts, e.g. the atomic parts of a Lego-house are Lego-bricks. The Lego-house is also composed of other parts e.g. large organic molecules, but these parts belong to lower levels and do not directly assemble to the Lego-house.

It is not trivial to distinguish the parts or the *environment* of a system. Natural systems self-assemble and living systems both self-assemble and evolve. Knowing the properties of natural systems like e.g. composition often requires scientific research. On the other hand the parts of man-made systems, artifacts, must be consciously designed with regard to questions of production and use, including their relations to the site.

The *structure* of a system can be divided into internal and external relations. An other division is into bonding and nonbonding relations. The bonding relations among things are of many different kinds, from gravitation to atomic bonds. Among the nonbonding relations are those to reference frames and the spatial relations. Fast, old, close and distant, are examples of such relations.

A system is *open* with respect to a certain property if this can be related to a property of the environment. A *closed* system has no environment. Some buildings are open to different kinds of use, they are multi-functional, by being universal or flexible.

*Space* is a nonbonding, mutual, separation-relation between things[1]. Space is a primary property that exists independent of a sentient organism. The *configuration* of a building is its internal spatial relations. The concept of *time* is analogous, it can be constructed as a non-bonding separation-relation between events.

The *laws* of a system are relations among its properties. In a moving body, speed, travelled distance and time are lawfully related properties. In a building, the angle of a roof must vary with different surface material to avoid penetration of rainwater.

## A SYSTEMIC VIEW OF BUILDINGS

### Basic systems model

The concepts in the previous section have been presented in order to develop a basic conceptual schema of the most general properties of concrete things. In this schema the concepts of property, system, level and state are the basic tools with which concrete systems like artifacts, social systems, buildings and the system user-building can be described.

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[1]This concept of space and its application to the modeling of buildings is discussed in a paper in preparation by (Ekholm & Fridqvist 1994).

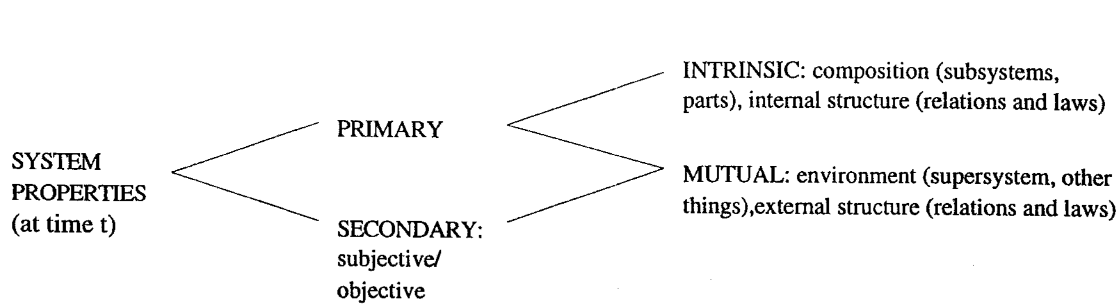


Figure 5. Classification of systems properties at time *t*.

The properties of a system (at a certain time *t*), can be summarized as follows: The composition (subsystems and parts) and internal structure (relations and laws) of a system are intrinsic, primary properties while its environment (supersystems and other things with which it is connected), and external structure (relations and laws) are mutual, primary properties. The secondary properties (from objective to subjective) of a system are mutual properties of a sentient organism and the system. See figure 5.

## Social systems, artifacts and sociotechnical systems

Here the basic concepts discussed above will be used for the description of buildings. First some additional concepts shall be elucidated, namely artifact, social system and sociotechnical system.

A *social system* is composed of animals. The structure of a social system is a.o. social activities like communication and work. *Work* is a socially useful activity (Bunge 1979). Depending on purpose, work can be divided into two main categories: economical and cultural. The objective of economical work is to act on things, to change their states, with the purpose of material gain. Cultural work is aiming at evoking thoughts, feelings and ideas in peoples minds. The activities performed by a person together with the mental properties that depend on the activity, is called a *role*. Thinking, communication and work are necessary conditions for developing knowledge and producing artifacts.

