OBJECT-ORIENTED CAAD[1] – DESIGN OBJECT STRUCTURE, AND MODELS FOR BUILDINGS, USER ORGANISATION AND SITE

ABSTRACT

In the early stages of the building design process not only building and site but also user activities and experiences are formed. In this project conceptual models of some fundamental characteristics of building, site and user organisation will be developed and implemented in a prototype CAD-programme. The programming work for the prototypes is done with Smalltalk on Macintosh computers. The tests of the prototype includes spatial coordination of the three systems. The models are based on an ontological framework which is also used for organising the basic object structure of the prototype CAD program.

In the design process, information about the design object is gradually developed. Starting from certain desired properties, the whole and its parts are formed by successive increase of detail. The project investigates how the data structure of the design object can be formed to serve this working method. The project also discusses possible future developments. One important question is how these models may be used in the development of the brief and in the building management stage.

INTRODUCTION

This working paper presents some preliminary results of a current research project at the div. of CAAD, School of Architecture, Lund Institute of Technology. The project is part of the BAS•CAAD[2] programme with the overall objective to develop theoretical foundations and methods for computer-aided design in the early stages of the design process. The project is financed within the national Swedish IT-BUILD programme with the objective to promote the development and application of IT in the construction industry.

BACKGROUND AND OBJECTIVES

Architecture in the traditional sense deals with the design of buildings and the built environment, regarding their technical, functional and æsthetic properties. A deeper analysis reveals that the design of buildings includes the forming of user activities and experiences. This means that architecture, as a praxis and as a field of inquiry, encompasses both the built environment, with site and building, and the activities and experiences of the users. (Ekholm 1987).

Commercially available object-oriented CAD-programmes are building oriented and do not support the representation of the site or the user organisation. The key to ac-

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[2]BAS•CAAD is the name of a research programme at the div. of CAAD, it stands for Building and User Activity Systems Modelling for Computer Aided Architectural Design.

complish a computer integrated design process is to make the computer support design activities in the earliest stages of the design process. The aim of this project is to investigate the possibilities of representing both the site, the building and the user organisation simultaneously as models in the computer. This would enable both the mutual coordination of these systems and the documentation of the information developed during the design process in a systematic way.

A data model of the user organisation would also make it possible to do computer aided programming work in the brief stage. The programme information can be used throughout the whole building process, in the design stage and during the building management stage. Thus a user organisation data model in the computer would be an important step towards a computer integrated building process.

The conceptual models will be implemented, tested and evaluated in an object-oriented prototype computer programme for CAD which will be developed as part of the project. The conceptual models are developed on the basis of a generic ontological framework which is also used for organising the basic object structure of the prototype CAD program. The programming work for the prototypes is done with Smalltalk on Macintosh computers. The prototype programme will hold databases for user activities, building and site. The tests of the prototype include spatial coordination of the three systems.

The basic object structure is implemented in a "design object" that may represent properties of the modelled things. In the design process properties are determined incrementally, starting from certain desired properties, the whole and its parts are formed by successive increase in detailing. The project investigates how the data structure of the design object can be formed to serve this working method.

The project also discusses possible future developments. One important question is how these models may be used in the development of the brief and in the building management stage.

ONTOLOGICAL FRAMEWORK

An ontological framework for conceptual modelling

In the design process designers develop conceptual representations of factually possible things, e.g. in architectural design both site, user activities and building are modelled. Conceptual modelling is a natural human capacity supported by traditional concepts and everyday language. However, in order to develop models for computer applications a theoretically well grounded framework is needed. The framework applied here is based on Mario Bunge's ontology of science and technology. It describes the basic structure of concrete things and defines and relates concepts like property, thing, system, and level (Bunge 1977 and 1979).

