Concepts of space in computer based product modelling and design#1

Abstract

The everyday understanding of space may be self-evident and unproblematic. However, as soon as we are asked for a formal definition, e.g. in the context of building classification or product modelling, the concept of space is subject of controversy and misunderstanding. To some, space is the emptiness in which things are embedded, i.e. something immaterial. To others, space has no separate existence but is a property of the material world. Still, according to both views, space can be experienced. In this paper we analyse some influential work within building classification and building product modelling and criticise these for applying a concept of space without factual reference. We explore the ontological foundations for the concept of space, and conclude that space is an aspect view on things; depending on the view, it may be seen both as a property of things and as a thing in itself. Finally we show how construction space can be represented as an object in a conceptual schema for computer based space information.

Keywords*: Space, building, construction, classification, product modelling, aspect model, spatial modelling, CAD*

1. Introduction

1.1 Background and purpose of the study

Space is one of the basic concepts by which we refer to the material world. We observe the world of things and how they surround us and we perceive these as constituting some kind of space. Already as infants we learn to know the extension of our own body and how it is spatially related to external things (Piaget and Inhelder 1956). If we enter a cave, or the London Tube, and face a wall we will get a unified understanding of space as both material and experiential. The material wall stretches upwards and bends over us to form a ceiling, and then it slopes downwards again, enclosing us from behind and connecting to the floor on which we stand. Here, experiential space and factual space are united. At other times, our experience of space is more subtle and depends on our imagination, as for example when we divide a beach into sunbathing territories and walking paths. Here we rely more fully on an inter-subjective, often culturally defined, understanding of experiential space.

The everyday understanding of space may be self-evident and unproblematic. However, as soon as we are asked for a formal definition, e.g. in the context of building classification or product modelling, the concept of space is subject to controversy and misunderstanding. To some, space is the emptiness between things, or the emptiness in which things are embedded, i.e. something immaterial. To others, space has no separate existence but is a property of the material world. Still, according to both views, space can be experienced.

Space has come to be an important concept in computer based information systems both for the building construction process and the facility management process (Björk 1992). The organisation or enterprise is located in and uses the building’s spaces. Much of the building’s spatial properties are determined on the basis of user organisation requirements. This is to a large extent done early in the design process independently of and before the loadbearing structure or the installation systems are determined. Therefore it is necessary that spaces can be represented independently of other entities in the product models. It is also necessary to observe the difference between the organisation’s spatial properties or "activity spaces" and the spatial properties of the built environment, e.g. rooms or furniture defined space.

The ontological status of the concept space applied in information systems for building classification and building product modelling today is unclear, and unnecessarily lowers their information quality. In the former, spaces are classified as something concrete with functions (ISO 1997a), and in the latter spaces are represented as abstract objects enclosed or bounded by concrete building elements. Examples of the latter are found in wellknown projects like COMBINE (Nederveen 1996) and BCCM, the Building Construction Core Model of STEP (ISO 1996). Some authors argue for the necessity of intermediary concepts or "abstraction mechanisms" with the purpose to assist during model development. Among these are (Björk 1992) and (Eastman and Siabiris 1995).

In order to enable communication among actors in the construction process and among computer systems, the concepts used in model development have to be formally defined and standardised. Such definitions go beyond everyday communication needs and require a theoretical foundation. A basic assumption in this paper is that information models must not only be computer interpretable and based on domain specific concepts, but they should also be scientifically true representations of the universe of discourse. This will ensure a longer lifespan as well as a higher degree of versatility of the models. This is also the objective behind the development of domain specific standards and information models based on these standards by among others ISO TC59/SC13 (ISO 1994a), and STEP (ISO 1994b), working committees of the International Standardization Organisation. Requirements on high quality information models based on standards are presented by West (1994).

The problem of co-ordinating different viewpoints in a product model is recognised by Björk who states that "A basic dilemma in many product models seems to be to reconcile the material and construction method viewpoint with the space-centered viewpoint. The use of abstraction mechanisms makes it possible to build schemas which accommodate multiple viewpoints". The aim of this paper is to deal with the dilemma observed by Björk and show that space can be represented as a property of things, in this case of buildings and their parts, as well as of user organisations and their "activity units". This concept of space has factual reference, and yet serves the information needs of building product modelling. The result is building information systems based on Technology rather than Technique, i.e. with better correspondence to scientific knowledge and less dependence on ad hoc concepts.

This first section of the paper has discussed the use of the concept space in different contexts. The second part presents the ontological foundations for a formal definition of the concept of space. The third part of the paper discusses the use of the concept of space in some influential scientific papers and in some important standardisation efforts concerning spatial modelling in the construction context. In the fourth part of the paper is presented a framework for building space information that can be applied in information systems for building modelling and design. The framework expresses how space related concepts from the previous sections can be represented in a scientifically consistent way. Finally conclusions of the work is drawn.

2 Ontological foundations for the concept of space

In order to achieve a more precise understanding of the concept of space it is necessary to investigate its ontological status. The theoretical background for this is based on Mario Bunge's "Treatise on Basic Philosophy", mainly volumes 3 and 4 on Ontology (Bunge 1977 and 1979).

2.1 Concepts of space

The Latin term *spatium* designates several different concepts like area, room, and interval of space or time (Webster's 1995). Neither in the old Latin language, nor in everyday speech today, does the concept space have a single or clear-cut meaning. According to dictionaries like Collins (Collins

1987) and Webster's (Webster 1995), a space may be for example: 1) the unlimited three-dimensional expanse in which all material objects are located (e.g. the universe), 2) an interval of distance or time between two points, objects, or events, 3) a blank portion or area, 4) an unoccupied area or room, and 5) a seat or place (accommodations on a public vehicle). These concepts reveal different understandings of space. According to definition 1), space is some kind of container with an existence independent of material objects, in definition 2) space is a relation among material objects, in 3) space is a geometrical concept, and finally in 4) and 5) space is a thing with certain spatial properties.

The idea of the existence of Absolute space, i.e. as something with an existence separate from things, was strongly advocated by Newton, but just as authoritatively objected by Leibniz. With the emergence of the theory of relativity, from Mach to Einstein, the idea of Absolute space or space as a container was abandoned from modern science together with the Ether-theory (Jammer 1969:142). The view of space as a purely mathematical concept is not considered relevant to the present investigation. The current view of space within science is as a relation between things. Space may also be seen as a property of a thing, like a cup, a bottle or a balloon. All of these have some kind of enclosing spatial property and could therefore, according to the convention of naming things by their properties, be called spaces.

The term space may denote a location where something exists or may exist, a *place.* The term place stems from the old Greek term p l a t e i a 'plateia' referring to a broad road or a flat area of ground (Webster's 1995). The term has the same Indo-European roots as the term "field". A place has certain spatial, material, and cultural properties which makes it possible for a thing to be located in, or use the place. In order that a thing shall function as a place, certain spatial properties are required, e.g. the carport must be large enough for the car to enter; material properties may also be required, e.g. the ice must be strong enough to be a place for ice-skating; finally cultural properties must be co-ordinated between that which shall "take place" and the place itself; a rock-concert for example is not always considered an appropriate event for a church. A possible distinction between the everyday use of the concepts place and space could be that *space* is an enclosed place.

