Elements and coordinating devices in architecture: An initial formulation

Alexander Koutamanis
Delft University of Technology
Faculty of Architecture
Delft
The Netherlands

ABSTRACT

Design representations of the built environment are essentially atomistic. A design is represented by its atomic components which may vary according to abstraction level, their properties and, if possible, their relationships. The utility of such representations has been amply demonstrated in academic research. However, the transition to practice means a substantial growth of the size of these representations in order to cover the many abstraction levels and the multiple aspects involved in the design and the management of the built environment. In most cases the complexity of larger representations renders them unmanageable for both computers and humans.

The paper outlines an approach which enriches the atomistic basis of the representation with connected but independent coordinating devices. This facilitates the transformation of the basic relational representations into multilevel structures where each level corresponds to different aspects and abstraction scales. Coordinating devices are instrumental for the representation of multilateral relationships and abstract spatial schemas which precede or supersede the placement and arrangement of elements.

1 ARCHITECTURAL REPRESENTATIONS

Human interaction with the built environment has always been complex and intricate. It involves multiple intentions, interpretations and practicalities. Our navigation and the accommodation of our activities in and around buildings are based on a flexible, often opportunistic amalgam of heterogeneous and sometimes contradictory considerations. These lead to a variety of different yet interlocked strategies for adapting ourselves to the affordances of the built environment, as well as to performance criteria and measures for the built environment. This complexity has been growing with technological and social advances which add to the opportunities offered by the built environment. At the technical level that primarily concerns architects and planners the rapid growth of subsystems that have to be integrated in buildings, the measurability of intuitively less tangible aspects and the ability to diagnose design failures has produced a richer spectrum of possibilities for the user of the built environment. At the same time, the designer appears increasingly puzzled and frustrated, arguably lagging behind the pace set by demand and by analogy to other engineering disciplines.

The proliferation of computer technologies has accentuated the problem. It has allowed us to create and manipulate virtual worlds which often appear to have a mind of their own, thereby severely testing our existing approaches. Still, the successes of representations, analyses and evaluations we have transferred to the computer have improved little beyond practical efficiency in designing. The relative failure of computerization to have a direct and profound influence on design quality reinforces the argument that architects have long been needing sharper conceptual instruments in order to tackle the growing complexity of design problems (Colquhoun 1981). Computerization and the related knowledge and technology transfer are no panacea by
themselves. Rather than rely on mere techniques for the improvement of the built environment we should refine the hypothesis underlying current research, that the initial goal of computational design studies is a deeper understanding of our cognitive processes.

Probably the most important among the new conceptual instruments are visual representations of the built environment. These form the basis for communication and play a crucial yet often neglected role in decision making. The development of formal representations has been a prerequisite to and a major product of computational studies of architectural design. The results have been useful improvements of analog representations, as well as interesting and often tantalizing analyses of cognitive aspects. Their structure, in particular, reveals the limitations of current approaches to the representation of built form and highlights the issues we should be addressing in our research.

The representation of the built environment traditionally assumes an atomistic form. A conventional representation such as a map or a floor plan comprises atomic elements such as individual buildings or building components. These appear at an abstraction level appropriate to the scope of the representation. Depending upon the scale and purpose of a map, buildings are depicted individually or are catenated into city blocks. Similarly, a floor plan at the scale of 1:50 depicts building components and elements that are ignored or abstracted at 1:500. Most other aspects of built form remain implicit in the representation, with the exception of those indicated as annotations by means of colouring and textual or symbolic labels. These convey information such as grouping per subsystem, material properties or accurate size. Relations between elements, such as the alignment of city blocks or the way two walls join in a corner are normally not indicated — unless of course they form the subject of the representation, as in detail drawings. Here again annotations play an important role. For example, a line denoting collinearity in a city map has to be distinguished from other lines denoting boundaries of open spaces, buildings or public transport lines.

Computer-aided design has largely adopted this structure. Drafting and modelling systems are based on the implementation structure of analog architectural representations. They contain graphic elements representing walls, doors, windows, stairs and other building elements or components. A major but hopefully temporary irritation is that the representations are at the level of these graphic elements, i.e. lines and shapes, rather than of the represented objects. Quite often there is no direct way of indicating the group of graphic elements that comprise an object. As a result, manipulation of the representation in the framework of e.g. design analysis is often unnecessarily cumbersome and time-consuming.