Property and thing

There are objects of two main kinds, concrete and abstract. Things are concrete objects with factual properties, while mental constructs are abstract objects with formal properties. Properties of things can be divided into substantial and phenomenal. Substantial properties exist independently of human interpretation, while phenomenal properties depend on an individual's interpretation. The phenomenal properties can be more or less *objective* or *subjective*, i.e. they can have more respectively less correspondence with the substantial properties. Properties are *mutual* or *intrinsic*. A *mutual* property is

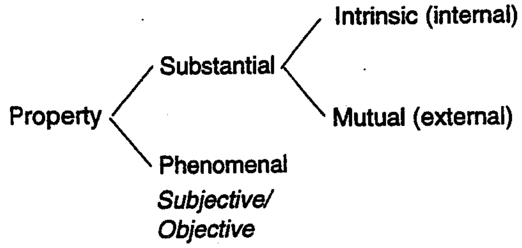

Figure 1. Kinds of properties.

an external relation between a thing and its environment and *intrinsic* properties are properties of its parts i.a. internal relations between parts of a system. See figure 1.

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 here defined as a mutual property of a thing and its environment, e.g. its users. A function is a *bonding* relation. Things with bonding relations affect each others state, e.g. integrating and repelling relations are bonding. *Non-bonding* relations, e.g. spatial relations, do not affect the states of the related things.

System

A simple or atomic thing has no parts. A complex thing with bonding relations among its parts is a system, if the relations are non-bonding it is an aggregate. A comprehensive description of a system's properties includes its composition, environment, structure, laws and history (Bunge 1979). The composition is the parts of the system, the environment is things that interact with the system without being part of it, and the structure is internal and external relations. See figure 2. A system's laws are relations among its properties, and its history are former states of the system.

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.

Between a part in the composition and the system as a whole is the *part-whole relation*. Basic to this relation is that the existence of a part precedes the existence of the whole. This relation is only defined for concrete systems. 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*. Together these systems make up a level order with subsystems in a lower level and the supersystem in a higher level. A *level* is a set of things where things in lower levels are parts of wholes in higher levels. A level order is a set of levels, where lower levels precede higher levels.

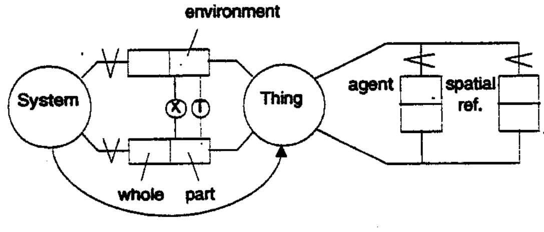

Figure 2. Basic properties of a concrete system.

Parts of a system

It is possible to distinguish two different approaches or views to identifying the properties of a system and its parts. One approach is a functional "top down" view of the system which leads to identification of "functional units". A functional view looks at the "behaviour" of the system i.e. its relations to the environment. 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 function 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 loadbearing and others are climate protecting. However the functional view gives no clear indication what the composition parts of the system are, since the same thing 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). It is also frequently used in everyday analysis since distinct functions often are properties of composition units.

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 parts of the system, they are delimited things that have properties and precede the whole (Bunge 1979).

Artefacts and sociotechnical systems

The properties mentioned above are extremely general and possessed by all systems, however the modelling of a specific system means to account for its specific properties. With the intention to develop an information framework for building user organisations, a first step towards specialisation is to view user organisations as sociotechnical systems, and buildings as artificial systems, artefacts. A *sociotechnical* system is an organisation of social individuals for some purposeful action, among the properties of the system are its activities. An activity is a sequence of goal-directed actions (ibid:197). Bunge distinguishes between cultural and economic activities, the cultural activities are carried out through communication and aims at changing peoples feelings, thoughts and ideas, and the economical activities aims at acting on and changing the states of things, as in the production of artefacts.

Artefacts are man-made or man-controlled systems. Artefacts are tools that make certain activities possible. When man uses an artefact to perform an activity, the activity is a property of the complex sociotechnical system of man and artefact, e.g. machines make new activities possible like drilling for oilwells and making computer tomographic images. An artefact is constructed for a purpose and serves as a tool to achieve it. Artefacts can be classified as cultural and economic or as having more or less properties of either kind (ibid:209).

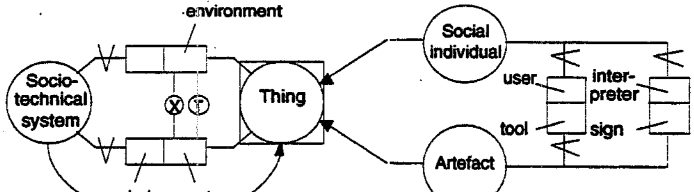

Figure 3. Properties of a sociotechnical system.