2.2 An ontological framework for space

2.2.1 Property

To describe an object is to account for its properties. In a general philosophical sense *objects* are either abstract or concrete entities toward which thought, feeling or action is directed. A *thing* is a concrete object with *substantial* or real properties, while a *mental construct* is an abstract object with *formal* properties. Substantial properties can be divided into factual and phenomenal (also called experiential), see Fig. 1. *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 perceived properties like colour and taste.

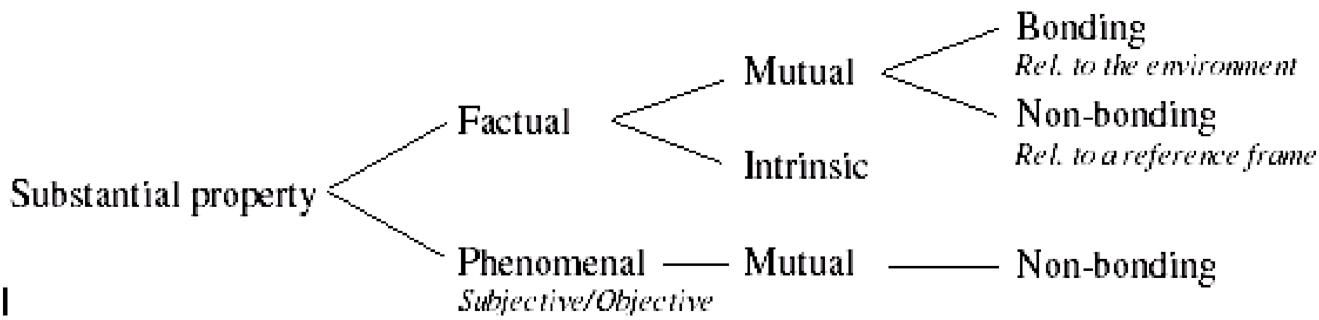

FIG. 1: Kinds of properties

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. 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. The relations between a thing and its environment are either bonding or non-bonding. Things with *bonding* relations affect each other's state, for example integrating and repelling relations are bonding. A *function* is a mutual property based on a bonding relation of a thing and its environment, for example an artefact and its users. Man-made things, artefacts, are designed with a purpose to have certain functions. 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 (Bunge 1977).

2.2.2 System

A simple or atomic thing has no parts. A complex thing with bonding relations among its parts is a *system*. An *aggregate* is a collection of things where only non-bonding relations are consi-dered. A comprehensive description of a system's properties includes its composition, environ-ment, structure, laws and history. The *composition* is the collection of the parts of the system; the *environment* is the collection of things that interact with the system, and the *structure* is the set of internal and external relations, as shown in Fig. 2. A system's *laws* are relations among its properties, and its *history* is comprised of the former states of the system (Bunge 1979).

The properties of a system are of two kinds, 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, but not the individual parts.

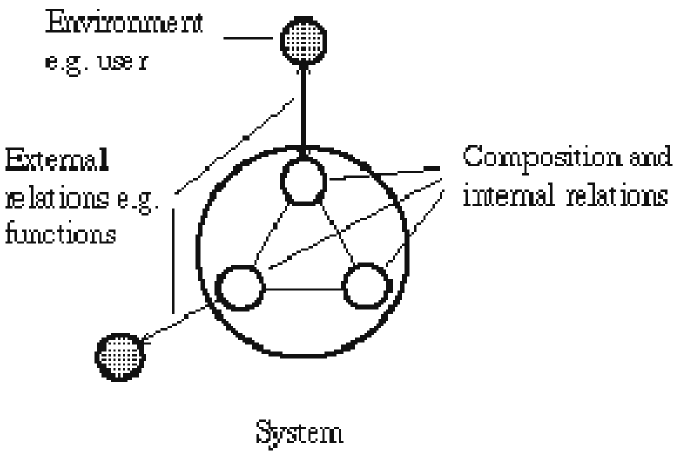

FIG. 2: Basic properties of a system (arrows indicate one-way or two-way interaction)

A compositional part of a system and the system as a whole have a part-whole relation. Fundamental to the *part-whole* relation is that the existence of a part precedes the existence of the whole. The part-whole relation is defined for things only, and must be distinguished from the set inclusion and the set membership relations which are defined for concepts 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*. This use of the term part does not exclude the term part being used for other concepts like "limited area", e.g. in "the blue parts of a coloured cloth" or "the edge is the sharp part of the knife".

2.2.3 Space

A spatial relation is a mutual relation among things; it is non-bonding and may also be called a separation relation (Bunge 1977:296). A spatial relation can be determined as a position of one thing in relation to another thing, the latter acting as a reference frame. In a three-dimensional Euclidean space, positions are determined as co-ordinates in a rectilinear system of co-ordinates.

Using the convention of naming things after their properties, a *space* may also be an aggregate of spatially related things. In this case space is seen as an intrinsic property of the aggregate, see Fig. 3. Any aggregate may be regarded as a space, both a constellation of stars, an alley of trees and a room of building elements are spaces. According to this definition there is no space without things, see Fig. 4.

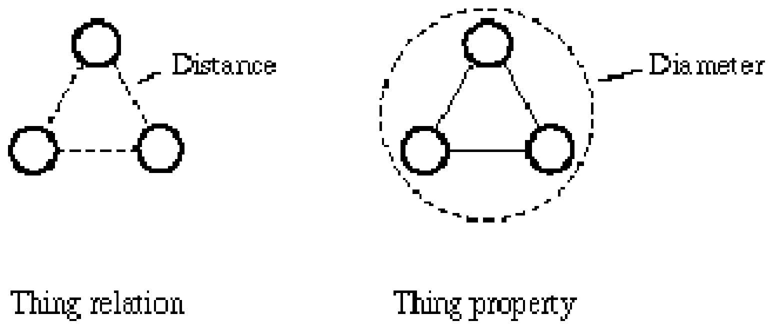

FIG. 3: Space as a mutual relation among things, and as a property of a thing

A space may be *enclosed*, which means that it has an inside region separated from the outside. This region may be void, as in a cave or a room, or it may be filled, as in an orange or an egg. A part that separates between the inside and outside of an enclosed space is called *boundary*, or if it is continuos, *shell*. The boundaries may be factual or experiential; a factual boundary may be enclosing to some things and open to others; the panes of glass of the aquarium lets through light but encloses water; the enclosing property may depend on the scale of the enclosed, e.g. a tiger may be kept inside bars while a mouse easily slips through.

Experiential space is a mutual property of the aggregate thing–observer. Experiential space may be more or less objective or subjective depending on the degree of correspondence between the experienced and the factual space, see Fig. 4. In architecture an experiential view of space is of great importance. Naturally, in architecture spatial experience is based on the geometrical proportioning and distribution of material things.