*Artifacts* are man-made or man-controlled systems. A building is an example of the former and a modern high-yeilding milkcow is an example of the latter. The degree of artificiality may vary from qualitative to quantitative. Artifacts are tools that make different activities possible. Depending on the character of these one can distinguish between *economic* and *cultural* artifacts. The former are used with the purpose to act on and change the states of things, while the latter are used with the purpose to give raise to thoughts, feelings or ideas in peoples minds. A house or a bridge is, in spite of their possible beauty, economic artifacts, while a statue is a cultural artifact.

When man uses an artifact to perform an activity, a new kind of system emerges, a *sociotechnical* system. The composition of a sociotechnical system is a set of persons and tools, and to the structure belongs activites performed with the help of the tools. Of specific interest of artifacts are two kinds of relations: the relations to the users, and the relations to the things it acts on during an activity. The former can be called "tool-relations" e.g. between the user and the handle of a spade, while the latter can be named "transformation-relations" e.g. between the system user-spade and the ground during digging. See figure 6.

An artifact used as a tool is always part of a sociotechnical system. A robot, although acting automatically, is controlled by persons responsible for the robots

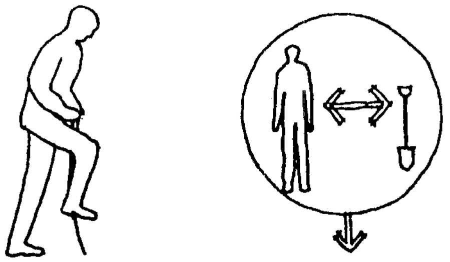


Figure 6. Tool-relations and transformation-relations of a sociotechnical system.

actions. Although a sociotechnical system has much in common with social systems they have fundamentally new, emergent properties, which motivates a separate classing.

Sociotechnical systems dominate modern society. To the composition of society belong social and sociotechnical systems. The latter are decisive to the survival, strength and whealth of a society.

Buildings may belong to the composition of sociotechnical systems, namely the systems man-building, which are formed with mans' use and interpretation of a building. This system is supersystem to the building, it has been studied as a system in its own right, with all its properties in (Ekholm 1987).

## Place and building

*Place* or *site* is a more general property than building. Construction activities are not necessary to make a place, already a natural setting may have the property of place for an activity such as fishing or speaking to an audience. Place (site) is a mutual relation between things. Specific spatial and functional properties are required for one thing to have a place-relation to another.

Buildings, in the more general sense of built facility, are artifacts with the property of being a place for man in activities that require a.o. controlled climate, protection against intruders, enclosed space, load-bearing ground structures as well as aesthetical and symbolic expression. Examples of such facilities are houses, streets, canals, bridges and parks.

Built facilities are often aggregated into *built environments* with networks of blocks, streets and infrastructural systems. Some of these facilities are very loosely connected like a street and a house, others are tightly bonded, e.g. through their heating systems in case of district heating. The relations of the former are mainly spatial, so only the latter are meaningfully treated as one system. On the other hand two separate facilities can be parts of the same sociotechnical system.

## Basic building properties

A complete account of a building's properties include its composition, environment, structure, laws and history. The same holds for a representation of a building during a design process, which must support the evaluation of both potential and alternative properties.

*Composition*

Buildings (facilities) are composed of different kinds of parts. The parts also vary from one building to another depending on the choice of material, construction method and user requirements. We restrict our definition of parts to precedents, i.e. things with an existence preceding the existence of the whole. Parts are distinguished for many reasons in relation to material, production and use e.g. craft and material, like timber work, bricklaying, sheet-metal work etc.; function relative to other parts, like load-bearing, climate protecting or connecting; and function relative to the users, like windows and doors, kitchen equipment and furniture (mobile building parts).

