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Ekholm, Anders

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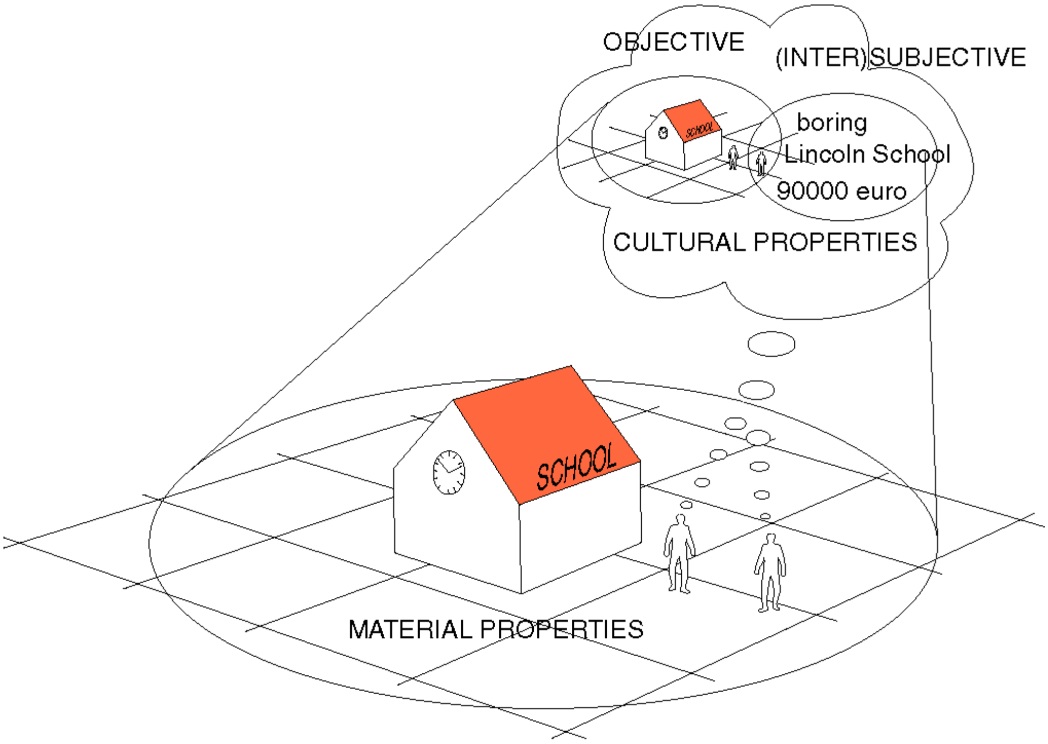
Theoretical foundations for information systems for construction and facility management

Anders Ekholm



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Theoretical foundations for information systems for construction and real estate management

Introduction

Information systems for the construction and real estate sector

The construction and real estate sector in Sweden, as well as internationally, consists of many small businesses and a few large ones. In the construction and real estate management processes, the work takes place in constantly new constellations, and in stages where different actors succeed each other. For such an environment to function, in addition to cooperation and the ability to improvise, common routines and a common method, as well as language, are required. For the construction and real estate sector, Information Technology, IT, is a helping element which, in addition to developing and improving various working practices, is supposed to facilitate the exchange of information and cooperation.

IT is sometimes said to include all kinds of information technology from telephone, fax and e-mail, through office administrative systems, electronic commerce and drawing systems, to model based computational and simulation systems. However, there is a big difference between technology that only transmits information and technology that can process the information in different respects. The Building Information Systems include only those technologies which, in addition to conveying the information, also support its development and processing.

The development of information systems for the construction and real estate sector takes place in an environment characterized by intensive information exchange, strong time pressure and high cost awareness. However, the Swedish construction and real estate sector has the advantage of having a strong tradition of systematized information management. There is a common language that covers large parts of the need for description of the domain and there is a consensus regarding both working methods and the need for continued development of cooperation in the construction and real estate management processes.

This chapter shows how the information systems of the construction and real estate sector can apply the established information systematics of the sector and its scientific basis. The scientific basis creates a common denominator in the development work. It enables coordination of standards, avoidance of misunderstandings and, not least, that the systematics can be based on general principles and not just meet the needs of the specific application.
The first part of the chapter, “Introduction”, gives an example of the difficulty of developing information systems for established fields of knowledge, in this case CAD for building design. The second part, “Information systems”, deals briefly with the design of information systems. The third part, “Semantics and Ontology for Conceptual Modeling”, describes a framework that can form the basis for modeling in the construction and real estate management domain. The fourth part, “Building and real estate management classification”, describes the main features of the sectoral system. The fifth and final part, ”Process and product modelling”, briefly deals with modelling languages with application examples.

Vision and reality in development - the example CAD

The development is led by visions of both needs and technology. The question of what comes first, technology or need, must be answered as the question of the hen or the egg: Both have been developed in a common process for a long time.

Sometimes the visions take on the character of mirages; as technology begins to approach vision, the complexity of the problems grows and the vision shifts like a mirage, from time to time. Despite the allure of visions, the development of information systems must be done using existing technologies and in close interaction with the users of the systems.

The development of CAD for the architect's design work can be taken as an example of the difficulties of developing information systems for a field of work filled with established knowledge and routine. The example is based on an article by Bryan Lawson, architect, and design theorist, in which he describes the development as an endeavour led by a number of elusive mirages (Lawson 1998).

The first mirage refers to the computer as *a design tool*. Design work is characterized by, among other things, the examination of different themes and their possible variations, something that can seem attractive for mathematical formalization and computerization. For example, automatizing the work with floor plans or facades was early considered to be within the limits of possibility. This line of development remains to some extent in research but is today less interesting because the complexity and number of possible aspects is still too extensive to create formalized design tools that are perceived as natural aids. One dilemma is that the design process does not start with a finished problem, but problem formulation and solution are developed together.

Instead of the computer as a designer, the development came to take a simpler and more immediate path towards the computer as a *drawing tool*. In later stages of design, the computer is superior to the pen both in terms of time saving and quality. A problem in drawing-based design, both manual and computer-based, is the errors that can occur in the work. The same object must be reported in many different places and at different scales, which easily gives rise to inaccuracies. Accounting standards laying down rules for the presentation of different parts and for the ranking of documents have been developed to avoid this.

The computer as *a modeling tool* is based on the idea of storing in the computer a model of, for example, the building. According to this idea, the building is not drawn, but it is built up by objects representing the parts of the building. Drawings in the form of plans, facades and sections are generated from the model. Incompatibility between objects in different states should not arise because they are generated from the same model. The supporting vision was formulated as the idea of the *building product model*, which should contain all information of interest throughout the life cycle of the building (Björk 1995). However, model-based design according to the original vision is a very distant mirage. The problems include, on the one hand, the lack of international standardization both for the parts of the building and the drawing-based presentation technique and, on the other hand, the costs of keeping a common model up to date, if is at all needed (Amor and Faraj 2001).

The model-based representation is a prerequisite for the computer as *an evaluation tool*. With various analysis and simulation programs, it is possible to study the aspects of the building, e.g. energy consumption, ventilation needs, daylight lighting, load, etc. A fully developed model of the building is not needed to provide the programs with the required data because, for example, a program for analysing energy consumption needs different data than a program for daylight calculation in the rooms. It may even be easier to enter this data manually into each program. Nor can one unilaterally optimize the characteristics of the building for each of the various sub-problems. The architect works with a wide variety of aspects at the same time and a technical solution usually has many different functions.

The analyses tools must be strongly integrated with the CAD program to support the designer in this stage of the work.

The problems also have to do with the fact that the objects initially designed are based on different views and thus relate to different characteristics of the building. The same physical part of the building can be seen both as a result of materials and work, such as a brick masonry, and as something that fulfils a function in the building, e.g., a space divider. Similarly, building parts and spaces are distinguished by different views of the building. The computer support should thus allow for several different representations of the building, while at the same time not having to be compatible with each other. The question of which these objects are and how the representations are to be adapted to each other is not yet fully resolved.

The problem with model-based computer support in the early stages of design practice is both that a large integrated product model does not meet the need for different and mutually incompatible views, and that small independent analyses programs make the work slow and can lead to sub-optimizations. The problem in the later stages of the design process is that a large integrated product model could bring great benefits, but the necessary international standardization is lacking in terms of both the classification of the building's parts and presentation techniques. Another difficulty is that it is not known how extensive such a model needs to be to respond to information needs in, for example, real estate management.

However, research is working on these issues (Eastman 1998). On the one hand, the analyses programs must be developed and become so easy to use that they work, for example, as a spelling program in a word processor. On the other hand, extensive international standardization work is underway to enable so-called interoperability between computer systems. The latter refers both to work in the established area of construction classification and in new areas such as process and product models for the construction and real estate sector. Finally, the idea of ”the large unified product model” must be questioned by studies of what information really needs to be present in the model, for example when transferring information between design and production and between production and real estate management.

Another aspect is that information systems are rarely developed with only the construction and real estate sector as a target group. Even less account is taken of the sector's different working methods in different countries. As a rule, software must be adapted to the specific requirements and needs of the sector including different national variations. It is expensive to develop CAD-systems for the construction industry because, due to a lack of standardization, they must be specially adapted to many small national markets. Nor can the design costs be made as advanced as for the automobile and shipbuilding industry where the design costs in relation to the total value of the final product are considerably lower than in construction.

This section has been intended to provide a picture of the complexity of the prerequisites for developing information systems for the construction and real estate sector. The example has only covered one of many areas, but it is to be expected that similar difficulties will arise in the others. The aim of the first section on information systems is to provide a basic insight into how they are structured and what is required to develop systems, for example for application in the construction and real estate sector.

Information systems

Application and benefit

Computer-based information systems are developed with the aim of supporting the management of information in an enterprise. An information system should enable the collecting, storing, processing and presentation of information. A distinction is usually made between three main types of computer-based information systems (Boman et al. 1997:5-6):

- Data-processing systems
- management information systems and
- decision support systems.

Data-processing systems process and store large amounts of information from routine-based processes such as payroll management, invoicing and travel booking. *Operational information systems* are an expanded form of data processing systems with the aim of producing supplementary information, e.g., statistics and analyses regarding the development of the enterprise. *Decision support systems* have advanced functions for decision support, they can, for example, search and compile information in databases about customer preferences, etc.

Depending on the level of development, the CAD-systems used in building projects can be examples of all three main types. Simpler drawing and modelling systems that mainly store and present information, e.g., regarding the geometry of the parts of buildings, are of the type *data-processing systems*. If the systems can compile information about the building, e.g., areas, volumes, and quantities according to different calculation principles, they are of the type *management information systems*, that in the case of model-based CAD could be called *product information systems*. If the system can also perform static calculations, energy calculations, simulate various processes in the building, or retrieve information about resources suitable for the building from the Internet, then the CAD-system is a *decision support system*.

Construction

An information system handles information about objects of interest to a business. The objects constitute the *domain* of the information system also called *interest area, object system* or *Universe of Discourse, UoD*. An information system consists of three main parts (ISO 1985):

- conceptual schema,
- information base and
- information processor.

See Figure 1. *The conceptual schema* consists of concepts that describe in a general way the objects of the domain and their properties; it is a *general conceptual model* of the chosen objects in the domain. The symbols of the conceptual schema are of three main types:

- entities
- attribute symbols and
- relationship symbols.

Entities denote objects in the domain, *attribute symbols* denote attributes with specified value spaces, and relationships denote *relationships* between entities and attribute symbols. See also the section on Process and product modelling.

The conceptual schema is read as statements about the domain's objects, e.g. how objects are related to each other through the relationships ”type-of” and ”part-of”, and what properties they have. The schema can also include rules for possible events in the domain by specifying how the state of the objects may vary. The scope of the conceptual schema is determined by the users' need for information.

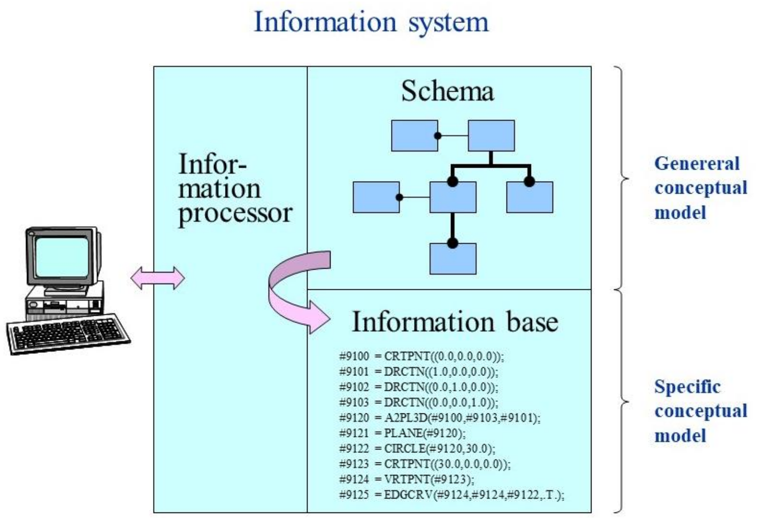

Figure 1 Principal structure of an information system

A modeling CAD-system can describe the parts of a house with, among other things, walls, joists, roofs, windows, and doors. The CAD-system has rules for how properties such as geometry and materials are specified and what values they can assume, as well as how the parts of the structure can be combined. For example, external walls must be cut off in a specific way against a roof, and that windows and doors in certain CAD-systems must not be freely located but must be included in walls.