On the other hand, academic research has extensively considered issues other than geometric information on shape, size and position of the components. The main differences between representations developed and employed in design research and the ones used in commercially available CAD systems are:

(a) Spatial primitives and spatial relationships have been cornerstones of research into the computerization of architecture. The most interesting generative techniques, such as rectangular arrangements and shape grammars, are based on explicit representations of spatial arrangement.

(b) The explicit representation of entities relevant to the designer, such as spaces and building elements, at a higher abstraction level than in CAD systems has been a prerequisite to most computational design studies. Using formalisms such a semantic networks, frames, scripts and objects, academic research has produced relational symbolic representations which share the following features:
• a representation consists of objects and relations between objects;
• objects are described by their type, intrinsic properties (i.e. relating to type) and extrinsic relations to other objects (e.g. relative position);
• properties are described by constraints on parameters;
• relations are described by networks of constraints that link objects to each other.

Relational symbolic representations have been successful in the framework of highly focused generative systems where structure and intention can be controlled. More ambitious holistic representations have attempted to integrate all relevant aspects and entities. The main intention of such representations has been to resolve real design problems as encountered in practice. However, in most cases holistic representations have a size and exhibit a complexity that often render the representations unmanageable for both computers and humans. In the present paper we consider one way of reducing the complexity and of improving the flexibility of relational symbolic representations. The basic premise of this approach is that spatial design representations are multilevel coordinated structures. Each representation level corresponds to a different abstraction level and possibly to different design aspects. While each level can be used as a self-sufficient representation, the coordination of all levels offers the comprehensiveness and flexibility required for tackling intricate and extensive problems. Coordination of levels can be based on the correspondence of elements, i.e. the presumed existence and invariance of the same entities on multiple levels, as in the multiscale representations developed in computer vision (Marr 1982; Rosenfeld 1984; Rosenfeld 1990).

In this paper we focus on another possibility for coordination. Rather than defining constraints on objects as fragmentary ad hoc relations, we can aggregate constraints into coordinating devices that operate in conjunction with elements, as well as independently. We propose that such coordinating devices are either local and centered on elements or global and abstract. Examples of local coordinating devices are found in the constraint framework that determines or guides the positioning of architectural elements relative to each other. Global coordinating devices are often manifested as grids, gratings and similar schemata that determine the overall spatial articulation of a design. These are encountered in typologic studies, comparative analyses and generative systems.

2 ELEMENTS: NOT JUST A LIBRARY

Architectural composition is often equated to the arrangement of items chosen from a finite set of ‘solid’ building elements and/or ‘void’ space forms. Building elements traditionally attract more attention than spaces. Especially within the confines of a single formal system (an architectural microworld) we encounter relatively compact and well-ordered collections of building elements which form the sine qua non of the system. The best example of such collections are the orders of classical architecture, where canonization of the system has been achieved by the canonization of a small subset of its building elements, those belonging or directly relating to the column.

The conspicuous presence of these elements in classical buildings has led to the view, voiced among others by Summerson, that a building with classical proportions cannot be classical if it does not contain elements from the classical orders (Summerson 1980, pp. 8–9). And while Summerson goes on to demonstrate how the orders were integrated in new building types and structures, with all kinds of ‘classical invention’, he retains a strict dichotomy between other aspects of the building and the closed system of the classical orders. Integration is discussed only locally, in the relationships
between a column and its immediate context, even with respect to the classical temples from which the orders were derived. Interestingly, this is as an instance of what in this paper we propose as a local coordinating device.

The attention paid to the arrangement and articulation of a specific subset of building elements has obscured other considerations and achievements in classical architecture. It has also propagated a particular image of architectural design that is more akin to the fine arts than engineering, both within architectural circles and to the wider public. Even after the classical orders had been dismissed by modernist architecture and replaced in theory by abstract systems about proportion and standardization such as the Modulor, this image remained an implicit yet powerful part of architectural methodology. Probably the best examples of this can be found in the ideas about industrialization in building that were developed and applied in the three decades after the second world war. These ideas were dominated by standardization of building elements in size and type and by modular coordination as the driving principle for the arrangement of these elements. The result, a hierarchical system of building elements and constraints on the placement of one element relative to another, has similarities with the classical orders.

The image of architectural design as the arrangement and articulation of a finite set of building elements has been influential in computer-aided design. It suggested a graphic system where the designer selects objects from a database and integrates them in a design by means of simple geometric transformations. Moreover, while the versatility and variability of architectural forms is restricted by the necessity of a compact database, the typological and parametric structure of the library should give the possibility (and method) of adding new elements. This too is reminiscent of the classical orders and in particular of the principles that allowed the invention of new orders, such as the ones proposed by French rationalists.

