Generic representations : an approach for modelling procedural and declarative knowledge of building types in architectural design

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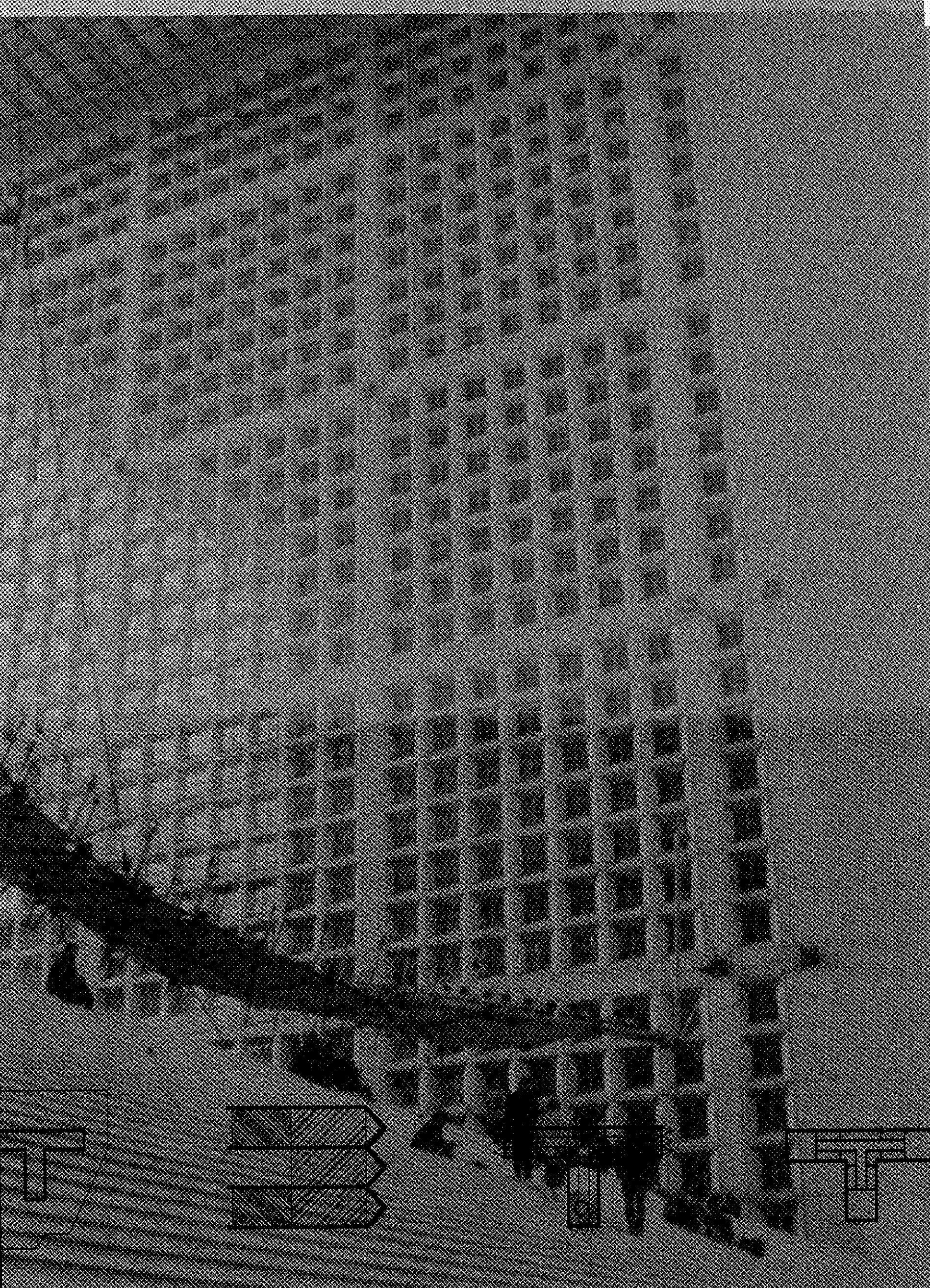
GENERIC REPRESENTATIONS

Henri Achten



BOUWSTENEN

GENERIC REPRESENTATIONS

An Approach for Modelling Procedural and Declarative Knowledge of Building Types in Architectural Design

PROEFSCHRIFT

ter verkrijging van de graad van doctor aan de Technische Universiteit Eindhoven, op gezag van de Rector Magnificus, prof.dr. Rem, voor een commissie aangewezen door het College voor Promoties in het openbaar te verdedigen op woensdag 22 Oktober 1997 om 16.00 uur

door

HENRI ACHTEN

geboren te Venlo

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1 INTRODUCTION

"Read them," said the King.
The White Rabbit put on his spectacles. "Where shall I begin, please your Majesty?" he asked.
"Begin at the beginning," the King said, very gravely, "and go on till you come to the end: then stop."

Lewis Caroll, Alice's Adventures in Wonderland

1.1 Design research

Design is one of man's endeavours that seeks to initiate, articulate, and establish change in the world. Both the activity of design and the products of design are themes that are continuous subjects of discussion, fashion, and research.

The word 'design,' in its common use, has a broad meaning. It indicates both design process (how a specific design comes about, which ideas were involved, how did the designer 'do it,' and so forth) and design product (what a design is like, its characteristics, style, and meaning). Design is often related to particular disciplines such as industrial design, architectural design, fashion design, and graphics design. Therefore, it can be studied relative to a discipline or as a general human activity.

Many products we use are the result of one or more design processes. Cutlery, furniture, wallpaper, and household appliances surround us at home. Houses, building blocks, street lights, highway layouts, light advertisements, signposts, etc. mark the outdoors. The tools, machines, office equipment, computers, telephones, working clothes, etc. used at work are products of design. Less material objects such as curricula at school, ballots, and traffic rules are also the subject of design activity. Usually it is possible to identify function and purpose for the objects of design. Design is an important factor in our life. Tools and means that better support the design process and the quality of design products can be achieved when we have a clear and unified understanding of design.

The scientific research field that studies the process of design is called design methodology. More recently, the term design research is used. The activity of design is influenced by the context in which it takes place. Architectural design, for instance, focuses on a particular set of objects (buildings, building blocks, interiors, and so forth). It takes place in a practice with specific participants that are involved in design (such as the principal, municipality, advisor, structural engineer, and HVAC engineer) and specific participants that are involved in production (for example the contractor, supplier, and supervisor). These objects, participants, and production processes are quite different from those in for example, industrial design. It would be natural to assume that they influence the nature of design. Most design disciplines therefore, have a research tradition that concentrates on their own field.

However, all discipline-focused research shares the basic assumption that the activity of design is a cognitive activity general to man. This assumption directs efforts to generalise findings from one particular field to others. The field of architecture for example, has been engaged in both general design research and architectural design research. Research from the field of industrial design has taken the lead in general design research in the past decade (Oxman *et al.* 1995). The study of design from general principles of thought, usually termed design thinking or design cognition, bases itself on principles from cognitive science.

It is beyond the purpose of this work to precisely define the differences between such research orientations as design methodology, design cognition, design thinking, etc. These approaches are generally indicated with the term 'design theory.' According to Cross they include the study of how designers work and think; the *establishment of appropriate structures for the design process*; the development and application of new design methods, techniques, and procedures; and *reflection on the nature and extent of design knowledge* and its *application* to design problems (Cross 1984, p. vii). The terms in italics indicate the general orientation of the current work:

1. What are appropriate structures for the design process?
2. What is the nature and extent of design knowledge in the design process?
3. How can design knowledge be applied to design problems?

The area of research is architectural design, and it is aimed to establish structures useful for design (statement *1*). These structures ideally meet two requirements: they need to be grounded in an understanding of designers. This means that they have to relate to how designers work, what their cognitive structures are like and what processes they use (statement *2*). Furthermore, they have to be productive. This means that it must be possible to support design (statement *3*) with such structures.

In this research, the building type is studied and the way it can aid in the design process. It is proposed that the building type provides procedural and declarative knowledge throughout the design process which can be considered as a sequence of design decisions. It is proposed furthermore that graphic representations can be a medium for supporting this knowledge. This proposal is based on the notion that establishing a graphic representation in the design process implies making design decisions, and that it is possible to identify such design decisions for each kind of graphic representation. A design decision requires declarative knowledge of the building type. A sequence of design decisions requires procedural knowledge of the building type. If these graphic representations are diverse enough they constitute building blocks for the design process. A method is developed to identify such kinds of graphic representations. This leads to the concept of generic representations.

1.2 The building type

One particular subject in architectural design stands out for its central role in the field of architecture: the building type. Building types are classes of buildings that have major characteristics in common. They often are identified by their function. Examples of building types are hospitals, offices, and airports. A building type encompasses a significant form of knowledge in design. When dealing with a theatre for example, the architect already has relevant information of theatres by virtue of knowing the theatre type. Knowledge of building types aids in designing buildings that belong to that type. Because it comprises common knowledge, the building type enables easy communication between design participants. Understanding the building type and knowing how to use this form of knowledge in design therefore aids considerably in design support. The building type is subject of research in architectural theory and design theory. Although there is general consensus about the relevance of the concept in these research disciplines, there is no unified approach to the subject[1].

The concept of building type is complex. It encompasses aspects that deal with form, function, and process. In domain theory (Bax 1979; 1989) these three dimensions (form, function, and process) are considered basic to the description of all architectural artefacts. The type conveys knowledge of these aspects in a unified manner. In other words and the same import, Oxman and Oxman (1990) state: "*In types, we have a complex body of knowledge which includes the characteristics of the type, associated knowledge of procedures for the modification and refinement of the type, as well as a semantic control of these procedures. The grammar of the type includes such knowledge as design heuristics, procedures for variations, and knowledge of the key design variables and their main states.*" The enumeration of properties associated with type show that it is necessary to clearly define how the concept of type is approached. From the literature survey, it appears that main distinctions can be made on (1) the role of building type, and (2) the nature of building type. These distinctions inform inquiry in the subject matter.

