Grammatical and syntactic properties of CAAD representations for the early design stages

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ABSTRACT

CAAD representations for the early design stages have traditionally focused on aspects apparently relating to design creativity, such as flexible, effortless and rich geometric modelling. However, modelling capabilities are generally unconnected to the control and analysis of design constraints that affect the further development of the design. These usually refer to functional and spatial aspects that are only implicit in a CAAD representation of design 'solids'. Moreover, the stability and reliability of control and analysis rely on the grammatical and syntactic quality of the representation. In particular, (a) the grammatical well-formedness of spatial and building primitives, and (b) the syntactic completeness and unambiguity of spatial relations are essential prerequisites to any meaningful analysis of aspects such as fulfilment of programmatic requirements, indoor climate, lighting or human interaction with the built environment. The paper describes a dual spatial *and* building element representation implemented on top of a standard drawing system. The representation attempts to minimize input requirements, while at the same time providing feedback on the grammatical and syntactic quality of the design description.

1 DRAWING AND REPRESENTATION

The recent democratization of information and communication technologies has reinforced the ongoing computerization of architectural design practice. The promise of increased efficiency, compactness and flexibility has resulted into a massive transfer of drawing activities to the computer. CAD systems offer most of the facilities available in analogue drawing practices and additional possibilities, mostly in terms of adaptability. Unfortunately it appears that the primary purpose of the application of CAD systems is to produce analogue drawings rather than process effectively design information. Consequently the structure of CAD drawings has long remained underdeveloped and their utility minimal. This contradicts two other developments in architectural practice.

The first is the explosive increase of design constraints, mostly externally determined in e.g. the brief and building norms, rules and regulations. The second development is the emphasis on early decision taking on the basis of concrete and comprehensive information from earlier experiences, cases or precedents. These developments are already linked to the huge production in digital documentation, on the assumption that documentation contains implicitly or explicitly the information required for performing analyses and for guiding the direction of a design (Leusen and Mitossi 1998). Derivation and abstraction of such information presupposes well-defined spatial representations that permit correlation of drawings with formal or functional requirements and analyses (Mitossi and Koutamanis 1998).

The obvious source for such representations is academic research, where abundant representations have been proposed in the framework of various tasks. Predominant among these have been representations from generative systems, for example shape grammars and rectangular arrangements (Stiny 1975; Steadman 1976; Stiny and Mitchell 1978; Stiny 1980; Steadman 1983). With the popularization of computer graphics in modelling and rendering software, attention has largely shifted to the support of design creativity. Probably due to the non-technical shortcomings of commercial software, relevant and flexible modelling of three-dimensional forms has apparently become a priority in academic research and teaching, frequently in relation to analogue techniques (Schmitt 1993; Mitchell and McCullough 1995; Neuckermans and Geebelen 1999)]. Geometric richness of architectural form definition and manipulation is being further augmented with new technologies (Schmitt 1996).

These developments have brought on advances in applications such as architectural modelling, including possibilities for a better understanding of the relationships between architectural form and geometry (Evans 1995). Nevertheless, there remain a couple of blind spots which influence the practical utility and acceptance of research products in the area of computational design representation. One of these is that most such products concentrate on the ‘solids’ of architectural composition, i.e. the building elements and components that have to be constructed (Yessios 1987).

In the resulting digital representations spaces, the ‘voids’ remain as implicit as in analogue media such as drawings and models. Yet spaces are at the subject of many design constraints that affect the further development of the design. These relate to formal and functional aspects that have to be analysed thoroughly and controlled carefully so that the design satisfices its programmatic, cultural and professional requirements. Even when the apparent focus of these constraints is a building element such as a door, the primary structure that emerges is that of a local coordinating device that regulates the spatial properties and consequences of the element (Koutamanis 1996).