The facilities offered by the CAD libraries of today are almost sufficient in this respect. On the positive side, library elements can be flexibly added to a design thanks to parametrization and new elements can be added to the library with or without references to existing elements. However, there is generally no typologic or other classification in the library and, as mentioned before, the representation is at the level of implementation mechanisms and not of the symbolized elements. It is conceivable that such shortcomings will be alleviated in the near future within the existing CAD technologies. Less probable is the addition of constraints on the coordination and positioning of elements relative to each other. Such constraints are evident in the formal structure of coherent collections of elements such as the classical orders. In research these constraints have been investigated and implemented in propagation networks which parametrically determine sizes in well-defined subsystems (Mitchell, Liggett et al. 1990). The constraints and their computational implementation are often labelled with linguistic analogies such as ‘grammar’ and ‘vocabulary’ (Mitchell 1990). These analogies and the similarities they suggest with the structures proposed in modern linguistics present and exciting framework for the analysis of architectural design as a cognitive process, much richer in connotations and possibilities than earlier linguistic analogies (Collins 1965). It should be stressed, however, that by drawing from linguistics architectural research might be unable to utilize the at least equally exciting potential of another kind of cognitive studies, those of vision. Such studies are arguably more important for the understanding of the visual representations used in design and of our predominantly visual interaction with the built environment.
Spaces are less frequently chosen as the atomic elements of architectural composition than building elements. This is frequently due to the interpretation of spatial arrangement as a fixed pattern that is locally elaborated, annotated and studded with building elements. Such an interpretation appears to underlie traditional design practices, as well as some computational design studies. For example, in a system that generates Palladian floor plans by means of dissections based on symmetry and modularity, spaces are not treated as atomic elements (Figure 2). The dissections are not meant to produce individual spaces, as in (Steadman 1983), but a pattern of spatial arrangement upon which building elements are added (Hersey and Freedman 1992). Such studies are the exception to the rule that spaces are the basic primitive in computational design research. In space allocation techniques explicit representation of each space meant that satisfaction of programmatic spatial and functional requirements could be directly controlled and evaluated (Eastman 1975). Also in shape grammars spaces appear to take precedence over building elements. In the generation of a Palladian floor plan exterior walls are defined in stage two, after the grid of the spaces has been defined in stage one. Interior walls are defined in stage four, following the definition of the room layout in stage three, and are in turn followed by the definition of principal entrances, windows and doors (Siny and Mitchell 1978).

Figure 2. Floor plan produced with the Palladio program by R. Freedman (Hersey and Freedman 1992)
For the purposes of the present study, probably the most interesting use of spaces as atomic elements is the dual graph representation (Steadman 1976; Steadman 1983). In it floor plans are described by two coordinated representations, one of building elements and one of spaces. The use of multiple representations, each for different aspects and/or abstraction levels, and the correlation of the representations are principles that underlie the representations proposed in the present paper. In particular the use of graphs to denote spatial relationships such as adjacency and access allows the representation and analysis of dynamic design aspects such as circulation at a higher level of abstraction that matches the normative thinking of building regulations and programmatic requirements (Koutamanis and Mitossi 1993b; Koutamanis 1995a).

Another relevant point in the dual graph representation is the direct relationship between a space and the building elements that bound it. Such a relationship is instrumental for the transition from one abstraction level to another in a multilevel representation.

Computational design research has produced useful insights into the representation of the built environment but no systematic study of its structure and function. Cognitive studies have addressed such issues extensively in a manner compatible to the means and ends of architectural design. Representing objects by parts and modules has been a common hypothesis for computational and cognitive studies of vision and visual recognition (Brooks 1981; Marr 1982; Tversky and Hemenway 1984; Biederman 1987). According to this hypothesis, a visual scene is segmented (parsed) into components which normally correspond with the canonical parts of the objects depicted in the scene. The arrangement of components is then matched to a known representation (i.e. one stored in memory) to identify the depicted objects. Our interest in this approach lies mainly in the following:

1. The representation derived from a scene has a multilevel structure, with each level corresponding to a different resolution (i.e. abstraction level). At the highest level an object is represented as a single component which is analysed into smaller components at subsequent (lower) levels. For example, a human form starts as a single component which is then subdivided into components for the head, torso, arms and legs. Each of these components is further subdivided, e.g. an arm into upper arm, forearm and hand. Again the hand is analysed into components for the palm and the five fingers (Marr 1982). This hierarchy permits correlation of the different levels. For example, the components of the upper arm, forearm and hand each occupy a subregion in the region of the arm at a higher level. It is therefore highly probable that they are subparts of the arm. The hierarchy also facilitates recognition of relationships between components of the same level, e.g. between the upper arm and the forearm or the forearm and the hand, as they are adjacent subregions of the same region.