A description of a specific object is developed as a *specific conceptual model* in *the information base*. A specific object, an *instance*, is created from the classes of the conceptual schema by specifying the value of one of the class's attributes in the information base. If the conceptual schema contains the class ”External wall Y” with, among other things, the attribute ”Geometry” (length, thickness, height), an instance can be created by entering values of these properties in the information base, e.g. (length=x, thickness=y, height=z) whereby ”External wall Y1” is represented in the information base.

The information base can be, for example, a data file or a relational database. The database can be physically located in one computer or laid out on several connected computers. The database can be unique to an application or shared by multiple applications. In product information systems, the specific conceptual model is referred to as *product model* and represents a possible or manufactured product. In the building context, the model is referred to as the *building product model* also called *building information model, BIM.*

Users must be able to manage information in the information base. This is done via a software tool called *information processor* that also enables the construction and modification of the conceptual schema and the database. If the information base is a database, the information processor is called the *database manager*. SQL, Structured Query Language, is the language used for information exchange with relational databases. A product model requires a database manager that can enable change of all or part of the model, manage versions, and control access to change the model. A *model server* is a physical computer equipped with an information system that can handle product model-based information.

Development of information systems

The development of information systems takes place through a design process and is characterized by a progressively increasing understanding of both the problems to be dealt with in the information system and how the information system should be structured. The different elements of the work include problem description, preparation of conceptual schemas, system design, prototypes, and tests, in a progressively increasing detailing to a practically functioning application. The work is often done in close cooperation between system developers and users.

In the development of information systems, the work is concentrated in a first step on information content and other user-relevant characteristics of the system. In the subsequent stage , technical issues and system building are discussed. To meet the users' information needs, an initial description of the activities is made in the form of a *process model* that describes the activities of the enterprise and the information flow between the activities. The process model makes it possible to determine the information which is of interest to the enterprise, and which is to be managed by the information system and forms the basis for the preparation of the conceptual schema. At the same time, the other requirements for the information system, how it is to be used and how it is to be constructed are also determined.

Conceptual modelling refers to the elaboration of the conceptual schema describing the domain including events, rules, and restrictions. The description of the domain should be based on both practical and scientific knowledge of the domain. Often, knowledge is not formalized in the way required to be managed in an information system, but the developers of the information system must also systematize the knowledge of the domain, e.g., through a classification of the domain's objects. To be stable and long-lasting, systematics should be based on general theories of reality that are gradually specialized to apply to the domain-specific objects.

In the modelling work for the development of the conceptual schema, three main types of models can be distinguished (Rumbaugh et al. 1991):

- object models,
- dynamic models and
- functional models.

The object model describes the domain's classes, attributes, and relationships. The object values are arranged hierarchically, partly in terms of the taxonomic relation ”type-of”, and partly in terms of the partitive relationship ”part-of”. The schema also specifies operations that the objects perform. The operations correspond to events in the dynamic model and functions in the functional model.

The *dynamic model* accounts for the time-dependent behaviour of the domain, i.e., events and processes. The dynamic model is needed for interactive systems, e.g., for managing bank errands. In dynamic modelling, scenarios are developed, e.g. process schemas, of typical events that the system should be able to allow.

The functional model describes the functional dependence between different states of the system and shows how different values are calculated, e.g. calculations of geometric information.

The development of the conceptual schema takes place through *object-based modeling*, which means that the domain is described as consisting of different objects, with properties and relationships. In the development of the conceptual schema, the object is in focus and properties are something that can be attributed to the object. The conceptual schema describes the general properties of the objects.

However, when the conceptual schema is to be implemented in a relational database, one must switch to value-based modelling. In *value-based modelling*, a specific object, a so-called instance, is created by specifying values for the object's properties in the information base. The specific object is uniquely identified by one of these attribute values; an individual could be created from the attribute ”name” e.g. ”John Smith”. In object-based information bases, a unique ID is instead used as an identifier, which means that the determination of properties can be made independent of the instantiation. For a deeper discussion of this issue, see (Boman et al. 1997).

Information systems shall support the user's handling of information about the objects in the domain. The possible statements are limited to those resulting from the implemented conceptual schema. This causes problems when one wants support for *product design*, which could involve the *description of new* objects that have not yet been defined in the conceptual schema and the *reclassification of instantiated objects* whose properties have been changed. Research on how so-called *dynamic* information systems for design should be designed is ongoing. See, for example, (Eir and Ekholm 2002, Fridqvist 2000, Leeuwen 1999 and Eastman and Siabiris 1995).

Language of the conceptual schema

The classes, attributes and relationships of the conceptual schema should be read as statements about the domain. The description must be unambiguous and without repetition for it to be applicable for programming and implementation in databases. Propositional logic and predicate logic can be applied to describe objects and their relationships in a way that is directly applicable in the elaboration of conceptual schemas, programming, and the construction of databases. Examples of logic-based so-called formal languages with which the statements can be made are Unified Modeling Language, UML, (Booch et al. 1998) and EXPRESS (Schenck and Wilson 1994). In connection with product modelling, EXPRESS is most often used, which is standard for the development of ISO's STEP standards.

The conceptual diagram is drawn up in text format, which allows for a complete description including rules and restrictions. In connection with the development of the information system, a graphical notation is also drawn up in the form of block diagrams to increase the understanding of the structure of the scheme, e.g., in communication with the users of the system. UML has such a graphical notation as does EXPRESS-G.

Semantics and ontology of concept modeling

Starting points

This section is based mainly on the works of Mario Bunge, most notably his ”Treatise on Basic Philosophy” (Bunge 1974a, 1974b, 1977, 1979, 1983a and 1983b). Other references are found on an ongoing basis in the text. Bunge’s work has been chosen as a framework because it combines a consistent holistic approach in an exemplary way with critical examination of different positions in the theory of science.

The conceptual framework presented here has previously been applied in the development of a theoretical foundation for Swedish and international building classification (Svensk Bygg-tjänst 1998). Classification concerns systematizing knowledge of a domain. The theoretical foundations of building classification can also be applied to the development of information systems for the construction and management domain.

Concept

The need to be able to communicate in an unambiguous and precise way places certain demands on the language, for example, when drawing up a technical description or a bill of quantities. This applies not least to the construction of the conceptual schema in an information system for these tasks. To be understood in a uniform manner, a statement must consist of concepts with a specific referent, an unambiguous definition, and an appropriate agreed designation. The question of the meaning of symbols and the meaning of concepts is dealt with in semantics. Here follows a brief survey of some of the basic concepts of semantics.

Concepts are mental constructs, with the help of which objects of various kinds, both abstract and concrete, can become objects of thinking. The concepts can be likened to the building blocks of thinking. A concept is said to *refer* to an object, this is the *referent* of the concept. For example, the concept ”house” refers to concrete houses and concept ”idea” refers to an abstract notion. See Figure 2.

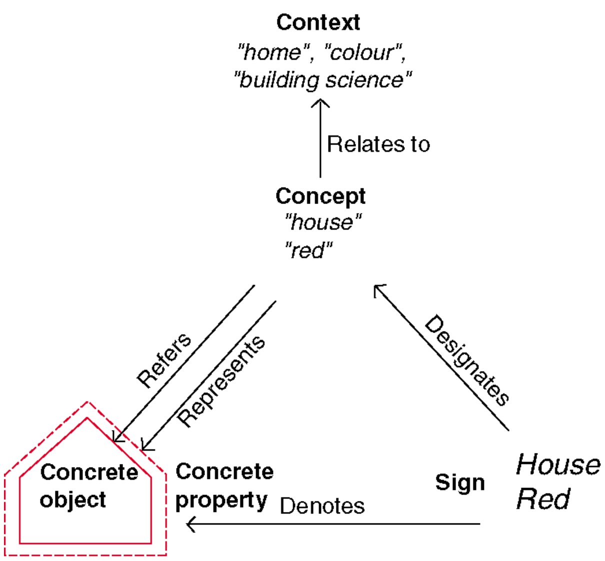

Figure 2. Relationships between characters, objects, concepts, and context

A concept can also *represent* a property of an object. An example is ”u-value” which refers to a climate-separating construction and which represents its heat-insulating property. Concepts that refer to objects as a whole are called *class concepts* or just *classes*, while concepts that represent an aspect or single property of the object are called *attribute.*

When using the term ”house”, other concepts may appear as associations or otherwise be related, e.g. ”home”, ”architecture” or ”joy”. Such other concepts to which the term relates to are referred to as *context.* Context is the broader conceptual environment of, for example, scientific theories, traditions of ideas, or personal associations that are necessary for the concept’s meaning to be understood. The *meaning* of a concept is also defined as the combination of referent and context.

A *definition* is a description of the meaning of concepts based on a specific purpose. The definition indicates the overall category to which the object belongs, as well as its characteristic distinctive features. If the definition of the concept ”house” is interpreted in this way, it may read: ”A house is a building with climate-protected spaces”. In the definition, ”building”, indicates the nearest superior ”coarser” class, while ”climate protected” and ”spaces” are characteristics that separates houses from other buildings, such as bridges or quays. The purpose of this definition may be to distinguish between different buildings in terms of function and construction in the context of technical descriptions.

Conceptual framework, theory, and model

Things and events are described in more detail using conceptual systems. A *statement* is a simple system of concepts while a conceptual framework and a theory encompass a larger number of related concepts. In a *conceptual framework*, key concepts that refer to objects within a domain are defined in a comprehensive, general way. A *theory* is a conceptual framework in which the concepts are logically related to each other.

Conceptual frameworks and theories can be worked out at several different levels of detail. The most general level is the *ontological* one which refers to concepts such as ”object”, ”property”, ”thing”, ”system”, ”structure”, ”space” and ”time”, which are common to any description of the material world. The *domain-specific* level refers to concepts used to describe things and phenomena characteristic of a specific area of knowledge. However, a domain-specific conceptual framework utilizes a variety of basic concepts taken from an ontological conceptual framework, such as space, time, and system. See Figure 3.

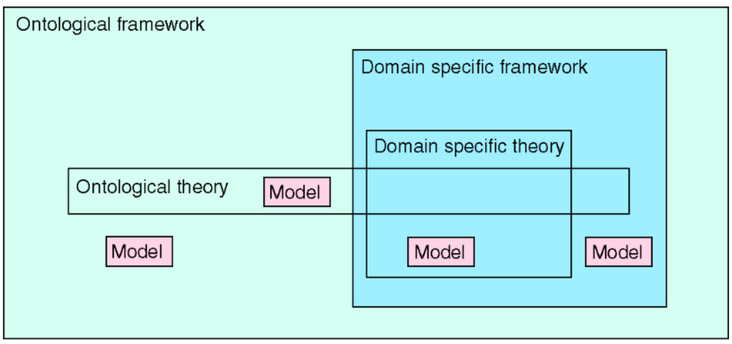

Figure 3. The scope of different representations

A *model* represents the properties of a thing and is based on either a conceptual framework or a theory. A single model does not give a complete representation of a thing but represents a selection of properties determined by the purpose of the model. Such a specially selected set of properties, often lawfully related, is referred to as an *aspect*. Aspects of the built environment may relate to environmental properties of construction products, load-bearing systems of buildings, etc.

A *concrete* model is a *thing* that has factual resemblance to the modelled thing, while an *abstract* model is a *conceptual representation* of the thing from some aspect. A concrete model is not a direct imprint of reality but is preceded by the construction of an abstract model. A model of a thing is thus not directly built ”as the thing is” but ”as we see the thing”, e.g. in everyday use, through a scientific theory or an artistic temperament.

In the context of computer-based information management, a conceptual model is also referred to as an *information model*. When we talk about computer-based models, we normally refer to information models and not to the concrete model built up in the computer's hardware. A *product model* is a computer-based information model and is defined by ISO as ”an information model which provides an abstract definition of facts, concepts and instructions on a product” (ISO 1994).

Signs, language, and communication

The transmission of concepts between people is made possible by signs or symbols that we can perceive with our senses, such as light signals, sound waves and sensory impulses. A *sign* is a thing designed in a particular agreed way so that both the sender and the receiver interpret it as the same concept. The sign *symbolizes*, or *denotes*, a concept, e.g., the term 'house' symbolizes the concept of "house". Signs are also said to *stand for*, or *denote*, another object, e.g., the signs 'house' and 'red' can stand for a concrete house or its colour.

The relationships between signs, concepts and objects can be accounted for as in Figure 2. The figure follows the principles of Ogden and Richard's sign-model (Ogden and Richard 1972), but the additions on representation and context have been taken from Bunge's' semantic theory.

Concepts that are transmitted in a communication process are referred to as *information*. In this context, information refers only to concepts and thus not to feelings or experiences such as of smells or music. The sender of information must design the signs to be interpreted by the recipient according to agreed *designation rules* or *code* for the correct concept to be understood.

The terms information and data are often reversed around the same phenomenon. *Data* most often refer to properties of objects. In these cases, data are attributes, while information is a broader concept that can include both classes and attributes.

Knowledge is a broader concept than information and can be defined as learned concurrent motor, perceptual and conceptual competences (Bunge 1983a). Having a skill means acting so that a given purpose is achieved, e.g., through the interaction of bodily motor skills, the reception of sensory impressions, and one's own thinking.