*Level order*

When a building is assembled, parts in lower levels are composed into wholes in higher levels. In each new level properties emerge so that the whole in some fundamental way differs from its parts. Considering the differences of properties of building parts, a few levels may be distinguished:

1) built facility (streets, houses, canals, bridges etc.),
2) the principle subsystems of the building (e.g. climate shell, HVAC system and structural system),
3) building elements (walls, floor structures, roof etc.),
4) building components (doors, windows, wall units etc.)
5) building material (studs, gypsum boards, mineral wool etc.). See figure 7.

This level structure reflects the assembly process and may be adequate for distinguishing parts of different complexity. Also other things like raw material are precedents to facilities but since they are not specifically designed for construction of facilities they need not be considered in a level order of building-parts.

The properties of the principal subsystems and building elements are mainly decided in relation to a specific building, while building components and building material are more generally applicable and possible to use in many different facilities. Industrial production with standardization, prefabrication and mass-production is best suited for parts in lower levels while parts in higher levels are more suited for on site production.

*Environment*

To the environment of a building belong the building's site, including the ground where the building is situated, with the climate factors, natural systems and artificial infrastructure, the building production systems and the users of the building. In some cases the building and its users connect into a supersystem, the user-building system.

*Structure*

The internal structure of the building is the sum of all relations among its parts. The bonding relations between the parts of a building can be caused by gravitation or fixing devices. Among the external relations are the tool-relations to the users and the transformation-relations to the site, both of which are bonding relations. Among the non-bonding relations are the spatial relations, including the buildings configuration, and the interpretation-relations to those who experience the building and appreciate its architecture and history.

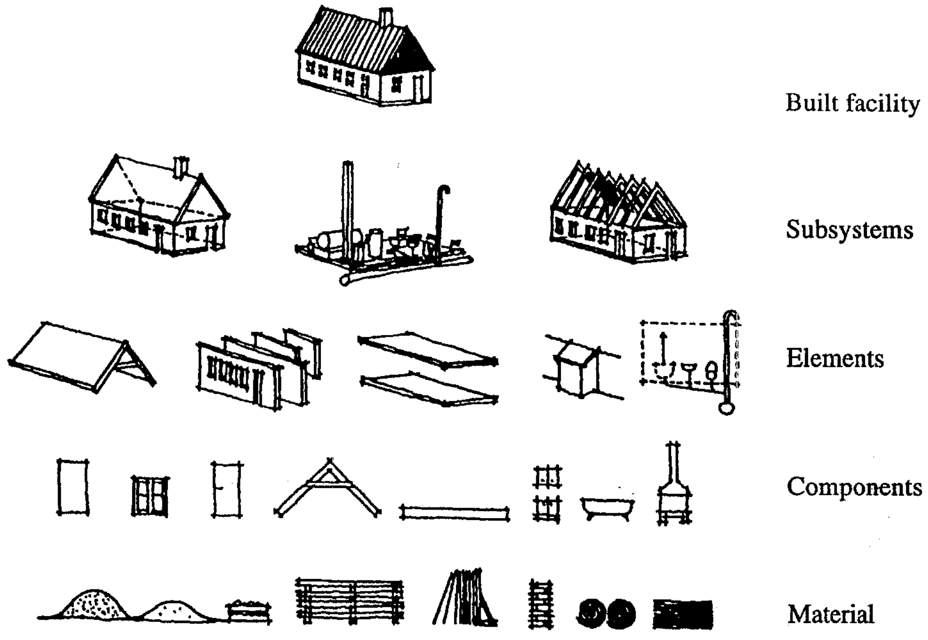


Figure 7. Level structure of built facilities. Things belonging to the levels: built facility, the principal subsystems, building elements, building components and building material.

*Laws*

The laws of a system belong to its structure and are relations among its properties. To the building's laws belong the loadbearing capacity of its loadbearing structure, its thermal u-value and the light transmission of its windows, etc. Laws are often chosen as aspects of study of the system.