A second blind spot concerns the stability and reliability of the representation. Even under carefully controlled conditions, the configuration of entities and their implementation in a computational design representation can contain errors and inconsistencies that render the representation partially or wholly useless for analysis or as a carrier of design guidance. Without neglecting the dangers of the linguistic analogy (Collins 1965), we could call these issues the syntactic and grammatical dimensions of the representations. These complement the semantic dimension that relates to the meaning of the graphic primitives used to denote spaces, building elements or other design entities.

2 THE SEMANTIC DIMENSION

For very practical reasons we have chosen to restrict our semantic basis to the basic integral entities of architectural thinking, spaces and the building elements that bound these spaces. In the framework of real-life projects we have collected sufficient evidence to that in early design stages these entities form the basis for practically all descriptions of a design, for making the necessary analyses of formal and functional aspects, for indexing and retrieving design information and for taking primary design decisions (Koutamanis 1995; Koutamanis 1997; Hartog, Koutamanis et al. 1998; Leusen and Mitossi 1998; Mitossi and Koutamanis 1998). In addition to that, a representation comprising spaces and building elements comes close to conventional drawings used in the early design stages. This similarity is essential for a quick and smooth transition from such drawings to structured design representations.

Subsequent refinement of the analyses and corresponding constraints will inevitably add to these primitives. Drawing from recent developments in cognitive science we expect that concepts such as the *geons* of the *recognition-by-component* theory (Biederman 1987; Biederman 1995) can be instrumental for not only refining the geometric structure of building elements but also for redefining our perception of an integral building element or component. Similarly we can complement our notion of space as a parcel or location with surfaces where predominant activities take place, such as the floor plane, the work plane or the horizon place (Nakayama, He et al. 1995). These surfaces can lie within a single space or transcend several spaces.

Also for practical reasons we have chosen to keep relationships between primitives implicit, as in conventional representations. Implementing and maintaining all relevant relationships is too cumbersome and tenacious to be accepted as a rationalization of conventional representation practices. Instead, relationships are recognized automatically on the basis of fundamental properties of the spatial or building primitives such as their shape, location and functional type. Recognition takes place on an if-needed basis and may return temporary properties, such as the floor area of a group of spaces, or an auxiliary or specialized structure, such as the geometric or topological fire escape route from a particular space. Automated recognition makes possible a high degree of abstraction and flexibility in the representation and avoids deterministic, normative characterization and classification of properties.

3 THE GRAMMATICAL DIMENSION

The grammatical dimension refers individually to each of the basic primitives in the representation. Depending upon the type of the primitive, we can define criteria of well-formedness, which determine its acceptability as a representation of a real space or building element. These criteria relate to the geometric structure of the primitive and in particular to the compatibility and redundancy of its primary features.

In a floor plan we represent spaces and building elements as closed polygons, circles or ellipses. The sides of the polygons must be three or more and can be rectilinear or curvilinear. The well-formedness of a shape relates to the number and position of its vertices and the resulting relationships between sides. One basic category of unacceptable forms is *self-intersecting shapes,* i.e. shapes with two sides that intersect at points other than their vertices. These shapes are impossible as spaces or building elements. Shapes with zero area are also treated as self-intersecting shapes.

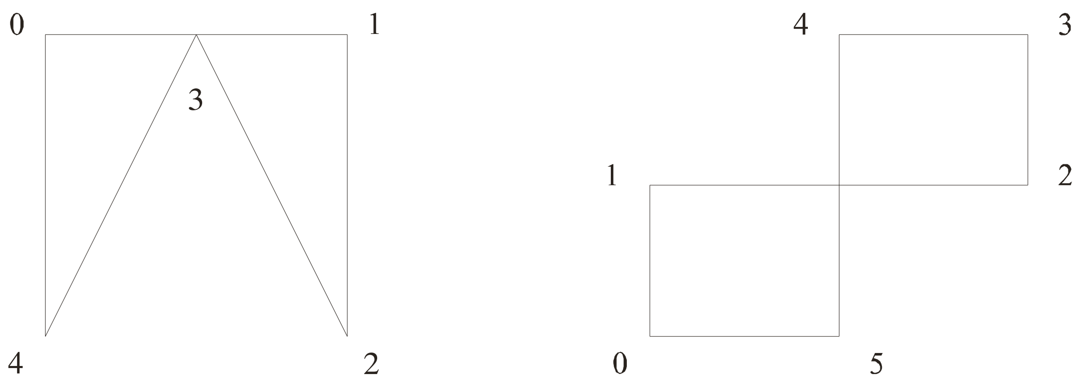

Figure 1: **Self-intersecting shapes**

Another basic category of unacceptable shapes is *open shapes.* These are by definition incomplete, as a space or a building element is always bounded by other, adjacent elements.