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[1] Design theorists such as Rowe (1987), Heath (1984), Habraken (1985), Lawson (1980), Schön (1988) have various approaches to type that differ with respect to terminology, place in design, role in design, and significance for architecture.

1.2.1 The role of building type

The concept of building type has a number of roles in architectural theory and design theory. Basically it can be considered either as a theoretical construct for practice or as a cognitive knowledge structure.

- *Type as a theoretical construct for practice*: The building type is a comprehensive means for ordering large amounts of knowledge related to classes of buildings. In this sense, it is established within the professional community and encompasses theory (*e.g.* de Quincy 1825, Argan 1963, Colquhoun 1967; *Casabella* 1985, Vol 49. No 509/510), norms (*e.g.* De Chiara and Callender 1981, Neufert 1992), description (*e.g.* Sherwood 1979, Polyzoides *et al.* 1982), and history (*e.g.* Pevsner 1979). It is both descriptive of existing buildings and prescriptive of future buildings.
- *Type as a cognitive knowledge structure*: The architectural design process considered as a cognitive activity, is a specific form of problem solving. It is knowledge intensive, lengthy, iterative, and deals with complex objects. In order to deal effectively with the design process, the architect needs relevant internal representations of knowledge (Akin 1986; Lawson 1980). These representations not only apply to knowledge of objects and facts (declarative knowledge) but also to knowledge of the design process (procedural knowledge). The building type as a form of knowledge seems to associate declarative knowledge (the kind of building) with procedural knowledge (designing that kind of building). In cognitive science, the schema is proposed as a kind of structure that may accommodate such functions[2].

The building type as a theoretical construct plays a role in explaining how the theoretical concept of type functions in the architectural community. The building type as cognitive knowledge structure plays a role in explaining how the concept of type functions in the cognitive process of the architect. It is tempting to project statements from the theoretical construct role on the cognitive structure role (stating that the cognitive structure has the same properties as the theoretical construct) or vice versa. The literature survey does not indicate that there is research on the mental representation of building types. There are only suggestions or propositions that the psychological schema may be the mental representation of a building type (Hamel 1990, p. 11, p. 34;

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[2] The notion of the schema(ta) is originally formulated by Kant in *Die Kritik der reinen Vernunft* (1781). The following theorists are generally associated with further development of the concept: Bartlett: *Remembering* (1932), De Groot: *Thought and Choice in Chess* (1965), Rumelhart: *Notes on a Schema for Stories* (1975), Elshout, Wielinga and Breuker: *De Analyse van Hardopdenkprotocollen* (1984), and Anderson: *Cognitive Psychology and its Implications* (1985).

Coyne *et al.* 1990; Sowa 1984, p. 128). If a theory of types is ever to be comprehensive, the use of the theoretical construct in the design process must at some point be explained in terms of cognitive knowledge structures. Until this matter is explicitly addressed however, it is necessary to warrant caution (Lakoff 1987) and to keep clear whether the issue is dealt with from a theoretical or cognitive point of view.

1.2.2 The nature of building type

The second distinction that is informative with respect to type focuses on basic assumptions on the nature of building type. These basic assumptions are the ambiguity versus explicitness approach, and the idealistic versus procedural position.

- *Ambiguity versus explicitness approach*: In order to explain how knowledge of a building type aids in the design process of a building belonging to a particular type, it appears that two basic approaches are used.
  The first approach states that the building type is inherently ambiguous (de Quincy 1825; Argan 1963; Colquhoun 1981; Rossi 1982, p. 40-41; Habraken 1985, p. 27-28). According to this approach, type cannot be defined in an explicit manner but only through its instances. For this reason, the approach is proposed to be called the 'ambiguity approach.' It accounts for the creation of related-yet-different instances of the building type by appealing to the indefiniteness of type. Although it seems to explain the process, it in fact offers no mechanism or principle that can be studied more carefully.
  The second approach states that the building type can be defined explicitly, and that it in this manner instructs designers to create instances of the type (generally associated with Durand: Perez-Gomez 1983, p. 4; Vidler 1977; Westfall and van Pelt 1991, p. 146-148). Therefore, this approach is proposed to be called the 'explicitness approach.' It aims to clarify the creation of instances of the type by identifying procedures and principles of instantiation.
- *Idealistic versus procedural position*: A pervasive notion about type is that there is something as a 'building type object' of which the architect has knowledge in some way. This goes beyond the interpretation that knowledge of the type is acquired and represented in the form of a knowledge structure such as a concept, class, or schema. It poses the existence of ideal types of which instances (concrete buildings) are imperfect examples. The view is first explicitly stated by de Quincy (1825) and versions of it still have currency

(*e.g.* Mitchell 1990, p. 86-94). Since it is related to the notion of Platonic 'ideas' in philosophy[3], it is proposed to be termed an 'idealistic' position.

The idealistic position influences research on building types. Since it assumes that 'building type objects' exist, it emphasises implementation of type-like structures. Such structures are taken to encompass the building type. Instances are created by making the general structure specific. The approach has a lot of attractiveness, not the least of which is the fact that it can be computationally modelled (in particular by means of the prototype: Gero 1990; Coyne *et al.* 1990; Oxman 1990; Rosenman and Gero 1993). However, it tends to ignore or downplay the importance of the design process which is required for instantiation.

The logical opposite to the idealistic position states that there is no such thing as a 'building type object' and insists on a pre-structured process of instantiation and articulation in which knowledge is applied as the means to create instances. Such a point of view can be called a 'procedural' position since it puts emphasis on the process rather than the type object. It is familiar to the problem of defining natural species in nature and theories of evolution[4]. From a design theoretical point of view, this position seems to include more naturally the architectural design process.

1.3 A model of building type in the design process

The previous discussion articulated current views on the role of building type (theoretical construct for practice and cognitive knowledge structure) and on the nature of building type (ambiguity versus explicitness approach and idealistic versus procedural position). The first tentative formulation of building type in the research work is concisely described as follows:

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[3] Russell (1961) states about the Platonic idea: "*There are many individual animals of whom we can truly say 'this is a cat'. What do we mean by the word 'cat'? Obviously something different from each particular cat* [...] *But if the word 'cat' means anything, it means something which is not this or that cat, but some kind of universal cattiness* [...] *Particular cats partake in of the nature of* the *cat, but more or less imperfectly; it is only owing to this imperfection that there can be many of them.*" (Russell 1990, p. 137 [remark] by HA).

[4] The notion in philosophy that everyday objects are incomplete instances of 'ideas' has lost ground particularly in biology where it has been superseded by evolutionary theory. Dennett identifies the source of this confusion where he states: "*We* want *to draw lines; we often* need *to draw lines* [...] *Our perceptual systems are even genetically designed to force straddling candidates for perception into one classification or another* [...] *Darwin shows us that evolution does not need what we need; the real world can get along just fine with the de facto divergences that emerge over time...*" (Dennett 1995, p. 202 [...] by HA).

The building type is a comprehensive source of knowledge established in the architectural design community. Knowledge of the building type is used during the design process. It informs both the order of decisions taken in the design process (in other words, it provides procedural knowledge) and the outcome of these decisions (in other words, it provides declarative knowledge); Figure I-1.

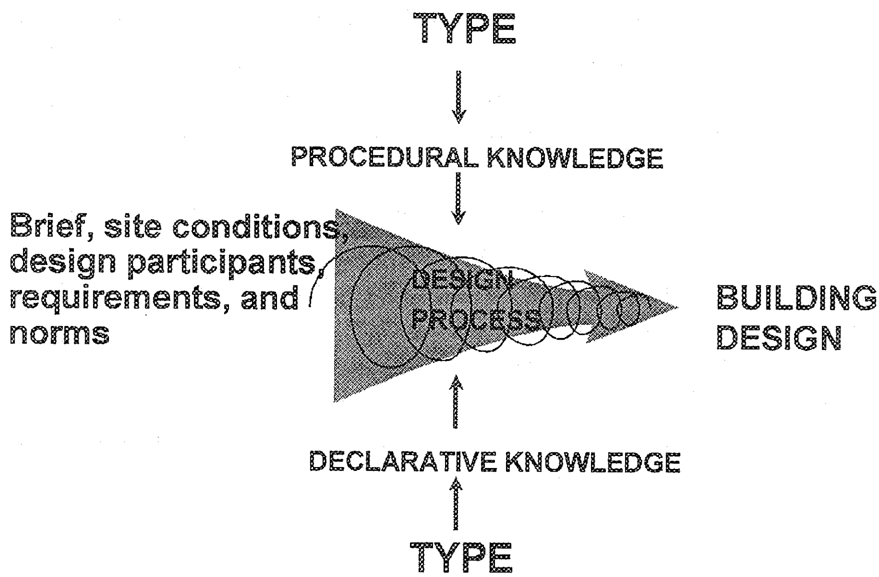

Figure I-1: Building type in the design process as assumed in the research.

The building type is not located centrally in the design process as would be the case when the idealistic position is taken. Rather than focusing on a 'building type object' it seems necessary to investigate the design process. Computational representations such as the prototype do not provide clues for this study, since they make no explicit statements on the interaction with the design process. Therefore, it is necessary to see if there can be found a representation which:

1. Supports design decisions.
2. Supports the changes and transformations of the design during the design process.
3. Encompasses knowledge of the design task.
4. Related to the way architects design.