In a sociotechnical system the purposeful relations can be called functions. The intrinsic functions are tool-relations and the individuals roles (Ekholm 1987). A *role* is an activity and a subset of an individuals behaviour performed for the systems purpose. *Toolrelations* exist between a person and the things a person uses as tools during an activity. Among the extrinsic functions are the extrinsic roles and transformation relations to the environment. See figure 3.

In social systems, individuals have the properties of experiencing and thinking. Conceptually man interprets the environment in two main ways, epistemically and semiotically. The former implies an epistemic view, i.e. to analyse the composition, environment and structure of the environment. The latter is a semiotic view, which means to interpret the environment as a sign in a communication system (Bunge 1974b:1).

In everyday language the immediate environment of a thing is called a place. A *place* is a natural or artificial environment of a system, it has certain cultural, material and spatial properties that makes it suitable for a thing or an activity to "take place". For example: spatially, a garage must be large enough to be a place for the car; materially, the ice must be strong enough for the lake to be a place for skating; and culturally, for religious reasons a church is not always considered an suitable place for a rock consert.

BUILDING, USER ORGANISATION AND SITE

A framework for building information

Construction works are artefacts with the property of being a place for man in activities that require i.a. a controlled climate, protection against intruders, enclosed space, loadbearing ground structures as well as æsthetic and symbolic expression. Examples of such construction works are buildings, streets, canals, bridges and parks. Building is a specific kind of construction works with loadbearing, climate protecting, servicing and spatial properties specifically designed to accomodate human organisations and their activities.

In the built environment construction works are aggregated into so called infrastructure units that are used by a social organisation for a purpose, e.g. the construction works of a university campus or an airport. An infrastructure unit is an aggregate, i.a., characterised by its spatial pattern (Ekholm 1995). Construction works are composed of functionally distinguishable composition units of different complexity, from simple to complex systems of assembled and transformed construction products.

In the production activity construction products are assembled and transformed into production results. The production activity makes use of both construction products, construction aids and human effort in the form of labour and information. The production results are both composition units and other results necessary for the production activities e.g. a prepared site.

All composition units have properties that are basic to the global properties of the system as a whole. A composition unit like a gypsum wall with a space dividing function may in its turn be composed of a door, a stud construction and gypsum sheathing. Also these smaller units are composition units, they have properties and a separate existence before the whole.

Infrastructure units, construction works and their parts make up a level order of increasing complexity, see figure 4. A theoretical study of the level structure of construction works is made by Ekholm (1987). In building product modelling, the RATAS

Model, (Björk 1989), the AEC Building Systems Model, (Turner 1990), and the NICK project (Tarandi 1991) are examples where a level order is presented.

Buildings are specifically designed places for human activities, the composition includes a structural framework with enclosing and loadbearing properties. The concept "site" refers to the immediate natural surroundings of a building i.a. a place on the ground, the climate factors (wind, rain etc.) and also other things that may have bonding relations to the building.

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

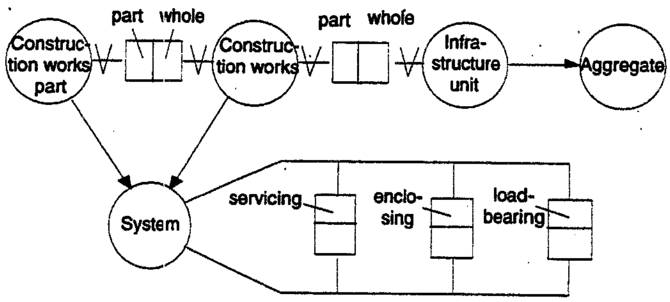

Figure 4. Properties of construction works.

User organisation

The organisation that uses a building is a sociotechnical system. The building belongs to the resources of the organisation to perform its activities. Generally an organisation is composed of sociotechnical parts with activities that contribute to the organisation's activities as a whole. For example a household is composed of parts with activities like cooking, washing, raising children, shopping etc. Similarly a hospital is composed of parts with activities like diagnosis, x-ray, surgery etc. Organisations are composed of parts in several levels, the identification of levels is dependent on the kind of organisations studied and on the purpose of the investigation.

The social environment of a user organisation can be considered a place. The expression "to find one's place in the organisation" is an example of this.