*History*

To the history of a building belong all of its former states and changes of state, during its construction and former use. To fully understand the history of a building it must be seen as part of a sociotechnical system. To this knowledge belongs the purpose with which it was designed, and the ideas and needs of its users.

## OBJECT-ORIENTED BUILDING PRODUCT MODELS

### Object-oriented modeling

In the context of CAD, different approaches have been made to represent knowledge about buildings, among these the object-oriented approach seems the most promising (Björk 1993). For this reason it is of interest to make a comparison between the conceptual model of a building based on the systemic account presented earlier and models based on the object-oriented approach.

In this section is made a short presentation of object-oriented modeling, and three product models based on this. However the comparison must be limited to discuss some basic concepts of the models and does not concern their relevance to different applications.

Object-oriented modeling is a method to describe things or concepts and their relations in the context of computer software development. The following account of the methodology is based on the book "Object-oriented modeling and design" (Rumbaugh, et al 1991).

The term "object-oriented modeling" means that "data" are quantized into discrete, distinguishable entities called *objects*. In the model, properties of an object are represented by attributes. A relation between two objects is called a link, which is either concrete or conceptual. An association is a set of links with common structure and common semantics.

The object-oriented methodology described by Rumbaugh et al, distinguishes between three kinds of system modeling: The *object model* represents the static, structural, "data" aspects of a system. The *dynamic model* represents the temporal, behavioral, "control" aspects of a system. The *functional model* represents the transformational, "function" aspects of a system.

The three models emphasize different aspects of the modeled object. If it is a concrete system the object-model may represent the composition and environment of a system at a specific time. A dynamic model can be a state space representation of the system at different times. A functional model may represent the structure and laws of a system at different times.

Classification is of fundamental importance in modeling, and object-oriented modeling supports most classification demands. It seems however that the definitions of the part-whole relation and the relation between levels in a composition can be developed further.

*Aggregation* is defined as "the 'part-whole' or a 'part-of' relationship in which objects representing the *components* of something are associated with an object representing the entire *assembly*". "Two distinct objects are involved; one of them is part of the other". It is also stated that "we define an aggregation relationship as relating an assembly class to *one* component class".

According to Bunge, the "part-whole" relationship is only defined for things, not for concepts. Also, the assembly class and the component class are levels. The relation between a higher level and a lower level is a *precedence* relation, if all the things in the higher level are composed of things in the lower level.

Object-oriented modeling of things should have an adequate representation of composition and level structure. The relationship between the class of parts and the class of wholes should be defined as a precedence relation among classes and the part-whole relation should be defined for things only.

## Discussion of some proposed building product models

In this section three product models are related to the systems approach to modeling, presented above. The models are General AEC Reference Model (GARM), the AEC Building Systems Model and the RATAS Model. The discussion is restricted to issues where conceptual disparities or ambiguities appear, the ambition is not to make a complete evaluation of the models.

### GARM

In GARM, a product can be represented as a so-called PDU, product definition unit, (Gielingh 1988). A *PDU* can be the whole product, but also sub-systems, elements, components, parts or features of a product. The information is given as a collection of characteristics of the product. Each characteristic of a PDU is related to an aspect. Examples of aspects are strength, cost, durability and safety.

A description of a PDU is done according to four fundamental aspects called "abstraction mechanisms":

1. Specialisation: Separates different application areas like Building, Civil Engineering, Process Plants, Ship Building and Terrain Mapping.
2. Decomposition: Shows how a product can be decomposed into smaller units.
3. Life-cycle: Distinguishes the stages "as required, as designed, as planned, as built, as used, as altered, as demolished".
4. Classification: Identifies occurences, specific and generic PDU's.

Aspects and characteristics are sometimes specific to the product type. Three major levels of specialisation are identified: General STEP, Industry-type (eg AEC) and Product-type (eg architecture). It is stated that "it is also possible that entities exist only on the Product-type layer and do not have a super-type". PDU's are said to belong to three different levels (ibid:14), the occurence level, the specific level and the generic level.