2. While elements are straightforward to define and even recognize, their applicability is limited to a small range of abstraction levels. For example, in Figure 3 the actual elements are thirty two bullets arranged along the sides of an imaginary square. Nevertheless, the image is normally described simply as a square. In other words, rather than describing the atomic parts we group them in one pattern that denotes the overall configuration. The same effect can be achieved by lowering the resolution of the image, as in Figure 3. By doing so the individual parts progressively lose their individuality and are fused into a solid square.
Figure 3. Elements and abstraction

In other situations the actual elements are interpreted as something different than what they actually are. In Figure 4, for example, the four incomplete disks are actually interpreted as four complete black disks partially occluded by an illusory white square (Kanizsa 1979).

Figure 4. Elements and illusory contours

Such instability and degradation of elements suggests that beyond certain levels of abstraction atomic elements are replaced by (general) coordinating devices. The question that arises — but will not be discussed in the present paper — is whether these devices are formed by some purely visual process that amalgamates the elements. An alternative explanation would be that the coordinating devices are separate entities which exist independently of the elements and may appear in representations with or without elements. The question can only be answered by further research into the visual and cognitive mechanisms involved in abstraction in
human recognition and in representations of the built environment (Koutamanis 1993). The principles that underlie representations of the built environment are similar but, being conventional, are at times arbitrary. A door, for example, appears as a straight line segment connected to an arc or diagonal line at the scale of 1:100 which forms an abstraction of the panels and posts at 1:10 but disappears altogether (becomes a small gap in the wall) at 1:500.

3. The representation of complex visual scenes can be based on a small set of basic components. Biederman has proposed that this set can be reduced to thirty six simple, typically symmetrical components, called geons (Biederman 1987). Similar principles have been employed for the recognition of line drawings of three dimensional scenes where the repertoire of possible edge junctions has been reduced to a small number of configurations labelled with respect to convexity / concavity (Guzzmán 1966; Clowes 1971; Huffman 1971; Mackworth 1973; Waltz 1975). In a austerely trihedral environment the number of possible junction configurations is just eighteen (Winston 1992). The same applies to the recognition of spaces in floor plans (Koutamanis and Mitossi 1992; Koutamanis and Mitossi 1993a). In an orthogonal environment there are only eight types of space corners. On the basis of such considerations we have devised a basic set of symbols which have been implemented in the Albelone font. Using the characters of the font we can represent any orthogonal floor plan as a two dimensional symbolic array (Koutamanis 1995b).

4. The arrangement of elements is normally represented in terms of a relational structure that links discrete components to each other with spatial / geometric relationships (Winston 1975; Marr 1982). As with the number of elements we have good reasons for supposing that the number of basic relationships is quite low. Biederman, for example, proposes that geons are derived from an image and related to each other by five properties of edges (Biederman 1987). In the recognition of line drawings correlation of edge junctions takes place on the basis of the labelling of each edge with respect to convexity / concavity in an iterative constraint propagation procedure (Waltz 1975). In orthogonal floor plans each space corner is linked to two other corners, one in the horizontal and one in the vertical direction. For a given space corner type there are two possible types of corners it can be linked in either direction (Koutamanis and Mitossi 1993a; Koutamanis 1995b). From such examples we can derive the hypothesis that certain relationships are implicit in the type of the elements: each element is characterized by specific expectations concerning the type and position of other elements to which it relates.

3 LOCAL COORDINATING DEVICES

While the representation of elements in both analog and digital design practices is explicitly supported by symbolic techniques, less importance has been attached to the manner by which elements are integrated in a design. This is normally left to the designer who has to position and connect each new element in a building representation with little help from his instruments. For example, many drafting and modelling systems still fail to address the physical impossibility of two objects occupying the same space, let alone attempt to interpret the designer’s intentions in overlapping objects. The unstructured and unguided manner by which elements are inserted in a design impedes the existence of explicit relationships between elements. In analog design media this is a logical consequence of their implementation structure. An analog representation is perceived, recognized and interpreted by the human viewer.
Computerized representations, on the other hand, should not be limited to human interpretation. By linking objects to each other the computer can provide meaningful feedback on the basis of qualitative and quantitative analyses which complement and support the designer's creativity.