An organisation utilises resources during the activity, to the resources belong humans, tools, equipment and buildings (Tegnér 1978). The organisation has a transformation relation to its environment during an activity.

The relations between the users and a building in an organisation are tool-relations, spatial relations and interpretation relations. The tool-relations emerge when the building or its parts are used for activities like "cooking", "hospital-care", "entering" etc. (Ekholm 1987). The spatial relations of the building parts are organised to make enclosed spaces, rooms, designated for specific activities. The spaces in the building where the activities occur are named after the activities e.g. "kitchen", "ward", and "entrance".

The interpretation relations are thoughts, feelings and ideas that emerge in the user during the experience of the building. On the one hand they are epistemic relations that emerge with the understanding of the building as a concrete system, and on the other hand they are semiotic relations that emerge when the building is interpreted as a sign e.g. of wealth or taste.

Whether a building is viewed as an artificial environment or a part of a user organisation is dependent on the kind of activity that is studied. A movable partition which can be used to divide a gymnasium hall into smaller spaces can be regarded as part of a school organisation when organisational change is studied. Kitchen equipment like a stove may be part of the houshold organisation during the cooking activity. If a thing is controlled and its state is changed during an activity there may be a good reason for including it in the studied system. In everyday life buildings are mostly regarded as environments, but in design situations the building is regarded as part of the modelled system.

The diagram in figure 5, is a starting point in identifying those objects that are of interest in building a conceptual model of organisations and buildings. Some of the most fundamental classes of properties are represented here. It is our intention to develop this schema further into more detail.

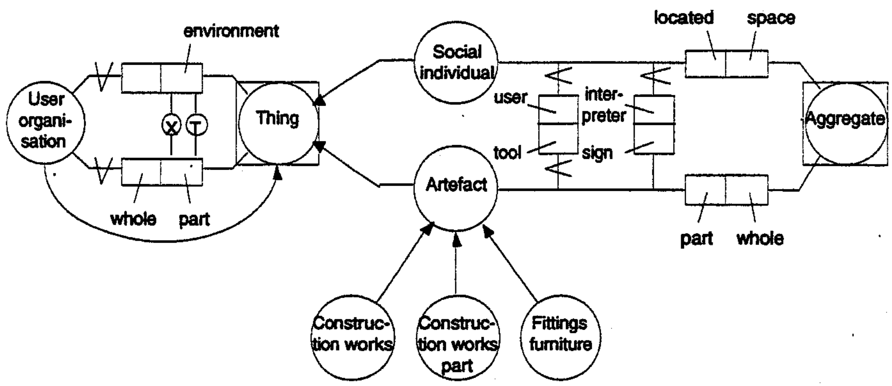

Figure 5. Properties of a building user organisation.

DESIGN OBJECT

The early stages of the design process

In the design process a representation of a factually possible user organisation, building and site is created. Although the sketches and early drawings made by an architect have the form of building drawings their primary purpose are not to describe the building parts. Instead these drawings display user activities, especially those related to the building, and illustrate building parts for experience and interpretation.

In the architectural design process the user organisation is treated as an object for design and not viewed merely as an environment that restricts the possible states of the building. This means that in an object modelling CAD program not only the building but also the user organisation must be represented as "design objects".

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 spacedividing which later is 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 figure 6.

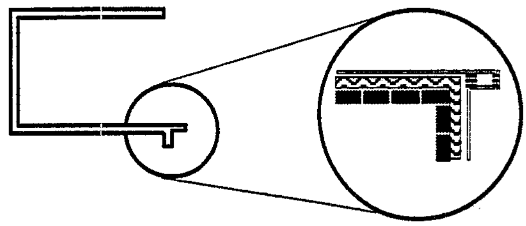

Figure 6. A construction design object must accommodate to growing complexity

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. 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.

Design object, conceptual model and represented thing

The design object is a computer based model of a concrete thing, existing or potential. The computer based model is a concrete thing that has specific similarities to the modelled thing.