Language is a system of socially agreed signs that enable communication. A linguistic sign is referred to as a *term*. The meaning of the sign is dependent on the practical and conceptual context in which it comes to use, e.g., the term 'foot' is interpreted as a body part by a doctor, as a command by the dog, and as a measure of length in the context of maps and drawings.

Languages can be both natural and artificial. Natural language has been developed in different cultures in everyday life. Artificial languages have been developed for a special purpose. There are artificial languages with the purpose of serving as an everyday language and which try to emulate the natural ones, such as Esperanto. More commonly, artificial languages are developed to provide increased precision in communication and to limit the possible statements to the only logically correct ones, as in the elaboration of the conceptual schema in an information system.

Logic studies how, based on given conditions, well-founded statements are formed. *Propositional logic* studies how to form logically correct statements from simple concepts, e.g., "*The house is red*", and *"The car is in the garage". Predicate logic* also makes it possible to express rules and conditions, e.g. "All houses are red" and "*If a house is black, not all houses are red".* Propositional logic and predicate logic are applied to describe objects and their relationships in a way that is directly applicable to the development of conceptual schemas, programming and building databases.

Object and property

Questions about the nature of reality, about what exists and how it is structured, are treated within the branch of philosophy known as *ontology*. In the sections that follow, some of the basic concepts of ontology are treated.

Through perception, the individual becomes aware of objects in the environment. *Objects* are generally defined as concrete or abstract entities of thoughts, feelings, or actions. Abstract objects such as feelings or thoughts have no concrete existence, they are *mental constructs* with abstract properties, while concrete objects, *things,* have concrete properties.

Similarities and differences between objects are due to their properties. A property has no independent existence separate from the object that has it; The distinction between object and property is purely conceptual and is not answered by material conditions. It can be argued that the concept of property is unclear and that it would be sufficient to distinguish between different kinds of objects. However, it is practical to distinguish between an object and its properties, e.g., in the context of design or scientific research. The distinction is also reflected in the word classes of the language, nouns, verbs and adjectives respectively, or the subject, object and predicate of syntax, respectively.

Natural scientists and philosophers such as Galilei, Newton, Descartes, and Locke distinguished between primary and secondary properties. The primary properties of things exist independently of an experiencing subject, e.g., mass and temperature, while the secondary properties are experienced through our senses, e.g., colour, loudness, external shape, and beauty. The primary properties of things are here referred to as material, while the secondary properties are referred to as cultural. See Figure 4.

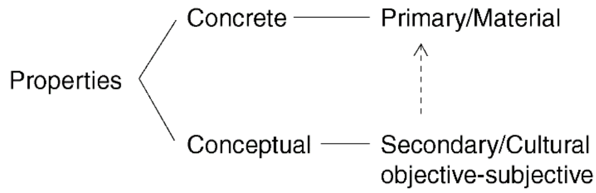

Figure 4. Basic categories of properties of things.

Secondary properties in a somewhat broadened sense can be said to be man's conceptions about things. This type of property includes not only the properties as experienced through our senses but also those that we can get to through reason, such as scientific knowledge.

Statements aimed at describing the material properties of things, in a way that is independent of the viewer, are called *objective*. They can be true or false depending on their conformity with the material properties. In the case of in-depth studies and with increased knowledge, previously true positions may be considered false or in need of supplementation. Statements aimed at describing the cultural properties of things are *subjective* if they depend on the individual and *inter-subjective* if they are based on conventions in a social system. Subjective statements differ from objective ones in that they do not aim to describe the material properties of things. Subjective properties are therefore neither true nor false.

Properties of properties

One must distinguish between the properties that are common to a set of objects and the properties that distinguish the objects in the set from each other. The former are called *general* while the latter are called *individual* or *specific*. To the general properties of a variety of houses may belong that they are built with some kind of brick construction. Individual characteristics in the set can be the type of brick construction, e.g., façade brick or load-bearing brick wall.

Properties that characterize a thing as a whole can be called *overall*. The overall properties are of two types, *resulting* (inherited) and *emergent* (or gestalt properties). The resulting properties of a whole are those that already exist in its parts. The mass of a building results from the mass of the building parts, and the width of the wall by the dimensions of the constituent components in the corresponding direction.

Emergent properties are new properties that are not found in the parts. Emergent properties are grounded in the properties of the parts and can be derived from them, but do not constitute the sum of the properties of the parts. A house has the emergent property of being a climate shelter and enclosing a volume of air. Something that the building parts individually do not have or do.

Internal and mutual characteristics

Properties of things can be considered either internal or mutual. The mass of a hammer is an internal property, while its impact force is a mutual property of a hammer and a carpenter. An *internal* property exists in the thing itself, while a *mutual* property arises from a relationship between things.

The mutual properties depend on the nature of related objects and their relation. A function arises from a binding relationship between things. A *binding* relationship means that the state of things in the relationship is affected. A *function* is here defined as a property of one thing that affects the state of another thing. When two things affect each other, such as when the carpenter holds the hammer or when the hammer hits the nail, they have a bonding relationship. The carpenter and hammer together have the function of hitting and forcing in the nail.

A mutual property can also arise when the relationship between things is *non-bonding.* Examples of non-bonding relationships are spatial relations such as location or size and temporal relations such as duration and order of turn. Properties that arise in non-bonding relationships are, for example, spatial and temporal properties and are here referred to as *comparative properties*.

Mutual properties arise also when a subject perceives and interprets an object. Pure perceptions are referred to here as *experiential properties.* They are active ”depictions” of events in the environment including the individual’s body but also depend on past experiences and ideas. Experiential properties are fundamentally subjective, they are personal experiences of a subject. Experiential properties can be divided into *sensory* that refer to direct sensory impressions and *introspective*, which are a person’s own emotions based on the experience of perceptions. Examples of sensory properties are loudness, colour, and warmth, while comfort, beauty and excitement are introspective properties.

The experience of a thing does not stop at perception but is also dependent on the formation of concepts and thinking. A special act of thinking involves *interpreting*, i.e., developing concepts for perceptions. There are two types of interpretation properties: epistemic and semiotic. *Epistemic* interpretation implies that the subject, via the experience of the object, seeks to obtain knowledge about its material properties. Therefore, epistemic properties can be objective. This form of interpretation is applied both in everyday life and in science. One can, for example, describe a perceived object as a concrete system with parts, relationships, and environment.

Semiotic interpretation means that the subject, in experiencing the object, seeks to reach knowledge of the information that the object conveys considered a sign in a communication system. Signs are interpreted as meaning-bearing objects, rather than as concrete systems. Signs can be linguistic, such as newspapers or books, or non-linguistic, such as light signals or road signs. Semiotic properties are intersubjective and are based on agreements in a social system.

To sum up, properties of things can be divided into material and cultural. The material properties are:

1. *Functional* (mutual properties based on binding relations with the environment). This category includes functions, including side effects and environmental impact to the environment.
2. *Comparative* (mutual properties based on non-bonding relations with the environment). Comparative properties are, for example, location, geometry, timings of production and use, pace, rhythm, and speed.
3. *Compositional* (internal properties based on parts and relationships between parts). Compositional properties are e.g., material, mass, density, surface texture and internal processes.

The cultural properties are:

4. *Experiential* (mutual properties determined by the individual's perceptions). The perceptions can be both sensory and introspective. Examples of the former are color, loudness and lightness, and the latter are comfort, beauty and safety.
5. *Symbolising* (mutual properties based on semiotic interpretation of the system). The symbolising properties can be divided according to whether the interpretation refers to linguistic or non-linguistic signs, books and road signs are examples.
6. *Administrative* (mutual properties attributed to the system in a social context). Administrative properties include ID, name, classification, and price, but also instructions for use and property declarations.

Figure 5 illustrates these main categories of properties.

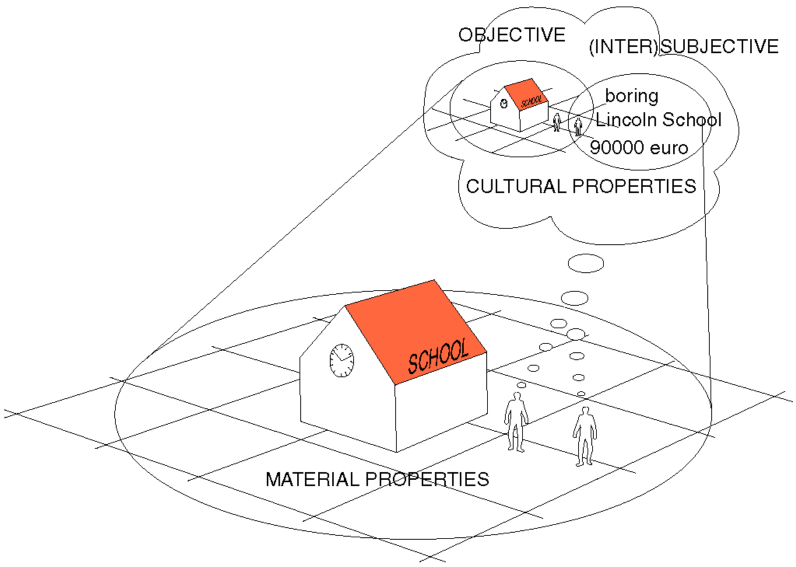

Figure 5. Main categories of properties in the object-subject relationship

System

A system is an object whose composition consists of a collection of objects with mutual relations. See Figure 6. A system can be either concrete or abstract. A statement, conceptual framework or theory are examples of abstract systems. A *concrete system* is a composite thing with bonding relations between its parts and to the environment. The *composition* is the parts of the system, the *environment* is things that affect or are affected by the system without being considered to belong to it, the structure is the relations of the system, internal and external, and *mechanisms* are subsystems that carry out the internal processes of the system.

The *state* of the system is the properties at a given time and the *history* of the system is made up of all previous states. An *event* is a change in the state of a system.

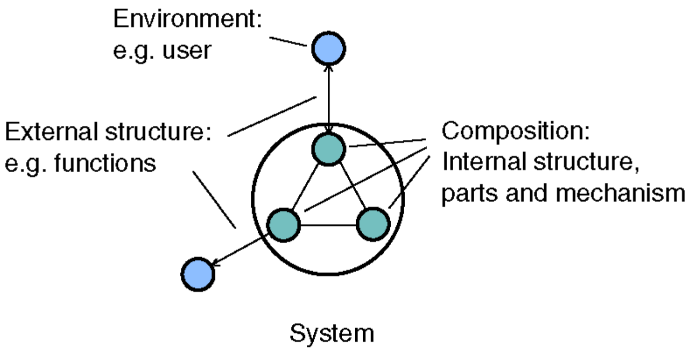

Figure 6. Systems with composition, environment, and relationships.

A system is built of things that are induced to work together, for example a masonry is built of, among other things, bricks. The bricks are included in the composition of the masonry. Between the system and its parts, there is a *part-whole relationship*. The term 'part' can refer to parts from both a functional and a compositional aspect. The functional aspect, representing a view *top-down*, refers to mutual properties including functions of the system in its environment, while the compositional aspect, *bottom-up*, refers to internal properties including the parts of the system, see Figure 7. Among other aspects are the spatial, temporal, or experiential ones.

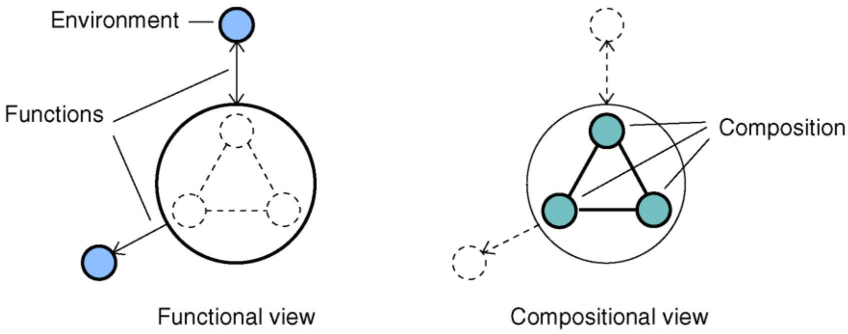

Figure 7. Functional and compositional aspect of a system

The reason for distinguishing between part-concepts from different aspects is that functional and compositional parts have a relationship not one to one but many to many. Examples of a functional ”part” of a structure is ”load-bearing”, while corresponding examples of a compositional part can be ”masonry” or ”stud construction”. The compositional aspect says nothing about the function of these parts, e.g. whether masonry is load bearing or space-separating. The same compositional part can be included in several functional systems, e.g. a mounted window that most often is part of both the building's lighting system and climate system.

If the parts of a system are also systems, they are called *subsystems*, and vice versa if the parts are systems, the whole is called *supersystem*. Subsystems, systems and supersystems are examples of a so-called level order. A *level order* or *hierarchy* is a set of levels arranged with respect to some relation. In a level order of composition, lower-level systems are part of the composition of higher-level systems. The relationship between levels is ”precedence”, i.e. systems in a lower level are formed before systems in a higher level.

In each higher level, properties emerge so that the wholes in some fundamental aspect differ from the parts. For example, in the clay/brick/masonry level, new properties emerge in respective level.

Space, time, and process

Even if things do not have bonding relationships, i.e. do not affect each other, it may make sense to consider them as wholes, e.g. because of their temporal or spatial relationships. Such a group of things with non-binding relations to each other is called an *aggregate*.