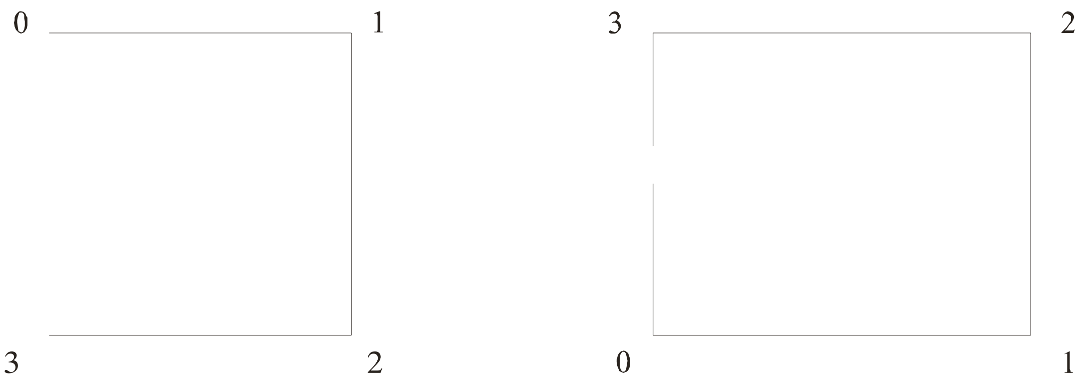

Figure 2: **Open shapes**

Other forms that are considered to be unacceptable on the basis of their general structure are judged by semantic rather than geometric criteria. For example, a rectangular space one hundred meters long and twenty centimetres wide is not impossible but highly implausible. The same applies to a near intersection, i.e. a similarly implausibly short distance between a vertex and a side. Corresponding acceptability criteria relate to the subject matter and can only be defined on an ad hoc basis for a specific class of designs or design representations. Abstraction plays an important role in the definition of such classes and criteria, as e.g. absolutely small sizes are highly unlikely in drawings on a scale of 1:200 or 1:500.

While self-intersecting shapes are obvious errors and can be readily detected, otherwise *erroneous shapes* are largely ignored. However, as CAD drawings are primarily meant for the production of documentation on paper, little attention is paid on invisible errors which do not alter the appearance of an object but may affect other important properties such as the number of its sides and its area or volume. Erroneous shapes are detected by the existence of redundant vertices. These are produced in abundance in CAD drawings and cannot be detected visually.

Redundant vertices fall under two basis classes: *coincident* and *trivial* vertices. Coincident vertices result into sides of zero length or, depending on their sequence, coincident sides. Trivial vertices result into redundant, trivial sides. Trivial vertices are generally vertices on the side of a shape, i.e. vertices with an angle of 180 degrees.