The absence of explicit relationships between elements in architectural representations does not imply lack of knowledge on the subject. Architectural and building textbooks deal extensively with the relationships between building elements and components. The positioning of one element relative to another derive from formal, functional and constructional decisions and have consequences for the articulation and performance of the building. Textbooks provide guidelines for practically all cases, from ergonomically sound distances between chairs and tables to the correct detailing of joints in roof trusses. The configurations they propose are usually treated with reverence and obedience, as some kind of basic architectural rules of global applicability. The frequent and faithful use of textbook examples has resulted in a corpus of architectural stereotypes. Even though such stereotypes may cause the designer to fall back to established and widely acceptable but otherwise unjustified solutions, they help reach levels of reasonable performance in both designing and the realized built environment. By obeying the underlying rules and reproducing refined and adjusted versions of the textbook stereotypes the designer ensures conformity with the norms of building regulations, professional codes and general empirical conclusions (rules of thumb).

The value of such stereotypical configurations for us lies in that they embody often complex relationships in a description that is intelligible to architects and lay people alike. The combination of two facilities that are still underdeveloped in computer-aided design, relationships between elements and representations which do not require extensive acquaintance with the computer and its conventions, make textbook stereotypes an obvious target of computerization. A prerequisite to their computerization is thorough analysis of the formal and functional patterns they integrate in a single representation. In the framework of the present study we concentrate on the representation of such patterns. Our analysis is based on the hypothesis that, once the overlapping constraint networks are untangled, we will be able to distinguish between properties intrinsic to an architectural element and more general or abstract relationships. These are focused on specific elements not because they belong to them but because these elements are critical to local configurations. Such relationships form local coordination devices which apply to interchangeable elements. One of the best examples of local coordinating constraints can be found in recommendations concerning doors. The significance of doors for the spatial possibilities of a room and their crucial role in the circulation system of a building (as evidenced in safety issues such as fire escape) have resulted in clear and often strict functional requirements and corresponding (sub)optimal solutions.

In textbooks recommended solutions generally appear piecemeal. Each aspect is presented separately by means of examples of good and bad solutions. These examples are annotated with the relevant relationships and usually ordered from general to specific and from isolated instances to bigger configurations (Figure 5). The reader of the textbook is then expected to make a selective mental aggregate on the basis of the aspects that apply to the problem in hand. Despite that incompatibilities between different aspects and examples are seldom addressed, forming an aggregate representation is generally straightforward. In the example of the door, one starts with basic decisions such as the type of the door. This is mostly based on spatial constraints and performance criteria. Depending upon the precise type, the designer proceeds with constraints derived from adjacent elements and activities. In the case of a single inward
opening left hinged door of standard width, as in the first part of Figure 5, these constraints determine the position and functional properties of the door, i.e. the distance from elements behind the door, and the swing angle, orientation and direction which facilitate the projected entrance and exit requirements. These can be adjusted by other factors unrelated to the initial decision. For example, the existence of a load bearing element in the initial place of the door may necessitate translation of the door or even a radical reformulation the initial design problem. Also the positioning and form of the door has consequences for the allocation of activities in the spaces it connects. Feedback from this allocation problem usually leads to the addition of new constraints to the door design.

![Diagram of door designs](image)

**Figure 5. Textbook representation of local coordination constraints**

Similarly to textbooks drafting templates offer useful insights into the stereotypical interpretation of local coordination constraints. In templates building elements rarely appear as mere holes. Each hole is accompanied by annotations in the form of dents, notches and painted text. These facilitate the geometrical positioning of forms, as well as the geometric interpretation of spatial constraints. The configuration of forms and annotations typically represents a simplified fusion of the guideline patterns in textbook examples (Figure 6). Even though the superimposition of different patterns makes the template less legible than the more analytical textbooks, the template comes closer to the mental aggregate of the designer. It is noteworthy that in such aggregates the parametric character of the local coordination constraints is reduced to a small number of typical cases without significant loss of flexibility and variability. This is probably due to the prescriptive (as opposed to prescriptive) function of both textbooks and templates in designing and drafting. The designer can adjust the variables given in the examples and produce thus variations of the typical cases.
The manner local constraints are centred on elements, the connections between elements and their stereotypical treatment in designing suggest that mechanisms such as frames or objects would be appropriate for the representation of local coordination devices. In a frame-based representation the relationships of e.g. a door with walls and other elements of the immediate context can be described as slots and facets which link the door frame with the frames of walls, spaces and other elements. Such an implementation strategy has obvious advantages for the representation of local coordination devices. One of the most important is that abstraction and inheritance would allow for interchangeability of elements. It is quite plausible that a single prototype would suffice for the representation of all kinds of doors. This could facilitate the manipulation of doors in computer-aided design, including the automated substitution of one door type with another if needed due to spatial conflicts or to a change in the designer’s preferences.