A model[3] is an artefact which shows similarities to another thing. The similarity between a thing and a model of the thing may concern both factual and phenomenal properties (Ekholm 1987). A model and the modelled thing have the same conceptual representation. This conceptual "model" represents certain common properties of the thing and the model thing, and refers to the class of things which include both the model and the modelled thing (Bunge 1974a). See figure 7. Since our understanding of things depend on interpretation and conceptual representations, the purpose of making a physical model is always to make possible a phenomenal similarity and sometimes to make possible a factual similarity. A design object can represent another thing in many different ways, factually by e.g. displaying a spatial representation on the computer screen, and phenomenally by e.g. a display of figures resulting from algorithmic computations of u-values, loads etc.

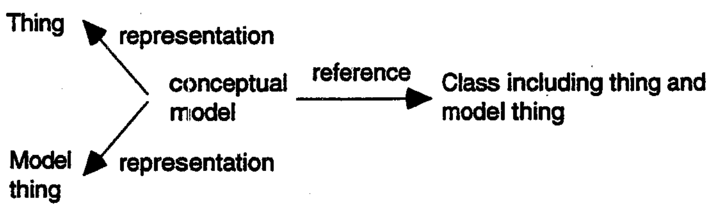

Figure 7. Relations between a conceptual model, thing and model thing.

DESIGN OBJECT STRUCTURE

Building product and user activities modelling has three levels of specialisation:

- Modelling of a specified building and its activities.
- Modelling of the general structure of buildings and user organisations.
- Modelling of the general structure of things.

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[3]The concept "model" can be derived from latin "modulus", which means small measure (Webster's).

Our task is to facilitate the highest level by development and implementation of conceptual models for buildings and user organisations, based on a general model for things. Other projects indicate that such a basic approach is necessary in developing an object modelling framework, see e.g. Turner (1989), Rumbaugh (1991) and Eastman et al. (1993).

Basic implementation structure

The basic unit for our modelling is the design object. A design object images the properties of the modelled thing through *property objects.* In addition it keeps administrative data for use by the designer and internally by the software, e.g the user's name for the object.

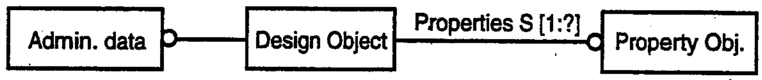

Figure 8. Design object

Properties of a complete model of a building and user organisation may range from physical measures like distance to esotheric estimates as beauty. To be able to store and manipulate such different kinds of properties we use a range of value objects. Initially we focus on modelling the spatial co-ordination of building and organisation in the horisontal plane. This allows us to reduce the number of value object subclasses to planar-shape and scalar. A *planar shape* describes shapes of design objects in the horisontal plane projection. A *scalar* has a number and a measurement unit that describes a measurable property like mass or distance.

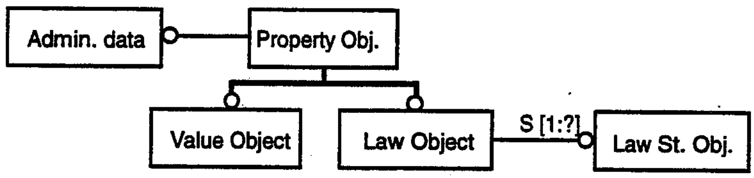

Figure 9. Property object

A *value object* stores a value. The value object classes have all the knowledge of storing and transforming data describing properties. This scheme will simplify adding new subclasses of value objects to allow modelling other types of properties in the future.

A *law object* is used to model restrictions on properties, individually or in relation to other properties. For example the three properties length, width and area might be related by a law, symbolically written $a = l * w$. A law is invoked whenever an attempt is made to change a value property object that is governed by the law. If the law changes properties, this might invoke other laws. Thus a law may indirectly govern a property, even in multiple steps. Additionally laws may inhibit attempts to set properties to unallowed values and send the user warning messages.

To facilitate calculation of a law without having to do symbolic algebra, a law is presently implemented as *law statements,* each of them describing how to calculate one property from the others.

A *law statement object* describes a restriction on a property or its relations to other properties. The restriction or relation is calculated through a law function. This is implemented as a Smalltalk BlockClosure, which is sent parameters obtained from a list of referents that points to value property objects.

Figure 10. Law statement object.

Modelling things and properties

Systems and aggregates are composite things, that are modelled using a value object subclass to list the parts. A system has one or several law property objects describing bonding properties. Parts of composite things use value object subclasses to indicate the whole-object.