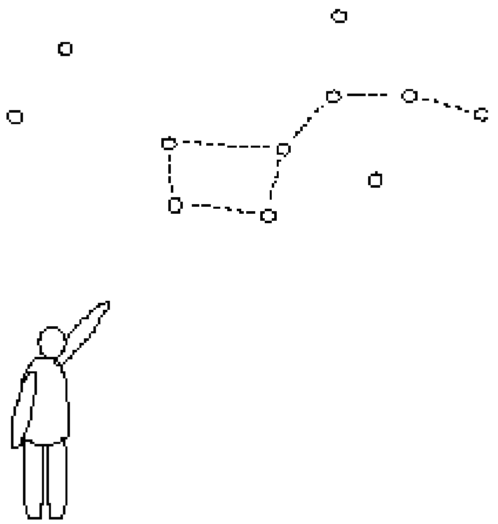

FIG. 4: Any aggregate can be seen as a space. Experiential space is a relation between a thing and an observer.

2.2.4 Shape

All things have spatial properties, but only some have shape. *Shape* is a clearly delimited external boundary of a thing (Bunge 1977). Not every thing has a shape, e.g. a social system or a gas cloud has no shape. The shape of a thing can be described by a "geometric representation item", e.g. as a cylinder, torus, block, sphere, or through a combination of these (ISO 1994c). Another term for geometric representation item is *form feature* (Shah and Rogers 1988). The shape of a thing is based on the shape of its parts including their spatial relations, see Fig. 5 #2.

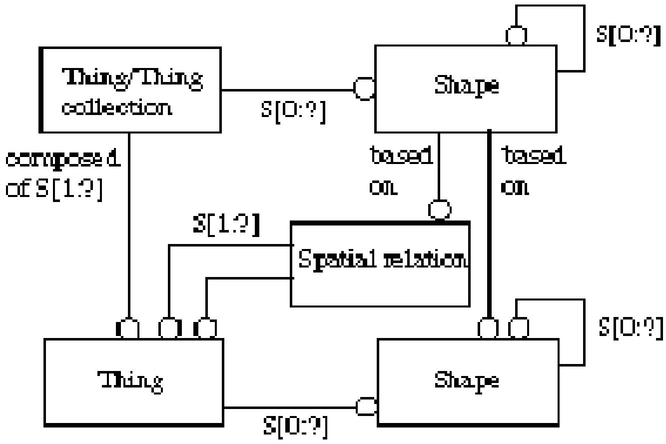

FIG. 5: Geometrical representation of a system

2.2.5 Aspectual views on a thing

To adopt a view of a thing is to observe a specific set of properties. A functional view focuses on bonding relations to the environment and on parts that contribute to the thing's function. A spatial view focuses on spatial properties. A compositional view of a thing identifies the compositional parts from which it is assembled, see Fig. 6. Examples of other views on a thing are colour and texture.

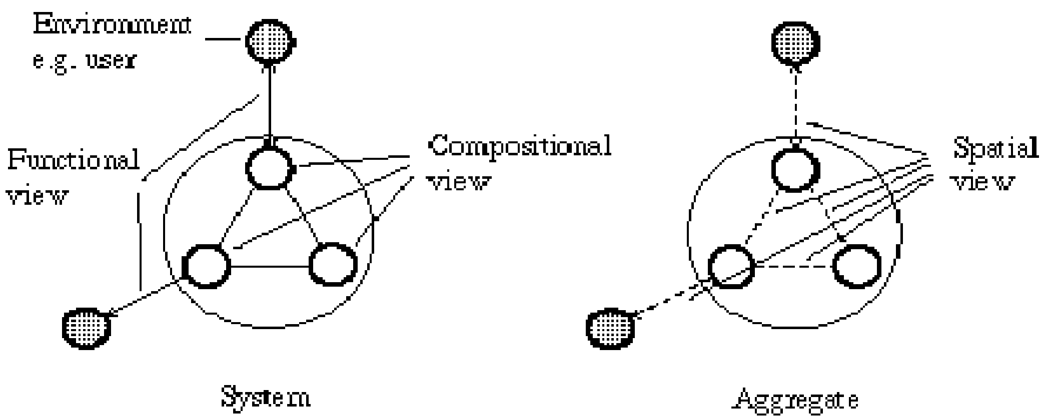

FIG. 6: Functional, compositional and spatial views on a system

The functional view gives no clear indication of the compositional parts of the system, since the same compositional part can have many different properties and can be part of many different functional systems. In both a compositional and a functional view, spatial relations may be considered, but they may also be regarded as a separate view on the system.

An *aspect* is a view on a thing, regarding a specific set of properties. An *aspectual part* is a thing, system or aggregate, composed of the subset of compositional parts that contribute to the properties of the aspectual part. Aspectual parts are functional systems, spaces or other aggregates for example based on colour or texture, see Fig. 7.

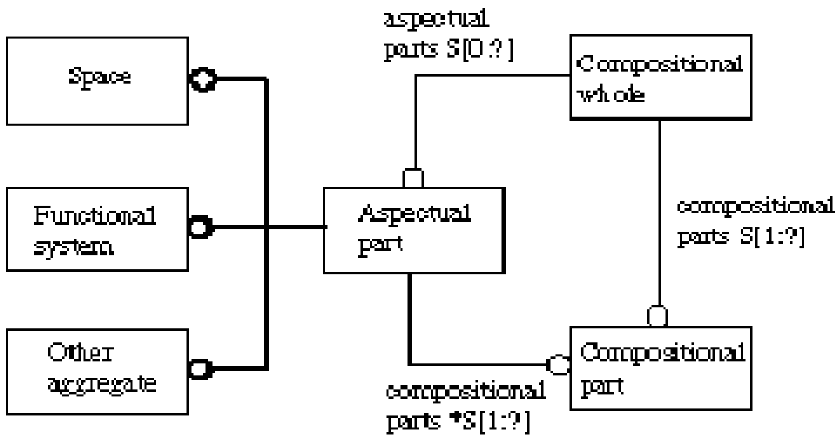

FIG. 7: Aspectual wholes related to the compositional whole and its compositional parts.

Different aspectual parts have different compositional parts, e.g. in a building, the parts of the climate protecting system may not be identical with the parts of the loadbearing system. A compositional whole is composed of its compositional parts, but it may also be seen as composed of aspectual parts. The compositional whole includes the set of aspectual parts, which means that the complete set of compositional parts includes the union of the sets of compositional parts of the aspectual parts. However it is not necessary for every compositional part to be part of any aspectual part. This is expressed in the constraint on the compositional parts attribute of the aspectual part.

The schema in Fig. 7 illustrates the compositional relations between different models of the same thing. They all represent things that may share members of the same set of compositional parts. The schema can therefore be used as a mechanism to integrate different aspect models in a computer based environment for concurrent design and modelling.

3. Examples of Spatial modelling for building information systems

In the construction context, space is treated as a factual material thing. The enclosed spaces in buildings are designed for occupancy of users, machinery and equipment. In current work within construction classification such spaces are classified by their basic function in relation to the users and other agents, for example office and communication spaces, and climate- and fire-zones. This is based on the view that space is a construction result equal to the building itself (ISO 1997a). This view seems questionable since buildings are erected in order to realise spaces.