In the text is stated that "a generalised concept for decomposition independent of the other abstraction mechanisms cannot be defined". However a decomposition model is presented, with three major classes of PDU's: systems, parts and features. A system is composed of parts that are composed of features. A feature is defined as "a region of interest on the surface of a part" (ibid: 15).

Systems are divided into Arrangements and Assemblies, the former have physically connected subsystems and the latter has non-connected subsystems (ibid: 16).

A PDU has one primary function and none or many secondary functions. The primary function is regarded as decisive for the decomposition in the the design stage of GARM. A complex design problem can be decomposed into a set of smaller problems wich are easier to solve (ibid: 16).

Apart from the "general" type of decomposition "GARM offers another, more flexible alternative to define composition: by means of the decomposition of Technical solutions in Functional units". A "technical solution" is said to "consist" of or "contain" a set of new "functional units" (ibid: 16). It is stated that "requirements given for parts of the product are dependent of more global technical solutions chosen in an earlier design stage" (ibid: 17). A functional unit is a PDU in the stage "as required". A functional unit has an "allowed parameter domain" that defines minimal or maximal values of "required characteristics" (ibid:19).

### Comments to GARM

GARM has had considerable influence as an example of a product data model and has been discussed as a potential ISO-standard. This makes the model important to analyse and criticize. Without ambition to make a more thorough evaluation, this study has risen a few questions about the model. Some questions concern the terminology and other the conceptual clarity.

In the short presentation of the model above, a PDU is said to have characteristics and aspects. Both are properties, an aspect is a general property while a characteristic is a specific property or the value of a specific property. Some PDU's in the Product-type layer do not have a super-type. This exception seems difficult to understand. If a member of a finer class is not a member of a coarser class under the same classing, there is something wrong with the classing.

In object-oriented modeling an occurence or an instance is an individual member of a class, not a class itself. As an example in the text, window-frames are classified by the properties measurement and position. Three classes, generic, specific and occurence with increasing degree of fineness are used. The classification is not convincing since one class seems enough. The idea of classing in degrees of fineness is not controversial but the terminology is not clearly defined.

In the description of decomposition levels is stated that a feature is "part-of" a part. The definition of a feature clearly indicates that it is not a precedent, but should be seen as a spatial region of a part.

The definition of system as aggregates and assemblies should be reconsidered. Only systems have bonding relations among the parts, aggregates have non-bonding, e.g. spatial, relations.

In GARM's alternative decomposition a "Technical Solution" in a higher level is decomposed into "Functional Units" in a lower level. It is stated that a Technical Solution in a higher level "restricts" the properties of Functional Units in a lower level. This "restricts"-relation may hold between concepts, "problems", but not between things. It must not be confused with the part-whole relation that holds between a thing and its parts. A system as a whole cannot restrict the properties of its parts. The whole cannot act on its parts, since the parts and their relations precede the whole.

The idea is that of state space restrictions, e.g. a wooden 2-storey house should not have a concrete wall on the second floor. In the model this idea is applied to the design process in the sense that an early stage decision restricts the possible decisions in later stages. However it is not necessary to presuppose that decisions go from the whole to the parts. In the design process it is just as probable that the properties of a part are decided prior to those of a whole, e.g. that walls must be constructed with steel joists before deciding the thermal or auditive properties of the wall.

In an illustration is shown the decomposition of a car into parts in different levels. The top element is a "car" defined as a Functional Unit. A Technical Solution i.e. a certain set of properties are chosen, in this case those of a Volvo 340. In the illustration lines are drawn from the TS "Volvo 340" to three different FU's, "motor", "car body" and "electric system", in a lower level. The lines represent the "restrict"-relation and indicate that the properties of the whole restrict the properties of parts. See figure 8.