The general concept of *space* can be defined as an aggregate of things considered solely with respect to spatial properties, e.g. distance, size, or internal space. Some rooms can enclose and make room for other things. The concept of *room* is a space with actual or experiential boundaries against, for example, light, sound, or air, and with an inner space that is not occupied by the limiting things and where other things can be accommodated (Ekholm and Fridqvist 2000).

By analogy with a spatial relation being defined as a separation relationship between things, *time* is defined as a separation relationship between events. A *process* is a series of events in a system. A watch has a regular process and can be used as a frame of reference for time measurement.

A system that undergoes a process can both affect and be affected by its surroundings. *Input* refers to the impact of the environment on the system and output refers to the impact of the system on the environment.

In the description of processes that are usually carried out in the construction sector one distinguishes the concepts of resource, activity, and results. An *activity* is a process that has a determined purpose. Activities can only be carried out by systems that can set goals, such as social organizations. *Resources* may be both input, i.e. material and information that affects the system, and the system's mechanisms, i.e. the subsystems that perform and control the activity, such as labour and machinery. *The result* is the system's output, i.e. material and information produced by the activity.

An example of the application of these concepts is a carpenter who, with a hammer, will nail two boards together. The activity is the nailing, the resources are partly the nails and boards, and partly the mechanism in the form of the carpenter with the hammer. The result is the joined boards.

Artifacts and sociotechnical systems

An enterprise is generally defined as a social organization that performs an activity. An artifact is a concrete system that is made or controlled by man. When humans perform an activity using artifacts, a new kind of system emerges, a socio-technical system. The activity is a property of the human-artifact system. In the example above, the carpenter with the hammer constitutes a socio-technical system.

Artifacts can both be environment of and part of an activity. If an artifact is both used and controlled in an activity, it can be considered to belong to the activity, while if the artifact is used without being controlled, it can be considered to be an environment of the activity.

Construction works are artifacts and enable activities: a road allows for driving and an irrigation plant along with processed land allows for cultivation. When buildings are used, they are mainly the environment of the activity. However, some parts are also usually controlled during an activity and can thus be considered part of the activity; Examples of such parts are doors and windows, furniture, and other mobile parts of the interior.

Classification

A *class* has previously been defined as a concept that refers to objects as a whole, which have one or more properties in common. The objects are said to be *members* of the class. The objects may have other characteristics in addition to those that characterize the members of the class. However, these are not considered in the classification. *Classification* means dividing a collection of objects into mutually distinct subsets based on a purpose (Hunter 1988). The sets are ranked in a tiered order, where sets in a higher level include quantities in underlying levels.

The purpose of the classification is the basis for distinguishing *properties of division*. Examples of a characteristic that can be used as a basis of division is colour such as red or green when you want to distinguish between fairway marks, or frame type such as "made of steel", "of wood" or "of concrete", when you want to distinguish between building frames based on the material constituent. In a stable and long-lived classification, the properties on which the classification is based should be the intrinsic properties of the object. A classification based on benefit to the user may be useful but may need to be changed if the knowledge of the object's impact on the user changes. The classification of drugs is an example of the difficulty of creating a stable classification based on the patient's reactions, as the knowledge of the benefits or harmfulness of different substances is constantly evolving.

The discernment of classes may be scientifically based, but it must take into account that the properties of things cannot be delineated unambiguously, e.g. the difference between window and window door may be difficult to pinpoint; Nevertheless, for classification, it is necessary to create distinct classes. This is done by so-called Boolean division into qualitatively distinct classes of the type ”A” and ”Non-A”.

A *classification* system is a conceptual system of classes that is related with respect to the relation ”type-of” and that allows the classification of objects in a set. A generally accepted classification system allows for effective communication. The construction of the classification system requires both knowledge of the concrete properties of the objects and careful consideration of the purpose of the classification: ”A classification system summarizes and orders existing knowledge” (Bunge 1983a). Classification systems developed in the field of construction for purposes such as description, quantity and cost calculation shall be used in the development of information systems for the corresponding data.

To be able to classify a certain number of objects, it is necessary to determine the purpose of the classification. Then it is possible to determine the properties of the objects that are of interest for the classification; In that regard, it is necessary to disregard characteristics which are not of interest. Finally, the objects are sorted into classes with respect to the selected properties.

The classification can be made with different degrees of fineness. A *course* classification is based on more general characteristics, while a *finer* classification is based on more specific characteristics.

For example, depending on the purpose, the fruits in a basket can be divided into apples and pears in the first level of division. The next level of division can refer to different varieties or different colours.

A *subdivision level* is a set of classes with the same degree of fineness. See Figure 8. In Fig. 8 and 9, the character ⊆ (subset of), e.g., a ⊆ *b*, means that the set of members of one class *a* being either the same as, or a subset of, the set of members of another class *b*. The sign ∈ (member of), e.g. *a*∈*b*, refers to a thing *a* being a member of a class *b*. The sign ∩ (intersection of), e.g. a ∩ *b*, refers to the members that are common in the sets *a* and *b*.

The purpose of a classification is to distinguish between objects in a set. For the classification to be exhaustive, each object in the set must be member of a class, and for it to be unambiguous, each object must belong to *only one* class. Without these criteria, there are unclassified objects and objects that belong to more than one class in the same subdivision level. In these cases, the classes have not been defined unambiguously. A practically useful classification must be:

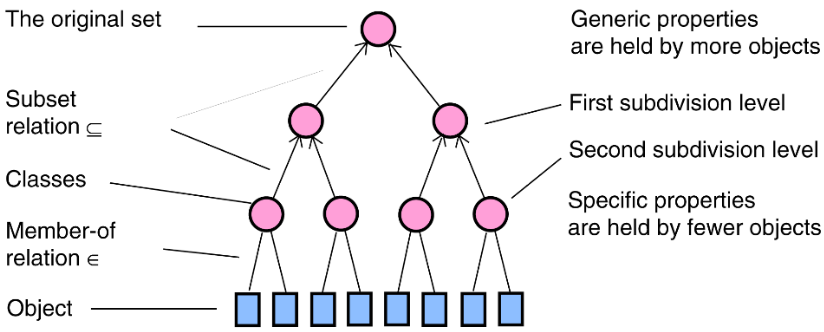

Figure 8. Classification concepts.

- exhaustive; the union of all classes in the first tier must be equal to the initial quantity, see Figure 8, and

- unambiguous; There can be no borderline cases where the same object belongs to more than one class in the same subdivision level. All classes in the same subdivision level must be disjunct, i.e. pairwise separated. A class in a lower subdivision level can be a subclass of a class in a higher subdivision level, see Figure 9.

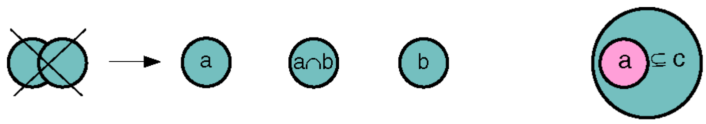

Figure 9. Relationships between classes in a classification.

The same concrete system can be viewed from different aspects and seen as different objects. It can also be classified into different classification systems with different purpose.

Design as conceptual modeling and problem solving

The knowledge necessary to work with product design or design in different areas is so fundamentally different regarding, for example, functions and materials, that it is impossible to achieve design skills without specific knowledge of the products to be designed.

However, there are general theories about artifacts and intellectual work that can be applied within every design area.

Design involves determining the properties of an artifact considering both user and production requirements. The English verb ”design”, refers to ”mentally imagine and plan” (Webster’s 1999). The corresponding noun ”design” means a ”conceptual project or plan in which goals and means are conceived”. Thus, the reference of the term design can be both the conceptual representation and the process that results in the conceptual representation.

A design can thus be the conceptual model of the intended artifact. The conceptual model is a system of concepts that refer to the artifact and represent its properties. The conceptual model is developed and documented during the design process. Conceptual models have been described before, partly in the section on information systems and partly in the section on models.

Design is a problem-solving process and has similarity to problem-solving both in everyday life and in science. A person must have both competence and goals to perceive a problem. A *goal* is defined here as an intended state of a system. The system can be abstract, as a scientific theory, or concrete, as an industrial product. A certain amount of *background* knowledge is necessary for a person to be able to define the goal and to see that a certain *solution knowledge* is lacking. A *problem* is defined here as a lack of solution knowledge, given a goal and a certain background knowledge. A detailed discussion of the problem concept can be found in (Bunge 1983a).

An assumed solution to a problem, also called a *hypothesis*, describes a goal and how it is to be achieved through a feasible approach that results in the goal. The hypothesis takes the form of a conceptual model describing the solution of the problem, which is either a theory or an artifact. If the solution is a theory, it is tested by examining the conformity with existing theoretical knowledge or by conducting experiments. If the solution is an artifact, it is tested through model studies and simulation or through design and testing of a prototype or finished product. What characterizes a design problem is its goal: a satisfactory state of an artifact and a way of achieving this.

A design process is initiated by a problem. At an initial stage, the problem is specified. It can be given the form of the question: Which object has such properties that the problem does not arise? The problem definition is followed by a stage of synthesis, which includes the development of the hypothesis and a testable consequence of this, e.g. a drawing or a prototype. Then an analytical stage follows, which includes the evaluation of the proposed solution. The question posed by the analysis is: What properties does this object have?

The synthesis is based on the object’s mutual properties (top-down), while the analysis is based on the object’s intrinsic properties (bottom-up). The new knowledge of the problem obtained through the problem definition-synthesis-analysis sequence is added to the background knowledge. One such design cycle, which continues until a satisfactory solution is reached, is by Herbert Simon called the ”Generator-Test Cycle” (Simon 1981). The cyclical course of the problem-solving process is presented in Figure 10.

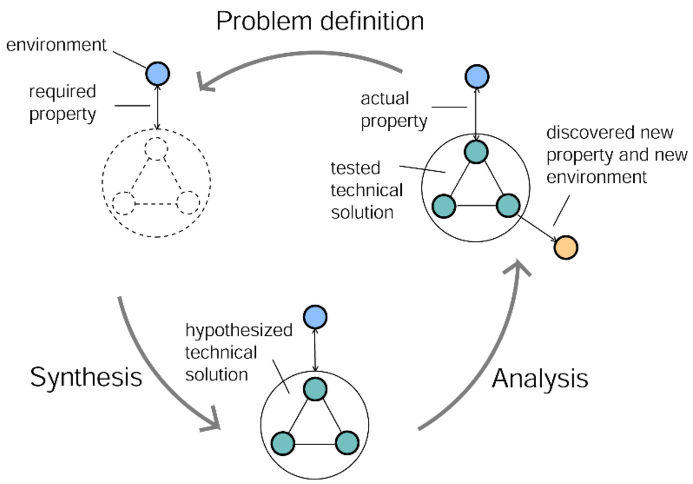

Figure 10. The cyclical course of the problem-solving process

Thus, problem solving involves:

1) identification of a problem given a background knowledge and a purpose
2) development of solution knowledge
3) test of the solution
4) supplementing the background knowledge and
5) identification of new problem.

A problem can be described as open or closed, and the problem-solving process can be routine or innovative. A *closed* problem can be solved with a routine that involves choosing a type solution and determining its specific properties. For an *open* problem, a type solution cannot be applied because new kinds of things or processes have to be investigated or invented. Open problems have been called ”wicked” (Rittel 1984).

The development of information systems to support problem solving has so far concerned routine problems and not open problems. Today's model-based CAD programs are an example of information systems that enable the solution of routine problems. They start from a static conceptual schema with a limited set of objects. The user can determine attribute values for a specific solution but cannot add new objects or value sets. Design information systems must enable the development of general conceptual models that can be developed and changed as the understanding of the problem deepens in the design process, e.g. by having a changeable conceptual schema, and they must allow reclassification of design objects, instances, instances, if the attributes motivate this.

Construction and management classification

The international standard for building classification SS-ISO 12006-2

Communication between actors in the construction and management processes requires that terms and concepts are common. The construction and management classification contributes to a common industry base for communication between actors and information systems by developing a uniform way of describing construction works and processes for design, production and management. The selection of classes and their degree of detail are determined by the purpose of the classification.

As an example, the purpose of the first Swedish system for building classification, the SfB system, which was introduced as early as 1950, was to meet the need for concepts and terminology for building descriptions, cost calculation and management of product information, especially in connection with the transfer of information from design to production (Giertz 1982).

Within the international organization for standardization ISO, a basic standard for building classification (ISO 1997) has been developed. The standard is now also available in Swedish translation (SIS 2002). The work has been carried out by ISO/TC (Technical Committee) 59 ”Building Construction”, SC (Sub-Committee) 13 ”Organization of information about construction works”. Swedish representatives have had an important role in the work, which was based on the theoretical basis presented in previous sections.

The classes in SS-ISO 12006-2 are intended to cover the entire life cycle of the construction work, including design, production and use. The standard does not contain classification tables but recommends which tables may be appropriate for the preparation by national or regional organizations. The purpose of the standard is that it should establish an international common approach to classification in the construction sector to support information exchange, for example in CAD, specification, and cost calculation.

Fundamental for building classification according to SS-ISO 12006-2 is to distinguish between different views of the concrete reality. The views reflect the need for information in different processes, e.g. at different stages of design. Examples include the classes ”element” (byggdel), ”work result” (produktionsresultat) and ”construction product” (inbyggnadsvara) which are alternative ways of classifying the physical parts of the construction work. The Swedish equivalent in the BSAB system is given in parentheses.