In contrast with the former, current work within building product modelling most often apply an abstract concept of space that does not refer to the material parts but to the void enclosed or bounded by these. This concept of space is used by Björk (1992), by Eastman and Siabiris (1995), in the Building Construction Core Model of STEP (ISO 1996), as well as in the COMBINE model (Nederveen 1996). The concept of space as a void is a version of Absolute space and is inconsistent with the definition of space as a property of things. A more detailed discussion of these different space concepts follows below.

3.1 "A conceptual model of spaces, space boundaries and enclosing structures"

An example of the introduction of intermediary concepts without factual reference is provided in the article "A conceptual model of spaces, space boundaries and enclosing structures" by Björk (1992). In the following is made a short analysis of central concepts in Björk's model. The discussion of the concepts is based on the definition of space made in Sec. 2 of the present paper. In Sec. 4 of this paper is shown how some of the concepts can be accommodated in a schema consistent with the theory put forward in this paper.

In defining the concept of space, Björk states that "There are two complimentary ways of defining a space. One is based on the complete physical separation of the space from other spaces by physical obstacles which provide visual, acoustic and inner climate shelter. Another way of defining space is as the locus of a homogeneous activity." Björk calls these spaces "functional" reminding that "such functional spaces are important to architects in the early stages of design." (ibid:204).

We would like to remark that is important to recognise that the concept "functional space" actually refers to the social organisation using the building, and not to the building. Functional space represents the geometrical extension of the organisation during an activity, see Ekholm and Fridqvist (1996). Thus, a separate concept "organisational space" is needed to be able to represent spatial properties of the organisation.

In his paper, Björk develops a set of requirements on a conceptual schema for space information drawing from an analysis of product models developed by himself and other authors. Björk concludes that the concepts "space", "space boundary" and "shell" are required, and relates these as follows: "...each space is enclosed in a 'shell'...the physically continuos separating structures (walls, floors)...are behind this shell". Furthermore "...the visual surface patches correspond exactly to the inner dimensions of the spaces facing these structures. The term space boundary will be used to denote the parts of this shell". "The basic space boundary entity that we wish to include is the unique space boundary shared by one enclosing structure (wall or floor) and one elementary space" (Björk 1992:205). In order to be able to specify different material and finish for visible surface patches, Björk identifies three "levels" of space boundaries: "Patches with a uniform surface, space boundaries shared by exactly one enclosing structure and one space, and space boundary assemblies" (ibid:206). A strongly reduced version of the schema developed by Björk is presented by the present authors in Fig. 11.

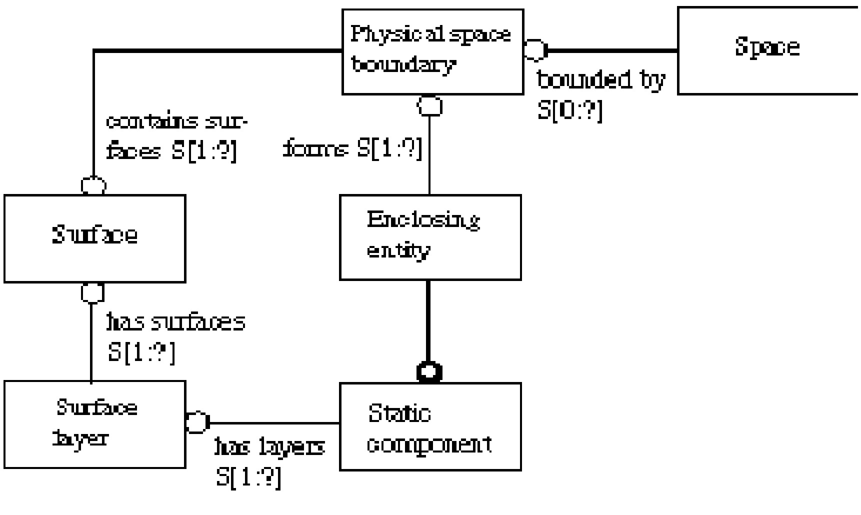

FIG. 11: Basic concepts in Björk's schema

In Björk's schema, Space is not a material thing or a property of a material thing, it is an abstract concept just like Space boundary and Shell, albeit the latter is not explicitly represented in Björk's schema. A Space boundary is "part of" the Shell and "formed by" the enclosing structure "behind the shell". These definitions indicate that Shell and Space boundary are introduced a thinking aid to perform a conceptual transition between Enclosing entity and Space. However such concepts are without factual reference and should, according to the assumption of this paper, be avoided. Rather, both Shell and Space boundary should be construed as properties of the Enclosing structure, the building elements.

3.2 "A generic building product model incorporating building type information"

Yet another example of the introduction of an intermediary concept of space without factual reference is provided by Eastman and Siabiris (1995) in the paper "A generic building product model incorporating building type information".

The paper presents a set of concepts with the intention "to provide a flexible kernel, upon which various building typologies, construction technologies or stylistic criteria can later be added", and proposes three interrelated component concepts of "building" (ibid:286):

1. CONSTRUCTED_FORM, material used in construction of the building: bricks, glass, mechanical equipment etc.
2. BOUNDED_SPACE, supported and bounded by CONSTRUCTED_FORM, defining areas of human occupancy and use, and
3. ACTIVITY, general (e.g. business lease space) and specific(e.g. obstetrics ward).

These three concepts are related in a further discussion where CONSTRUCTED_FORM and ACTIVITY are seen as "independent areas of knowledge". They are "are mediated through the BOUNDED_SPACEs, the boundary definitions that provide envelopes for the ACTIVITYs, defined by the CONSTRUCTED_FORM". CONSTRUCTED_FORM are "bounding entities whose surfaces serve as the interface between the building construction and the internal spaces" (ibid:287).

ACTIVITYs are defined as "the conceptual definition of human activity that are to be housed within the building." Furthermore, "At the coarsest level, they are simply named and defined in terms of rough area. They may be further specified with regard to furniture and fixed equipment and necessary environmental conditions". "Activities are assigned to BOUNDED_SPACEs" (ibid:289).

The BOUNDED_SPACEs "provide the conceptual and formational link between a building’s CONSTRUCTED_FORM and its ACTIVITYs". "BOUNDED_SPACEs are the enclosed regions within a building that are available to accept human activity, bounded on all sides. The boundaries modulate the dimensions of light, color and texture, thermal energy and so forth, defining the properties of the space enclosed. The CONSTRUCTED_FORM provides these properties..." "A building is made up of at least one and possibly many BOUNDED_SPACEs." (ibid:289).

In the EDM modelling environment, ACTIVITYs, BOUNDED_SPACE and CONSTRUC-TED_FORM are all represented as solids, i.e. as shape models. ACTIVITYs are located within BOUNDED_SPACEs, CONSTRUCTED_FORM has place between BOUNDED_SPACEs (ibid:294). CONSTRUCTED_SPACE, an abstraction of CONSTRUCTED_FORM as a spatial solid, defines the materials, placement of doors and windows on the building. USE_SPACE, which "represents the inside shell of the constructed region", abstracts a view of those properties relevant to just inside activities (ibid:295). Eastman and Siabiris conclude that "a central design development issue is defining a consistent set of [such] shape models" (ibid:294). The concepts are related by the present authors in a schema in Fig. 12.