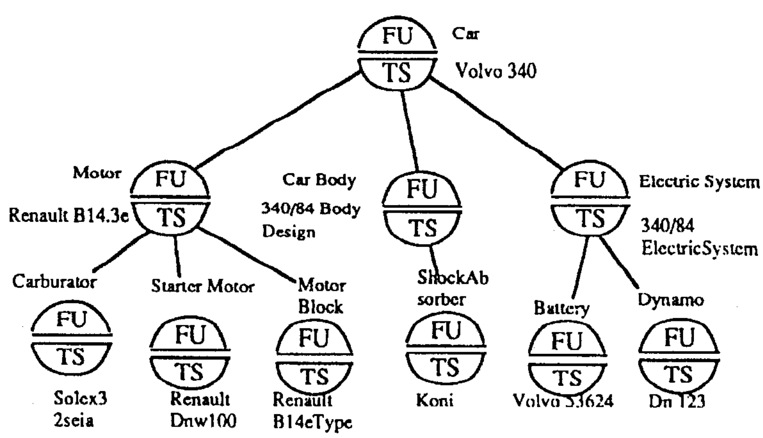


Figure 8. The FU-TS schema of a "car" in GARM.

The figure is ambigous since it illustrates two different concepts, decomposition levels and design process, that must not be confused. Decomposition of a thing in different levels has not been defined in GARM. In the description of GARM has been stated that "a generalized concept for decomposition cannot be defined". The schema does not represent the decomposition levels of a car, but a specific top-down design process. This sequence of design is not the only possible. The "FU-TS"-schema seems rather to represent a design process than the product composition.

The GARM also has a theory of the distribution of responsibilities for different stages and solutions in the design process. It seems prescriptive and restricts the kinds of design processes possible.

To conclude the GARM needs to be further developed concerning most of the basic concepts with which to build the model, such as property, class, composition etc. It also has to discuss the design process in a more general fashion.

### AEC Building Systems Model

The AEC Building Systems Model has been developed within the IGES/PDES AEC Committee[2]. The objective of the model is to "present a high-level conceptual schema of an AEC product model". The product here is a "finished, occupied building, divided into systems". The term Product Data "denotes the totality of data elements which completely define a product for all applications over its expected life cycle" (Turner 1990: 5).

Among the fundamental concepts of the model is the object. An object may have one or more properties. Most "designed" objects go through three phases:
- Generic, exact attributes are not specified.
- Specific, most attributes are known.
- Occurence, when the location and orientation of a specific object has been determined, exactly or approximately (ibid: 10).

An AEC product model is a representation of an AEC project. It is a unique combination of a project phase and a project type (ibid: 12). AEC project types include: buildings, process plants, ships, civil projects, and space habitats. AEC project phases include: programming; concept design, preliminary design, or design development; detail design; construction documentation; construction planning or construction scheduling; construction; maintenance and operation; redesign, or design for re-use; demolition.

Building and site uniquely define a building project. Building systems are connected to site systems. Typical building properties are building type, primary activity, secondary activity, building symbology and other characteristics.

A system is designed to satisfy needs and perform a function. A system has system components and properties. A system component may also be defined as a system with its own system components. A component has ports with joints.

There are different kinds of building systems: structural, electrical, circulation, plumbing, heating, lighting. They can be divided into active, passive and associative. Alternatively they can be classified as space related, fabric related and service related systems (ibid: 15).

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[2]This committee is part of the US-national Initial Graphics Exchange Specification (IGES) committee within the Product Data Exchange Specification (PDES) project.