The class ”element” is defined by the function of the part in the finished construction work while the class ”work result” refers to the part as the construction of adapted and assembled built-in goods. The class ”construction product” refers to the part as a resource to be built into the construction work with its own function, construction and material properties. A cost estimate for the construction work can, for example, be carried out at an early stage regarding ”element” or ”designed element” and before the production stage with ”work result” based on resource costs.

Another example of a division between views oriented towards function and composition is the class ”construction entity” which is described partly with regard to function for the user, e.g. school building, and partly with regard to ”form”, i.e. composition such as house-building, bridge or tunnel.

The ISO standard is based on a process model that distinguishes results, processes, and results. The processes in the life cycle of a construction work are according to the ISO standard: ”design”, ”production”, ”maintenance” and ”demolition”. For processes, the standard recommends in particular the preparation of tables for ”the stages of the life cycle of a construction work”, ”project stages”, ”management processes” and ”work processes”.

In SS-ISO 12006-2, a diagram is presented in which the different classes are related to each other. See Figure 11. All classes are ”construction objects” with properties. The diagram of the ISO standard shows the ”type-of” relationship between classes and relationships between members of the classes, e.g. ”composed-of” or ”result-in”. Relationships between construction objects must be defined for model-based information systems, e.g. for product modelling. The relationships between construction objects have not been defined in established building classification because it was developed for the needs of traditional drawing-based design where the relationships are evident from the method of production.

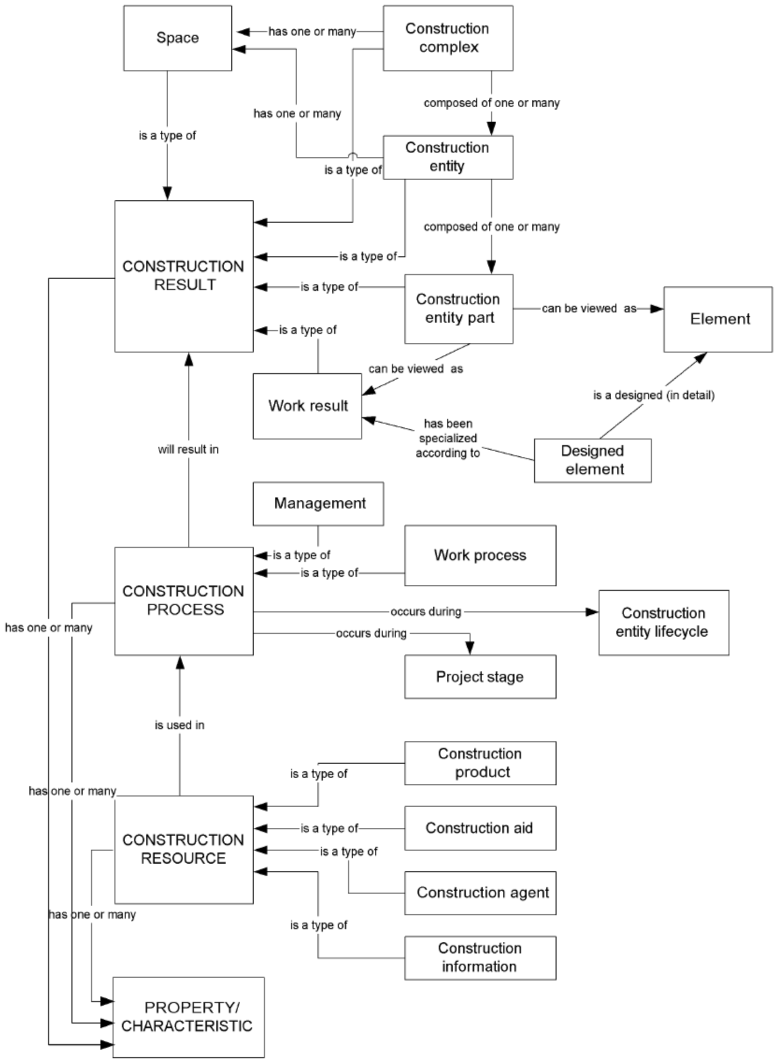

Figure 11. Relationships between results, processes, and resources in SS-ISO 12006-2

The diagram in Figure 11 reflects the common approach to processes and resultat, to wholes and parts, as well as to views of interest, developed in the ISO group. The approach recurs in the applications of the standard made in different organizations nationally, regionally, or company specific. The purpose of complying with the standard is to create the conditions for the exchange of information structured according to different national and regional systems. Although the detailed design of tables varies, many classes will be equal through the common standard.

BSAB system history, scope

The BSAB system is based on the first Swedish system for building classification, SfB. This classification system was developed in the late 1940s by the Samarbetskommittén för Byggnadsfrågor (Cooperation Committee for Building Issues), SfB. The work took place at SAR Centralkontoret Förening (National Swedish Architects Organization Central Office Assembly) under the leadership of architect Lars Magnus Giertz. The work resulted in ByggAMA ”Advice and instructions for building specifyers” whose structure was based on the SfB system's classification principles. At the same time, the Central office published a cost book and Svensk Byggtjänst (the Swedish Building Centre) the first edition of Svensk Byggkatalog (Swedish Construction Product Catalogue) all arranged according to the SfB system.

The SfB-system focused on the need for the transfer of information from design to production. The system was organized so that one could describe the physical parts of the construction work from three stand-alone aspects. There were tables for building parts, works and materials. The purpose of the building subdivision table was partly to structure drawings for different parts of the building. The various tables made it possible to describe a specific part of the building in terms of its function, mode of production and materials.

The SfB-system responded to the needs of the construction sector and received international dissemination. Responsibility for the development and maintenance of the system was taken over in the late 1950s by CIB, the International Council for Construction Research and Building Information, and later transferred to Svensk Byggtjänst and finally to the Irish Construction Research Institute An Anas Forbartha. The SfB-system is no longer developed, but the continued development is now being carried out within different national systems.

The increasing scope of installation systems in buildings and the development of new coordinated AMA publications for Ground, House, Plumbing, Cooling, Electricity and Administrative Regulations AF AMA, was the background to the development of the classification system BSAB in 1972 through Byggandets Samordning AB (The Construction's Coordination Ltd). BSAB 1972 has the same basic structure as the SfB system and is a further development of this. The responsibility for the BSAB system was taken over in 1976 by Svensk Byggtjänst, which in 1983 came up with a new version of the system, BSAB 83. Developments in the field of IT with, among other things, electronic commerce and object-based information management, the expanded need for joint terminology and the real estate management's need for systematics form the basis for the latest version of the BSAB system, BSAB 96, whose publication began in 1996 (Svensk Byggtjänst 1998).

Classes in the BSAB system

Fundamental to building classification are characteristics of things that are of interest in the construction and management processes in design, production, and use. BSAB 96 follows the principles of division into main classes according to SS-ISO 12006-2, although the class definitions in BSAB 96 are not verbatim translations of the ISO standard definitions but have been adapted to Swedish conditions and experiences. BSAB 96 defines the main classes ”activity”, ”infrastructure units”, ”construction works”, ”spaces”, ”elements”, ”designed elements”, ”work results”, ”resources” (built-in goods; machinery; construction site equipment; tools; clothing; protective equipment; consumables), ”management results” and ”geometric form”.

The different classes of BSAB 96 are based on different aspects of the built environment. In Figure 12, each image corresponds to an existing or planned classification table and the arrows illustrate the different views.

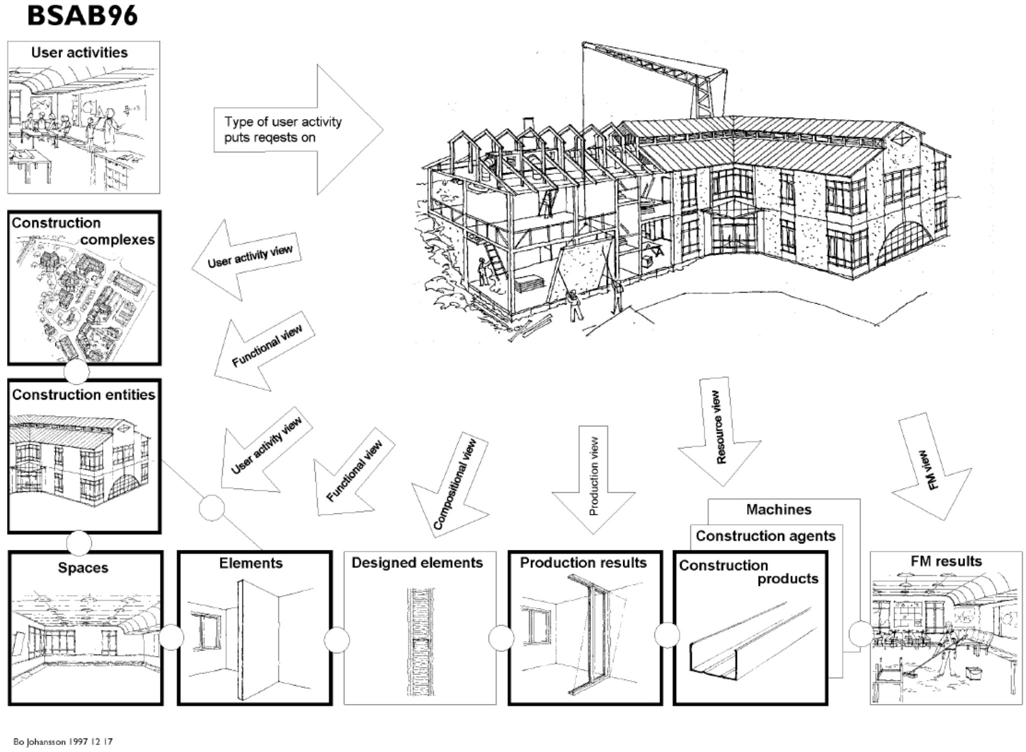

Figure 12 Views of the BSAB system towards the built environment

In the built environment, special, geographically dispersed, groupings of construction works can be distinguished, which are characterized by their joint use for a limited activity. Such groupings of construction works are referred to as *infrastructure units* in BSAB 96. See Figure 13. In SS-ISO 12006-2, the corresponding term ”construction complex” is defined as ”two or more adjacent construction entities collectively serving one or more user activity or function”.

A *construction work* is permanently attached to the ground and has load-bearing, delimiting or media-supplying properties and is used by a user activity for a specific purpose. There is no clear correspondence between the users' activities and the design of the construction work. Within certain frameworks, the same construction works can be used for different activities, just as the same activity can be used in vase in several different and different types of construction works.

The term *'construction works'* is defined in BSAB 96 as ”a terrestrial structure that forms the environment for specific activities” (Yngve et al. 2002). SS-ISO 12006-2 defines the term ”construction entity” as an ”independent material construction result of significant scale serving at least one user activity or function”.

A main division of construction works distinguishes between buildings and engineering works. Buildings have spaces, usually climate-delimited, for different activities, while engineering works are other construction works.

The classification of construction works is based on both production aspects and utility aspects that are met in each subdivision level in the classification.

Compositional properties such as material and principle of construction are essential for the division of construction works into different categories; For example, there is a large difference between houses, tunnels, and masts. Since the compositional properties are fundamental to the functions, functional requirements can have consequences for the compositional properties.

Space is a spatial aspect of a building, as well as a frame or installation system, it consists of a certain subset of the building's parts. A space consists of a group of parts of a building, it has delimiting properties, e.g. against light, sound or air, and an inner space that is not occupied by the delimiting parts, where other things, such as an activity, can be accommodated. Spaces can have different function for the user, they can therefore be classified in terms of use, e.g. space for accommodation, office room and lager space.

In BSAB 96 and in the Swedish version of SS-ISO 12006-2, the concept of *space* is defined as ”for a specific activity functionally delimited environment in construction works” (Yngve et al. 2002). In the English version, the term 'space' is defined as 'Three-dimensional, material construction result contained within, or otherwise associated with, a building or other construction entity. A space may be bounded physically or notionally”.

A building part is a physical part of the construction work identified from the point of view of a main function. In BSAB 96, the term 'building part' is defined as 'part of a construction work which fulfils a major function in the construction work'. In SS-ISO 12006-2, the corresponding term ”element” is defined as ”construction entity part which, in itself or in combination with other such parts, fulfils a predominating function of the construction entity”.

A building part is defined by a functional aspect without regard to technical solution, material content or method of production. The term also includes building parts for installations which are referred to as ”installation systems” and are defined in BSAB 96 as ”building part whose main function is the supply of media”.

A *work result* is a physical part of the construction work identified by its construction. In BSAB 96, the concept of production's *result* is defined as ”result of an activity on the construction site for the production of part of or all of the construction works”. According to SS-ISO 12006-2, the term ”work result” is defined as ”construction result achieved in the production stage or by subsequent alteration, maintenance, or demolition processes and identified by one or more of the following: the particular skill or trade involved; the construction resources used; the part of the construction entity which results; the temporary work or other preparatory or completion work which results”.

A work result is defined from a compositional aspect, it is determined with respect to material and method of construction, but not with respect to function. Some work results directly result in a part of a construction work, but others are indirectly necessary for the construction work to be produced, e.g. preparatory work such as temporary buildings and the erection of sheds. When classifying work results, it is the result of the work, such as masonry and layers of sheet metal, that is classified, but the criteria for the division into classes are based on the type of activity, e.g. bricklaying or sheet metal.