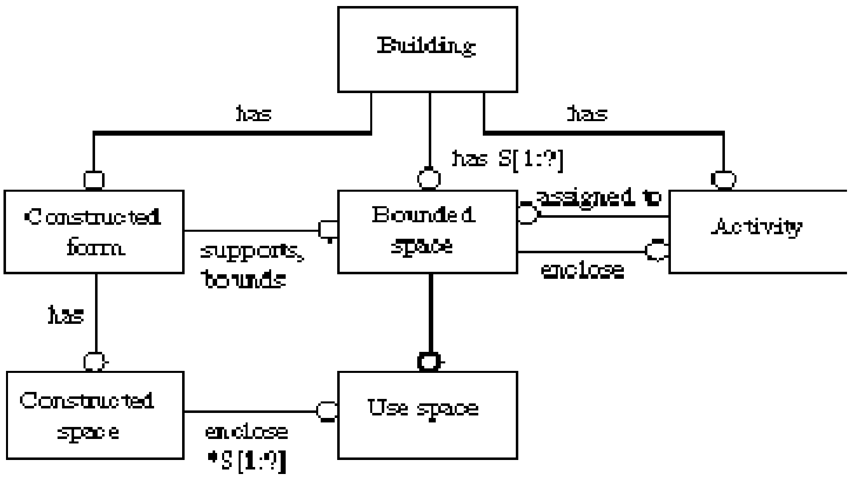

FIG. 12: An analysis of basic concepts in Eastman and Siabiris' article

According to Eastman and Siabiris the material content of the building is represented by the model entities CONSTRUCTED_FORM and ACTIVITYs. Although BOUNDED_SPACE is described as an enclosed region, it has no material content since this is provided by CONSTRUCTED_FORM. BOUNDED_SPACE "is a conceptual and formational link", i.e. the concept is introduced as a conceptual thinking aid without factual referent. According to the hypothesis of this paper, such intermediary concepts are not necessary in order to develop useful and true representations of a building and its users.

Eastman and Siabiris conclude that it is necessary to check CONSTRUCTED_SPACE and USE_SPACE for consistency. One might imagine that for example a window in CONSTRUCTED_SPACE must be related to the inside view of that window in USE_SPACE. The need for consistency check between CONSTRUCTED_SPACE and USE_SPACE is a consequence of the redundancy in the model and would disappear if the spatial properties of the building were only represented once. Similarly, spatial properties of activities should only be represented once.

3.3 ISO Organisation of information about constructions works

According to the draft standard ISO/CD 12006-2 "Building construction, Organisation of information about construction works, Framework for classification of information" (ISO 1997a), a space is a "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". This definition clearly states that space is something material, a construction result. However, both the definition and an illustration of the relation among the concepts in the standard reveals an ambiguity. The schema of Fig. 8 shows the illustration in the Standard interpreted in the EXPRESS-G notation by the present authors.

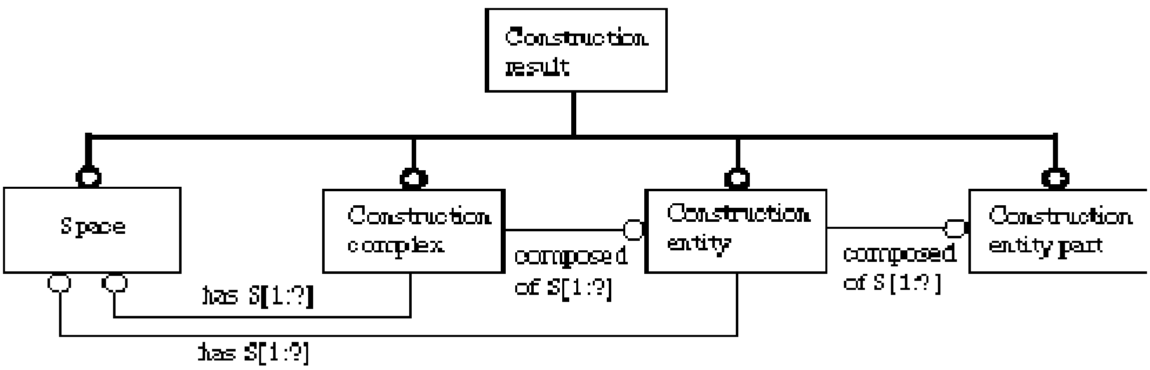

FIG. 8: Relations of the concept of space to other construction results according to ISO

The concept Space in the schema may be interpreted to have two different meanings, and thus designates two different concepts. The concept "has" in the schema means that Space is a property of the related entity. The referent of the concept "space-property" is a Construction complex and a Construction entity. On the other hand the referent of the concept "space-Construction result" is a Construction result equivalent with the others but of a different class.

In the first case a Construction complex and a Construction entity may have one or many Spaces, i.e. certain places with enclosing properties, like rooms in a building. According to this interpretation, Space is an aspect of a Construction complex or Construction entity, consistent with the theory presented in the previous section. But, contrary to the schema, Construction entity parts may also have such spaces, which is obvious if we consider e.g. a prefabricated volume element like a bathroom, which clearly is a Space.

In the second case Space is seen as a class equivalent with other construction results. However, since the other Construction results have spatial properties they also may be classified as spaces. This classification breaks the rule that classes of the same rank must be disjoint (Bunge 1977 and Ekholm 1996).

A schema that expresses the intention of the ISO standard in a more appropriate way is presented in Fig. 9. Here, a Construction complex, a Construction entity and a Construction entity part are Construction results. Following the principle of the schema in Fig. 7, a Construction entity space is composed of Construction entity parts, and it is an aspectual part of the Construction entity. A Construction entity space may have the same exterior parts as the Construction entity as a whole, as in the case of a climate shell, or it may encompass other kinds of parts of the Construction entity, as in the case of a fire zone or a room. Similarly a Construction complex space, e.g. a town square, is an aspectual part of a Construction complex, and a Construction entity part space, e.g. a prefabricated bathroom, is an aspectual part of a Construction entity part.

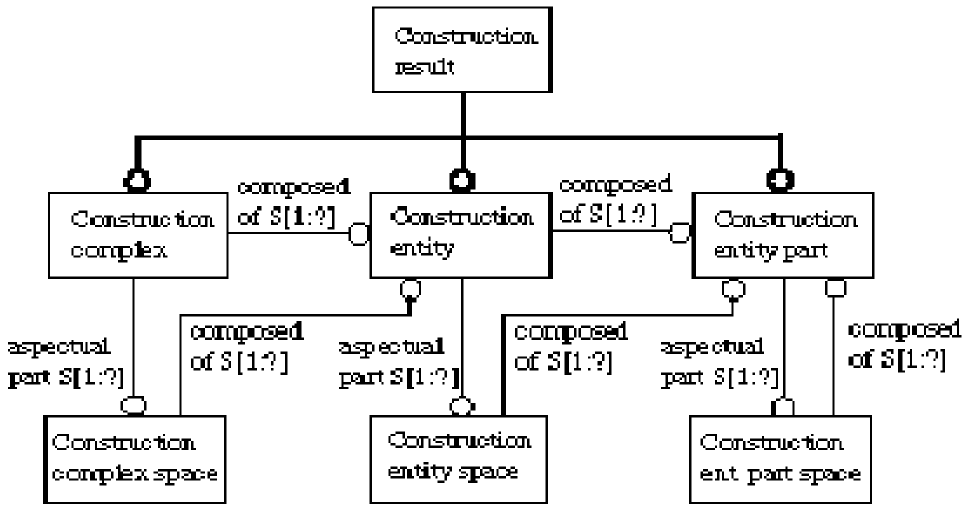

FIG. 9: Space as an aspect of each kind of construction results

3.4 Industry Foundation Classes, IFC

The Industry Alliance for Interoperability, IAI, has the purpose to enable interoperability among different AEC software applications. This has committed the organisation to develop the so called Industry Foundation Classes, IFC, as a basis for information sharing across disciplines and technical applications (IAI 1996).