The same advantages apply to other examples of local coordinating devices, such as the one that determines the positioning of stairs in a space. Here too we make use of overlapping constraint networks which relate the length of the ascent line to the preferred tread and rise and the height of the stair, the type of the stair to the form of the ascent line and the dimensions of the space, the form of the stair and the positioning of the starting and the ending points of the ascent line. These relationships could be represented in a system consisting of the frames of the basic elements relating to the problem: the stair itself, the space that accommodates the stair, the floor levels connected to the stair and the entrances to the space.

Such a frame system is locally (i.e. in the area of the door or the stair) compact and relatively uncomplicated. However, one would expect that the approach and the frame system would be extended to the whole of the building, as a number of smaller systems each covering a particular part and/or aspect would be redundant or limited and hence less appealing in practice. The resulting frame system would ultimately exhibit the complexity and size problems we have set out to reduce. Moreover, as we can see from the examples of the door and the stair, the local constraints derive from the superimposition of wider systems on the formal properties of the door or the stair. In both cases the local constraints are based on projected pedestrian circulation patterns. The explicit representation of these patterns as e.g. generalized cones in the spaces and through the doors of a design would ultimately be preferable to the integration of circulation constraints in the elements of the design, as it would allow for the analysis and evaluation of circulation both locally and globally.

The logical consequence of the above is that local coordinating devices, being intricately linked to both general aspects and specific elements, occupy multiple
intermediate levels in the multilevel representations we propose. Many form a
refinement of global devices at a higher resolution. This is probably best illustrated in
purely formal coordinating devices, such as the proportional system of a classical
column and the spatial framework that relates it to other elements in the floor plan and
permits transition from a free-standing column to a detached one, a three-quarter and a
half column, and ultimately to a 'flat' pilaster without loss of identity, or the implicit
rules for the termination of walls in De Stijl architecture. Other local coordinating
devices concern the interaction between different design aspects in critical or sensitive
situations. In the examples of the door and the stair we have seen how circulation,
construction and other formal and functional aspects can be crystallized in coherent and
comprehensive devices that permit concentration on and detailed treatment on a localized
design problem.

4 GLOBAL COORDINATING DEVICES

Global coordinating devices generally appear in two forms. The first is sketches and
diagrams which explain the central idea (i.e. the general spatial articulation) of a design.
Such abstract representations—even though many are devised post factum—are
commonly seen as the embodiment of the driving forces in the development of the
design. Be that as it may, for our purposes they form a useful précis which can be
placed at the top of a multilevel representation. The other form of global coordinating
devices is the product of studies aimed at e.g. formal analysis and typologic
classification. Being usually applicable to more than one designs, these are expressed in
more general terms than central ideas of specific designs. Schemata such as grids and
space grouping by e.g. zoning are employed to represent these global coordinating
devices.

Probably the most celebrated of such devices is the 5 x 3 grid proposed by
Wittkower as the underlying grid of Palladian villas (Wittkower 1952). This grid has
been universally accepted as the canonical formal expression of the intuitive perception
of the Palladian villa’s "triadic composition": two symmetrical sequences of spaces
laterally flanking the central series of spaces along the main axis (Ackerman 1977). As a
result, the 5 x 3 grid forms the basis of most Palladian studies, including the Palladian
shape grammar (Stiny and Mitchell 1978). In the Palladian grammar the first stage
invariably concludes with the definition of the 5 x 3 grid which serves further as a
template for the definition of spaces and the positioning of building elements.

It is tempting to consider such devices as a mere visual abstraction which
eliminates the individual characteristics of elements and returns a kind of skeleton, as in
Figure 3. This, however, would suggest that they are more or less accidental products
of various, possibly unrelated design decisions. Another option is to treat devices such
as the Palladian 5 x 3 grid as standard patterns that are systematically repeated in
slightly changed versions. Such a view underlies most computational studies, even
though there is no historical evidence that Palladio set out to exhaust the possibilities
presented by a single pattern. The 5 x 3 grid appears to be an fusion of different
preoccupations and influences, from notions of harmony to the traditional centralized
arrangement of the local house type (Ackerman 1977).