It seems that graphic representations may constitute such a representation. Graphic representations (drawings, sketches, diagrams, etc.) are used throughout the design process to represent the state of the design. They generally function as

an aid for short term memory and long term memory (Hamel 1990, p. 52). The graphic representation provides the architect with new input (Akin 1986, p. 49-50). In early stages of exploration, sketches aid in reconstructing the design task (Verstijnen 1997). Akin (1986) distinguishes five properties of graphic representations: 'multiplicity' (multiple representations of the same reality are possible), 'consistency' (parts of the representation are always interpreted the same), 'functionality' (a representation conveys a specific purpose), 'abstraction' (a representation focuses on specific aspects of reality), and 'organisation' (a representation functions because of some structural qualities). These properties indicate how graphic representation consistently encode the things they represent. Furthermore, graphic representations are extensively used in architecture to convey knowledge. The combination of graphic representations with the previous statement about the role of type in the design process results in Figure I-2.
The process-arrow which is empty in Figure I-1 is now articulated. The key element is a graphic representation. A graphic representation establishes the state of the design object. In order to make the graphic representation, it is necessary to make design decisions (for example, drawing a closed shape

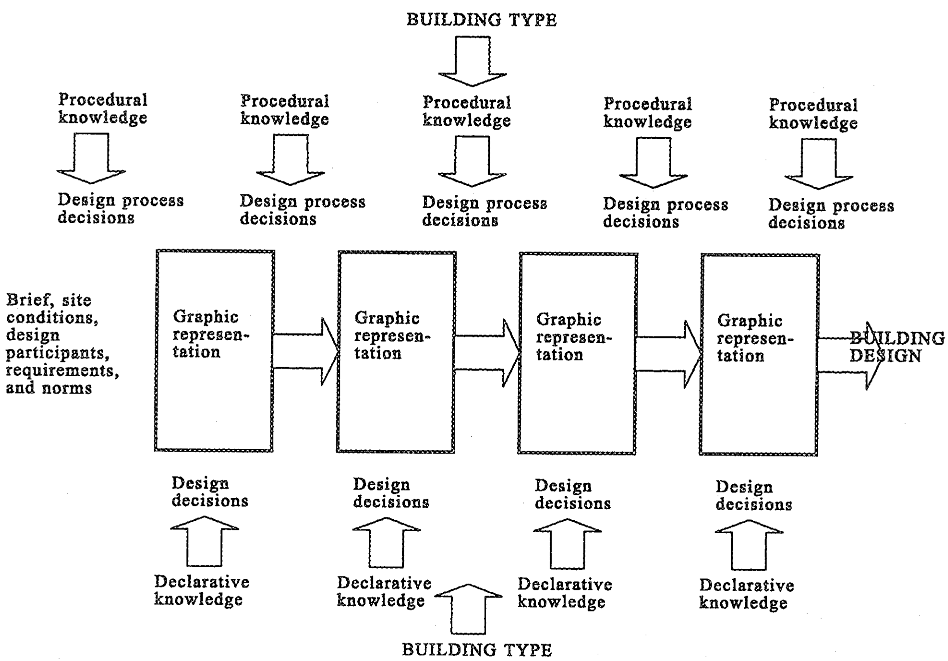

Figure I-2: A model for the relations between graphic representations, design decisions, declarative knowledge, procedural knowledge, and building type in the design process.

requires deciding on the topology of the shape, relative proportions of the layout, and tentative surface area). Design decisions require knowledge of the design task, the brief, site, design participants, etc. If the design task is a building belonging to a particular type, then this knowledge derives for some part from the building type. Since the graphic representation is concerned with the state of the design object, the required knowledge is declarative knowledge. Each graphic representation therefore, encodes declarative knowledge of the building type. The declarative knowledge is valid for all instances of the building type. Therefore, it is independent of the appearance of the building design.

A sequence of graphic representations establishes a sequence of design decisions. In each step of the sequence a state of the design object is defined. The transitions from one state of the design object (graphic representation encoding particular design decisions) to the next state of the design object (graphic representation encoding other particular design decisions) can be defined on the basis of possible transitions from one graphic representation to the next. Such transitions are about the sequence of design decisions, and therefore require decisions about the design process. If the design task is a building belonging to a particular type, then this knowledge derives for some part from the building type. Since it concerns the sequence of design decisions, the required knowledge is procedural knowledge.

1.4 Research hypotheses

The model introduced above raises a number of hypotheses that are addressed in the research. The basic proposition of the model is that graphic representations consistently encode design decisions. This means that given a graphic representation of the design object, it must be possible to determine which design decisions are being taken. The first research hypothesis therefore is:

1. Graphic representations consistently encode design decisions.

Given the variety of design decisions and the complexity of the design process, this also implies a variety of graphic representations. Therefore, it must be the case that there are sufficiently diverse graphic representations. Thus, the second research hypothesis is:

2. It is possible to identify sufficiently diverse graphic representations which encode specific design decisions.

The model presupposes not only that there are sufficiently diverse graphic representations, but also that it is possible to formulate how to go from one graphic representation (design decision) to a next graphic representation (design decision). Also, there must be some constraint and order in these transitions - if a graphic representation can be succeeded by any other graphic representation this does not constitute procedural knowledge. Therefore, the third hypothesis is:
3. It is possible to define the transitions between graphic representations and to establish a sequence.

If at this point the hypotheses are confirmed, the result is an inventory of graphic representations with specific knowledge content. However, this does not yet confirm the main thesis: that the sequence can be used to model procedural and declarative knowledge of a building type. In order to demonstrate this, it is necessary to apply the sequence of graphic representations to a concrete building type. Therefore, the fourth hypothesis is:
4. It is possible to map procedural and declarative knowledge of a building type on the sequence of graphic representations.

If at this point the hypotheses are confirmed, the result is a procedural approach to building type that takes into account the design process by means of graphic representations.

1.5 Organisation of the thesis

Each Chapter of the research thesis deals with a specific hypothesis formulated above. Furthermore, the order of the Chapters is related to the notions 'form,' 'process,' and 'function' as discussed on p. 4.

Chapter 2: Generic representations
Graphic representations are highly diverse in their appearance. A number of generally acknowledged properties of graphic representations are discussed for graphic representations in architecture. However, there is not yet a structured approach for analysing graphic representations on the design decisions they imply. In Chapter *2* an approach for this analysis is proposed that should result in a set of graphic representations with specified design decisions: generic representations. Chapter *2* addresses hypothesis *1*.

Chapter 3: Survey of graphic representations

The methodology developed in Chapter *2* must be applied to a set of graphic representations. The procedure as followed in the research is explained. The analysis results in a set of generic representations. The set is discussed in terms of its completeness. In this Chapter, the graphic representations are analysed on the basis of their 'form'; what clues about design decisions can be derived purely on the basis of the graphic entities present in graphic representations? Chapter *3* addresses hypothesis *2*.

Chapter 4: A sequence of generic representations

The principles of a sequence of generic representations must primarily follow from properties of generic representations themselves. If this is not the case, it means that the sequence derives its structure from somewhere else, and it can not by itself form a medium for encoding procedural and declarative knowledge of the building type. In this Chapter the general principles of a sequence of generic representations are worked out. The aspect of 'process' is analysed. Chapter *4* addresses hypothesis *3*.

Chapter 5: Generic representations of the office building type

The application of the sequence of generic representations requires a concrete building type. Of this particular type, declarative knowledge has to be acquired. The building type chosen for the sequence of generic representations is the office building. A methodology for knowledge acquisition is introduced and applied to the office building. The knowledge base is presented and applied to a sequence of generic representations. The application results in a sequence of generic representations that are specific for the office building. It shows to which extent generic representations can model procedural and declarative knowledge of a building type. In this Chapter, also a tentative design aid system that applies a limited number of generic representations is discussed. The 'form' and 'process' aspects are insufficient to encode a building type. It is necessary to add 'function' in order to establish instances of a building type. Chapter *5* addresses hypothesis *4*.

Chapter 6: Conclusions

In the concluding Chapter the outcome of the research work relative to the hypotheses formulated above is addressed. It is discussed to which extent the model of Figure I-2 is correct in posing that this is a procedural approach for modelling building type. The methodology of the research is discussed. The general discussion of Sections *1.2.1* and *1.2.2* is returned to and addressed in light of the research results. Furthermore, future work is discussed.

2 GENERIC REPRESENTATIONS

A Theory of Graphic Representations

Introduction

Chapter *1* defines the tentative relations between procedural and declarative knowledge, building types, and graphic representations in the design process. In this Chapter the hypothesis that graphic representations can be a medium for encoding type-related knowledge is dealt with. Properties of graphic representations are presented based on work by Akin. The discussion illustrates claims that graphic representations consistently encode the things they represent. It points to some relevant aspects that are not yet well defined and which determine the applicability of graphic representations.

2.1 Properties of graphic representations

Graphic representations are used as one of the major media through which the architect develops the design[4]. A problematic character is how to derive from or encode in graphic representations knowledge of the design object.

The first task is to demonstrate that graphic representations are and can be used as a medium for knowledge representation of the design object. Akin (1986, p. 186) states that "*representations are external to the mind and serve as the medium through which the mind accepts information.*" In this way he makes a direct link between representation and information. Drawings and sketches convey information to the architect. The information is about the design and represents its state in the design process. By consulting the drawing, the architect knows what the design is about. Because of the use of conventions, the information is available to other designers as well. Akin distinguishes five properties which informally characterise external representations. These are:

- *Multiplicity*: It is possible to make multiple representations of the same reality, that is, the same object can be represented in a number of different ways.
- *Consistency*: A representation has some constant way of depicting things (for example by using defined symbols, rendering, or notation) which enables the viewer to interpret the representation whatever it depicts.
- *Functionality*: A specific kind of representation has a specific kind of use. A perspective projection, for example, shows the three-dimensional build-up of an object as it would appear when one would be looking at it. The functionality of the perspective is limited for other purposes such as measuring dimensions and floor areas, or for providing an overall overview of the organisation of a building.
- *Abstraction*: A representation presents a subset of all the properties something in reality has. An adjacency graph of a building for example, represents only spaces (nodes), and the way these spaces are aligned to other spaces (vertices). It does not represent such properties of the building as materialisation, finishing, or acoustic quality. This requires a different representation.

