A CONCEPTUAL FRAMEWORK FOR CLASSIFICATION OF CONSTRUCTION WORKS

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Anders Ekholm, Dr
Div. of CAAD, School of Architecture, Lund University, Lund, Sweden
E-mail: anders.ekholm@caad.lth.se

SUMMARY: *Classification is a means to facilitate communication among actors in a field of practice. In the construction sector classification plays a major role in specifications, structuring of documents, calculation of costs, etc. The need for general classification systems grows with the increased internationalisation of the construction market and the rapid development towards a computer integrated construction process based on computer aided product data modelling. These processes require standardised ways of describing construction artefacts, and classification is a means to achieve this. Classification within the construction sector is based on pragmatic tradition and national needs, but internationally applicable classification tables must be founded on a neutral conceptual framework. The ISO Technical Report 14177 ”Classification of information in the construction industry” aims at providing such a framework. This study analyses some basic concepts within the ISO Technical Report, among others facility, space, element, and work section, and suggests further developments. Fundamental semantic and ontological theories are applied to define some basic concepts within classification and to build a conceptual framework for construction works. A general conclusion of the study is that the proposed framework is useful as a foundation for identifying classes for construction works. Among the more specific conclusions are that: 1) a separate classification of socio-technical user systems may be a useful background for classifying infrastructure units, construction works, and spaces according to the activities they support; 2) a classification of construction work parts as ”shape objects” is needed in the earliest stages of the computer-aided design process; and 3) a definition of space that includes its boundaries is proposed.*

KEYWORDS*: classification, construction, facility, element, work section, space, CAD.*

1 INTRODUCTION

1.1 Background and scope of the project

The objective of the study at hand is to contribute to the development of classification in the construction industry. Classification is a means to facilitate communication among actors in a field of practice. In the construction sector classification plays a major role for structuring information in specifications, structuring of documents and calculation of costs, for example. A multitude of national classification systems exist and the increasingly international market for building services has enhanced the need for neutral international standards. Computer technology and user-interface have developed during the 80’s and 90’s in a way that initiates new needs for classification. Of special interest in the next few years, are the relations to the standards for building product models currently under development (CIB 1995).

Within ISO/TC59/SC13, a working committee of the International Standardisation Organisation, there is a project with the objective to develop principles for the building sector’s classification system. Results of this work are presented in the ISO Technical Report 14177 ”Classification of information in the construction industry” (ISO 1994 a). Based on this report, work on an internationally co-ordinated element classification table has started within ICIS, the International Construction Information Society.

The objective of this study is to analyse the basic principles for classification of construction works, and to suggest changes in these which accounts for the new needs and possibilities of IT today. This, and continued work on terminology and definitions both in Sweden and internationally, shall lead to useful results for the construction industry.

The study presents a framework for conceptual modelling and discusses some general classification concepts. With this background, concepts in building classification are analysed, with emphasis on concepts representing physical parts of construction works. The demands for classification in the early stages of the design process and for product modelling are discussed, and conclusions and areas for further research are presented.

The term ‘construction works’ is used here as a synonym to facility, see the definition in section 4.1.1.

2 A FRAMEWORK FOR CONCEPTUAL MODELLING

2.1 Frameworks and aspect models

To bridge the gap between researchers in construction classification and product modelling it is necessary to develop a framework for construction information that can be used by both groups. In the following, an attempt is made to fill in some of the gaps, and make a contribution to the development of a unifying conceptual framework for the construction industry.

A commonly-accepted conceptual representation must have a sound theoretical foundation as well as be relevant to the practical needs for different applications. Depending on the degree of specificity, conceptual representations have different scope and complexity. Bunge (1974 a) identifies four different kinds of conceptual representations, three of these are of increasing complexity concerning objects of a specific species, and the fourth concerns a larger collection of objects belonging to the same genus. The examples for the construction context are provided in parentheses by the author:

1) Schema or model object, is a list of outstanding properties of an object of a given species (e.g. construction product information).
2) Sketch or diagram, is a graph of the components of an object of a given species and their functions and relationships (e.g. construction drawings, process flow charts).
3) Theoretical model or specific theory, is a hypothetico-deductive system of statements representing some of the salient features of a thing of a given species (e.g. *u*-value theory and theory of moment of force in beams).
4) Framework or generic theory, is a theory representing the features common to all things of a given genus (e.g. basic definitions and generic structures of construction works information).

Bunge reminds the reader that conceptual representations of real things have shortcomings; they are incomplete, and at best ”fairly faithful”. To overcome these problems it is necessary on the one hand to make several different representations of the same thing, where each representation focuses on different aspects; and, on the other hand, to improve the existing representations by recurring research efforts.

Examples of theories of different complexity and scope can be seen in the rapidly-developing product modelling research today. Björk discusses five ”layers” of representations in product data modelling (Björk 1995):

1) information modelling language,
2) generic product description model,
3) building kernel model,
4) aspect model, and
5) application model.

The first three of Björk’s layers are generic theories or frameworks, and may have different scope ranging from generic objects, through products in general, to buildings. The fourth layer deals with specific theories for buildings of specific kinds while the fifth layer contains specific applications of aspect models.

Proposals for frameworks belonging to the second layer, generic product description model, concerning products of different kinds have been developed in connection with STEP, the Standard for Exchange of Product Model Data (ISO 1995 a). The General AEC Systems Model, GARM (Gielingh 1988) is an example of this. The IRMA, Information Reference Model for AEC, (Luiten et al 1993) is another example of a generic product description model.

Frameworks belonging to the third layer, building kernel model, have been developed by a number of researchers (Björk 1989 and 1992, Froese 1992, Luiten 1994, and Turner 1990). The current work on the Building Construction Core Model is another example (Tolman and Wix 1995).

The emphasis in product data model research in the construction industry has shifted from providing global theoretical models to describing aspect models covering the data needs of very particular domains. The COMBINE project (Augenbroe 1994) and CIMSTEEL project (Watson 1995) are examples of such models belonging to the forth layer, aspect models, in the schema. Eastman, in his review of the evolution of building modelling, regards the dynamic application of different aspect models in a design situation as the only viable approach to provide the building product model needed (Eastman 1992).

The ontological framework presented in this study belongs to the second layer in Björk's schema, the generic product description model. This ontological framework has relevance for the efforts in STEP to develop a generic theory or a ”core model” that is common to the entire industry. In its turn it is based on a philosophical synthesis of a set of extremely generic concepts like ”object” and ”relation”. If ”language” is interpreted as such a set of concepts it may be regarded as belonging to the first layer of the schema called ”the information modelling language”.

The proposal for a conceptual framework for construction works developed in this study belongs to the third layer in Björk's schema. It has relevance for the efforts to develop a core model within STEP for the building industry, the Building Construction Core Model (Tolman and Wix 1995). The conceptual framework for construction works can be used to identify classification classes, for example classes relevant for product modelling in the early design stages.

2.2 Semantics of science: Terms and concepts

In everyday thinking, as well as in science, properties of things in the real world are represented by concepts. In languages and in formal descriptions these concepts can be designated by symbols. In order to avoid confusion in communication, the relations between symbols, concepts and the real world must be clarified. Some of the misunderstandings between representatives from the construction classification and the product modelling worlds can be traced back both to the use of language and to the different meanings of concepts. An example is the term ‘element', which in construction classification is considered to stand for one characteristic function of a physical part of a building (ISO 1994), while the term in product modelling stands for a combination of properties (ISO 1995 b).

In order to be able to discuss relations between terms, concepts and facts, and more specifically to discuss differences in reference and representation of concepts, some useful definitions are necessary. Traditionally the relations between symbol (term), concept and reality are presented with the so called Ogden's triangle, but this schema does not distinguish between reference and representation (Ogden and Richards 1994). Instead the definitions presented here are based on Bunge's contemporary semantics of science (Bunge 1974 a, Bunge 1974 b).

The terms used in a language are symbols and designate concepts, e.g. the term ‘house' is a symbol that designates the concept ”house”. The designation relation is conventional, that is it is based on rules. The reference of the concept ”house” is the class of all things with house-like properties. A concept therefore represents certain properties of an object, for example the concept ”house” represents certain spatial, functional and experiential properties of things belonging to the class of houses. The sense of the concept ”house” is given by a context of related concepts emanating from personal associations, cultural tradition or scientific theories.

There is also a direct relation called denotation between a symbol and the reference class of the corresponding concept. For example the term ‘house' denotes the reference class of the concept ”house”. Similarly there is a direct relation called connotation between the symbol and the sense of the designated concept. An example of the connotation of the term ‘house' are concepts related to ”house” in personal associations, cultural traditions or scientific theories. Finally there is a relation of proxy between a symbol and the property represented by the corresponding concept. A sign with the term ‘house' may proxy, or stand for, house properties. These relationships are shown in Fig. 1.