Tzonis and Lefaivre have analysed the classical canon as a system of elements,
relationships and coordinating devices which constrain rather than direct design
decisions (Tzonis and Lefaivre 1986). This system consists of three major levels:
genera, taxis and symmetry. The term genera (preferred over 'orders') denotes the
"well-determined sets" of architectural elements which are formed on the basis of fixed local relations. Taxis is responsible for the overall organization of a classical building and contains two sublevels (schemata): the grid, which parametrically divides the building into spatial components, and tripartition. A rectangular grid and a simple tripartition schema produce a 3 x 3 pattern. The deletion, addition, repetition and embedding of parts in this generic pattern transforms it into the layout of a classical building, including Wittkower's 5 x 3 Palladian grid. Symmetry is the collection of relationships that constrain the positioning of a particular genus inside the divisions determined through taxis with respect to each other and to the overall structure of taxis. The three levels in this formulation of the classical canon have direct correspondences with the division between elements and coordinating devices proposed in the present paper. The genera are the elements of classical architecture—spaces are treated as the final products of the taxis level rather than as separate entities positioned on the basis of taxis. Symmetrical relationships are closely linked to local coordination devices. The most relevant of the three for our study, taxis, is both a representation and an analysis of the generic general coordinating device of classicism.

Taxis patterns have the advantage of being visually and conceptually compact and coherent and at the same time the products of two distinct sublevels. The resulting flexibility demonstrates the superiority of such analytical global coordinating devices to sketches or diagrams depicting the central idea of a particular design. For example, choice of a different grid results in a direct transformation of a design into something different but yet recognizable as related to the original. The persuasive comparison of curvilinear or free-form patterns such as in designs by Alvar Aalto and Hans Scharoun to similar rectangular floor plans is the intuitive equivalent of such transformations.

Another advantage of analytical global devices such as taxis is their connectivity to cognitive issues which, even though largely neglected in architectural research, form the basis for our interaction with the built environment and its representation. In their formulation of taxis Tzonis and Lefevre propose that tripartition is responsible for the symmetrical articulation of classical layouts such as the Palladian 5 x 3 grid. Their anthropocentric view of tripartition in classicism is closely related to spatial reasoning and in particular to the division of the world by projective prepositions, i.e. prepositions which convey information about the direction in which an object is located with respect to another. Such prepositions describe orientation and position on the basis of reference frames consisting of a division of the world in general directions, an origin and a viewpoint for the speaker or viewer (André, Bosch et al. 1987). The affinities between the resulting spatial pattern (Figure 7) and the 3 x 3 generic classical pattern imply that such reference frames can be used for the analysis of classical buildings with respect to e.g. well-formedness at the level of global coordinating devices (Koutamanis 1990). By extension they suggest that other forms of analysis, e.g. of movement and orientation in buildings, could be applicable on the basis of global devices.
Figure 7. A spatial reference frame after (André, Bosch et al. 1987)

The three levels of genera, taxis and symmetry form an essentially top-down system for classical architecture, both in designing and for the representation of classical buildings. The correlation of the three levels (Figure 8) provides useful insights into the relationships between elements and coordinating devices in the top-down context that underlies the fair share of traditional and computational design approaches. In this system the (building) elements of the genera are positioned in accordance with the overall taxis pattern and are linked to each other and to it by symmetry. The subordination of elements to coordinating devices presents an integrated solution to the problem of multilateral relationships between elements. Such relationships are instrumental for the recognition of e.g. a number of people standing behind each other as a queue or of a series of columns as a colonnade. Atomistic relational structures where each person or column form discrete entities with bilateral relationships do not offer the directness and economy of an explicit representation of the concept of a queue or a colonnade. Such a representation can be easily achieved by the addition of cumulative objects to the relational structure. However, maintaining the relationships between the actual elements and cumulative objects is rather tedious for both the computer and the designer, especially if the representation is frequently transformed so as to address different design aspects. The formulation of the classical canon by Tzonis and Lefaivre presents two other possibilities for the representation of entities formed by multilateral relationships. The first is abstraction to a component of taxis. A colonnade, for example, can be abstracted to a boundary between to spaces. This option should be the designer’s favourite, as it allows for choice between different configurations in the same way that bullets are chosen for the sides of a square in Figure 3. The second possibility is the use of symmetry patterns. These describe in abstract terms the arrangement of interchangeable elements according to constraints added to taxis. In the multilevel representations we propose such patterns and constraints are accommodated in local coordinating devices.
Figure 8. A correlation of the levels of the classical canon according to (Tzonis and Lefaivre 1986)
5 MULTILEVEL DESIGN REPRESENTATIONS