In the usage scenario for Industry Foundation Classes by IAI (IAI 1996:2-5) is stated that it is common in a building program to represent spaces with so called bubble-diagrams. A bubble represents the spatial extension of something. Whether this concept of space refers to the building or the user organisation is unclear. Most probably it at first refers to the user organisation, and then it is reclassified by the designer to refer to the building, representing its spatial properties. Such ambiguity should be avoided. Therefore, two separate entities, one representing building space and the other organisational space would be a better solution.

Central to the IFC is a core model that defines and relates the key concepts of the standard. In this core model there are three different IfcElement classes: The IfcAssembledElement represents "all elements which are assembled, constructed or integrated into an assembly on the project site" (ibid: 3-15). An IfcWall is an IfcAssembledElement that " bounds or subdivides Spaces". An IfcManufacturedElement is a "supertype for product elements which are pre-manufactured and placed, attached, or connected at the IfcProject site" (IAI 1996:3-70). An IfcSpaceElement is an "abstract supertype for all types of space (open volume) elements" (IAI 1996:3-106), the IfcZone is a "view based delimited volume for the purpose of analysis and calculation. They (the zones) cannot overlap with respect to that analysis" (IAI 1996: 3-120), and an IfcSpace is "an area or volume bounded actually or theoretically" (ibid: 3-102). These concepts are illustrated in a schema by the present authors, see Fig. 10.

Space may be seen either as a property or as a thing having the property. The definitions indicate that IfcSpace is neither an IfcManufacturedElement nor an IfcAssembledElement, and therefore it must be a spatial property of these. However, if this is the case the proposition that an assembled element "bounds or subdivides spaces" is misleading since it refers to a pair of things, not a single thing. If Space had been a property of Wall, "has" would have been a more appropriate term than "bounds". Therefore an IfcSpace must be an abstract intermediary concept applied "ad hoc" rather than an attempt to develop a true representation of reality.

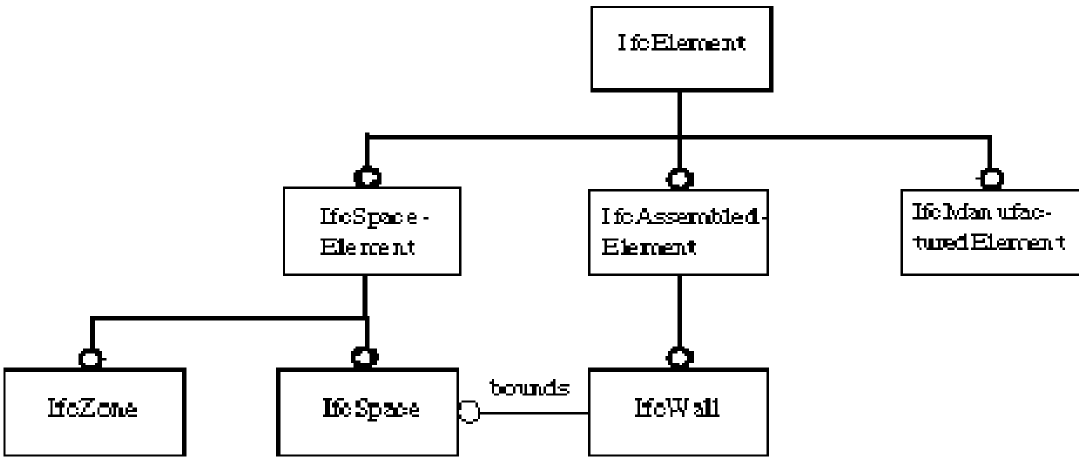

FIG. 10: An IfcSpace is seen as bounded by an IfcWall

3.4.1 Building Construction Core Model, BCCM

The work within STEP on the Building Construction Core Model is related to the current work on the IFC classes. The development work is supposed to be done within IAI while the BCCM is intended to standardise the achievements from the IFC classification work. (Personal communication with Thomas Liebich)

4 A schema for space in the construction context

4.1 Development of a schema for space in the construction context

4.1.1 A definition of space

Construction works, or alternatively construction entities#3, may be understood as specifically designed and built places. Buildings are construction entities with enclosed places, they are spaces. Of specific interest to the users are spaces for occupancy, i.e. rooms. Spaces or rooms within a building are often named after the activity that occurs, or thing that is positioned in the space, e.g. bath-room, dining-room or bed-room.

The spaces of a building are characterised both by spatial properties like area and volume, and by enclosing properties, e.g. enclosing to light, sound, air or fire. Enclosing is not necessarily a material property but may also be dependent on a person's interpretation. An office space may have floor, ceiling and furniture, e.g. a bookshelf or a screen, but no walls; still it is experienced as an enclosed space. The properties of rooms in buildings are designed for occupancy of users, machinery and equipment. A space function program developed in architectural programming contains requirements on the buildings spaces, e.g. surface materials, fire resistance and sound reduction levels. Spaces are classified by their basic function.

Based on these considerations, Ekholm (1996) has proposed the following definition of space in the construction context: "A space in the construction context is an aggregate of construction works (entities), their parts and other things defined only with regard to their materially or experientially enclosing properties".

4.1.2 Space and functional systems as aspectual parts of a construction entity

An information system for spaces is useful during all stages of the construction process; during design when the user requirements on the building are specified, during production, when work activities and building material is located in the building's spaces, and during the use and maintenance stage when user activities and facility maintenance concern the spaces. Such a system should contain information on the construction entity parts that make up and are related to the spaces. The system should be non-redundant and use the same construction entity parts database as other information systems for the same building, e.g. energy and quantity calculation systems.

This would be possible to achieve with a representation of the building's spaces according to the principle shown in section 2, that is as aspectual parts of the construction entity as a whole, see Figure 13. The same principle can be applied for all aspectual views on the construction entity as a whole; both spaces and functional systems like the loadbearing system, heating system, and electrical system can be seen as aspectual parts of the construction entity. This principle can be used to enable integration of different aspect models of a building, e.g. in concurrent design.

A Construction space representation may be used for example to represent the rooms for occupancy, and would then only encompass those Construction entity parts that are considered of importance to that application. Another important application may be to control the spatial relations of construction entity parts represented in different aspect models.