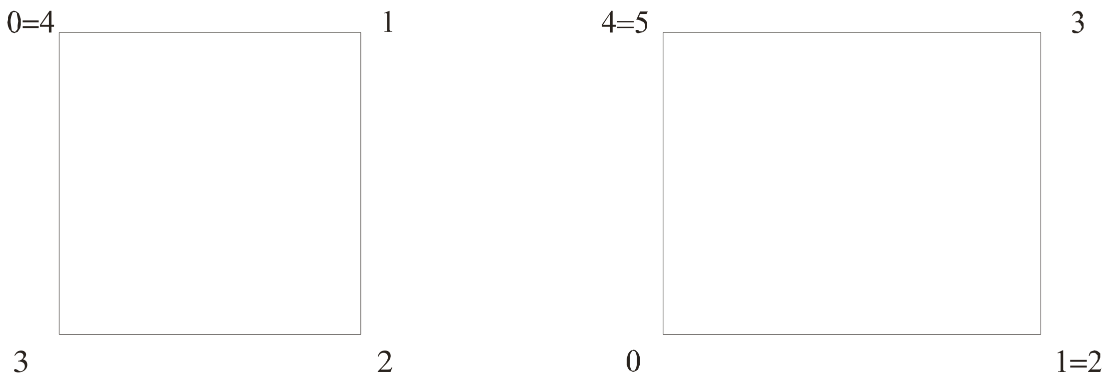

Figure 3: **Coincident vertices**

Erroneous shapes pose a significant problem for the reliability and utility of computational design representations. Redundant sides mean that a rectangle may be mistaken for a pentagon and consequently generate misleading information, e.g. that a space has five walls instead of four. Also measurements of area and volume can be severely altered by redundant sides. Sides of zero length are not only redundant but also illogical. Consequently, a CAD program may refuse to accept an erroneous shape of this type in certain geometric operations.

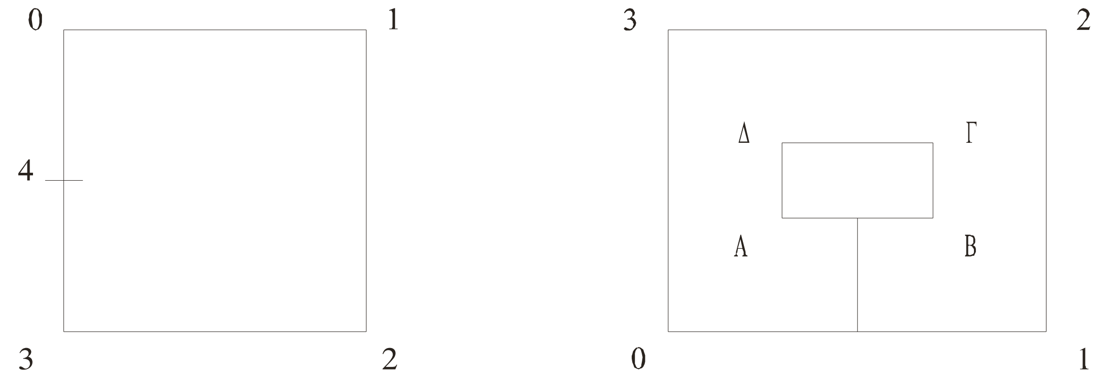

Figure 4: **Trivial vertices**

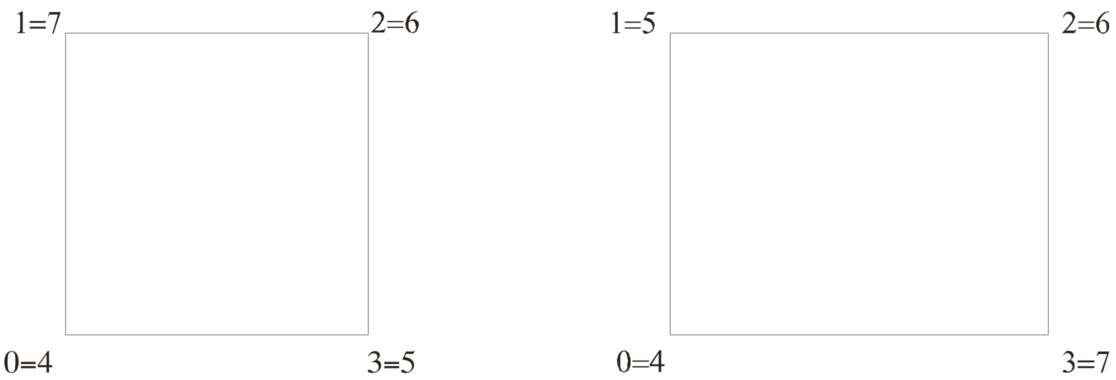

Figure 5: **Measurement errors; *left*: shape with zero area; *right*: shape with an area twice that of the apparent shape**

4 THE SYNTACTIC DIMENSION

The syntactic dimension refers to the local and global relationships between primitives in a design representation. These relate to the relative positioning of different objects in the design and primarily to adjacency conditions. In a floor plan this means that grammatically correct adjacent objects that are share (part of) one or more sides. The syntactic well-formedness of the floor plan is evaluated on the basis of violations of this condition.