A *designed element* is an element whose construction has been determined, i.e. detailed work results have been stated. In BSAB 96, the concept of a designed element is defined as ”technical solution of an *element*”. In SS-ISO 12006-2, the corresponding term ”designed element” is defined as ”Element for which the work results have been defined”. As an example, the element ”interior walls” where one of many technical solutions can be the work results ”wall frames of steel sheet studs for cladding” and ”plasterboard on studs in wall, columns etc. indoors”. The concept *designed element* can be used, among other things, in life-cycle cost calculations since both function and structure have been specified.

Objects can be characterized in basically three independent ways, through ID, classification, and properties. ID is a unique identification of the object but says nothing about its properties. Classification makes it possible to distinguish one object from a variety of others but is not a detailed description of the object. Objects are described in a more detailed way by attributes. An *attribute* is a conceptual representation of a property of an object, such as color, mass, length, or material. In BSAB 96, attribute is defined as a ”statement of the property of objects”.

Resource is defined in BSAB 96 as ”objects used in the execution of an activity”. In BSAB 96, the concept includes labor, embedded goods, machinery, construction site equipment, tools, clothing, protective equipment, consumables, capital, land, and documents.

In BSAB 96, the term *embedded product* (inbyggnadsvara) is defined as ”goods intended to be incorporated into construction works”. In SS-ISO 12006-2, the corresponding term ”construction product” is defined as ”Product, component or ‘kit of parts’ intended for incorporation in a permanent manner in buildings or other construction entities”. This definition is taken from EPIC.

Embedded products are production resources, intended to be used directly or after processing as part of the construction work. Assembled and adapted embedded products in their place in the construction works can either individually or in collaboration form one or more elements.

In the theory section, different main categories of properties have been described. The interest in the properties of the built environment’s objects is grouped into different aspects, such as function in use, manufacturing, and the environment. To support communication, it is important that characteristics are perceived and referred to in a standardized way. Work is underway to develop a classification of properties within BSAB 96. Standards for the presentation of properties vary with the type of object and are difficult to achieve. The most noticed and used is the CIB Master List (CIB 1993).

Below is a scheme that relates to basic concepts presented in the previous sections. The diagram shows, among other things, how infrastructure units, construction works and their physical parts can be classified from different aspects. See Figure 13.

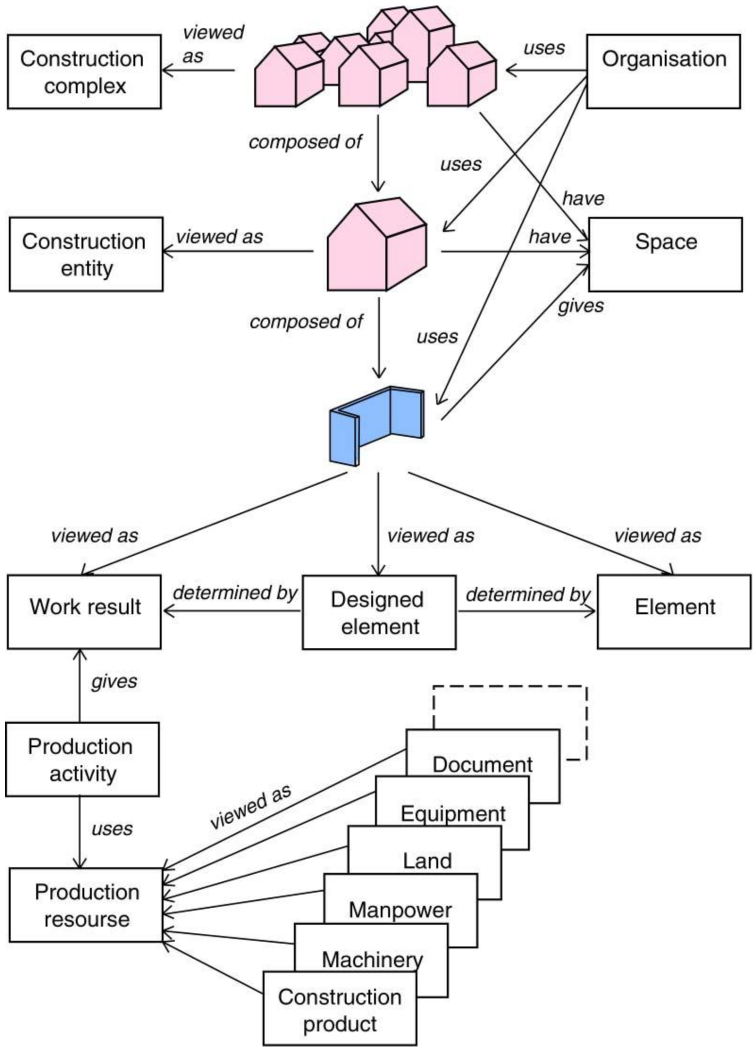

Figure 13 Relationships between concepts in BSAB 96.

Further development of BSAB 96

Over the past 10-15 years, building design has undergone a successive change from manual to computer-aided design. Within computer-aided design has begun a development from drawing-based to model-based design. The drawing-based design handles graphical objects, e.g. the lines, patterns and signs that build up drawings. The model-based design instead handles ”building objects”, i.e. parts of the building that are relevant for the property determination. Geometric properties and graphical representation are only some of several attributes that characterize the construction objects, other attributes can be function, material, and regulations of execution. The result of model-based design is an object-based model, a product model. Models enable new types of information management and form the basis for computer-integrated construction and management processes (Wikforss 1994 and Eastman 1999).

The development of information technology and the desire to establish a common IT platform broaden the need for common terminology and classification for the construction and real estate sector. In the established applications of building classification, the construction work has mainly been determined either through a design process or as a reference example. With the expanded use of model-based information management both in the early stages of the design and in the management process, the need for classification increases.

This need is partly different from the later stages of the construction process. A recent investigation (Ekholm 2001b) shows the need to supplement BSAB 96 with tables for:

1. Parts of the structure, including systems, for *general functional account*, which at later stages can be divided into elements.
2. Parts of construction works for *detailed functional account* in the early stages of design and in the management stage.

Examples of parts for general functional account are partly so-called “storbyggnadsdelar” (large elements), such as outer wall, roof, stairs and joists, and partly ”functional systems” such as frame systems, climate systems, air handling systems, and lighting systems. Large elements are needed when describing the properties of parts whose technical solution has not been determined, e.g. to specify requirements for properties such as u-value, sound reduction and fire class. They can be used to make general cost calculations, as well as for the designation of layers in connection with CAD design.

The need for detailed functional accounting in the early stages and in the management stage refers to parts that from a use and management point of view are essential to describe, for example, regarding requirements for function. Such parts are, for example, windows, doors, refrigerators, fireplaces, etc. A use for this classification can be for structuring object libraries in CAD-systems. Such object libraries can be found in ArchiCAD and Architectural Desktop. Items can be downloaded to the library via the Internet for use in your own project. The objects are often ”parametric” which means that different properties such as geometry, colour, surface layer, etc. can be indicated by the user. Product information with GDL objects is an example of this development (GDL 2002).

Management classification

In recent years, real estate management has been given increasing amount of attention. Previously, the technical management of the property has been at the centre, now the facility is seen as a production resource where the customers’ / users’ benefits are increasingly addressed. This change in approach is marked by the shift in terminology from real estate management to real estate business. *Real estate management* is defined by the previous approach as ”a process of maintaining construction works” (TNC 1994). Real *estate business* refers to ”an activity whose purpose is to provide space internally or externally with service” (Broman 1994).

The real estate company is characterised by four main functions: the enterprise function, the market function, the managerial function and the developer function (BFR 1994). Management is considered one of the activities of real estate business where other activities such as ownership, purchase, sale and construction of real estate are also included. Real estate business also includes life-cycle adaptation, resource optimization, use of premises, customer orientation, market analysis, broad information to market and customers, product development of services and equipment, etc. (BFR 1996).

The project “Management Information 2002, FI 2002”, has worked to develop information systems for real estate business, for example by mapping its processes (Svensson et al. 2000). The FI 2002 project focuses on three main processes in FM-business.

Figure 14 illustrates how these processes produce results that support the customer. The term FM-business, after the one English term Facilities Management, is an increasingly common synonym for real estate management.

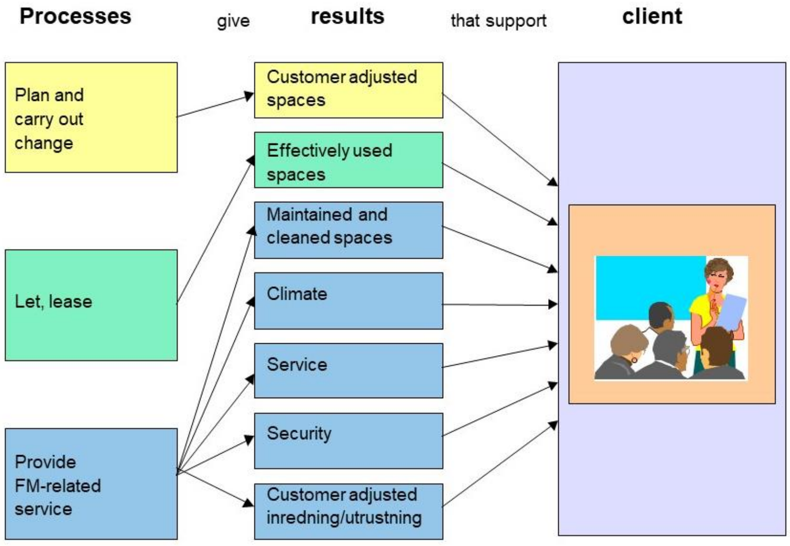

Figure 14 The relationship between the FM company's main processes and the customer's activities

FM-operations make extensive use of information systems. Three main types of systems are distinguished:

- administrative/technical database systems
- CAD-systems and
- real estate or geography-related information management.

The FI 2002-project's requirement for classification is that this must meet the needs both in the operational part of the FM work where the FM company's services are produced and delivered to the customer / user, and in the economic / financial work. The need of classification is given for:

- activities in the FM business
- resources, e.g . construction products, equipment, FM-organization
- results, such as spaces, elements and administrative resources, and
- information, which guides and controls the processes.

The need for classification of resources and results is largely met by the BSAB system, among other things, through ongoing development of classification of buildings' works and spaces, as well as their properties.

The need for a special classification of management results within the BSAB system has been highlighted in the report Management classification (Yngve 1999). Management results are defined as ”real estate-related services”, examples of main division are seen in Figure 14, e.g. ”customised spaces”, ”maintained and cleaned spaces”, ”climate” and ”servicing”.

By analogy with the classification of ”work results” (see the section on the BSAB system), what is classified is not the service itself but the result of the service.

In the report Management classification, a conceptual model is presented that shows how FM-operations are related partly to the customer's operations and partly to the built environment. The model ties in with the conceptual model that describes the construction of the BSAB system. See Figure 15.

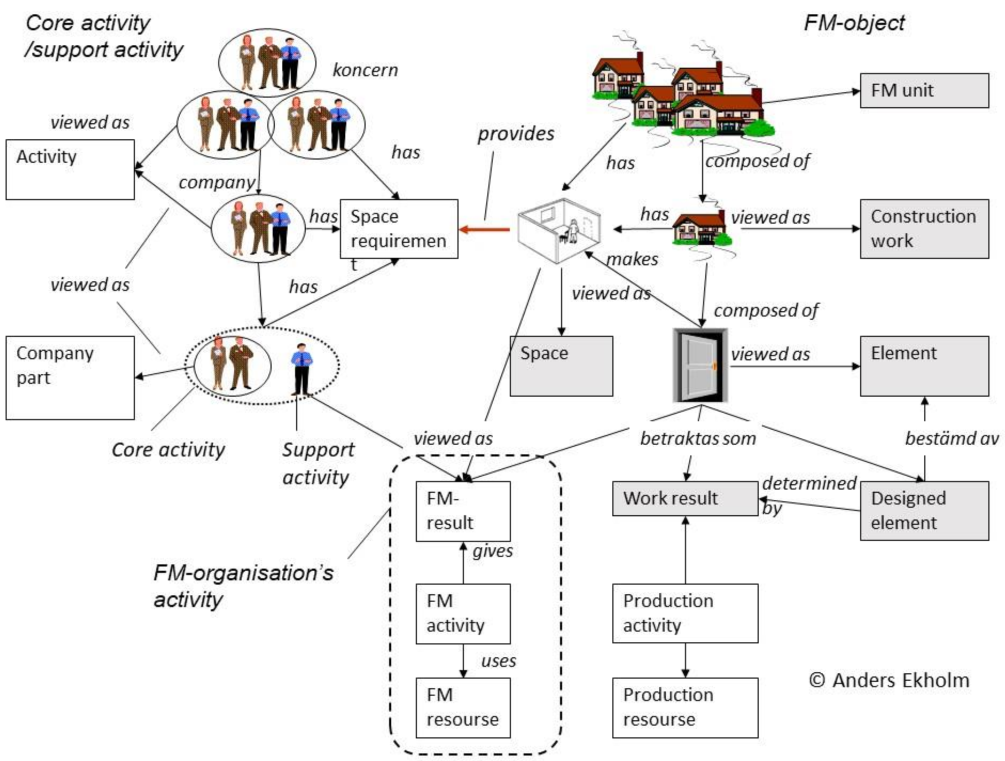

Figure 15 FM-activities in relation to the customer's business and to the built environment

Building classification at different stages

Building design involves determining the characteristics of construction works considering the requirements associated with use, production, and operation. The results of the design are partly a detailed interpretation of the structure, a conceptual model, and partly its material representation in different types of documents such as drawings, texts and scale models. A design information system must enable the product model to be given a growing complexity and increasing degree of detail, both through the addition of new attributes and through the specification of functional parts and technical solutions, see Figure 16.