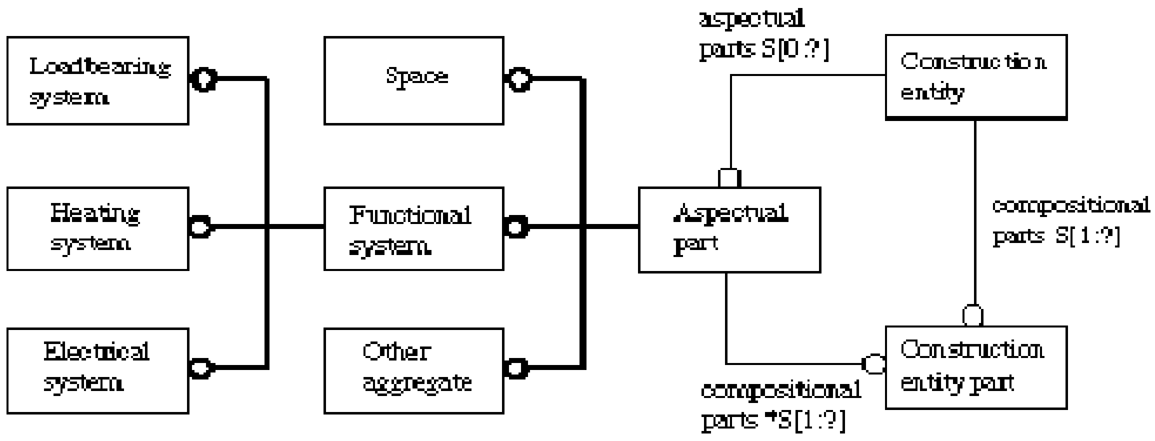

Figure 13: Construction space as an aspectual part of the construction entity as a whole

4.1.3 Principle structure of a schema of construction entity space

The paper by Björk may be taken as a summary of typical requirements on an information system for spaces. Björk's requirement on the concept of enclosed space is as follows: "There should also be a clear distinction on the entity level between subparts of enclosed spaces and assemblies of spaces (such as apartments, fire zones and heating zones)" (Björk 1992:205). Another requirement is that: "It should [also] be possible for analysis and design purposes, to aggregate several enclosing structures into larger entities, for instance representing the total outer shell of the building (ibid:206).

Furthermore: "The decomposition along the (enclosing) structure's direction can be done either based on the physical structure...or based on the adjacency of sections of the structure to individual spaces". The former "leads to the notion of layers, where each layer is of a particular material". Surface layer and internal layer are identified (ibid:206). Björk reminds that surface material is part of enclosing structures, and that "The same wall in a given space may (thus) contain many surface entities" (ibid:205).

Finally the concept of opening is defined. "Enclosing structures are pierced by openings which allow the movement of people, light, air and fluids etc."...."It seems useful to include both the relationships to spaces and enclosing structures in our model" (ibid:208).

Based on the analysis in the previous sections, a comprehensive schema for space information can be designed, see Fig. 14. This schema represents Construction entity space as an aspectual part of a Construction entity. The Construction entity space is composed of Construction entity parts which in their turn are composed of Element parts. The concept of Element part has been defined in the context of building classification by Ekholm (1996).

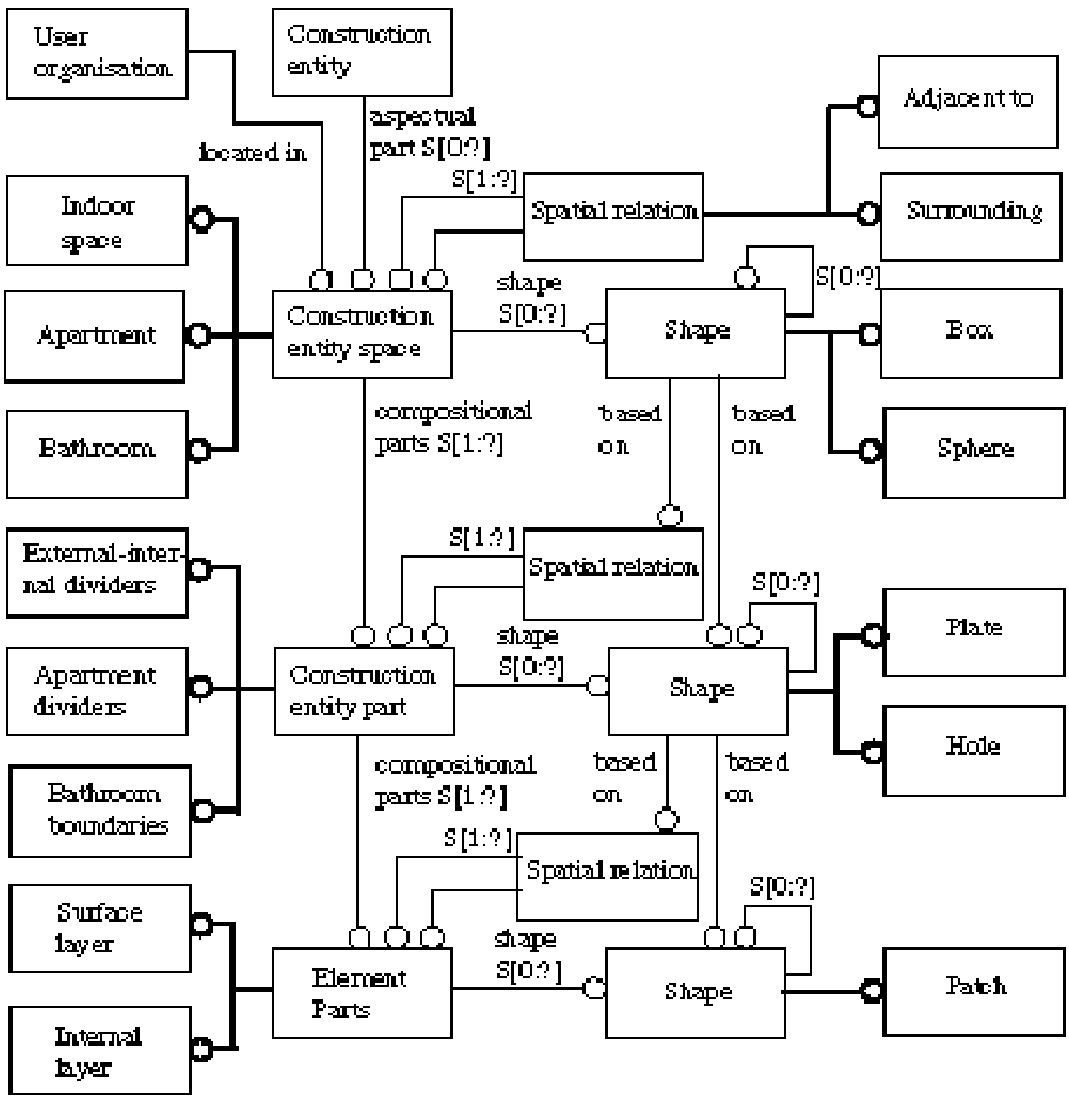

FIG. 14: Principle structure of a comprehensive schema of construction entity space

Both Construction entity space and its parts have Shape and Spatial relations to other entities of the same kind. The shape of the Construction entity space is based on the shape of the Construction entity parts and their spatial relations. Shape is defined by topology, position and dimensions. A Shape may be composed of smaller Shapes. Examples of Shape are Box, Sphere, Plate, Hole and Patch. The Hole-shape makes it possible to define positions and dimensions for Opening components in Construction entity parts. A hole is a property of the part where the opening component is situated, not of the opening component.