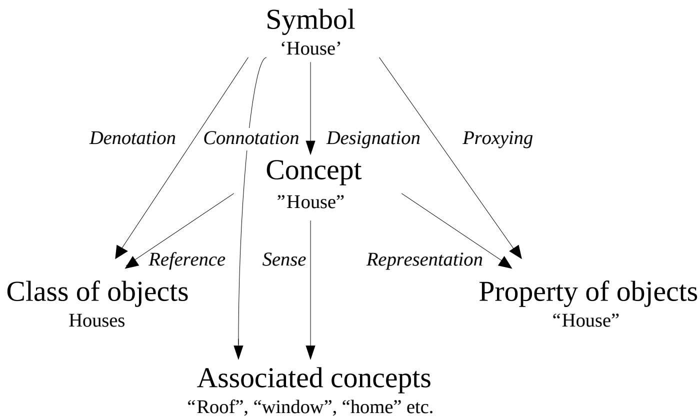

FIG. 1: Basic semantic concepts

2.3 An ontological framework for conceptual modelling

In the construction design process the designers develop conceptual models of factually possible things, for example construction works. In order to achieve clarity in communication, research and technical development it is necessary to have a common conceptual framework where basic terms and concepts such as property, thing, system, and level are defined and related. Such a framework is of an ontological nature and represents the basic structure of reality, the concrete world of things (Bunge 1977, Bunge 1979). Below, the ontological framework applied in this investigation is presented. The objective of the investigation is to define the basic concepts used in classification of construction works.

2.3.1 Property and thing

To describe an object is to account for its properties. In order to distinguish different kinds of properties a comprehensive theory of properties is necessary. In a general philosophical sense objects are either abstract or concrete entities toward which thought, feeling or action is directed. Concrete objects are *things* with *substantial* or real properties, while abstract objects are *mental constructs* with *formal* properties (Bunge 1977). Substantial properties can be divided into factual and phenomenal, see Fig. 2. *Factual* properties exist independently of an interpreting mind, while *phenomenal* properties depend on an interpretation of a sentient organism. The phenomenal properties can be more or less *objectiv*e and *subjective*, that is they can be more respectively less in accordance with the factual properties Examples of phenomenal properties are percieved properties like colour and taste.

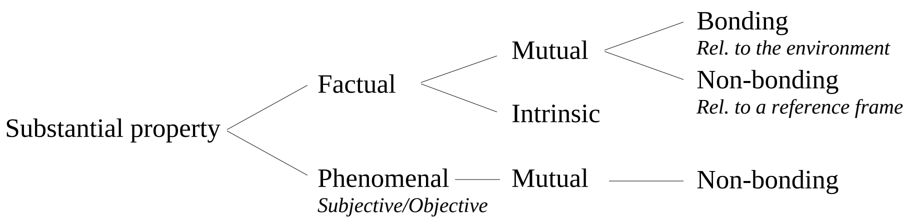

FIG. 2: Kinds of properties

Factual properties are either intrinsic or mutual. *Mutual* properties are relational, they depend on relations to other things like the environment or a reference frame. The relations between a thing and its environment are bonding. Things with *bonding* relations affect each other's state, for example integrating and repelling relations are bonding. The relations between a thing and a reference frame are non-bonding. *Non-bonding* relations do not effect the states of the related things, examples of non-bonding relations are spatial relations like position or shape. Phenomenal properties are mutual non-bonding relations between a thing and an interpreting mind.

Generally the distinction between intrinsic and mutual properties depends on the demarcation of the system. A mutual property may be construed as an intrinsic property of a larger system. Man-made things, artefacts, are designed with a purpose to have certain functions. A *function* is a mutual property of a thing and its environment, for example of an artefact and its users. A function is a bonding relation. *Performance* may be defined as a measure of relative quality. In that sense it is a mutual property based on a non-bonding relation to some reference frame.

2.3.2 System

A simple or atomic thing has no parts. An *aggregate* is a collection of things with only non-bonding relations. A complex thing with bonding relations among its parts is a *system*. A comprehensive description of a system's properties includes its composition, environment, structure, laws and history. The *composition* is the set of the parts of the system, the *environment* is the set of things that interact with the system and the *structure* is the set of internal and external relations as shown in Fig. 3. A system's *laws* are relations among its properties, and its *history* is comprised of the former states of the system (Bunge 1979).

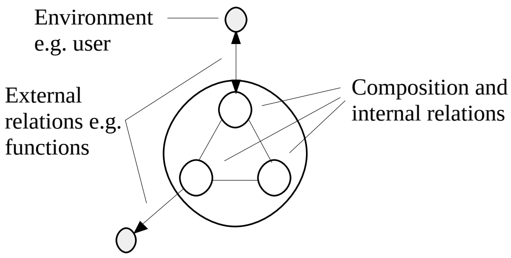

FIG. 3: Basic properties of a system (arrows indicate one-way or two-way interaction)

The properties of a system are resultant and emergent. A *resultant* property already exists among the system's parts, such as weight, while an *emergent* property, such as the stability of a structure, is new, and characterises the system as a whole.

A compositional part of a system and the system as a whole have a part-whole relation. Basic to the *part-whole* relation is that the existence of a part precedes the existence of the whole. The relation is defined for things only (Bunge 1977). If the parts of a system are systems themselves they are called *subsystems*. And if the total environment of a system is a system it is called a *supersystem*.

A *level* is a set of things where things in lower levels are parts of wholes in higher levels. The levels subsystem, system, and supersystem together make up a level order. A *level order* is a set of levels, where lower levels precede higher levels. Seen from the direction bottom-up, when a system is assembled, parts in lower levels are aggregated into wholes in higher levels. In each new level properties emerge so that the whole in some fundamental way differs from its parts.

2.3.3 Artefacts and socio-technical systems

Artefacts are man-made or man-controlled systems; they are tools that make certain activities possible. When man uses an artefact to perform an activity, a new kind of system emerges, a *socio-technical* system (Emery and Trist 1960). The *activity* is a property of the complex socio-technical system of man and artefact, e.g. construction works enable activities like driving a car smoothly at high speed on a road, or farming in arid areas using the distribution of water in pipes.

In a socio-technical system the purposeful relations are functions. The intrinsic functions are tool-relations and the individuals roles (Ekholm 1987). *Tool-relations* exist between a person and the things a person uses as tools during an activity. A *role* is a human activity and a subset of an individual's behaviour performed for the system's purpose. Among the extrinsic functions are the extrinsic roles and transformation relations to the environment, see Fig. 8.

2.3.4 Functional and compositional views on a system

To adopt a view on a system is to observe a specific set of properties. A functional view on a system focuses on some of its bonding relations to the environment while a compositional view on a system is directed towards its composition and internal relations. In both cases spatial relations may be included, but they may also be regarded as a separate view on the system. The complete description of a concrete thing, e.g. a building, must among others include both the functional and the compositional aspects, see Fig. 4.

A "black box" model of a system with input and output defined is an example of a functional view. A closer study may reveal that certain functions are related to specific areas of the system, the functions of these areas contribute to the global functions of the system. The study of the human brain is an example of this kind of functional analysis. Similarly a study of a building will reveal that certain areas are load-bearing and others are climate protecting. However the functional view gives no clear indication what are the composition parts of the system, since the same product can have many different properties and can be part of many different functional systems. The functional approach to identifying parts has been used in the GARM (Gieling 1988) and is also frequently used in everyday analysis.

The other approach is a compositional "bottom up" view of the system, which identifies the composition units of the system and studies how their properties contribute to the functions of the system as a whole. According to the definition of the part-whole relation the composition units are compositional parts of the system, they are things that precede the whole, that is they exist before the whole (Bunge 1979).

To conclude, a functional view does not reveal the compositional units of the system; this is only achieved through a compositional view. On the other hand, the naming of things often uses a functional characteristic as basis, so compositional units can also have functional names.

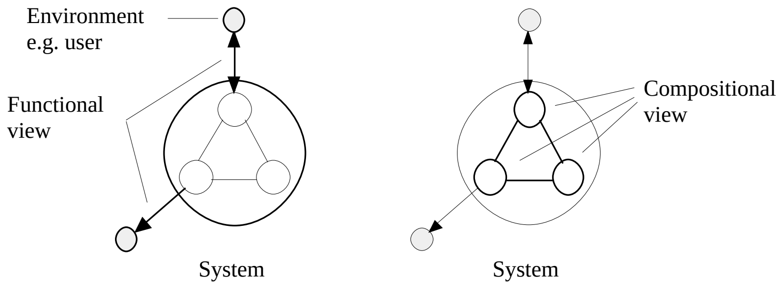

FIG. 4: Functional and compositional views on a system

3 CLASSIFICATION

3.1 Classification and knowledge

In order to classify a collection of objects it is at first necessary to define the purpose of the classification. Then the properties of interest to the classification may be distinguished, and finally the objects can be sorted into classes with regard to the chosen properties. This requires both factual knowledge of the objects of interest and that the purpose of the classification is carefully considered. In classification it is also necessary to make methodological abstractions; that is, disregard properties that are not of interest (Bunge 1983).