[4] Graphic representations are not solely the medium in which the architect develops the design. Other representations such as scale models, and other factors such as consulting principal and other design participants obviously influence the design and provide other representations of the design object. Nor should the claim be interpreted in the sense that graphic representations encode all (relevant) knowledge of the design object.

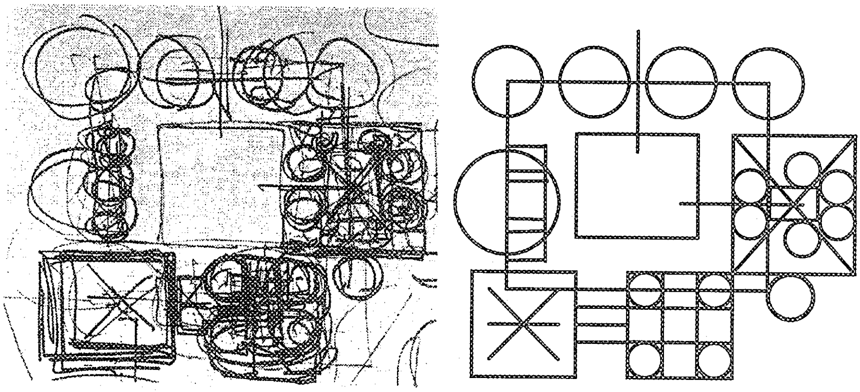

Figure II-1: Two drawings of Community Centre of Salk Institute, Louis Kahn. Left: sketch by Louis Kahn (from Ronner et al. 1977, p. 153); Right: line-drawing derived by hand from sketch (by HA). Both sketch and drawing demonstrate the properties of multiplicity, consistency, functionality, abstraction, and organisation.

- *Organisation*: A representation functions in a specific way. This depends on how it is cognitively perceived by the viewer. A graphic representation, whatever it depicts, is based on lines and coloured surfaces and communicates its content through these constituent elements. Akin mentions the example of movies, where organisation refers to the minimum speed of twenty four frames per second in order to perceive animation.

The properties of graphic representations outlined above hold for all external representations. External representations enable reduction of content. Through this reduction of content the user is able to convey specific issues. However, the properties as outlined do not yet indicate how it is possible to determine which design decisions a graphic representation implies. This requires additional concepts. In order to argue for a more specialised approach, graphic representations as they are used in architecture will be discussed on the basis of these properties.

2.2 Content and organisation in graphic representations

In this section, it is the intent to demonstrate in more detail the role and properties of graphic representations in architectural design. The notion that graphic representations can convey specific purposes in architecture, is not new. Major sources throughout the history of architectural theory employ graphic representations in this manner.

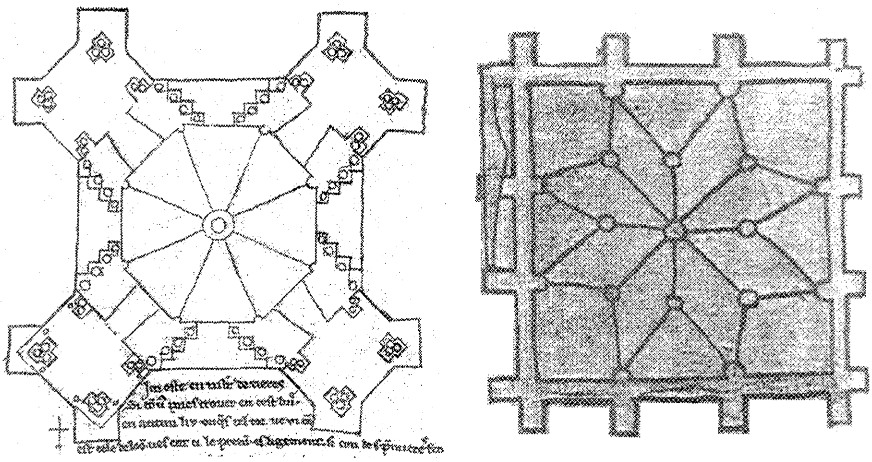

Figure II-2: Two illustrations from Villard de Honnecourt's lodge book; left: tower of Laon cathedral; Right: star vault construction in square plan (from: Bucher 1979).

The oldest preserved books on architecture are *The Ten Books of Architecture* by Vitruvius (written, according to Kruft 1994, between 33 and 14 BC). Vitruvius' requirement of an architect is among other things, that "*he must be a good draughtsman and have a command over geometry, in order to make correct perspective drawings and plans*" (Kruft 1994, p. 24). Although there are no illustrations preserved from Vitruvius, it is possible to infer that the conventions of depiction called perspective and plan did play a role in architectural design in Antiquity. His descriptions of the orders, kinds of temples, and organisation of theatres have become canonical and often appear in the same form in later publications by other theorists. One of the most extensively illustrated books on architecture published in the Middle Ages, was Villard de Honnecourt's lodge-book (1225-1250; see Figure II-2). The graphic representations serve both a representative and an instructive purpose[5].
Many old books on architecture that are still preserved date from the 15th and 16th century. An early illustrated book on architecture is Colonna's *Hypnerotomachia Poliphili* (1499; attribution by Tzonis and Lefaivre 1990). Alberti's *On the Art of Building in Ten Books* (1485) does not count many illustrations (trans. Rykwert et al. 1988)[6]. Cesariano's *Ten Books of*

[5] Kruft notes that Villard de Honnecourt's lodge-book may be claimed *"strictly speaking the only manuscript of the High Middle Ages exclusively devoted to architecture that has a didactic purpose"* (Kruft 1994, p. 36).
[6] Rykwert accounts for this lack of illustrations where he notes: "[Alberti] *writes, moreover, not just for architects and craftsmen, but for princes and merchants, for the patrons —perhaps for them primarily. That is why he writes in Latin only, and that is why the book, in its original form,*

Architecture of Lucius Vitruvius Pollio (1521) is the first Italian translation of Vitruvius. It is well illustrated, after the manner of the first illustrated Latin edition of Vitruvius' books by Giocondo (1511).
Serlio's *The Five Books of Architecture* (1611), received its fame particularly through its wealth of illustrations. The book encompasses major conventions of depiction used in architecture today: diagrams (for illustrating geometry), plans, sections, elevations, perspectives, and details (see Figure II-3).

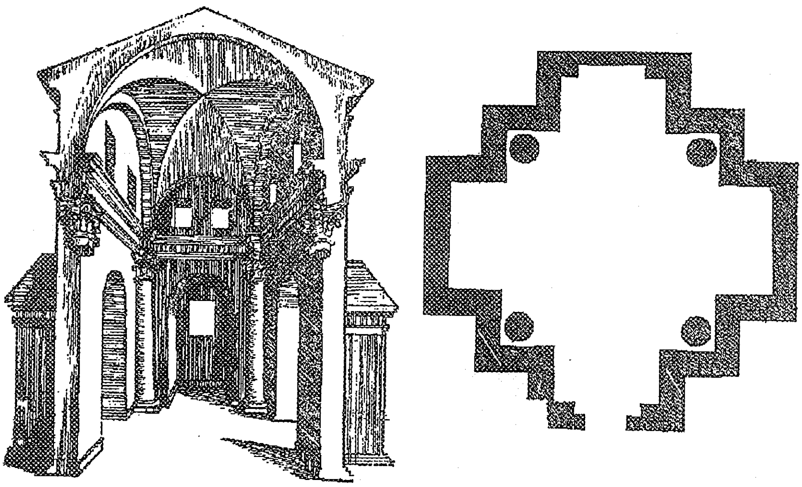

Figure II-3: Serlio (1611). 3rd Book, 4th Chapter, Fol. 14. Section combined with perspective; Plan.

The approach of *The Five Books of Architecture* rests mainly on the drawings which are used to instruct those interested in architecture. It may be considered the first instructive handbook on architecture (Tzonis and Lefaivre 1990, p. *112*).
Graphic representations often depict final products of architecture such as buildings, building elements, interiors, ornaments, etc. Thus, they present knowledge on the appearance of these products. The graphic representations discussed above exemplify in particular the properties of consistency and abstraction. The property of consistency is demonstrated by the fact that graphic elements are recognised to depict columns, capitals, vaults, walls, etc. The property of abstraction is demonstrated by the fact that the drawings depict the appearance of building elements (and not, for example, their material or

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required only the fewest and tiniest illustrations. He wants to hold their attention by the elevated tone of his argument and by the elegance of his language." ([] by HA) construction detail) or that they leave out aspects such as masonry or tiling patterns on the floor.

Durand's *Préçis des Leçons d'Architecture* (1804) is a major document showing how a rigorous set of graphic representations can be used to encode design knowledge. An example is Plate *21* which shows how via the use of axes the composition of building can be achieved (see Figure II-4). The limited set of graphic entities (lines) shows the procedure how to establish the composition and can thus be considered a graphic design method. The example shows the particular potential for encoding a sequence of design decisions based on graphic representations. The drawings of axial systems display the properties of functionality and multiplicity. The property of functionality limits the kind and appearance of elements that are required to communicate the purpose of the graphic representation. The property of multiplicity aids in allowing the functional representation to encode this particular aspect of reality (by the use of axes).