A fundamental category of syntactic errors is *coincident shapes*, i.e. grammatically correct shapes which share the same set of vertices. Such coincident shapes are a physical impossibility, as they occupy the same space. Sometimes coincident shapes may result from complex design intentions concerning e.g. temporal aspects or activity allocation in the same space. However, such intentions relate to non-geometric properties and should be implemented separately form the basic representation of the design, for example as annotations.

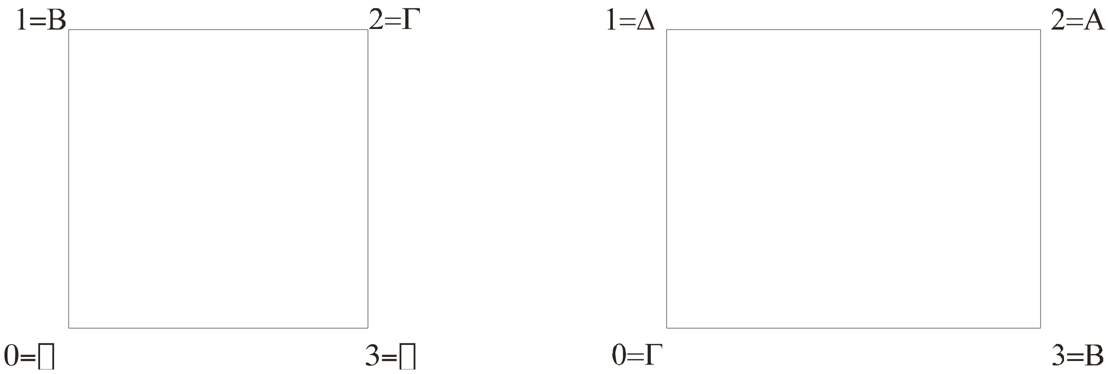

Figure 6: **Coincident shapes**

Overlapping shapes coincide only in part, i.e. have intersecting perimeters. These too represent a physical impossibility. Overlapping can be detected either on the basis of intersecting sides or by that some but not all of the vertices of one shape are inside another.

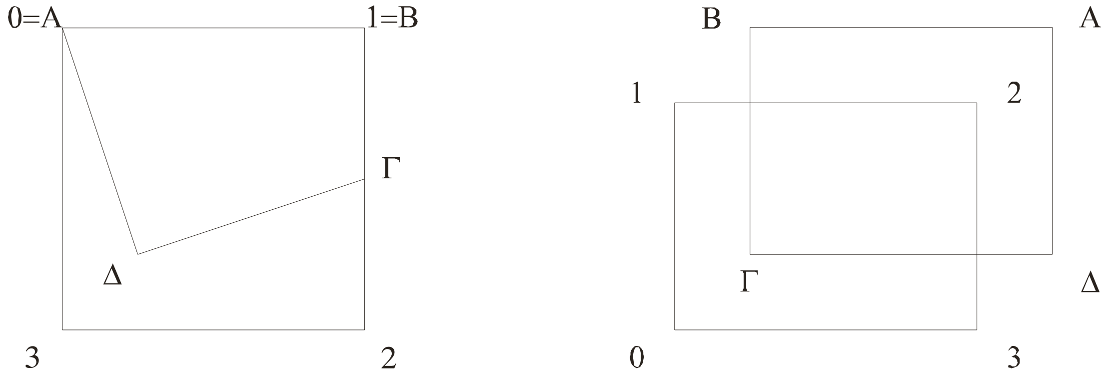

Figure 7: **Overlapping shapes**

Inclusion is an intricate condition. On the apparent level we can claim that it is also subject to the physical impossibility of two objects occupying the same space. This, however, fails to account for entities such as holes (Casati and Varzi 1994). The conventional solution in CAD drawings is to use auxiliary information, such as "obstacle" shapes which replicate included objects and link them to the including one. Our approach is to employ local intelligence mechanisms which detect included shapes, analyse their properties and treat them in the appropriate manner. Such mechanisms reproduce human reading of design representations and therefore presuppose reference frameworks that clearly and succinctly state the rules of the game.