Multilevel representations build on and expand the natural abstraction of architectural representations. This abstraction relies heavily on visual techniques in order to highlight the conceptual structure of a design. To a certain extent a multilevel representation can be compared to the conventional sequence of drawings at different scales. These scales represent the same objects at different levels of abstraction. Similarly in image processing and computer vision the use of multiple resolutions allows the formation of sequences of progressively more accurate and precise segmentation and recognition. What in the former case can be described as cognitive economy, is in the latter an efficient and effective way of reducing complexity in computer processing of data. The similarities end when we compare the lack of coordination between different drawing scales to the hierarchical modular and pyramidal representations in computer vision and image processing (Marr 1982; Rosenfeld 1984; Rosenfeld 1990). In both cases higher abstraction levels serve as reference frames for subsequent (lower) levels. In representations of the built environment, however, the only link between different levels in human recognition and interpretation.

Any analysis of elements and coordinating devices demonstrates that integration of all entities in holistic relational structures has a limited applicability, to design problems of a limited size and complexity. As a problem expands to more elements, aspects and abstraction levels, atomistic relational representations grow beyond what is expected to be manageable for computation by computers and direct comprehension by humans, even if compact implementation mechanisms such as frames and objects are employed. In the present paper we consider the development of multilevel representations which derive from equivalent visual representations. In these representations architectural elements, i.e. spaces and building elements, form overlapping coordinated networks similar in intention to the dual graph representation (Steadman 1976; Steadman 1983). These networks are complemented by local and global coordinating devices which occupy different levels of the representation. The function of these devices is to integrate relationships in consistent and coherent local or global frameworks which regulate the positioning and properties of elements.

The representation of coordinating devices is essentially different to that of elements. Global devices are generally abstract schemata which, if expressed by means of relational structures, lose much of their elegance and compactness. It is therefore quite probable that for the representation of general coordinating devices we should explore the possibilities offered by purely visual techniques. Local coordinating devices, being usually centred on the specific elements which form their focal points, are even more vexing. On the one hand, it is reasonable to propose that, as with global devices, visual means could be the appropriate implementation for the representation of local devices too. On the other hand, stereotypical mechanisms such as frames allow the integration of local coordination in the representation of elements. The basic danger of this approach is that the addition of these constraints to the representation of elements will certainly increase the complexity and the size of the representation. This also means that the number of levels in the representation will be reduced, with obvious consequences for its flexibility and abstraction potential.

The reasons for choosing a certain type of representation and specific means for the implementation of elements and especially coordinating devices also depend on the functionality of the multilevel representations we envisage. As with similar representations in computer vision, we can expect that the application of the representation to the description of a particular design is essentially a bottom-up process with limited top-down constraining (Marr 1982). Use of such representations,
however, is usually seen as a top-down process for both recognition and design (Mitchell, Liggett et al. 1990; Rosenfeld 1990). The economy and effectiveness of the top-down approach are reasons enough for adopting this view. Nevertheless, it should be noted that there are cases where a bottom-up mode prevails. In computer vision, for example, a form may be recognized as human on the basis of a small detail which appears at a low level, e.g. the thumb, rather than global characteristics at the higher levels of abstraction. Similarly it is plausible that local design decisions can have far reaching consequences on all levels. Such bottom-up influences are common in feedback following a negative evaluation of parts or aspects of a design.

In the essentially top-down mode we assume for the use of multilevel representations is designing, the relations between the level of elements and global coordinating devices are rather unambiguous and follow the model of (Tzonis and Lefaivre 1980). A space occupies a discrete, directly identifiable region in the pattern of a global device. Its relationships to other spaces (adjacency, access, grouping) are proscribed by the structure of the global device. Building elements are similarly constrained by the global devices but also by requirements derived from the arrangement of spaces. Obviously the insertion of a building element also generates constraints which apply to other building elements and spaces. Such constraints and other forms of feedback are the domain of local coordinating devices. These apply and refine the global devices to specific frameworks, usually centred on critical elements. The relationships between global and local coordinating devices are subjects for further research. While local devices can be described as focused, augmented formulations of global affordances, addition or fusion of the local patterns does not necessarily produce the global coordinating devices of a design.

6 REFERENCES