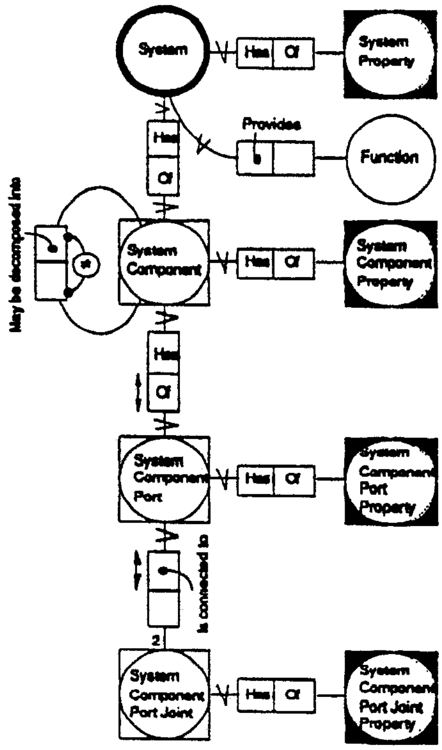


Figure 9. AEC Systems Model hierarchy.

Site systems are artificial or natural, active, passive or associative. Site properties are length of day, growing season, snowfall etc. (ibid: 20).

## Comments to the AEC Building Systems Model

The use of generic, specific and occurence in the model is not correct from a classification point of view. In a class, a generic property is held by all members, while a specific property is held only by some members. An "occurence" is a member of a class. During design, properties are not decided in the direction from generic to specific but in degrees of completeness and exactness as is also mentioned. The stages in a design process can be characterized by the kind and degree of exactness of attributes that are designed.

The definitions of systems in the model seems compatible with the ones presented earlier in this paper, only some short comments shall be made. The system hierarchy presented in the text is not a proper decomposition order. Neither is it a hierarchy in the original sense of an action order. Ports and joints belong to the structure of systems and are relations, not parts. A "binary" port is either an internal or external connection. A "unary" port is either input or output to the system. Finally a relation is a kind of property of a system and can be modelled as such. See figure 9.

*Spatial Systems Model*

This is a separate paper, but can be seen as a part of the AEC Building Systems Model. It starts with the scheme for a "general system hierarchy" which was commented on earlier. A "spatial system" has "spatial system components" that are classified into "enclosure system components" and "space" (Turner 1989)

Spaces are classified, according to use, in construction-space or occupied space, the latter can be circulation, service and assigned. Use (function) is a relation between a thing and a user. The thing must have certain properties to be used, e.g. strength, surface material and spatial poperties. Components are things and space are relations among things. Therefore space can neither be represented as a thing nor have functions.

## RATAS Model

The RATAS-project is an effort to develop a national Finnish system for computer aided design in the construction industry. The RATAS building product model was developed as part of the project to achieve a national building product data model standard. The model is described in (Björk 1989) and (Björk & Penttilä 1989).

The RATAS Model describes a building using objects (entities), and relations between objects. Two types of relations are involved, the "part-of"- relation and the "connected-to"-relation. An attribute represents properties of the building or parts of the building. An attribute has a domain of values. Objects belong to classes specified with attributes. Lower level classes inherit attributes from higher level classes. To limit the need for data in a representation specific views of the model can be taken.

In the modeling work is used a so called "abstraction hierarchy", to make a sub-division of the building into meaningful systems and parts. The model distinguishes five basic abstraction levels: building, system, subsystem, part, and detail. It is pointed out that objects from the higher levels in the abstraction hierarchy are especially useful in early design stages, for defining functional requirements and for making high-level design choices. It is also stated that objects from the lower abstraction levels are more "physical", and often contain more attribute data. See figure 10.

The RATAS building product model can be seen from different viewpoints e.g. the data transfer view, as a database, as a conceptual structure, and for graphical representation. Applications include cad-systems, knowledge based systems, calculation, wordprocessing and project management. Instead of trying to build a complete building product model, which would encompass between 20 000-100 000 objects, the conclusion of the work in RATAS is that a small step development of prototypes for different applications is a managable way to procede.

Some areas for future research are spelled out: 1) The structure of the fundamental data model underlying the conceptual building model needs to be rigorously defined. 2) The description of shape and location data is important and should be undertaken on an international level e.g. in STEP.
3) Different types of connected-to relations have to be investigated, this is seen as highly industry-specific.

### Comments to RATAS

An advantage of the RATAS Model is that it has been developed in close contact with the construction industry. However RATAS is also theoretically well founded.