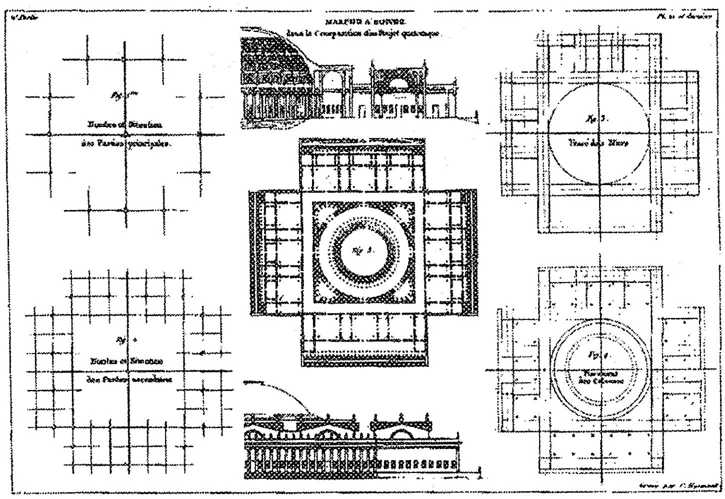

Figure II-4: J.-N.-L. Durand, Plate 21 "*Marche a Suivre dans la Composition d'un Project quelconque*" from *Préçis des Leçons d'Architecture* (1804). Plan development through system of axes.

Although conventions of depiction and conventions of encoding enable architects to interpret drawings consistently, this does not yet demonstrate how graphic representations encode specific knowledge contents. This feature of graphic representations can be discussed on the basis of studies on formal characteristics of architecture undertaken from the 1960'ies onward.

Figure II-5: Nolli-type drawing by Herdeg. From: Herdeg 1990, p. 37.

These contemporary studies often explicitly concentrate on the analysis of graphic representations to reach this goal or on the use of graphic representations to communicate the results of formal analyses. The National Building Agency publication *Generic Plans* (1965) shows a survey of possible building plans presented by careful use of a restricted set of graphic elements in schematic drawings. Sherwood *Modern Housing Prototypes* (1979) discusses general characteristics of building types in a series of consistently drawn diagrams. Herdeg *Formal Structure in Indian Architecture* (1967) and *Formal Structure in Islamic Architecture of Iran and Turkistan* (1990) presents surveys and analyses of vernacular architecture through strictly defined conventions of depiction and encoding (see Figure II-5). More specific uses restricted to a particular case are demonstrated by analyses of Palladian villa's (Wittkower 1973, p. 73: see Figure II-6), figure-ground analyses of mass-space distribution in buildings (Zevi 1974, p. 50-51), and refinement analysis (Oxman and Oxman 1992).

The graphic representations discussed above exemplify in particular the property of organisation. More specifically the way graphics are constructed from the manner in which they are defined is a matter of organisation. In the

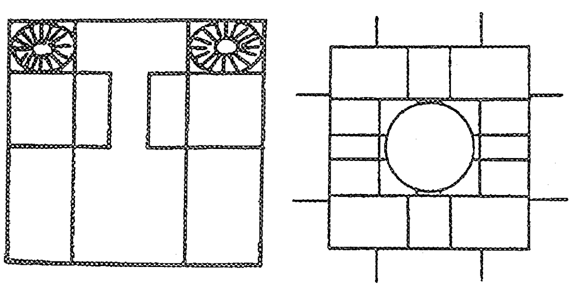

Figure II-6: Rudolf Wittkower. Study of Palladian villa's. From: *Architectural Principles in the Age of Humanism* (1973), p. 73.

formal studies mentioned above, it is used through the careful application of a limited number of graphic entities.

The review above presents a brief historical overview of the use of graphic representations in historical sources:

- (33-14 BC) Vitruvius: *The Ten Books of Architecture.*
- (1225-1250) Villard de Honnecourt: *Lodge-book.*
- (1485) Alberti: *On the Art of Building in Ten Books.*
- (1611) Serlio: *The Five Books of Architecture.*
- (1804) Durand: *Préçis des Leçons d'Architecture.*
- (1965) National Building Agency: *Generic Plans.*
- (1967) Herdeg: *Formal Structure in Indian Architecture.*
- (1973) Wittkower: *Architectural Principles in the Age of Humanism.*

The examples from these sources demonstrate that graphic representations are instrumental in conveying architectural knowledge. Graphic representations vary to a great extent in their appearance as is exemplified in the depiction of plans, vault construction, section, and perspective, plan development through axial systems, Nolli-type drawing, and schematised plans. The following observations about the examples are of particular interest:

- Under the assumption of a particular convention of depiction (plan, perspective, section, etc.) a graphic representation does not need extensive textual elaboration in order to produce a correct interpretation (the examples presented in the text - Villard de Honnecourt, Serlio, Durand, Herdeg, and Wittkower - are quite straightforward to interpret). This means that the constituent graphic elements of the graphic representation provide strong clues about the interpretation, and that these elements do not change very much over a long period of time.
- In the identification of the graphic representation (such as 'wall with columns and vault system,' 'wall with columns,' 'axial system,' 'public-private space,' and 'subdivision of a shape') the identified elements are not the most basic elements (vertices, lines, planes, etc.) but aggregates of these elements with a particular interpretation (*e.g.* closed polygonal shape with constant thickness and particular hatching indicating a wall, closed filled-in circle indicating a column, set of lines and circles indicating a vault system, etc.). This means that the architectural elements that play a role in decision making have a match in graphic entities. Furthermore, these entities are not established on the lowest level (vertices, lines, planes, etc.) nor on the highest level (interpretation from the complete drawing), but rather on a

'middle level' (aggregates defining architectural elements) of the graphic representation.

- A 'correct' architectural graphic representation (that is, a graphic representation that makes sense in a particular convention of depiction and encoding) presents a feasible and well-balanced whole. Consider for example the left graphic representation of Figure II-6. The convention of depiction is the plan. The convention of encoding consists of lines forming either rectangular shapes or oval shapes with internal lines. Under these conventions, it is proper to speak of 'rooms' and 'stairs.' The 'stairs' are confined within a rectangular shape. They fit exactly in this shape, and do not cross the boundaries. The lines of the rectangular shapes are aligned and do not overlap. Under the assumption of the plan and the interpretation of 'rooms' and 'stairs,' the drawing would not make sense if the rooms were shifted, overlapping, or if the stairs were larger than the space they fit in. This demonstrates that in a well-constructed graphic representation a number of conflicts between elements are 'solved.'

2.3 Graphic units and generic representations

Not all design decisions made in a design process are represented by means of graphic representations. Structural engineering calculations and actions such as consultation of design participants and checking norms occur throughout the design process and are not represented as such by graphic representations. However, the results of these actions are ultimately reflected in the graphic representations of the design (Koutamanis 1990). The notion that graphic representations encode knowledge of a building type therefore, can be constructed as follows:

- At some point in the design process, a graphic representation is established that represents the state of the design.
- In the graphic representations, elements that play a role in the decision process are depicted.
- Design decisions relative to the graphic representation are about the elements and the relations between the elements.
- If the design decisions are known, it is also possible to state which knowledge is required.

One particular strategy that can be taken to extract knowledge from graphic representations is by analysing its constituent elements (conventionally identified as vertices, lines, and planes). Studies of graphic representations such as automated plan recognition (Koutamanis 1990) and emergent shapes (Stiny 1990, Nagakura 1990) aim to extract knowledge from graphic representations on this basis. Their approach is to yield understanding in a bottom-up manner, studying primitive elements of graphic representations and constructing *meaningful* aggregates of these elements.

The size and complexity of graphic representations is the cause that this kind of bottom-up construction gives rise to a combinatorial explosion. There is also a problem of determining the meaning of graphic elements. This can only be achieved under the assumption that the images actually constitute architectural images such as plans (in the case of automated plan recognition) and organisation of spaces (in the case of emergent shapes).

Given the discussion in the previous section, it is proposed that by using conventions of depiction and convention of encoding, architects structure and constrain the combinatorial explosion. In this way, the number of interpretations of different kinds of graphic representations may be limited[7]. Conventions of depiction constrain the options how to interpret a graphic representation by allowing such forms of depiction as plan, section, perspective, axonometric, etc. Conventions of decoding constrain the options how to aggregate graphic entities by allowing only particular sets of line-thickness, hatching patterns, symbols, etc. This approach is also reflected in work by Gross *et al.* (1988); Gross (1990) and Ervin (1990), who acknowledge and implement the knowledge encoding properties of diagrams.

In the research work, the graphic representations that are studied are constrained to the convention of depiction of the plan. As has been observed with respect to the graphic representations above, graphic entities on the 'middle level' exhibit constancy in appearance and meaning. Therefore, it is proposed that graphic representations can be analysed by identifying these entities. They are called "graphic units."

- *Graphic unit*: A specified set of graphic entities that has a generally accepted meaning within the design community. Examples are: black circles denoting columns, closed polygonal shapes with letters denoting functional zones, and line-drawings denoting furniture.

A graphic representation consists of graphic units. Identification of the graphic units gives the elements that play a role in the decisions taken when this particular graphic representation is established. The concept of the graphic unit

[7] This view coheres with the general cognitive theory on representations outlined in Eckardt (1993, p. *144-152*) which insists on a triadic relationship between an object, a representation, and an observer of the representation. Thus, a representation is interpreted relative to an observer who may have some predefined assumptions about the nature of the representation.

separates between appearance and meaning. The general definition of the appearance allows for a great variety in the graphic representation while preserving constant interpretation.

A 'zone' for example, is defined by (filled) closed polygonal shapes. The boundary of the zone is represented by single lines, which can be left out in the case that the zone-area is filled with a hatching pattern. These features define the appearance of the 'zone.' The meaning of a zone is defined as an area which has specific properties. This definition of zone makes no statements about the particular shape of the zone; it can be linear, curved, circular, polygonal, etc. However, once a particular element has been recognised as depicting a 'zone,' it is clear how the element is used in design, what its significance in the design process is, and which decisions it relates to.