The distinction between classes can be based on Boolean or Cartesian partitions. The former is qualitative, of the form ”A” and ”not-A”, while the latter is quantitative of the form ”more A” and ”less A”. Only the former distinguishes definite classes. A detailed description of the application of Boolean principles is given in Bindslev’s presentation of the CBC-system (Co-ordinated Building Classification) (Bindslev 1969).

To classify is not to build a theory, ”classifications summarize and order available knowledge” (Bunge 1983). Bunge draws attention to the fact that classifications come in several depths and that ”we should prefer the deepest of all for being the more realistic. If we want deep classifications we need theories, the deeper the better: for example, biological systematics (based on the theory of evolution), the periodic table of the elements (based on the atomic theory), the classification of hadrons based on the quark model, and the classifications of materials based on their constitutive relations or specific laws” (ibid).

3.2 Classification rules

A classification may be scientifically founded but it is a conceptual operation to create order in a set of objects. To a certain extent it must disregard the fact that things do not have sharp boundaries; properties come in degrees, not in distinct packages. A classification based on the factual intrinsic properties of a thing is called a *natural classification* while a classification based on factual mutual properties or phenomenal properties like appearance is called an *artificial classification*. A natural classification can be based on properties like heat conductivity or constituent material. A classification based on use is artificial, although use, as a mutual property of a thing and the user, is based on intrinsic properties. Artificial classifications can be based on external appearance like beauty or meaning, expressed e.g. in the (questionable) proposition ”only beautiful buildings have architectural qualities”.

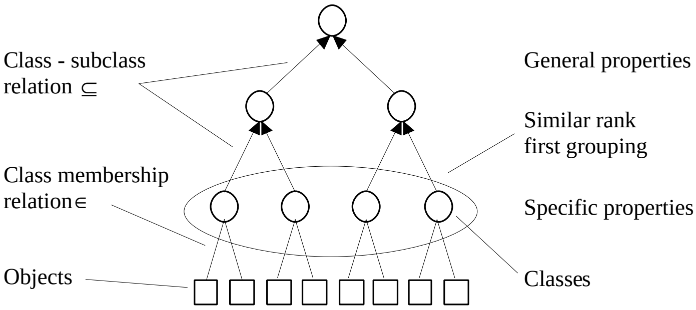

FIG. 5: Classification concepts

In a classification a collection of objects are sorted into different classes where each class is a set composed by its members, and determined by properties relevant to the classification. Properties that determine the classes in a collection can be ordered by increasing fineness from general to specific. Properties of a higher rank are general and properties of lower ranks are specific to the members in the collection. See Fig. 5.

The purpose of a classification is to distinguish between the objects in a collection. In order for the classification to be exhaustive, every object in the collection must be assigned to a class, and in order to be definite each object may only belong to one class. Without these criteria there are unclassified objects, and objects that belong to more than one class of the same rank. In both cases the classes are not properly defined.

In a classification some important rules must be followed (Bunge 1983). The classification must be:

1) exhaustive, the union of all classes in the first grouping must equal the original collection, see Fig. 5, and
2) definite, there must be no borderline cases. All the classes of the same rank must be pairwise disjoint. Two classes are either disjoint, or one of them is included in the other. An object may not belong to more than one class of the same rank, see Fig. 6.

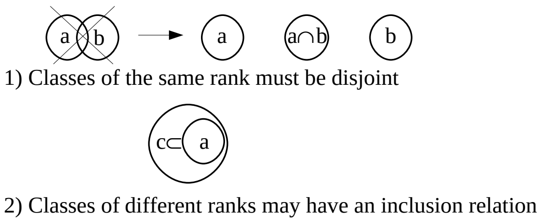

FIG. 6: Relations among classes in a classification

3.3 Direct and combinatory grouping

An attribute is a conceptual representation of a property of a concrete or abstract object. The attributes in a classification table represent characteristic properties relevant to the objectives of the classification.

The members of a class have characteristic properties in common. There are two different principles of grouping objects 1) direct grouping and 2) combinatory grouping (Wåhlin 1976). In a direct grouping the classes are identified through a combination of properties that serves the purpose of the classification, the object's use can be among these. A direct grouping of the parts of a building is wall, floor, foundation, roof, window, etc. In a combinatory grouping one or more sets of attributes can be freely combined. The latter classification structure is termed ”faceted” (ISO 1994, Wåhlin 1978).

A facet is an exhaustive set of properties of similar kind e.g. functions that makes it possible to categorise all members in a collection. A study of building classification systems shows that principally three main facets are used namely ”function”, ”construction activity” and ”material”. An example of a facet is the ”main function” used in the Swedish BSAB system, with the attributes ”loadbearing”, ”enclosure” and ”servicing” that in an exhaustive way can be used to classify parts of a building (Häggström 1994).

A faceted classification makes it possible to freely combine a set of properties that characterise an object and is capable of accepting new objects to be classified. ”A faceted classification has a distinct advantage over an enumerative one in the kinds of search strategies it empowers as well as in expert system applications making use of the synthesis and decomposition of class numbers” (Svenonius 1992).

If a thing has more than one of the properties of the facet it is necessary either to make a decision which property should be used as primary for the classification, or to specify the facet further. In BSAB 96 ”loadbearing” is primary to ”enclosure” and other properties since there is a user need to be able to separate all loadbearing components for example for tendering purposes.

The same collection of objects can be classified in different classification systems, for different purposes. A pre-fabricated wall may be classified as a construction product e.g. B211 Non-structural wall (EPIC 1993) and as an element e.g. 43.CB Internal wall (Häggström 1994). The same physical part in this example belongs to different classes, but in different classifications. However each of the classifications follow the basic principles of being exhaustive and definite.

4 CLASSIFICATION OF CONSTRUCTION WORKS

4.1 Basic concepts

The basic concepts in construction works classification represent properties that are of interest in the design, construction and management processes. The fundamental units of interest are construction works, users and producers. In this section some classification concepts are defined in relation to the earlier presented systems model. The concepts discussed here and in the ISO Technical Report (ISO 1994 a) are: facility, space, element, designed element, work section, production activity, construction product, construction aid and attribute. In the new Swedish BSAB 96 system the related concepts infrastructure unit and construction type are of interest and also discussed here.

4.1.1 Facility or construction works

According to the ISO Technical Report a facility is: ”A physical structure or installation, including related site works, serving one or more main purpose”. A building is defined as: ”a type of facility comprising partially or totally enclosed spaces and providing shelter” (ISO 1994 a). The sentence ”including related site works” is excluded in BSAB 96, where ”site works” are regarded as a separate kind of facility.

An analysis of the examples of classifications of facilities in the ISO Technical Report show that they are based on four different kinds of properties. The first three are functional, a) function with users, b) function with an installation, and c) function with an environmental agent, and the fourth, d), is based on intrinsic properties. Intrinsic properties of the last category are loadbearing, enclosing, servicing, and spatial properties of the facility. These properties are used to support different kinds of functions. Examples of classes based on these different aspects are shown in Table 1.

TABLE 1: Examples of properties used for classification of facilities

Properties for classification	Examples of classes
Function with users	Museum, Pedestrian tunnel
Function with an installation	Railroad, Boilerhouse
Function with an environmental agent	Seawall, Rainshed
Intrinsic properties	Building, Bridge, Mast, Tunnel, Dam

Since functions are based on the intrinsic properties of the facility, for example a school building has a spatial structure suitable for class-rooms and an auditorium, it is of interest to classify facilities according to how they are used or their intended use. But a classification based on use is artificial since it only indirectly concerns the buildings intrinsic properties. The ISO Technical Report does not discuss this problem but recommends that facilities are classified according to user activities.

In the work of ICIS, the International Construction Information Society, WG 3, there is an agreement that a classification of facilities based on intrinsic properties is also feasible and useful. For this purpose a suggestion has been made to introduce a new concept, the ”construction type”. A construction type is defined as: ”an independent physical structure with common object functions and basic geometry which therefore have a common set of elements” (ICIS 1994)

The term facility used in the ISO Technical Report has the disadvantage of being somewhat vague. The term ”construction work” has been used by Giertz to denote the class of ”buildings, roads, bridges, silos, off shore rigs etc.” (Giertz 1982 a), the term is also used in civil engineering (ISO 1994 a). ”Construction works” designates the same concept as ”construction type” and has advantages over the latter since ”type” denotes membership of a certain subclass of constructions. Construction work reminds of the Germanic words ”bauwerk” and ”byggnadsverk” where ”verk” is used with the same meaning as ”work”. The conclusion is that if another term than facility should be suggested, then ”construction work” should be considered.

A *construction work* is an artificial system, built for a purpose, it has a static ground construction, and relations to the environment like the surrounding nature and users, see Fig. 7 (Ekholm 1987).