A final consideration on the syntactic dimension is the global *completeness principle*: the area or volume inside each building mass should be completely occupied by grammatically and syntactically correct (on the local level) shapes representing spaces or building elements.

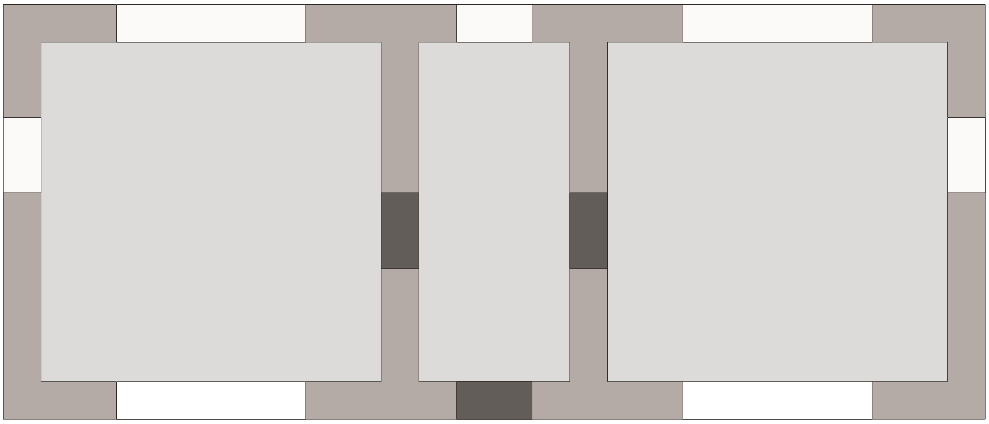

Figure 8: **Complete floor plan**

5 DISCUSSION

The grammatical well-formedness of each space and building element in a design representation is essential for the utility and reliability of information it contains explicitly or implicitly. For example, errors in the area measurement of even modest numbers of spaces can have severely distorting effects on analyses of activity allocation. Similarly, the syntactic well-formedness of the whole representation determines the completeness of the same information, as well as the unambiguity of spatial relationships in the representation. Overlapping spaces may also distort an area analysis, while the lack of adjacency between a door and a space means inability to detect access and identify a circulation route automatically. For such reasons the grammatical and syntactic quality of a representation become prerequisites to any meaningful computerized analysis of most design aspects, especially in situations where local intelligence plays a role. The transformation of a general design representation of spaces and building elements into input for a simulation of interior climate or lighting presupposes unambiguous identification of relevant geometric and functional factors, as well as of their interrelationships. Feedback from the simulation to the representation is even more demanding, as it may also introduce new entities that derive from relationships.

One of the main characteristics of early design stages in architecture is a large degree of uncertainty in decision taking. The conventional instruments of type, precedent and analogy are currently being analysed and complemented with specific information and focused information-handling facilities that support design guidance. Well-formed representations are an obvious choice as information carriers, as well as for the interactive interfaces that link information and decision taking, including evaluation of consequences. The ability to identify spatial design entities and connect them to analysis results and external information offers several advantages, including:

- Minimization of user input, in terms of both graphic objects and object properties (Mitossi and Koutamanis 1998)
- Direct input of design information in analyses of formal and functional aspects (Hartog, Koutamanis et al. 1998)
- Direct integration of analysis results in the spatial representation
- Transparent and explicit handling of design entities and their interrelationships along the semantic, grammatical and syntactic dimensions

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