The "abstraction hierarchy" of the RATAS model is a composition level order, where things in a lower level are parts of things in higher levels. Just as in the other models discussed here, the concept of level is not explicitly defined. There is a risk that objects in higher levels are regarded as more abstract and objects in lower levels more "physical". Although objects in all levels are concrete things.

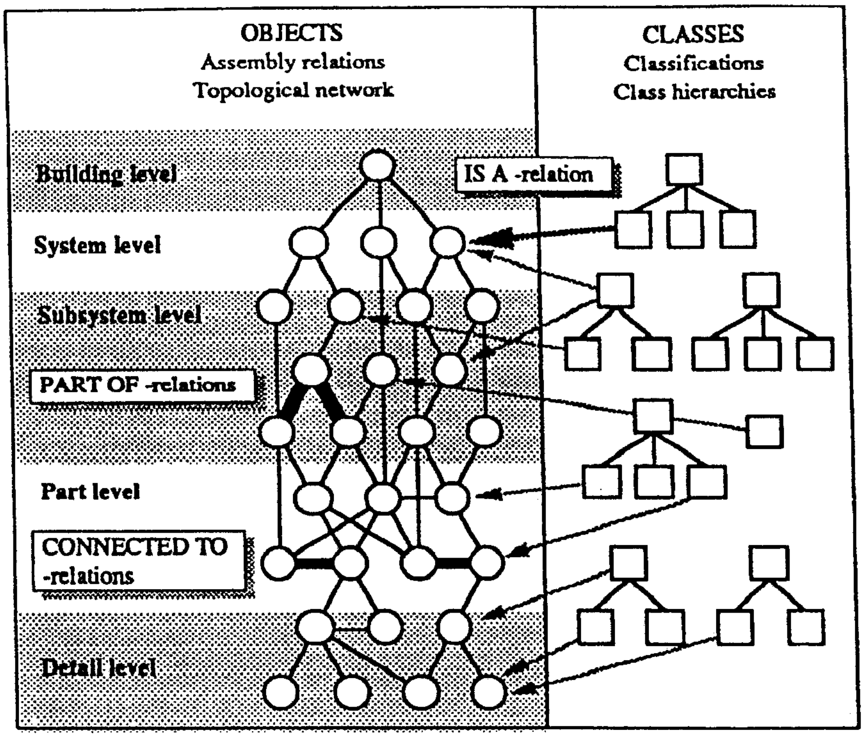


Figure 10. The RATAS "abstraction hierarchy"

In RATAS, "space" is modeled as an object similar to the concrete things in each level. According to the theory presented earlier in this paper, space is a relation among things and not a concrete thing in itself. If the model shall have a true representation of the concrete world, then space must be modeled as a relation among things.

## CONCLUSIONS

In the beginning of this paper was stated that the design of buildings to a certain extent also includes the design of mans activities and experiences. This is especially true for the early stages in the design process. Here the process is signified by the coordination of demands from the user-system with the technical and economical possibilities of constructing the bulding. It is reasonable to conclude that in the early stages of the design process, not only the building, but also the user-system, should be represented as a model in object-oriented databases.

Spatial coordination of the user-system and the building is a dominating design activity in the early design stages. Representing spatial properties is an imporant issue, but space should be represented as a relation among things e.g. bulding parts and users during activities, not just as the concept "space".

The design process is characterized, both by the concentration on different aspects of the designed object in different stages of the process, and by the increasing detail of description. How this affects the structure of object models is an important issue to investigate in future research.

The basic ontological concepts presented here seem to add to the conceptal foundations of object-oriented modeling. The "aggregation"-relation between a class of parts and a class of wholes should be defined as a "precedence"- relation and it must be recognized that the "part-whole"-relation is defined for things only.

It seems feasible to base a general product model on the schema for systems properties presented in this paper. This schema may also be valid as a theoretical background in building classification and standardization, e.g. in the development of building element tables and building specification systems.

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