Through the use of graphic units it is possible to categorise the variety of graphic representations as belonging to a particular kind of graphic representation with a specific set of graphic units. Such graphic representations with the same graphic units deal with the same design decisions, irrespective of the particular appearance. It is proposed to call these kinds of representations that have specified graphic units "generic representations." They are termed "generic" because they consist of generally defined graphic elements - graphic units - rather than specific graphic elements and because they deal with the same kind of design decisions.

- *Generic representation*: A class of graphic representations denoting a particular state of the design object. A generic representation consists of a specified set of graphic units.

If the link between design decision and generic representation is valid, it is possible to discuss a sequence of design decisions by means of a sequence of generic representations. Each generic representation consists of a specified set of graphic units. Therefore, going from one generic representation to the next (one design decision to the next) is reflected by changes in the graphic units of the generic representation.

The graphic unit and generic representation provide the tools to establish which design decisions are taken in a particular graphic representation, and to define how generic representations can be put in a sequence (see Figure II-7).

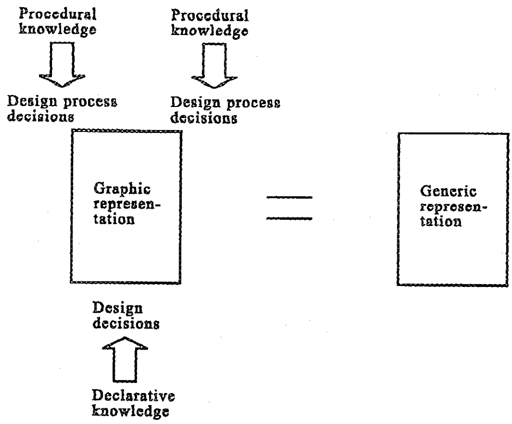

Figure II-7: One step (graphic representation) in the model of Section *1.3* is represented by a generic representation.

The model of Section *1.3* (Figure I-2) to conclude, can now be described in terms of the concepts introduced in this Chapter (see Figure II-8). If a graphic representation can be classified as a particular generic representation by means of its graphic units, then the elements that play a role in the design decisions that are taken in that specific graphic representation can also be identified by means of the graphic units. The generic representation deals with particular design decisions. Since these require declarative knowledge of the building type, for each generic representation it is possible to map this knowledge. The sequence of generic representations can be established on the basis of the graphic unit.

Substitution of Figure II-7 in Figure I-2 of Section *1.3* leads to Figure II-8. This figure states in compressed form the basic approach of the research. By means of this model, it is possible to discuss procedural and declarative knowledge.

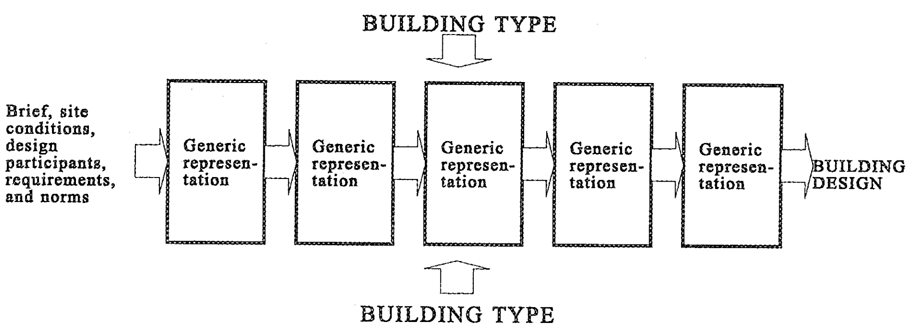

Figure II-8: The model of Section *1.3* more precisely defined. Graphic representations are substituted by generic representations.

2.4 Procedural and declarative knowledge

Declarative knowledge, as stated by Hamel (1990), is the class of knowledge that contains facts and principles in a discipline such as construction techniques, structure, ergonomics, installations, dimensioning, materials, cost calculation, history, norms. It is essential to point out that declarative knowledge does not inform in which order design decisions are taken. In the research work, declarative knowledge is the knowledge encoded in generic representations by means of graphic units. The graphic unit determines which design decisions are taken in the generic representation.

Procedural knowledge is the class of knowledge that contains information about actions and how to proceed in a discipline such as kinds of design goals, information sources, aspects of assignments, means to comply to norms and their limitations, structure of subproblems (Hamel 1990). The order in the design process requires knowledge of the proper sequence of design decisions. This knowledge therefore, is procedural knowledge. Since the order of generic representations is defined in the model as a sequence of generic representations, procedural knowledge in the model is associated with the transitions between generic representations (see Figure II-7). In the research work, procedural knowledge is encoded in the state transitions of generic representations. These transitions can be explicitly defined on the basis of graphic units and generic representations.

The building type offers the architect knowledge of form, function, and process of a class of buildings. Declarative knowledge is required to determine the single generic representations. Therefore it is associated with the aspects of form and function of the building type. Procedural knowledge is required to determine the order of generic representations. Therefore it is associated with the aspect of process of the building type.

Conclusion

Graphic representations consistently encode the things they represent. In order to establish their use as a medium for encoding procedural and declarative knowledge, it is necessary to define what design decisions are taken when a designer is using a particular graphic representation. The approach formulated here is to focus on the constituent elements of a graphic representation: graphic units. Through description by means of graphic units it is possible to arrive at graphic representations that deal with specific design decisions: generic representations. The next Chapter deals with the question if it possible to establish generic representations on the basis of the graphic unit and whether these generic representations are diverse and varied enough to support the numerous design decisions that a design process requires.

3 SURVEY OF GRAPHIC REPRESENTATIONS

Generic Representations in Architecture

Introduction

In Chapter 2 the required terms are introduced to analyse the relation between graphic representations and design decisions. In the present Chapter, a methodology for analysis based on the notions of graphic unit and generic representation is presented and applied to graphic representations taken from books on architecture. The implications of the resulting set of generic representations are analysed. For this purpose, the relations between generic representations on the basis of graphic units and on the basis of groups of generic representations are discussed. This results in assessing the completeness of the survey and identifying possible hiatuses.

3.1 Methodology of analysis

The analysis of graphic representations proceeds by applying the notions graphic unit and generic representation introduced in Chapter *2* on concrete graphic representations. The procedure is as follows:

1. Survey and selection of sources with graphic representations.
2. Selection of graphic representations.
3. Analysis of graphic representations.
4. Definition of generic representations.

3.1.1 Survey of sources

As has been demonstrated in the previous chapter, architects and architectural theorists have used graphic representations to convey architectural issues in their writings. The aim of the research is to investigate graphic representations as a medium for knowledge encoding. It is necessary therefore, to find a varied sample of graphic representations that can be used for the analysis. The selected sources must display variation in approach of graphic representations (addressing issues such as scale, composition, process, etc.), vary in time (in order to capture a historical body of material), and they have to be generally accessible (in order to rely on widely available material).

It has not always been possible to retrieve the original sources for a number of graphic representations found in the sources of the survey. A number of them appear originally in other sources. Appendix *A* provides an annotated list of the sources used in the selection.

3.1.2 Selection of graphic representations

Building types address the spatial-functional organisation of buildings. These aspects are best represented by the plan. Knowledge of building types encompasses the complete building. The graphic representations that are taken from the books therefore, must be plan-based and depict major aspects of the building. Furthermore, graphic representations must display some salient features about the design. This means they should not exceed some level of complexity in what they depict (see discussion with respect to Figure III-2).

The selection process is illustrated by showing the selection of graphic representations in the case of Villard de Honnecourt's *Lodgebook* and Durand's *Précis des Leçons d'Architecture donnees a l'Ecole Royale Polytechnique*.

Villard de Honnecourt: Lodge book

The graphic representations are taken from Bucher, *Architector. The Lodge Books and Sketchbooks of Medieval Architects.* The pages with drawings that make up the lodge book are numbered in Bucher (1979) in the same manner as in the lodge book (*e.g.*, the seventh page in the lodge book is indicated here as *V7*). Some drawings can be discarded directly: they depict figures, animals, plants, details, etc. A number of plan-based graphic representations are left:

- *V14*: Labyrinth.
- *V18*: Tower of Laon cathedral. Plan of a floor.
- *V28*: Left below: Ideal Cistercian plan. Right below: Choir of Cambrai cathedral.
- *V29*: Ideal plan; in this case Chevet of St. Stephen in Meaux.
- *V33*: Choir of Saint Mary of Vaucelles.
- *V41*: Star vault construction in square plan.
- p. *181*: Schematic study of *V18*.

The descriptions of the drawings, for example "Tower of Laon cathedral," "Ideal Cistercian plan," and "Choir of Saint Mary of Vaucelles" are taken from the text by Bucher. The description aids in determining what the drawing represents.

From this set, not all graphic representations are used in the analysis: the Choir of Cambrai cathedral on *V28*, and the images of *V29* and *V33* are discarded because they are incomplete in depiction.

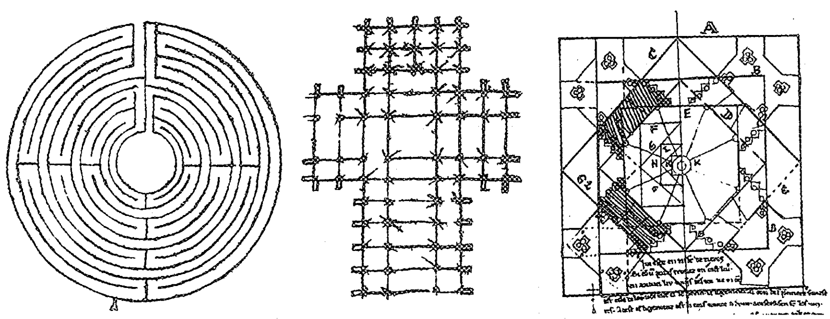

Figure III-1: Remaining images from Villard de Honnecourt's sketchbooks after selection criteria have been applied (*V14*, *V28* left below, and p. *181* Bucher (1979).