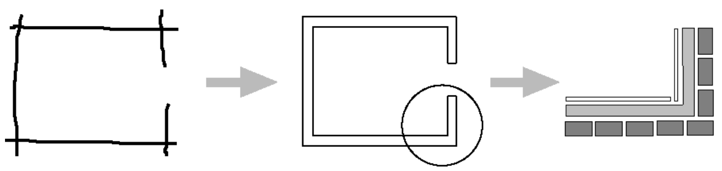

Figure 16. A model object must be adaptable to growing complexity.

At the earliest stages of product determination, it may be important to describe the geometry of objects in a way that allows information to be correctly transferred between different software. Standardization of geometric description is the basis for efficient CAD. In general accounts, overall general areas of the building can be suitable objects, such as walls, ceilings, and joists, as well as entire systems such as frame and water system.

These ”large elements” occur to some extent in the BSAB system. When the emphasis is on the functioning of the construction work in relation to the users, other functionally determined parts may be relevant, such as interior units for kitchens, laundry, and sanitary facilities. This requires a more detailed function-based classification than the BSAB system’s elements, e.g. an adjusted construction product classification may be useful for this purpose.

In the construction document stage where the technical solutions of the building are determined through detailed drawings and technical descriptions, it is the objects elements and work results of the established building classification that are applicable. The technical solution for an element is given at a general level by determining the designed element, and in more detail by indicating the respective work results, see Figure 17.

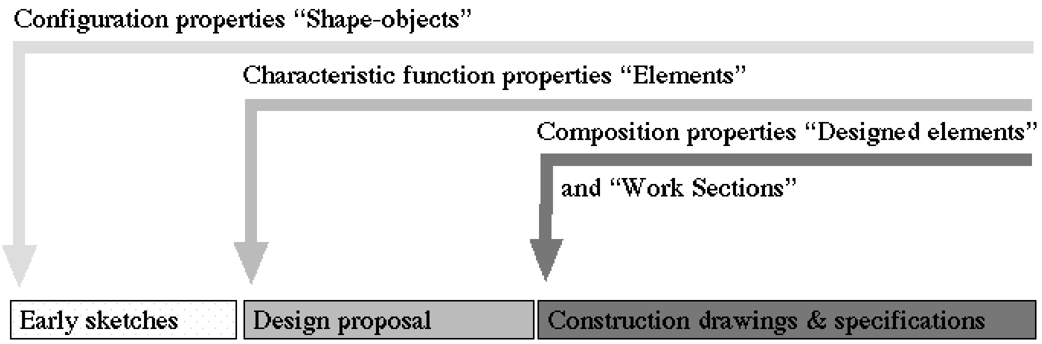

Figure 17. Examples of classification at different stages of the design

In the management stage, as in the early stages, there is a need both for overall accounting and for detailed function-based classification, and a need just as in later stages of the construction process for technical specification with elements. The maintenance perspective places its own requirements on the classification of management results (Yngve 1999).

Industry Foundation Classes, IFC

The International Alliance for Interoperability, IAI, was formed in 1995 on the initiative of Autodesk Inc and representatives of the American construction industry. The aim is to enable *interoperability*, exchange of information without the need for intermediate human interpretation, between different object-oriented software for e.g. CAD, calculation, and time planning. This objective is to be achieved through the development of an international standard, Industry Foundation Classes, IFC, which establishes a common way of defining concepts, terminology and file transfer formats between applications (IAI 1996).

IFC can be described as a conceptual framework that is intended to cover all objects of interest in the construction and management sector. It should be applicable to the construction of conceptual schemas and information exchange between different applications. The goal of IFC is to create the common concepts, and a common terminology as well as a common file transfer format for participating systems.

IFC is in many respects based on STEP’s various standards. See below the section ”Product Information Systems”. ISO 10303 Part 11 refers to EXPRESS used as the language for information modeling, Part 21 is used as an object-based file format for information transfer, Part 41 defines the basics of product description and Part 42 the geometric descriptions.

IFC has so far been published in five official versions. The first, version 1.0 includes only a very small part of the total framework. With version 1.5, the basis for application in commercial software was created. Experience and problem with this led to the release of an update called version 1.5.1. Version 2.0 has expanded the coverage of the domains, and the latest version 2.x is based on a platform with a stable kernel that can remain unchanged for a long time. Changes made for different applications and adaptations may later be incorporated into future weeks.

IFC uses EXPRESS as the language for drawing up conceptual schemas. The linguistic symbols in EXPRESS, entities, attributes and relationships have been used as a starting point for the definition of the basic conceptual models of IFC. For a brief description of EXPRESS see the section Process and product modeling. The latest version IFC 2.x, which in short is described here, has a so-called ”meta-model” consisting of IfcObject, IfcRelationship and IfcPropertyDefinition. See Figure 18.

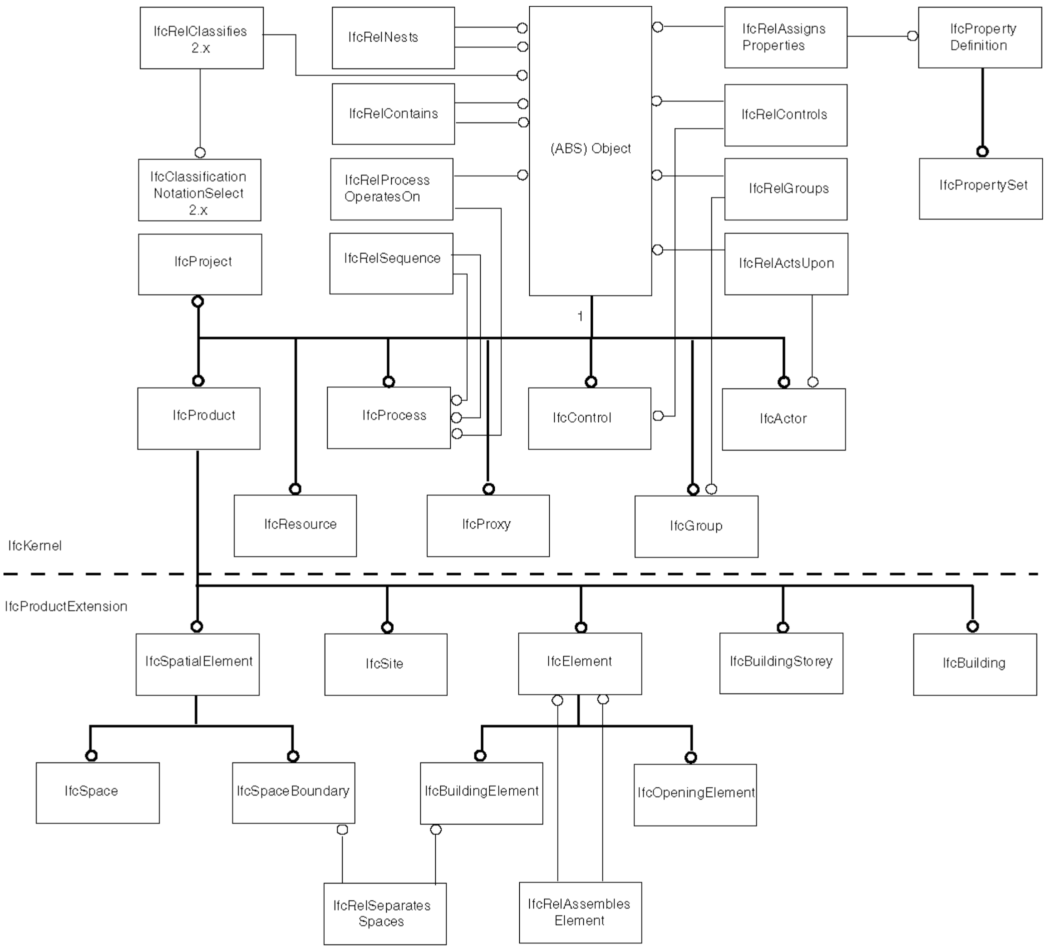

Figure 18. Parts of IFC in EXPRESS-G

These basic entities then specialize into general classes such as IfcProduct, IfcProcess, and IfcControl as well as various relationships such as IfcRelContains and IfcRelGroups. In this level, basic functionality such as location, process stages, the relationship part-whole, connections and groupings of objects are treated. Together, these classes make up IFC’s Core model “Kernel”.

The next level is called the Core Extension Layer, ”Kernel Extension”, and consists of specializations of the classes in the Kernel. IfcProductExtension defines basic objects for the construction and real estate sector such as IfcElement, IfcSpace, and IfcBuilding. Parts of the IFC Kernel and IfcProductExtension are shown in Figure 18. Outside the core with its additions is the Interoperability Layer, which in this context can be translated as ”Industry Common” which refers to classes common to the entire construction and real estate sector or to several different disciplines. Here you will find, for example, IfcWall, IfcBeam and Ifc ElectricalAppliance. In the next level there are specialized extensions for individual disciplines.

IFC objects have certain predefined properties where relevant, such as geometry. Other properties can be attached to the objects partly with IFC-defined IfcPropertyDefinition and partly with the applicator-defined IfcPropertySet. With the objects and their properties, one can describe different domains, such as the production of buildings or the management of construction works.

IFC in relation to SS-ISO 12006-2 and BSAB 96

It is a stated purpose of the IFC to become an industry standard for the transfer of object-based information between different software in the construction and management sector. To be applied, the IFC must support the transmission of information structured in accordance with SS-ISO 12006-2 as well as various national and regional systems based on this state. In the following section, a brief comparison is made between IFC and SS-ISO 12006-2 and the Swedish BSAB system based on the ISO standard.

In order to compare IFC and SS-ISO 12006-2, the same diagram as before is shown in Figure 11 in the section on SS-ISO 12006-2 but here elaborated in EXPRESS-G. See Figure 19.

For a brief description of EXPRESS-G, see the section on process and product processing. In addition to that description, the number ”1” in the diagram at the ”type-of” relationships indicates that an object may belong to only one of the special classes, while ”andor” means that an object can be classified in several ways.

A comparison between the IFC schema and the other two shows that the structure of the IFC framework differs from that of the ISO in that the IFC does not present a specialization from a general domain description to specific domains in construction and management. Rather, the IFC schema shows a collection of classes that can be used to build domain-specific schemas. However, there are certain dependencies between the classes, e.g. ”type-of” that mean that the framework is not entirely neutral but is based on a notion of certain domains. The IFC framework is based on the basic symbols of the EXPRESS language, unlike SS-ISO 12006-2, which is linguistically neutral and is based on a model of the built environment based on system theory and property theory.

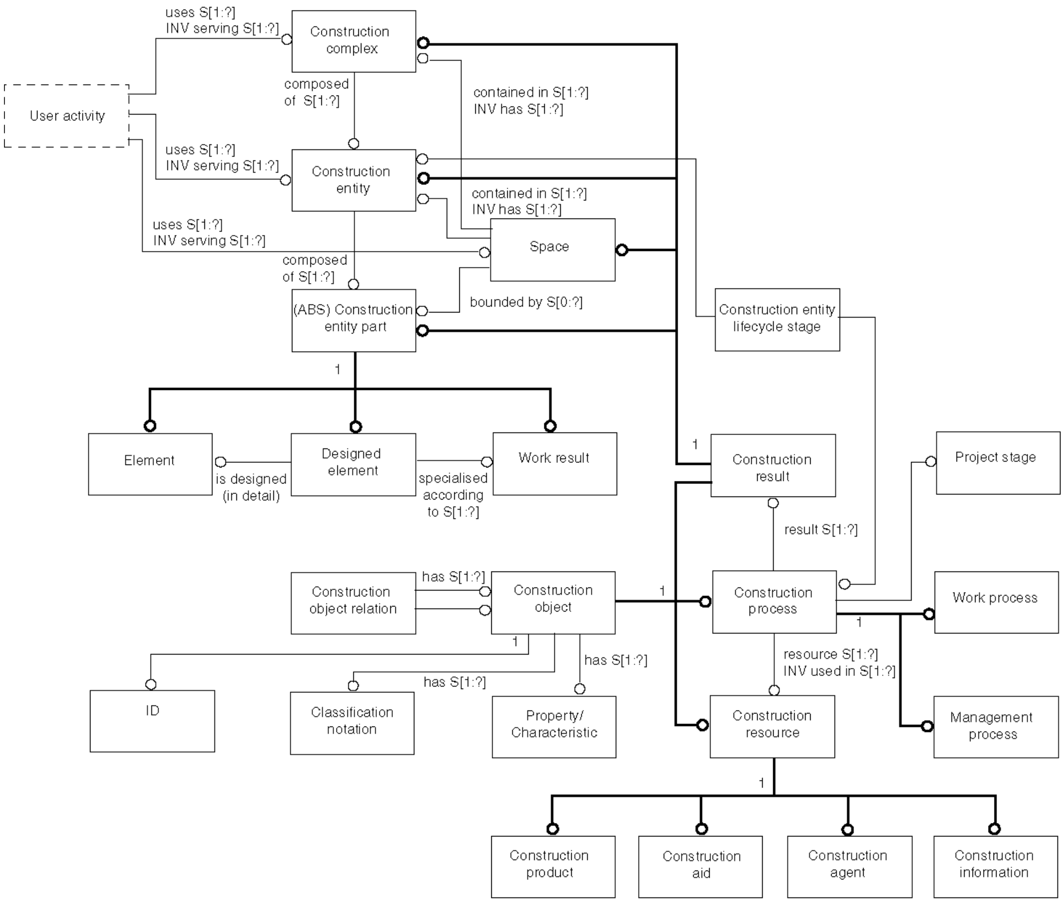

Figure 19. SS-ISO 12006-2 in EXPRESS-G (Entities within dashed lines have been added by the author to make the account more complete)

The scheme in Figure 18 allows for some comparison between the frameworks. IfcElement is a superclass of IfcBuildingElement and IfcOpeningElement. The latter class refers to openings, voids, which can be filled with the former. IfcOpeningElement derives from the need in CAD and is not found in the building classification.