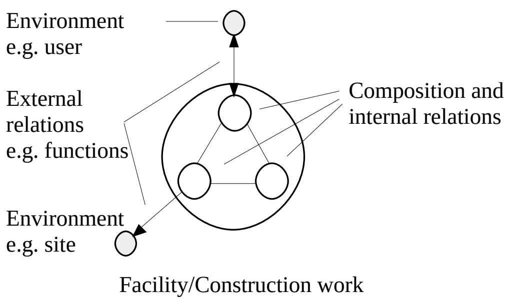

FIG. 7: A system model of a construction work with function, composition and internal structure

A construction work, as a whole, is a system of interacting parts which may be divided into three main functional groups, loadbearing, enclosure (against for example climate and intruders), and servicing. Construction work parts interact and constitute systems of different kinds with new functions. There are construction work parts of varying complexities. Atomic parts like ”wood frame” and ”gypsum sheath” make up a simple system with the property ”internal wall”. Examples of simple systems are wall, floor structure, roof, washbasin, bathtub, socket and water tap. A wall is a system of interacting parts with the composite function ”wall”. More complex functions are often properties of systems in higher levels where many parts interact like loadbearing structure or climate system.

Construction works are parts of socio-technical systems; they are used as tools that make different activities possible. The properties of the construction work are basic to many of the activities performed by the users. It should be noted that there is no one-to-one relation between a user organisation and a construction work, which may accommodate several different organisations. Vice versa, the same organisation may occupy several different construction works. Therefore, it is not the use that delimits its extension, but a combination of intrinsic properties like loadbearing, enclosure and servicing that separate the construction work from its environment.

4.1.2 Infrastructure unit

Although it is not included in the ISO Technical Report, the concept ”infrastructure unit” is used in BSAB 96 which makes it relevant to mention here. An infrastructure unit is not a large construction work, it can be defined as an aggregation of construction works that is used by a social organisation for a purpose. An infrastructure unit is not a system since the definition of a system includes bonding relations among its parts, see section 2.3.2. It is an aggregate with spatial relations that are necessary for the functional properties in use. The infrastructure unit and the social organisation together make up a socio-technical system with activities as its main properties, see Fig. 8. Just as facilities in the ISO Technical Report are classified according to user activities, infrastructure units in the proposal for BSAB 96 are classified according to the activities of the socio-technical system, for example university, hospital, airport.

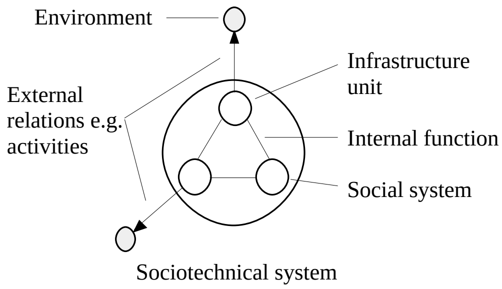

FIG. 8: An infrastructure unit can be seen as part of a socio-technical system

4.1.3 Space

In the ISO Technical Report spaces are defined as: ”Three dimensional spaces within and around buildings and other facilities, bounded actually or theoretically” (ISO 1994 a). This is not a proper definition since it presupposes the concept to be defined.

The attributes in classification tables for spaces, just as in classification of infrastructure units and facilities represent functions in relation either to the users e.g. ”lavatory” and ”dining-room”, or a kind of installation e.g. ”boiler-room”, or an external agent acting on the facility e.g. ”rain”-shed. This indicates that a space is a thing with certain geometrical enclosing properties and that it can have a function.

A *spatial relation* is a non-bonding separation relation among things, and *space* is a set of spatially related things (Bunge 1977). The concept ”space” refers to a set of things and represents their spatial relations,

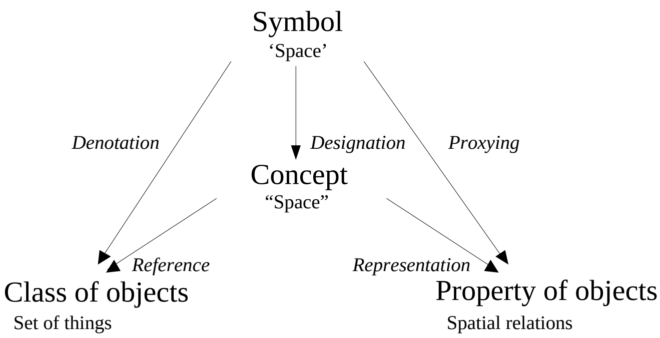

FIG. 9: Reference and representation of the concept ”space”

see Fig. 9. The things need not constitute a system but form an aggregate. A consequence of these definitions is that the only way to describe and classify space is as things with spatial relations.

Spaces in a building are made up of building parts. These parts have material properties and spatial relations that constitute a suitable environment for user activities and things. Characteristic for spaces in buildings are their enclosing properties. Although non-exhaustive, a definition of ”space” that could be used as a basis for classification in the construction context is: ”A *space* in the construction context is an aggregate of construction works, their parts or other things with materially or experientially enclosing properties”. An example of such a space is a room in a building see Fig. 10. Outdoors, e.g. a street-space may consist of a street, pavements and the surrounding buildings. From the definition follows that a part of the building may be a space, for example a pre-fabricated volume element, that a building as a whole may be a space, and that a group of buildings and other construction works may be a space.

Classification of spaces in the construction context is based on their functions in use in a socio-technical system. Construction works and spaces within and around these may also be classified according to their geometrical properties, basically their shape. One example of such a classification is the distinction between houses based on their overall shape for example rectangular, L-formed, U-formed or courtyard shape with their variants.

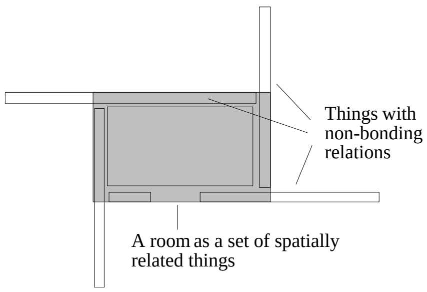

FIG. 10: Space as an aggregate of things with spatial relations

4.1.4 Element

According to the ISO Technical Report an element is: ”A physical part or system of a facility with a characteristic function (e.g. enclosing, furnishing or servicing building spaces), defined without regard to the type of technical solution or the method or form of construction” (ISO 1994 a).

The elements of a system are identified through a ”top-down”, functional, view. Three major kinds of elements are distinguished in the appendix B2 of the ISO Technical Report:

- structure/enclosure elements;
- services engineering elements; and
- fixtures/equipment elements.

TABLE 2: Categories of use for an element classification according to ICIS

- Specification:
  - Clients brief
  - Written descriptions of design proposals
  - General inform. on design requirements
  - Specification
  - Bills of quantities
  - Historical data on designs
- Drawing Organisation:
  - Drawing numbering
  - CAD layering
  - CAD libraries
- Cost Analysis:
  - Historical data on costs
  - Cost planning
  - Bills of quantities
- Data Filing:
  - Construction product data filing
  - Project data filing
- Construction Management
  - Project management
  - Construction management
  - EDI transactions
- Property Management:
  - Commissioning
  - Property maintenance
  - Life cycle costing
  - Decommissioning

Lars Magnus Giertz, developer of the original SfB system, distinguishes three different actors with separate interests, partly coinciding and partly conflicting, relevant for identifying elements:

- the owner, with concerns for enclosure of space, and maintenance costs;
- the architect: with concerns for elements grouped into functional sub-systems; and
- the constructor: with concerns for elements grouped into sub-contracts and sequence of building operations (Giertz 1982 b).

In the ISO Technical Report is listed a wide range of uses of an element classification. The list of uses has been structured and supplemented by ICIS WG 3 as shown in Table 2 (ICIS 1994).

The original SfB system was developed to facilitate communication between the design and construction phases of the building process. The table for elements was partly set up to be used for identifying different kinds of drawings, the term used was 'byggnadsdelar' which translated directly from Swedish is 'parts of the building' (Bygg AMA 1950). The original table for elements in SfB is shown in Table 3. This English version is taken from Giertz (Giertz 1982 b).