Durand: Précis des Leçons d'Architecture donnees a l'Ecole Royale Polytechnique

The *Précis des Leçons d'Architecture donnees a l'Ecole Royale Polytechnique* (hereafter: Précis), are a three volume set named *Premier Volume*, *Second Volume*, and *Partie Graphique des Cours d'Architecture* (hereafter: Partie).

Graphic representations depicting facades, sections, etc. are discarded from the analysis. Of the resulting set of plan-based graphic representations, not all are used in the analysis.

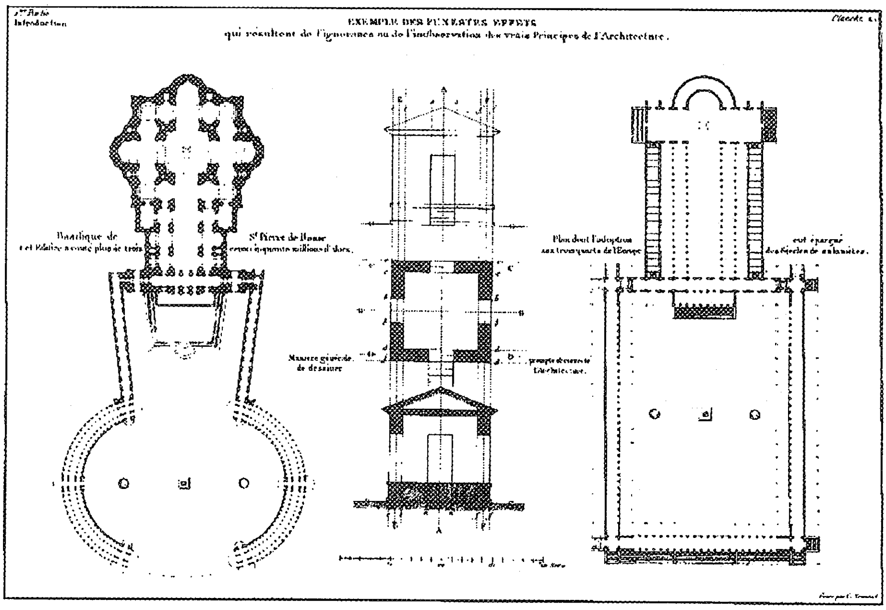

Figure III-2: Jean-Nicholas Louis Durand: *Précis* (1804), Premier Volume, Plate 2. Sample page of the *Précis*.

Figure III-2 shows a page from the *Précis*, Plate 2. Five drawings can be distinguished. The facade and section drawings are discarded from the analysis. However, the left and right plans also are not selected for the analysis. These plans are quite complex and present drawings in which most design decisions are taken and have been fixed. They represent a large number of decisions at the same time, of which it is not possible to delineate the order of establishing the decisions. In that sense, they seem less applicable for analysis. Contrary to the left and right figures, the central plan displays a limited number of elements. It exhibits the property of reduction which enables identification of features with more ease and reliability than the left and right figures.

Durand's *Précis* also include many graphic representations that do not completely depict buildings. These are interesting for the research however, since they demonstrate particular principles. Figure III-3 shows a number of these graphic representations. They all demonstrate how specific sets of elements can be placed and arranged relative to each other in a grid. These graphic representations do not depict a complete building. Because of their strong reduction of content they display important principles in architectural design, that are not easy to find in more elaborate (complete) representations of buildings. Therefore, these kinds of drawings are included. As has been noted in Section 2.2, Durand's *Précis* is one of the first sources in which a consistent and rigorous manner of presentation is used throughout the book. The *Précis*

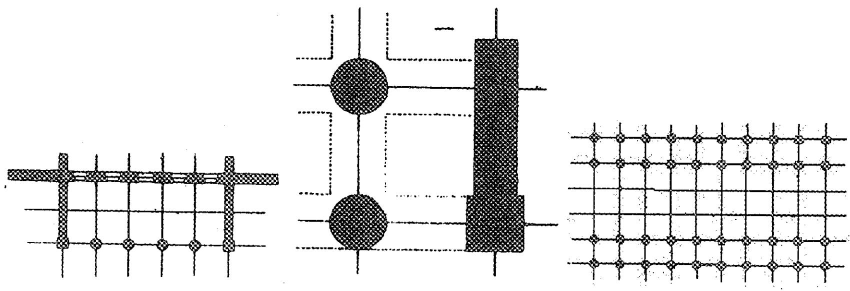

Figure III-3: Jean-Nicholas Louis Durand: *Précis*, Premier Volume, 2e Partie, Plate 1 (1804). Three graphic representations from Plate 1.

provide a large number of cases for the analysis.
In the manner described above, collections of plan-based graphic representations that depict buildings in various ways are established from the sources mentioned above.

3.1.3 Analysis of graphic representations

The aim of the analysis is to establish the graphic units that are part of the graphic representation, the associated design decisions of the graphic units, and the general knowledge content of graphic representations. These knowledge contents are defined indirectly by analysing what design decisions a graphic representation implies when it is established. The graphic unit is used as a means to extract these decisions. Graphic units consist of a set of graphic entities with a specific meaning. It is necessary to distinguish between graphic entities and meaning because graphic entities by themselves are insufficient to establish design decisions graphic representations imply.
This can be demonstrated by the examples in Figure III-4. On the left, a circle, triangle, and square are depicted. In the middle, a layout is presented. The right figure shows a complex black contour and a hatched contour. The left and the middle figures can be described by lines. However, with respect to the decisions involved, the circle, triangle, and square are different from the layout:

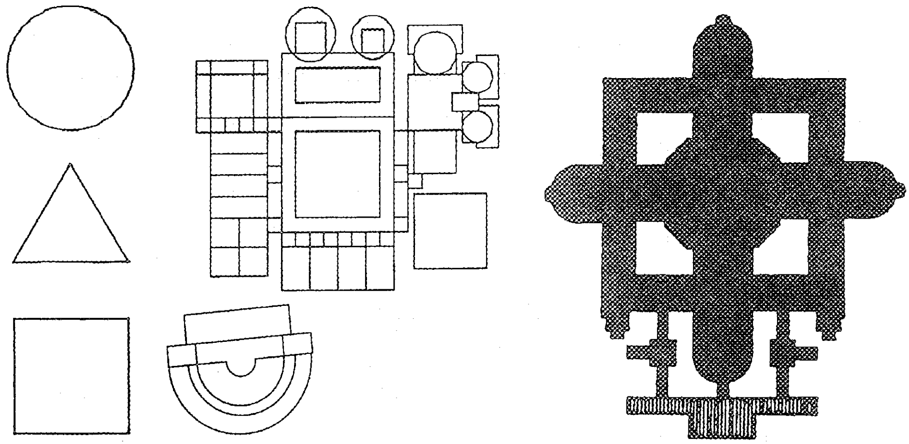

Figure III-4: Three drawings with different graphic units. Left: 'simple contours' (Ching 1979, p. 54). Middle: 'contours' (Mitchell and McCullough 1991, p. 136). Right: 'complementary contours' (Zevi 1974, p. 51).

1. Circle, triangle, and square are instances of regular n-sided polygons (n=3, 4, 5,...), including the circle. These shapes can be characterised by the term "simple contour." Under the assumption that the graphic representation depicts a building[9], the "simple contour" represents the building envelope, where the lines indicate the edge of the building envelope.
2. The shapes that make up the layout are composite forms of rectangles and circles, and more complex shapes. Under the assumption that the graphic representation depicts a building, this drawing represents a differentiated building layout, where the lines of the shapes indicate borders between major spaces.
3. The shapes of the layout are not always "simple contours," but in all cases they are "contours." Therefore, it is possible to conclude that drawing a *simple contour* implies the decision to limit the possible shape to a specific class of shapes. Drawing a *combination of contours* implies the decision to use particular contours and to establish their relations concerning place and relative scale.
4. Thus, two graphic units can be distinguished: *simple contour* and *contour*, which are instances of two generic representations: "simple contour" (which has one graphic unit, the *simple contour*), and "combination of contours" (which has one graphic unit, the *contour*).

[9] The graphic representation taken by itself does not support a unambiguous choice between interpreting for example the circle as a column, building part, building, or city. The building assumption aids in the interpretation and in establishing the decisions involved with this graphic representation. Without the assumption and interpretation analysis is not possible.

Both the layout (middle figure) and the filled-in black and hatched drawing on the right of Figure III-4 can be conceived of as combinations of contours. However, they are different from each other:

1. In the layout, all shapes are represented by lines only. Under the assumption that the graphic representation depicts a building, it represents a differentiated building layout, where the lines of the shapes indicate borders between major spaces.
2. In the filled-in black and hatched drawing on the right, a graphic distinction is made by adding colour (black or hatching pattern) to complex shapes. Furthermore, there is no graphic clue about how the complex shape is constructed from more simple shapes. Under the assumption that the graphic representation depicts a building, it represents the mass-space distribution of the building[10], where the lines and edges indicate borders between space and mass, and the colours (black, white, hatched) identify either mass or space.
3. In the layout, there is no distinction between mass and space. In the filled-in black and hatched drawing there is a distinction between mass and space. Therefore, both drawings imply different design decisions. In the first case, as has been noted above, the layout implies the decision to use particular contours and to establish their relations concerning place and relative scale. In the second case, the filled-in black and hatched drawing implies the decision how to articulate mass and space and their edges.
4. Thus, a new graphic unit can be identified: *complementary contours*, and a new generic representation: complementary contours (which has one graphic unit: *complementary contours*).