Examples of Spatial relations are Adjacent to, and Surrounding. These relations allow for example a combined representation of a set of adjacent spaces like a group of rooms that make up an apartment or an office. The relation Surrounds allows the representation of a larger space that is subdivided into smaller spaces. There are of course other spatial relations not mentioned here. The spatial relations used for Construction entity spaces may also be applied for Construction entity parts and Element parts.

The schema allows a representation of different spaces based on the characteristics of their parts. For example, the Indoor space consists of the Indoor-Outdoor dividers. An apartment consists of the Apartment dividers and a Bathroom consists of the Bathroom boundaries, i.e. the enclosing parts making up the bathroom. In this way any zone or region of the building and its parts can be retrieved for analysis. In order to compose a set of spaces into a larger space, e.g. a set of rooms into an apartment, a set union operation is applied. The apartment is the union of the rooms, which means that although the rooms share the same walls these are only "counted" once in the operation.

The inside of a room may be painted or covered with wall-paper. These Surface layers are Element parts that make up the composition of Construction entity parts. A set of surfaces and a single surface may be represented as an Element part. A limited area of a surface in a room may be represented as a Patch.

The relation between the User organisation and Construction entity space is illustrated in the schema by the relation "located in". Examples of explicit representations of the User organisation in building information schemes have been developed by Eastman and Siabiris (1995) and Ekholm and Fridqvist (1996).

The user organisation that uses the building’s spaces belongs to the environment of the spaces. The question of which parts belong to the construction spaces and which belong to the organisation depends on the context. For example, in one case a bookshelf is considered a building element and belongs to a Construction space, while in another case the bookshelf is considered part of the user organisation. Spatial layout design deals with the spatial co-ordination of Construction entity spaces and the spatial properties of the User organisation located within the spaces.

4.2 Conclusions

In this paper we have tried to show that

1. Ontological theory may serve as a foundation to define a concept of space, useful in the construction context.
2. Space can be represented as a thing with spatial properties.
3. Current work within construction classification and standardisation may be criticised for applying an abstract concept of space without factual referent.
4. Aspect models can be seen as representing Aspectual parts of a Compositional whole, which both are composed of Compositional parts.
5. It is possible to integrate different aspect models in a comprehensive schema, useful e.g. for concurrent design.
6. Based on a definition of space as a property of things, a schema for Construction space can be developed which relates and defines several different kinds of space and spatial properties.

Further research may show how this schema can be implemented. Of specific interest may be to study applications for the earliest stages of the design process, when the requirements from the user organisation is transformed into properties of the building’s spaces. Other applications are of interest as well, e.g. in the facility management stage, when much of the information about the building is connected with its spaces.

5 References

Björk B.-C. (1992). A conceptual model of spaces, space boundaries and enclosing structures. *Automation in Construction*, Vol. 1, no. 3, pp. 193-214.

Bunge M. (1977). Ontology I: The Furniture of the World, Vol. 3 of Treatise on Basic Philosophy. Dordrecht and Boston: Reidel.

Bunge M. (1979). Ontology II: A World of Systems, Vol. 4 of Treatise on Basic Philosophy Dordrecht-Boston: Reidel.

Collins (1987). The Collins Dictionary and Thesaurus in One Volume. London: Collins.

Eastman C. M. and Siabiris A. (1995). A generic building product model incorporating building type information. Automation in Construction, vol. 3, no. 4, pp. 283-304.

Ekholm A. (1996). A conceptual framework for classification of construction works. *Electronic Journal of Information Technology in Construction (ITcon)* Vol. 1. Stockholm: Royal Institute of Technology. URL: http://itcon.fagg.uni-lj.si/~itcon/.

Ekholm A. and Fridqvist S. (1996). Modelling of user organisations, buildings and spaces for the design process. In *Construction on the Information Highway*. (Ed. Ziga Turk). Proceedings from the CIB W78 Workshop, 10-12 June 1996, Bled, Slovenia.

IAI 1996. IFC Project Model Specifications. Ver. 0.94. Industry Alliance for Interoperability

ISO (1994a). Classification of information in the construction industry. ISO Technical Report 14177:1994(E). Geneva: International Organization for Standardization.

ISO (1994b). Industrial automation systems and integration - Product data representation and exchange - Part 1 Overview and fundamental principles. ISO 10303-1:1994(E). Geneva: International Organization for Standardization.

ISO (1994c). Industrial automation systems and integration - Product data representation and exchange - Part 42 Integrated generic resources: Geometric and topological representation. ISO 10303-42:1994(E). Geneva: International Organization for Standardization.

ISO (1996). Building construction core model, BCCM, ISO 10303. ISO TC184 SC4 WG3 N496. Geneva: International Organization for Standardization.

ISO (1997a). ISO/CD 12006-2 Building construction-Organisation of information about construction works-Part 2: Framework for classification of information. Draft ISO Standard 20th May 1997. Newcastle upon Tyne: NBS Services

ISO (1997b). Report by working group 3 of ISO/TC59/SC13 "Building Construction, Organisation of information about construction works", Norges Byggstandardiseringsråd, N75E.

Jammer M. (1969). Concepts of Space. Cambridge Massachussetts: Harvard University Press.

Nederveen van S. (1996). COMBINE Task 2 Final Report. Delft: TNO Building & Construction Research.

Piaget J. and Inhelder B. (1956). The Child’s Conception of Space. London: Routledge and Kegan Paul.

Schenck D. A., and Wilson P. R. (1994). Information modelling: The EXPRESS Way. Oxford: Oxford University Press.

Webster (1995). Webster’s New Collegiate Dictionary. Springfield Massachusetts: G.&C. Merriam Company

West M. (1994). Developing High Quality Data Models. Vol. 1-3. Report No. IC94-033. London: Shell Petroleum Company Limited.

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2 The framework diagrams in this paper are developed in EXPRESS-G, the graphical counterpart of EXPRESS, a formal language which was developed to be used within STEP (Schenck and Wilson 1994). In an EXPRESS-G schema a circle shows the direction of a relation towards the entity pointed at by the circle/arrowhead. A broader line indicates a subtype relation. The cardinality of a relation is indicated by the figures within the square brackets and expresses the number of entities that occur in a relation. The syllable letter S expresses that the entity at the arrowhead is a set in which the order of the instances is unimportant and that each instance may only be related once. An asterisk * indicates a constraint.

3 According to ISO (1997a), a Construction entity is "an independent material construction result of significant scale, serving at least one user activity or function". A Construction complex is "two or more construction entities serving one or more user activity or function". In another ISO document (1997b), Construction works is "everything that is constructed or results from construction operations".