TABLE 3: Building Elements in SfB 1950

(0)	Accessories generally (compare (50) and (60)	
(01)		fasteners
(02)		ironmongery
(1)	Ground and foundation	
(11)		ground shapes
(12)		ditches, ducts, drains
(13)		retaining walls, soil supports
(14)		roads, paths, hard surfaces
(15)		soft surfaces, lawns, planted areas
(16)		substructures generally, other than (17) and (18)
(17)		pile foundations
(18)		pad foundations, footings, foundation beams
(2)	Building elements (primary)	
(21)		walls, external walls
(22)		partitions, partition screens
(23)		floors
(24)		stairs, ladders
(25)		ceilings
(26)		flat roofs, terraces, balconies
(27)		roofs (inclined)
(28)		building elements above roof
(3)	Building elements (secondary)	
(31)		windows
(32)		doors
(33)		additions to floors, floating floors, etc.
(34)		handrails and balustrades for stairs
(35)		gates, barred openings, etc.
(36)		terrace lights, balcony balustrades, parapets, etc.
(37)		roof lights, roof trap doorways, etc.
(38)		eaves, gutters, downpipes, roof walkways, etc.
(4)	Building elements (finishes)	
(41)		wall finishes externally
(42)		wall and ceiling finishes internally
(43)		floor finishes
(44)		stair finishes
(45)		plints, mouldings, fillets, window sills, etc.
(46)		terrace finishes
(47)		roof coverings
(48)		completions (sheet metal, etc.) to roof coverings
(5)	Services (mainly piped ducted)	
(50)		accessories
(51)		culverts, chutes
(52)		services - drainage
(53)		services - water
(54)		services - gas, compressed air
(55)		services - space cooling
(57)		services - space heating
(58)		services - ventilation
(6)	Services (mainly electrical)	
(60)		accessories
(63)		services - power, lighting
(64)		services - telecommunication
(66)		services - lifts, escalators
(68)		services - lightning conductors
(7)	Fixed furniture (commonly used)	
(71)		furnishing of entrances, etc.: racks, etc.
(72)		furnishing of rooms generally
(73)		furnishing of kitchens and related rooms
(74)		furnishing of toilets, baths, dressing rooms
(75)		furnishing of laundries and related rooms
(76)		furnishing of rooms for cleaning and storing
(77)		furnishing of secondary spaces
(8)	Fixed furniture (special for schools, hospitals, etc. (to be used as needed)	
(9)	Site elements and site finishes other than those mentioned in group (1) (to be used as needed)	

The original SfB system was organised so that the physical parts of the building could be described from three separate tables each representing a specific view. There were tables for ”elements”, ”production activities” and ”materials”. The table for elements is an example of a direct grouping of the parts based on a mixture of properties to identify an element. In later applications ”elements” have been seen as a facet describing functional properties of the buildings parts. The original idea was not purely functional but to make a combination of different properties so as to be able to identify the parts of the building uniquely without specifying their material contents. One of the starting points for the development of the CI/SfB Construction Indexing Manual was a criticism of the element concept for not being a ”pure” facet but a mixture of properties like position, material, function, shape and uses (Giertz 1982 b).

Traditionally building classification only accounts for so called characteristic functions, e.g. loadbearing, enclosure and servicing. To be classified as an element, a part of the construction must have at least one characteristic function, see Fig. 11. A part without a characteristic function is not an element but may be part of an element. Examples of such parts are ”wood frame” and ”gypsum sheath”. They are results of separate construction activities but does not by themselves have a characteristic function, see Fig. 14.

If a part has two or more characteristic functions a main function must be distinguished in order that a part may only be assigned to one class of the same rank. The primary property is called the *main* characteristic function. In BSAB 96 there is a rule that if a part is both loadbearing and enclosure, the order is that loadbearing is primary and enclosure is secondary. The ranking is conventional and based on the Swedish contractors requirements on the tables. However the generality of this order may be questioned since from the user’s point of view, enclosure may be considered more basic than loadbearing.

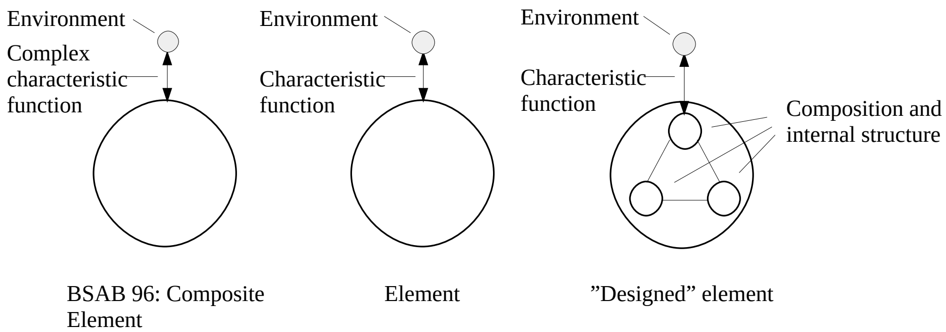

FIG. 11: Construction work part as ”composite element”, ”element” and ”designed element”

Just as with the concept ”space”, there is a similar ambiguity with the meaning of the concept ”element”. The term ‘element’ designates several different concepts, all with reference to physical parts, compositional units, of construction works. One concept represents a complex of properties of the part, as in classifications using direct groupings e.g. the original SfB system. This view is typical of ordinary language and is the most common among construction classification professionals as well as practitioners in the construction industry. Another concept represents the characteristic function of a physical part, and is used within the combinatory approach in faceted classification, for example in the development of the new BSAB 96 system, see Fig. 12.

The difference in meaning of ”element” reflects the two main approaches, direct and combinatory, in classification and must be observed in communication between actors in the field. The definition in the ISO Technical Report can be interpreted in both ways and thus be accepted for both applications, however the different interpretations may lead to completely different conclusions. In both cases ”element” refers to physical parts of construction works, the difference lies in the scope of the concepts. The concept used for direct grouping gives both a more generic and complete representation of a part, while the concept used to represent only one characteristic function gives a more specific and limited description. In the very beginning of the design process the combinatory concept of ”element” cannot be used since the functions of the parts are not determined far enough at this stage.

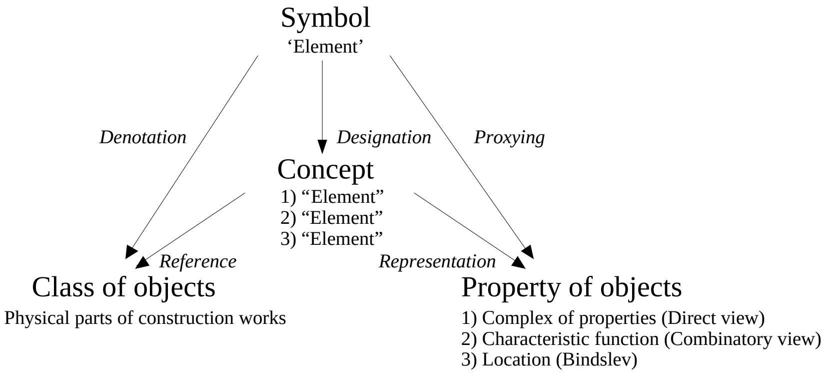

FIG. 12: Reference and representation of different ”element” concepts

A somewhat different idea of the element concept is presented by Bindslev in his CBC system. Elements according to Bindslev are general location properties (Bindslev 1969, Bindslev 1992). Giertz has explained Bindslev's concept of elements as ”dimensionally and functionally defined space” (Giertz 1982 a).

The CBC system describes the building or building project using a ”general code”. The code consists of a classification part and an identification part. The former is a combination of codes from the three SfB classification tables that enables a complete description of a certain class of physical parts of the building, and the latter is an identification of a particular member of the class. This is exemplified with the code (22)Fg2.1234 that denotes a clay brick construction ”located in the building element 'partitions'” (Bindslev 1969). This analogy implies that an element is a space that can be filled with constructions. It reveals a conception of space as a separately existing void entity. This contradicts both physical science and common sense where an element is regarded as a physical thing. Another interpretation is that Bindslev's element concept represents spatial properties of physical parts so that Bindslev's elements are spatially defined parts of the building, see Fig. 12.

To organise a table for elements raises also other questions that cannot be subject for this investigation, e.g.: How fine-grained should an element classification be? The use of the tables is a determining factor for their structure. An element table is to be used in the context of specification and the degree of detail must allow different technical solutions. How should the tables be structured? The order of the attributes in the BSAB 96 element table is based on the sequence of the construction activity, and an order of complexity of work (Häggström 1994). A third question is whether to integrate tables for different kinds of construction works or settle with a common conceptual basis but with different applications. In the BSAB 96 system roads, railways etc. use the same tables as buildings, see Table 4.

4.1.5 Composite element

In the BSAB 96 system there is a strict order in the classification which rules that if a physical part is both loadbearing and enclosure it must belong to the class of loadbearing parts. The reason for this is determined by the users of the tables, for example contractors find it relevant. If the *main* characteristic function is not determined or unknown, the part is classified as a *composite element* (Häggström 1994). The composite element is intended to be used in the early stages of the design process when the main function has not yet been determined, see Fig. 11.

In the the ISO Technical Report, appendix B 2: ELEMENTS, is suggested that the primary element is a useful attribute in classification for the early stages of the design process. The ISO Technical Report distinguishes between primary elements and functional parts or systems. Examples of primary elements are ”foundations”, ”lowest floor”, ”internal walls” etc. Examples of functional parts are ”main fabric”, ”false ceilings” ”floor finishes” etc. The functional parts represent a further specification of the properties of the primary elements. The question of classes for the earliest stages in the design process is discussed further in section 5.