A *basic property* is a property of a simple thing, and it is independent of other things. Examples are: mass, width, length. A *complex property* is derived from other properties of the same thing, as 'area' is derived from 'length' and 'width', or from other things, as 'weight' is derived from 'mass' and 'gravity field strength'.

A complex property is modelled using a law property object to define the derivation.

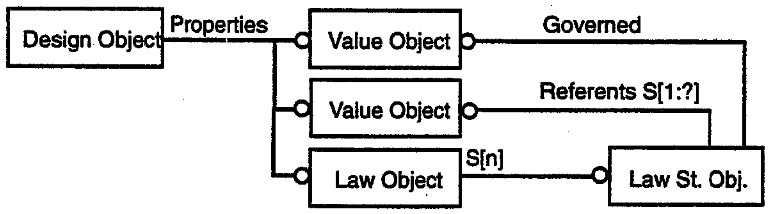

Figure 11. Modelling of complex property.

A *resulting property* is a property of a complex thing, and is the sum or union of the parts' equivalent properties. A resulting property is modelled using a law property object to define how the value is obtained. All properties referenced by the law property object must belong to *parts* of the design object.

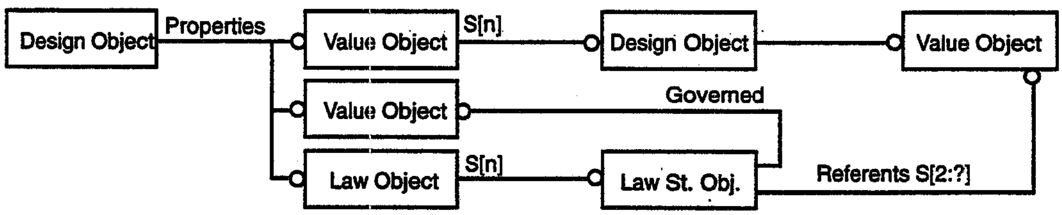

Figure 12. Modelling of resulting or emergent property.

An *emergent property* is a property of a system, that none of its parts possess. An example is weight, that is an emergent property of an gravitational system. An emergent property is modelled using a law property object to define how the value is obtained. All properties referenced by the law property object must belong to parts of the design object.

Basic operations on design objects

Design objects are manipulated with six basic operations. Three operations add information to the model – composing, detaling and specialising, while three delete information – decomposing, simplifying and generalising.

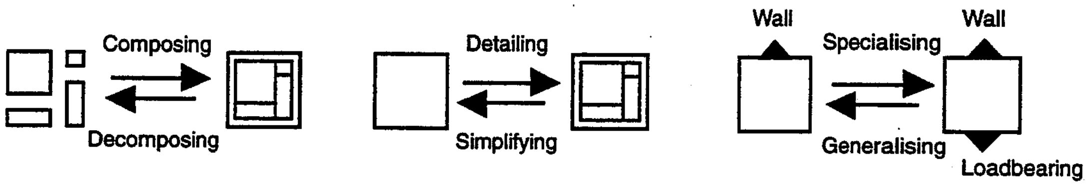

Figure 13. Basic operations on design objects.

Composing specifies relationships in the model by assembling objects into composite objects, creating a higher composition level. The properties of the parts must be expressed by the composite object through resultant or emergent properties.

Detailing extends the detail of a model by inserting parts into a simple object, thereby creating a lower composition level. This operation generally requires that the former properties of the detailed object are made into resultant or emergent properties, by addition of law objects. It also calls for decisions on what parts the object should be detailed to, and what properties they must have. An example of detailing is to identify and insert into the model the compositional parts of wall.

Specialising makes an object more specific by adding properties. An example of specialising is adding the property 'load-bearing' to a generic wall, thus creating a load-bearing wall.

Decomposing is the inverse operation to compose. It disassembles a composite object into its parts. Relations between the lost composite object and other objects have to either be transferred to the now visible parts, or else to be deleted.

Simplifying is the inverse operation to detailing. It decreases the detail of an object by deleting some or all of its composition levels after possibly transferring their properties to the root object.

Generalising is the inverse operation to specialising. It makes an object more generic by deleting properties. Properties derived from those deleted must be either reformulated or deleted.

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