The ISO classes Element, Designed Element and Work Result are different views of the parts of the construction work and correspond to different information needs depending on the stage and actor. The Work results class does not exist in IFC. Therefore, when applying the BSAB system, it must be represented by a temporary solution, e.g. with the class IfcProxy supplemented by reference to specific work results in BSAB 96, e.g. ”brick masonry”.

IfcBuildingElement has subclasses such as IfcWall and IfcFloor and in many respects corresponds to the Element class of the ISO standard. However, IfcElement may have determined material which is not possible for ISO Element, which is only defined by function, i.e. not compositionally.

In SS-ISO 12006-2, Element is a ”part-of” Construction Entity. IfcBuildingElement can be part of both IfcSpace, IfcSite, IfcBuilding and IfcBuilding Storey. To describe this, the relationship IfcRelContains is used. In SS-ISO 12006-2, space is part of the Construction Entity while a space in IFC is not listed as part of a construction works but by IfcBuildingStorey. IfcBuildingStorey, in turn, can be part of the building through IfcRelContains.

A hospital, an airport or a road between two localities, consists of several buildings that together enable the business to be conducted. This group of construction works is referred to as Infrastructural Unit in BSAB 96 and Construction complex in the ISO standard. The concept in IFC that is closest is called Building complex and is created in a rather complicated way by the relationship IfcRelGroups between IfcBuilding and IfcGroup. The latter is given the text attribute GroupPurpose which is referred to as ”BuildingComplex”.

A comparison between the classes in IFC and those in SS-ISO 12006-2 and in BSAB 96 thus shows both similarities and differences. Classes in the Core and Extensions to the Core are found in SS-ISO 12006-2, and classes in Industry Common and further specializations are found in BSAB 96. The main difference lies in the relationships between objects. A major problem for IFC is that it does not apply the same basic view to the domain as the international standard for building classification SS-ISO 12006-2. One explanation may be that the IFC has been based on the needs of the drawing language, e.g. a wall in the building is first and foremost considered to be part of a storey, not as in the ISO standard to be part of the building.

For IFC to be put to practical use in the construction and real estate sector, an adaptation to already established standards such as SS-ISO 12006-2 is required. Areas where IFC can have an immediate application are standardization of the geometric representation of objects in CAD-systems, as well as standardization of relations between objects. It is in these areas that are not covered by the established classification that IFC can become significant already in the short term. There is a lot of work to be done before IFC can have practical application, but as interest in object-based information transfer increases, so should the need for standard harmonization. SS-ISO 12006-2 has shown how a common basic structure can be built for the domain and, with the right development, IFC can form the content of a common national framework for construction and real estate management.

Process and product modelling in construction and real estate management

Product Information Systems

Information systems have been developed to support information management in businesses of various kinds. The section on information systems mentioned, for example, support for payroll management, invoicing, travel booking systems, statistics, and analyses of the development of the business, as well as the search and compilation of information in databases on customer preferences, etc.

Information systems have also been introduced in the manufacturing industry to support product design and product manufacturing, for example in the form of CAD/CAM (Computer Aided Design/Computer Aided Manufacturing). The need in these processes for collaboration and exchange of information between different actors has led to a large-scale standardization work.

Within ISO, a special technical committee ISO TC 184/SC 4 has been set up to develop the necessary common standards for product information systems. The purpose of the standards is to create an industry-wide framework to be used in the development of conceptual schemas. The standards referred to as ”Application Protocol”, AP, have the overall name STEP, ”STandard for Exchange of Product Model Data” (STEP 2002).

The work to date has led to the development of a wide range of APs in various industries such as aviation and automotive, shipbuilding and offshore. The construction industry is represented, but only to a lesser extent. Equivalent international statedardization for the construction and real estate sector is mainly carried out within IAI, the International Alliance for Interoperability, through the development of the framework IFC, Industry Foundation Classes.

The development of a STEP standard takes place according to an established methodology. It begins with a description of the context in which the standard is to be applied and requirements for its scope and information content. To determine the scope, a description of the processes in which the exchange of information takes place is developed. The process is written in a so-called ”Application Activity Model”, AAM, which clarifies what information should be added to an activity and what information should be the result of the activity. The process description is prepared with the support of different modeling techniques, but above all IDEF0 is used, see below. The result of the process description forms the basis for the development of a so-called Application Reference Model, ARM, which is a conceptual model for the domain information the system handles information about. An ARM is described in EXPRESS, which is a language for data definition. A brief description is given in the section on EXPRESS.

The following steps relate to integration and quality assurance, among others the a so-called ”Application Interpreted Model”, AIM, is developed which includes an addition to ARM with common resources so-called ”Integrated Resources” developed within the entire STEP work, e.g. for geometry information and metadata regarding document management. For those interested in a detailed description of the AP development methods, please refer to STEP’s web pages on http://www.tc184-sc4.org/, including http://www.tc184-sc4.org/SC4_Open/SC4_Standards_Developers_Info/Files/ACF21AC.pdf.

IDEF0

IDEF0 which stands for ”Integration Definition Language 0 for Function Modelling” is a method for documentation and graphical description of processes (Marca and McGowan 1988). IDEF0 is based on a basic process model in which a process or activity is represented graphically by a rectangle with the name of the activity and with arrows symbolizing input, output, control, and mechanism. The model can be used both when the process handles information and concrete things. See Figure 20.

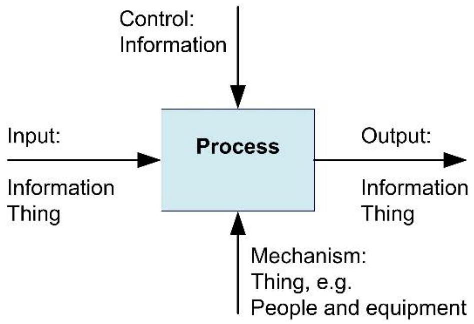

Figure 20. A process according to IDEF0

In information management, input corresponds to information that is added to the activity and output is information produced in the activity. The information is present in different media, but the medium is not in focus, but it is the meaning of the information, its semantic content, that is important.

A distinction is made between information as input and as control. The former refers to information processed in the process while the latter refers to rules and restrictions on how the activity is carried out, such as quality plans and instructions for work routines. The lower arrow indicates the process from a compositional perspective and refers to the concrete things that carry out the information management in the process, e.g. people and equipment, these are called *mechanism*.

As an example of the application, we can mention the development of a simple application for managing information about the activities of a building in connection with program work (Ekholm 2001a). The process model distinguishes the activities ”activity description and ”space description”, see Figure 21. Input is information about the business, control is information that the process should be initiated and methods for the implementation, output is the business description, and mechanism is the participants in the work, for example, users and architects as well as aids like computers.

The activity description provides input to the next step, which involves the preparation of a space description, also called a ”space function program”. The results of the activity description are a description of the activities of the activity, including their spatial extent and relationships, the nature of the activities, the number of people and equipment that contribute to carrying out the activities of the activity.

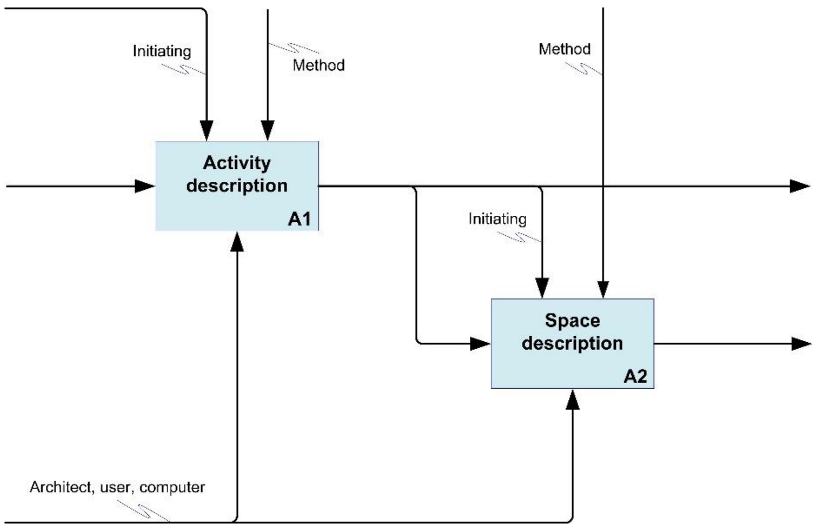

Figure 21. Process description with IDEF0

A process in IDEF0 can be divided into sub-processes in an unlimited number of levels. The methodology describes processes as strictly sequential, but it has no time dimension. IDEF0 diagrams can be prepared with computer tools but have no built-in logic that can be used for calculations and are intended only for human interpretation.

EXPRESS

Artificial languages for information modeling are based on the so-called Entity-Relationship (ER) model developed to facilitate implementation in relational databases (Chen 1976). The ER model assumes that a domain can be represented by the concepts of ”entity” and ”relationship”. An ”entity” represents an object in the domain, it can be a thing or a property of a thing, and ”relationship” is a relationship between objects, e.g. between a thing and a property.

EXPRESS, which is based on the ER model, is an ISO standard, Part 11 of ISO 10303, and is used as a language for product modeling in STEP work. EXPRESS has both a text-based and a graphical variant. In the text-based variant, the domain is represented by a *schema*. The schema constitutes the conceptual model of the domain and contains all the model's statements about the domain's objects, their properties and relations (Schenck and Wilson 1994).

EXPRESS-G is the name of the graphic variant of the language. It is used in connection with the development of the schema, e.g. in communication with domain experts and future users of the information system. The graphical representation cannot replace the text-based one but must be supplemented with text, e.g. to express rules and restrictions.

In EXPRESS-G there are three main types of symbols named ”definition”, ”relation” and ”composition”. “Definition” is a rectangular symbol for entities. It describes both complex data types, i.e. objects and their properties, and simple data types, i.e. attribute values such as text strings, numbers, etc. ”Composition” is a rectangle with rounded corners and is used to indicate how the scheme is composed if it is accounted for on different pages. A ”relationship” specifies an attribute from one entity to another entity and is displayed with a line terminated with a circle showing the direction of the relationship. Numbers in square brackets indicate ”cardinality”, i.e. the numerical relationship between entities. Cardinality [1:?] means ”one to many”, [0:?] means ”none or many to many”. The ”type-of” is shown with a thick line, where the number 1 indicates that the same instance can only be of one type. If the same instance can be of several types, then the designation is called ”andor”.

In the example of process modeling, the activity ”activity description” was shown as part of the program work in connection with building design. Figure 23 shows how a conceptual schema can be designed in EXPRESS-G for an information system for activity information in the previously mentioned processes as shown in Figure 22.

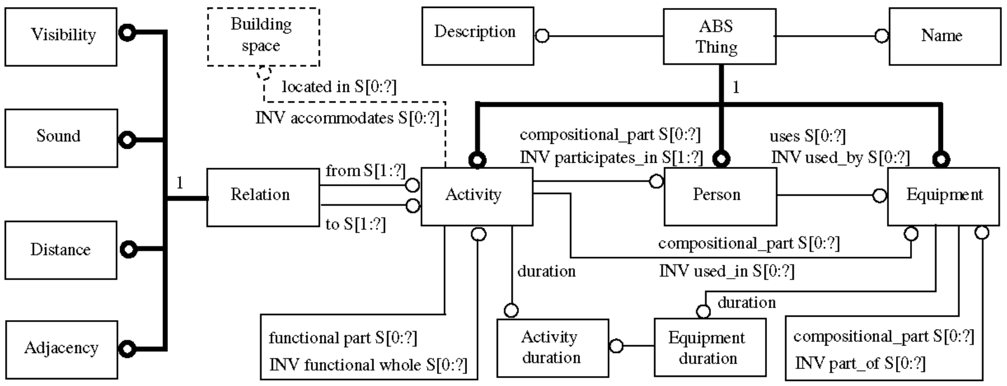

Figure 22 Concept scheme in EXPRESS-G for business description

In an application based on the schema, one can determine the attributes of an activity in the form of sub-activities, relationships to other activities, duration, people and equipment, name and a description. This information is needed to be able to make a business description. To make a space program must be provided with additional information about requirements for the characteristics of spaces. For this, an application for building design is required. These applications should be integrated and accessible to a designer in the program.

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