TABLE 4: BSAB 96 draft version 1994-04-14, table for elements

NOTATION / HEADING

0 COMPOSITE ELEMENTS INCL. SERVICES ENGINEERING ELEMENTS
- 01 Composite elements
- 02 Composite services engineering elements
- 03 Composite elements incl. services engineering elements - other

1 SUPPORTING SOIL, SUBGRADE, PROTECTING LAYER IN GROUND; FOUNDATION AND RETAINING STRUCTURES
- 10 Composite supporting soil, subgrade, protecting layer in ground; foundation and retaining structures
- 11 Supporting soil (natural, excavated, reinforced)
- 12 Subgrade
- 13 Layer in ground for protection of construction works
- 14 Layer in ground for protection of nature
- 15 Foundation structures
- 16 Retaining structures

2 LOAD CARRYING STRUCTURE
- 20 Composite load-carrying structure
- 21 Load-carrying structure in bridge, jetty, quay/embankment, and such like
- 22 Load-carrying structure in tunnel, rock-chamber, and such like
- 23 Load-carrying structure in mast, tower, lighthouse, and such like
- 27 Load-carrying structure in building
- 29 Other load-carrying structure

3 PAVEMENTS AND CIVIL ENGINEERING WORKS COMPLETIONS
- 30 Composite pavements and civil engineering works completions
- 31 Pavements
- 32 Civil engineering works completions

4 SPACE-ENCLOSING ELEMENTS; BUILDING COMPLETIONS; SURFACE FINISHES, AND ROOM FITTINGS & FIXTURES
- 40 Composite space-enclosing elements; building completions; surface finishes, and room fittings & fixtures
- 41 Roofs (not carcass); climate separating parts and completions
- 42 External walls (not carcass); climate separating parts and completions
- 43 Interior space-enclosing elements
- 44 Interior surface finishes
- 45 Building completions
- 46 Room fittings & fixtures
- 49 Other space-enclosing elements; building completions; surface finishes, and room fittings & fixtures

5 PIPE AND DUCTWORK SYSTEMS, DISTRIBUTION NETWORKS
- 51 Water conduit -, sewage -, gas -, and district heating networks, etc.
- 52 Water and gas systems, etc.
- 53 Waste management systems
- 55 Cooling and heat pump systems
- 56 Heating systems
- 57 Air treatment systems
- 58 Fire protection systems

6 ELECTRICAL AND TELECOMMUNICATIONS SYSTEMS
- 60 Composite electrical and telecommunications systems
- 61 Electrical and telecommunications ductwork systems
- 62 Electricity production system
- 63 Electricity power system
- 64 Telecommunications system
- 66 Systems for voltage regulation and electrical separation
- 67 Systems for electrochemical protection of installations, etc.

7 TRANSPORT SYSTEMS ETC.
- 70 Composite transport systems
- 71 Lift systems
- 73 Escalator and moving pavement systems
- 75 Service systems for material and item transport
- 76 Control and drive systems for machine driven gates, doors, etc.

8 CONTROL AND MONITORING SYSTEMS
- 80 Composite control and monitoring systems
- 81 Control and monitoring systems for property management
- 82 Control and monitoring systems for process installation
- 83 Control and monitoring systems for transport installation
- 84 Control and monitoring systems for treatment and transport of waste
- 85 Control and monitoring systems for energy provision systems
- 86 Control and monitoring systems for electricity provision systems

9 OTHER ELEMENTS INCL. OTHER SERVICES ENGINEERING ELEMENTS
- 91 Reserved. Recommended place for ”Common work and occasional manufacture” in connection with building production

4.1.6 Designed element

According to the ISO Technical Report a *designed element* is an element for which the ”technical solution and form of construction” have been determined (ISO 1994 a). For example, an ”enclosure” element may be designed as a construction of gypsum board and studs, then it is defined as a designed element. In the ISO Technical Report there is no explicit definition of the concepts ”technical solution” and ”form of construction”, but from their use it may be reasonable to assume that the concepts together have a meaning which includes composition, internal structure, and aspects of the production activity. To see a part as a ”designed element” is to recognise both the part’s characteristic function and its compositional properties, see Fig. 11 and Fig. 14.

The ISO Technical Report states that the concept of designed element is of importance for cost information and product modelling since it includes both functional and material properties. The concept of designed element represents a combination of functional and compositional properties of a part. The same concept should be possible to apply both in standardisation of technical solutions for specific functions and for classification of construction products.

4.1.7 Work section

According to the ISO Technical Report a work section is: ”One or several physical parts of a facility, viewed as the result of particular skills and techniques applied to particular construction products and/or designed elements during the production phase” (ISO 1994 a). According to the definition, the concept work section has reference to the construction work part and its assembly.

Wåhlin has shown how the reference of the concept of work has shifted in the Swedish AMA’s back and forth between work activity, used resources and result (Wåhlin 1986). Although the term ‘work section’ has connotations to both activities and results, it mainly denotes the result of the activity, see Fig. 13. The reason for this is stated in the ISO Technical Report: ”The most useful approach to the classification of activities is from the point of view of their result, i.e. physical parts of the facility being constructed”. Production activities and production resources depend on the production methods used, since the methods are often subject to changes, they might not be suited for standardisation. It is for many reasons more convenient to set requirements on the finished result. This may also be a reason for the shift in meaning of the concept of work section from activity to result.

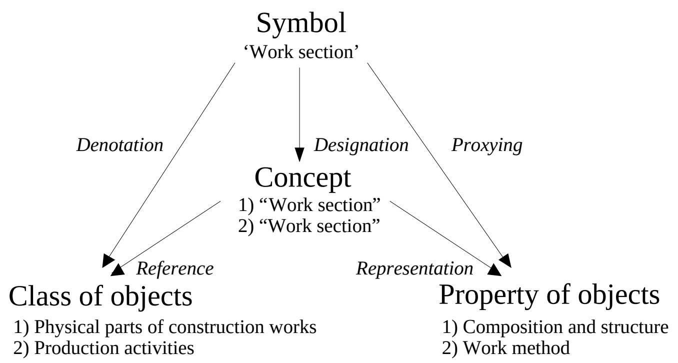

FIG. 13: Reference and representation of different ”work section” concepts

A work section is not defined by its function in a specific facility, it is a construction result characterised by the used construction products, and their material substance, and the production activity. Seen as a result, a work section is a ”bottom-up” or compositional view of a physical part of a construction work. As a result, a single work section has a function but may not have the characteristic function required of an element. Combinations of work sections may result in things with required element properties, see Fig. 14. Work sections of the same kind may in principle have different element properties, e.g. out of two concrete walls with the same composition, only one may be load bearing.

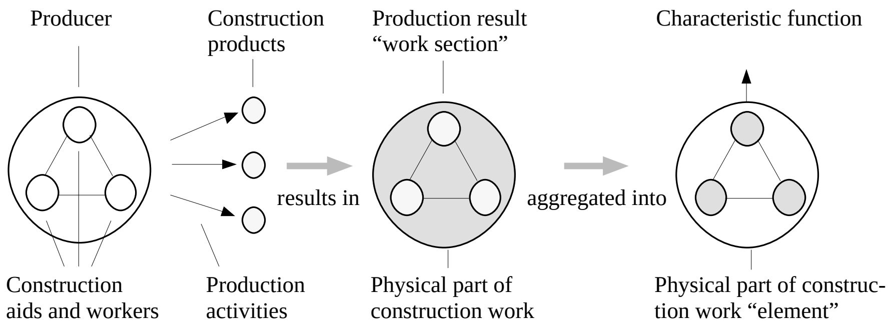

FIG. 14: A work section is the result of production activities on construction products

The produced result is a construction work part with certain properties. In BSAB 96 there are other kinds of work sections as well, e.g. ”scaffolding” and ”snow-clearance”. These are not physical parts of construction works, but still necessary for the production process.

4.1.8 Production activity

A production activity uses resources and produces results. The resources are construction products, construction aids and human effort (labour and thought), the results are both physical parts of construction works and other things or processes necessary during production (ISO 1994 a).

A producer might be viewed as a system that acts with production activities on the construction products to produce construction work parts. Production activities are particular skills and methods in work which transforms and assembles particular construction products into so called ”work sections”, results, e.g. ”work of clay brick in building”, and ”window”. The aim of the production activity is to achieve work sections with ”element”-properties, see Fig. 14.

4.1.9 Construction product

Construction products are defined as: ”Products, components and ‘kits of parts’ incorporated or intended for incorporation into facilities, including furniture and equipment” (ISO 1994 a). Construction products are things with the purpose to be used as, or transformed into, parts in construction works, e.g. in situ-concrete. Construction work parts and construction products may have the same composition and internal structure, the main difference is that the former is produced on site while the latter is produced ”off site” with the intention to be assembled on the site.

A classification of construction products has been done by a working group organised by EPIC, the European Product Information Co-operation (EPIC 1993). Construction products are grouped according to main function, shape and constituent material or products, see Fig. 15.

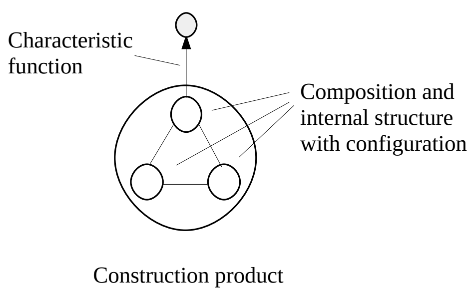

FIG. 15: Construction product as a system

4.1.10 Construction aids

Construction aids are defined as: ”Scaffolding, formwork, machines and tools (including required energy), consumable stores, construction products used for temporary structures and facilities, and other objects needed for the purposes of the construction process which are not incorporated into and do not furnish or equip the facility”, (ISO 1994 a). Construction aids are parts of the production system, see Fig. 14.

4.1.11 Attribute

A specific table for attributes can be of use for ”internal arrangement of technical documents, structuring of product data bases, structuring of other classification tables according to primary attributes, and definition of requirements for projects and resources generally” (ISO 1994 a). The CIB Master List is a list of attributes used for the arrangement and presentation of information in technical documents for design and construction (CIB 1983).

In Fig. 16, the attributes are related to the property model presented in section 2.3.1. The attributes represent factual or phenomenal and intrinsic or mutual properties that the construction work has either by itself or in relation to some other thing, for example a user or a reference frame. The types of attributes that are of interest to the construction industry are: performance, function, shape, location, material, price, and production time (ISO 1994 a).

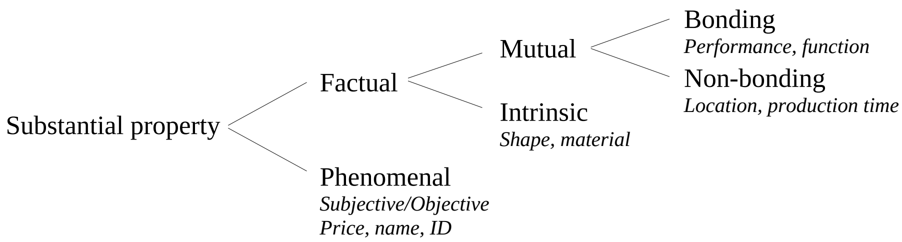

FIG. 16: Attributes related to the property model

Shape attributes and material attributes are compositional, that is they are factual, intrinsic properties. The performance attributes that are mentioned in the ISO Technical Report are functional, that is factual, mutual properties that emerge in bonding relations to the environment. The concept ”performance property” in the ISO Technical Report is used with the same meaning as the concept ”function property” in this paper. In other contexts *performance* is a measure of relative quality, it relates a thing’s properties to some standardised reference frame. Performance used with this meaning is a comparison relation and thus non-bonding. The function attributes in the ISO Technical Report are in fact not intrinsic properties of construction works, but properties of the composite system of construction works and users. Terms like transport, industry and commerce stand for activities of these socio-technical systems.

The location and production time attributes are factual mutual properties in non-bonding relations to environmental reference frames for space, time and computation. Price attributes and other often needed ”administrative” attributes like name or id are phenomenal properties in relation to information handling social or socio-technical systems.

5 CLASSIFICATION FOR PRODUCT MODELLING

5.1 Design object

Representations of factually possible construction works are created in the design process. During design, properties are determined incrementally, the designer works on a ”design object” that is increasingly more specified. If the design object models a building part, it may initially represent something space-dividing which is later decided to be a wall. Then properties are determined for proportions between wall and window, wall material, wall thickness, sound insulation, surface material etc., see Fig. 17.

The functional demands on the physical parts of the construction work most often require technical solutions where several smaller parts interact in systems of varying complexity. Complex properties may not be held by one single part, but several parts must interact to achieve the wanted function, e.g. the wall function or the floor structure function. The parts that make up a system like a wall, may have different spatial extension, e.g. the floor carpet may be extended up on the wall to make a skirting and the vapour barrier may be continued inside the ceiling, on the outside the brick work may extend as one work section all over the facade. The impression is a collage of overlapping units. This is especially significant to on site construction while prefabricated units must have a more unified extension.

The design object must be able to accommodate the growing complexity without ad hoc solutions, the basic structure of the object must allow successive composition of new parts as well as decomposition into separate units (Eastman 1994). It is also an advantage if the same object structure can be used throughout the whole design process from inception and brief to production planning and real estate management.

If a design object has the properties sketched above it is not critical what level of composition the initial design object represents, it is possible to start the design process with a very simple object representing only a spatial extension of some object e.g. some enclosure. In the early stages of the design process where the emphasis is on the use and experience of the facility, design objects may represent spatial properties of physical parts like wall, floor, roof, window, door, etc. Different design objects may be distinguished in order to be able to represent physical parts with different function and production requirements.

A design object may represent other things than constructions. There are at least three major kinds of things that are of interest to represent in the early stages of the construction design process: organisations, construction works and site (Ekholm and Fridqvist 1995).

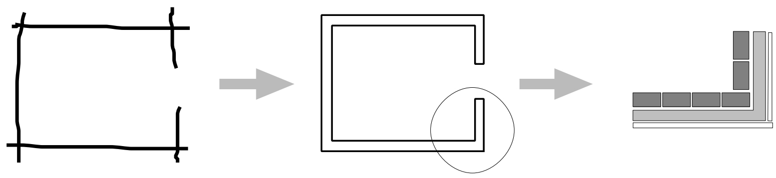

FIG. 17: A construction design object must accommodate to growing complexity

5.2 Classification and design objects

The need for classification during the design process is different from that in traditional classification. Other classes are of interest than those needed for tendering and calculation, for example. The objects in the beginning of a design process must be able to have varying functional and compositional properties.

In the earliest stages of the design process it may be most important to identify classes of parts according to shape, e.g. horizontal or vertical plate, circular or rectangular beam or column etc. (Tarandi 1994). The location in the construction and other properties can be assigned in the sequence the designer finds relevant. This implies that a classification of parts in the earliest stages of the design process could be done by a shape-facet.

In the design proposal stage it is possible to classify the design objects as elements according to their characteristic function and finally in the construction drawings stage, the design objects may be classified as designed elements composed of separate work sections seen as construction results, see Fig. 18.

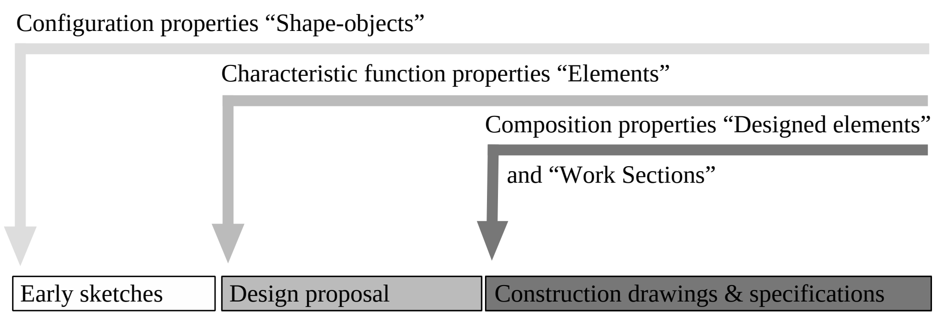

FIG. 18: Example of tables for classification of parts during different stages in the design process

It seems reasonable that the collection of parts in a building project can be classified according to a series of different classifications. Objects with a certain property may be retrieved separately from the database in a computer-aided design process. In this way traditional building classes as well as other relevant classes like fire resistance, sound insulation etc. can be organised. The only requirement is that these new properties can be classified in a standardised way, and added to the design object during the process.

6 CONCEPTUAL SCHEMA OF CONSTRUCTION WORKS

6.1 Framework for building information in the ISO Technical Report

The different concepts discussed in previous sections belong to a framework for construction works information. A schema is presented in the ISO Technical Report that relates basic concepts for describing construction works, see Fig. 19. The schema shows a level order with buildings in the highest level followed by the levels of elements, work sections and construction products in successively lower levels. These are all seen as produced physical objects with examples of different attributes listed. The schema is developed according to the NIAM information modelling technique (Nijssen G.M. and Halpin T.A 1989).

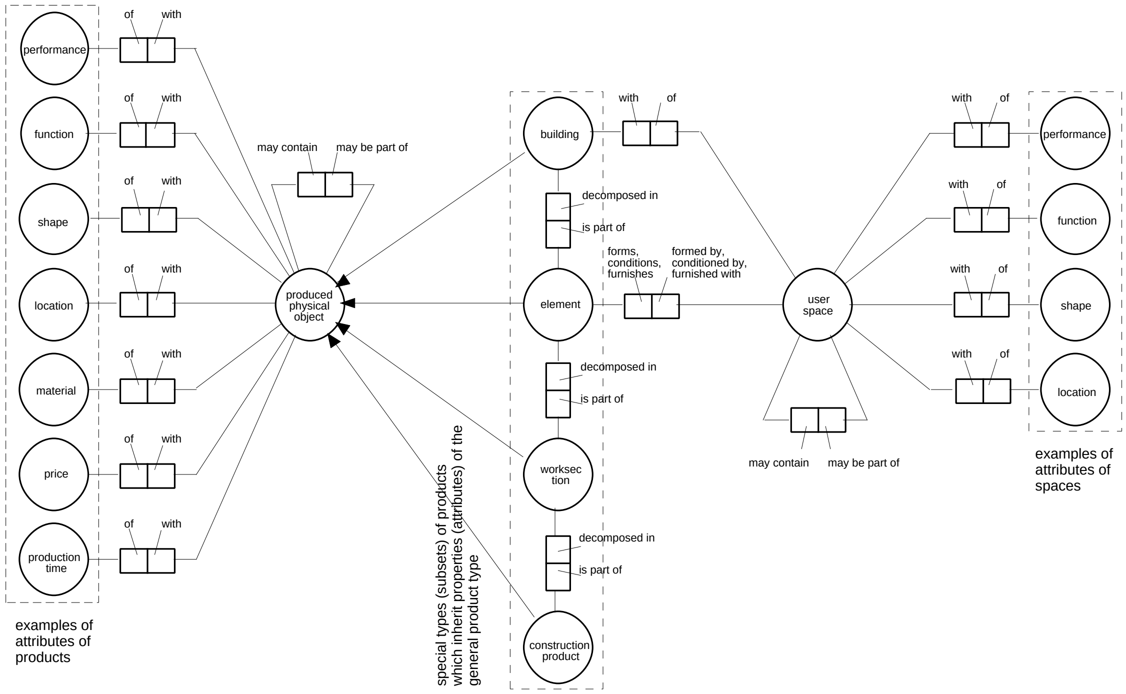

FIG. 19: Schema in the ISO Technical Report relating basic construction information concepts

The ontological starting points in this paper lead to a somewhat different schema than ISO’s. In this study an element is identified through a ”top-down” functional view on the part, and a work section is identified through a ”bottom-up” compositional view on the same part. A complete description of a part includes both its element and work section properties. The definitions of element and work section in the ISO Technical Report are in accordance with the ontological starting points of this study. However the schema in Fig. 19 shows a different conception where a work section is a part of an element and a construction product is part of a work section.

6.2 Framework for construction works information

This section presents a conceptual schema for construction works that relates some of the basic concepts discussed here, see Fig. 20. This schema is presented in EXPRESS-G, a graphical notation technique of the EXPRESS information modelling language. EXPRESS is the official information modelling language within STEP, and an international standard (ISO 1994 b), also described in (Schenck and Wilson 1994).

The concrete functionally distinguishable things that are produced in the construction process, namely the construction artefacts, are infrastructure units, construction works, construction work elements, element parts, and spaces. These construction artefacts have properties of specific interest to the construction process like production time, price, function, etc. The functions of a thing are the relations to its environment, for example the site and the users.

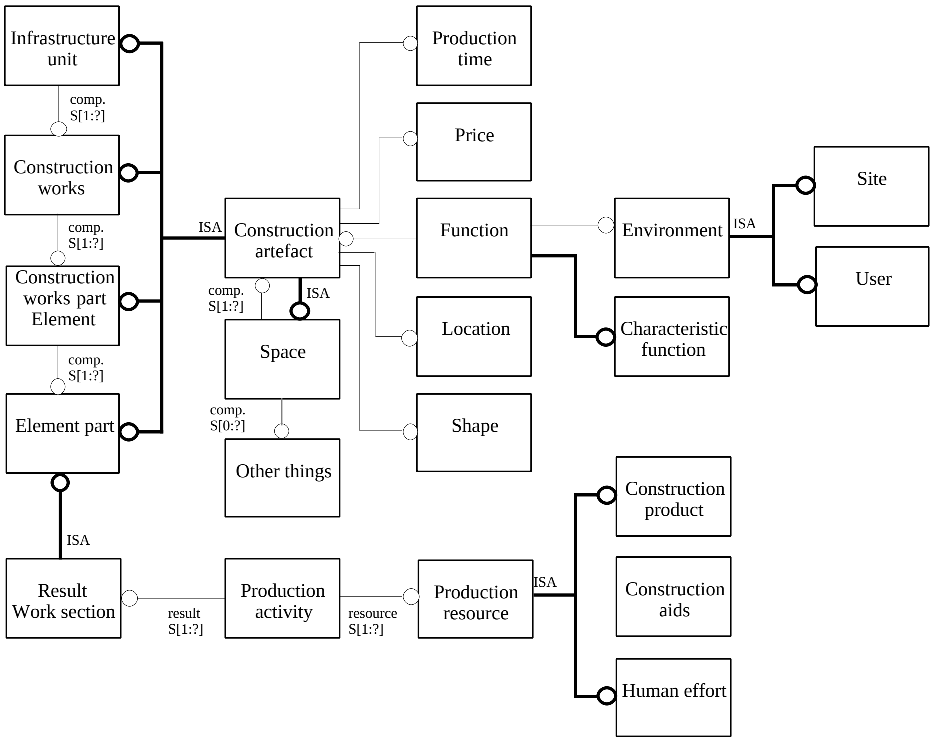

FIG. 20: Level order and main properties of construction works

Infrastructure units are aggregates of construction works used by a social organisation for a specific purpose, for example the construction works of a university campus or an airport. An infrastructure unit is characterised by its spatial pattern. Construction works are concrete systems composed of construction work parts of different complexity, from simple to complex units. Spaces are aggregates of construction works, their parts and other things with certain spatial and functional properties.

Infrastructure units, construction works and their parts make up a composition level order of increasing complexity with the levels:

- infrastructure unit (town, village, university campus etc.)
- construction works (streets, houses, canals, bridges etc.),
- construction work elements (column, wall, duct etc.)
- element parts (wooden studs, gypsum sheets, etc.).

In this level ordering, the element parts constitute the lowest level. Each physical thing that is assembled in its place in the construction is by definition a part, it has properties that contribute to the properties of the construction work as a whole. However, to build a more complex part that has the characteristic function of an element it may be necessary to combine one or many atomic parts, for example the wooden studs and gypsum sheets that together make up the element wall. This is recognised in the Nick information model (Löwnertz and Tarandi 1994, Tarandi et al 1995).

The question of levels within the collection of construction work parts is not elaborated further in this paper since the subject deserves a separate study. An interesting question is whether the most complex systems of parts belong to the level of construction works or constitute a separate level of parts. It can be argued that the loadbearing, enclosure and servicing properties characterise the construction work as a whole. A theoretical study of the level structure of construction works is presented by Ekholm (Ekholm 1987 and 1994). In building product modelling, the RATAS Model, (Björk 1989), and the AEC Building Systems Model, (Turner 1990), are examples where a level order is presented.

Construction work parts are assembled and transformed construction products. The construction process uses the resources construction products, construction aids, and human effort (i.e. worker's labour and thought) and produces results that are both parts of construction works and other things and processes necessary for the production process. To analyse a part as work sections is a compositional view of the part. It includes aspects of the production activities and used resources including construction products and their constituent material.

7 Conclusions of the study

This study has applied basic concepts in semantics and ontology to build a framework for construction works classification. The conclusions of the study are partly of a general character, and partly concern the continued work with the ISO Technical Report.

The study has aimed at relating traditional and pragmatically-developed concepts in construction classification to an ontological theory of properties. This theory has been used as a tool to analyse the traditional classification concepts and to give them and their relationships a precise meaning. The work has both confirmed and questioned the meaning of traditional concepts. The introduction of the idea of ”views” on the physical parts has been valuable to explain both the element and work section concepts as functional respectively compositional views. Finally the traditional classification concepts are related in a generic conceptual schema of construction works.

Other researchers for example Vanier (Vanier 1994) have recognised the need for a conceptual framework as a background for building a classification system. He has found that in conceptual modelling, as a means to represent real world objects and their relationships, the favoured method by many researchers is an object-oriented approach. However object-oriented modelling does not claim to rest on a general property theory, see for example (Rumbaugh et al 1991). A hypotheses worth testing is that Bunge’s ontological theory (Bunge 1977) could enrich and contribute to a further development of object-oriented modelling.

Among the more specific conclusions are those that relate directly to the ongoing work within ISO TC59/SC13 with the classification framework presented in the ISO Technical Report:

- The conceptual framework for construction works presented in the ISO Technical Report must be further developed and clarified to support the international work on development of classification tables in ICIS and STEP.
- A separate classification of socio-technical user systems may be a useful background for classifying infrastructure units, construction works and spaces according to the activities they support.
- The classifications of infrastructure units, facilities and spaces in the ISO Technical Report are based on functions in use. A classification based on intrinsic properties is also feasible and should be considered.
- A new definition of ”space” that recognises its material boundaries is required.
- The difference between element concepts based on direct and combinatory grouping needs to be recognised in the ISO construction information standard.
- Classification of parts for the early stages of the design process has a different purpose than traditional classification, which is aimed for the later stages of the process. A classification table for ”shape objects” is needed for CAD in the early stages of the design process.

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