Describing the form aspects of graphic units results in a vocabulary which uses terms such as regular n-sided (n=*3*, *4*, *5*, ...) polygonal shapes, closed polygonal shapes, filled-in (black, white, hatched, etc.) polygonal shapes, interlocked surfaces, etc. for shapes; single line, double line, line weight, linetype, etc. for lines; and direction, parallel, module, irregular distance, colour, and hatching, etc. for describing sets of graphic entities. During the analysis, the vocabulary becomes more sophisticated. The vocabulary demonstrates that it is important to carefully distinguish between graphic

[10] The technique that is used in the graphic representation is generally referred to as figure-ground analysis. Conventionally, material is depicted black and space is implied by material. By reversing this code the graphic representation shows how space is articulated. The technique is also applied on the urban level in the so-called Nolli-type map. The meaning of the same shapes changes from "material" (white) versus "space" (black) into "public space" (white) versus "private space" (black).

entities that occur in a drawing. These provide the first clues on the basis of which graphic units can be identified.

Through the use of graphic units it is possible to distinguish between graphic representations that apply the same sets of graphic entities but that differ because the graphic entities are interpreted differently (different graphic units). Different design decisions can be identified on the basis of graphic units. In the manner outlined above, all graphic representations are described in terms of graphic units.

3.1.4 Definition of generic representations

The analysis of graphic representations on the basis of their constituent graphic units yields a large set of drawings that are described in terms of graphic units and their associated design decisions. This analysis must result in ordered sets of generic representations which have the same graphic units. Such a set of similar graphic representations constitute examples of a generic representation.

Analysis proceeds by single graphic representations at a time. Given the number of graphic representations, a consistent grouping and naming of graphic units is not established in one run. The ordering process is iterative and requires a number of cycles. It is performed in two major stages, each of which has a number of cycles for refinement and consistency checks:

1. Textual description of each graphic representations in terms of graphic units. This yields a vocabulary for describing forms and a vocabulary of graphic units. The graphic representations are grouped on the basis of similar graphic units. The grouping process is text-based and controlled by checking whether the graphic representations are similar in appearance.
2. Detailed graphic analysis of graphic representations. On the basis of a particular format (see Section *3.2*), the graphic units are extracted from the graphic representations and the generic representation is depicted in a structured manner. This stage gives a further check on consistency and naming. It yields a structured set of generic representations.

In order to facilitate the first stage, a tool is required that can combine graphics (the analysed graphic representations) with text (comments on the meaning of the graphic representations), and that easily allows making different orders. The tool that is used for this purpose is an html-viewer[11] and an ASCI-text editor. This tool has the following advantages:

- Easy combination of graphics and text.

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[11] Netscape Navigator™ Version 3.01, Copyright © 1994-1996 Netscape Communications Corporation

- The hyperlink functionality of the html-language allows partitioning of the groups so that speed and size of presentation of the groups are not compromised by the number of graphic representations.
- Cross-referencing by hyperlinks to sources to support a check whether all graphic representations are used.

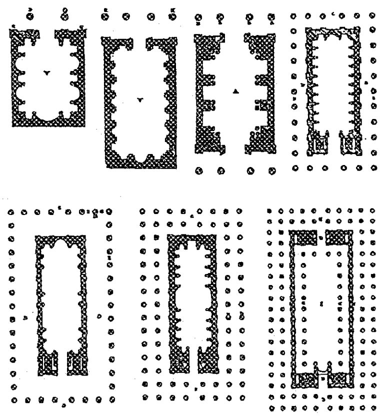


Figure III-5: Seven plans by Rusconi (1590) in Tzonis (1986), p. 175, figure 104.

All graphic representations of the set are scanned electronically and systematically numbered by filename. The encoding of the files is drawing-based. For example, Tzonis (1986) p. 175, figure 104 counts seven graphic representations of classic temples that are depicted in the same way (see Figure III-5). The images are scanned in two rows. The upper row is coded: tz_f104a.gif and the lower row is coded: tz_f104b.gif (*tz*: Tzonis (1986), *f104*: figure 104, *a/b*: distinguish between rows). If any single plan is used from these rows, a numeral is added.
In the second stage the constituent graphic units are analysed in more detail. Generic representations are identified on the basis of these findings. This stage requires careful extraction of graphic units from the graphic representations. Since graphic representations are already available in electronic format, this process is performed by graphics software.

3.2 Presentation of case studies

The set of generic representations can be described by the following features: (1) *name*, (2) *source*, (3) *graphic representation*, (4) *textual description*, (5) *graphic units*, and (6) *iconic representation*.

<table>
<tr><th colspan="2">Name of the generic representation (number)</th></tr>
<tr><td>Graphic representations:
- picture of case -
Image from the source list on right side of table

- source of picture -
Text identifying the image</td><td>Sources:
- list of sources and pictures -
Sources of the images, place in the source, and brief description of the image included in the graphic representation section
Description:
- description of graphic representations -
Text describing the use of graphic representations in the design process, the related design decisions, and the graphic units found. The graphic units are named and given a number to distinguish them more easily. The numbering corresponds to the summary in Section 3.4.</td></tr>
<tr><td>Graphic units:
- drawings of graphic units -
The graphic units as they occur in the graphic representations section above. It is possible that graphic representations have more than one graphic unit. The numbers correspond to the text in the Description section.</td><td>Icon (number):
- schematic representation -
The salient features of the graphic representations are shown by a drawing consisting of graphic units. In this way, the properties of the diverse drawings in the graphic representations section are made clear. The icon therefore, shows the generic representation that can be derived from the graphic representations of the case study. The number corresponds to the summary in Section 3.5.</td></tr>
</table>

Figure III-6: The format of presentation of generic representations.

3.2.1 Name of generic representation

A generic representation can be concisely described by a name indicating its characteristics. The name is a statement in terms of the graphic units that make up the generic representation. By naming the generic representations, the architectural issues concerned are concisely identified.

3.2.2 Sources of generic representation

A list of all cases of graphic representations found in the literature that have the same knowledge content with respect to generic representations. There are often multiple graphic representations on a single page in a source. Where indicated in the source, the numbering of the original author has been followed. Where identification of figures is unclear, the following convention is applied: numbering by letters of the alphabet, starting at the top-left, ending bottom-right, working in a top-down manner.

Since identification of the graphic units in the graphic representations is context dependent (what does the image represent?) each source in the list that is depicted in the graphic representation section has a brief description of what is depicted.

3.2.3 Graphic representation

In this section, a number of graphic representations from the source-list are shown. Preferably, the oldest images are presented. Not all graphic representations are drawn from original sources. For example, images from Rusconi's *Dell'architettura* (1590) are taken from Tzonis and Lefaivre's *Classical Architecture* (1986) (for an annotated list of sources see Appendix *A*). The source-list states both the origin and the book from which the graphic representations are taken, as well as their location in the latter source (*e.g.* Rusconi (1590) in Tzonis (1986), p. 175 figure 104). In the caption of the graphic representations part, a short hand notation is used, mentioning the original source and the location in the source from which the drawing is actually taken (*e.g.* Rusconi (1590), p. 175).

3.2.4 Textual description of generic representation

The textual description briefly indicates the function and decision aspects of the generic representation, and identifies the graphic units that constitute the generic representation. Functional aspects concern the use the graphic representation is put to in design. Decision aspects concern what decisions are taken when this specific generic representation is drawn. The graphic units define the generic representation. Since there can be more than one graphic unit in a graphic representation, the graphic units are numbered in a consistent manner in order to identify them in the graphic units section.

3.2.5 Graphic units

From the drawings presented in the graphic representations section, the constituent elements that make up graphic units are extracted and presented in this section. By showing graphic units as they are part of the drawings, the diversity in appearance of graphic units is demonstrated, and how the relationship *form* of the graphic unit and *interpretation* of the graphic unit is established. The numbering of graphic units corresponds to the numbering in the description section and the numbering of graphic units in Section *3.4*. (page *87-90*).

3.2.6 Iconic representation (number)

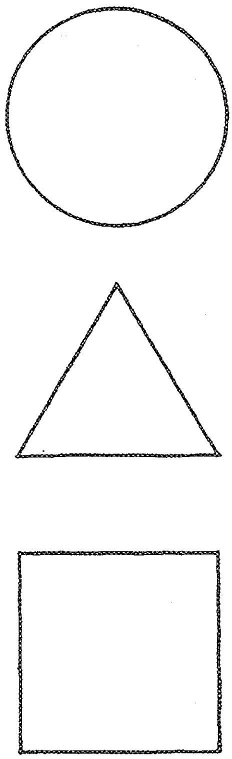
The graphic units that constitute the basis for the generic representation are highly specific and related to the source from which they are taken. Since most drawings of the survey depict specific building designs and almost no drawing represent the same design, it is difficult to provide a general understanding of the properties of the generic representation by the appearance of graphic units. In order to clarify the generic representation, it is depicted in an iconic manner which shows the salient features of the generic representation. The graphic units that make up the iconic representation of the generic representation are identical throughout all iconic representations in the survey. The iconic representation of the generic representation is numbered according to the list of generic representations of Section *3.5* (page *90-91*).

3.3 Survey of graphic representations

The following pages show the results of the survey of graphic representations structured in the manner described above. In general, the analyses are put in the order from simple cases to complex cases. For example, the first generic representations are simple contour (1), combination of contours (2), complementary contours (3), and proportion system (5) on pages *37-40*. They each have one graphic unit and are less complex than generic representations such as schematic subdivision and schematic axial system in contour (41), schematic subdivision in contour (21) on p. *61-62*. These generic representations have an increasing amount of graphic units. Furthermore, the analyses are put in an order that conveys how generic representations can become more complex by means of adding graphic units. For example, in the series proportion system (5), proportion system in contour (14), and proportion system in elaborated structural contour in tartan grid (35) on pages *40-42* cases are shown that become increasingly complex by adding graphic units *contour*, *elaborated structural contour*, and *tartan grid* to proportion system.

Simple contour (1)

Graphic representations:



Ching (1979), p. 54

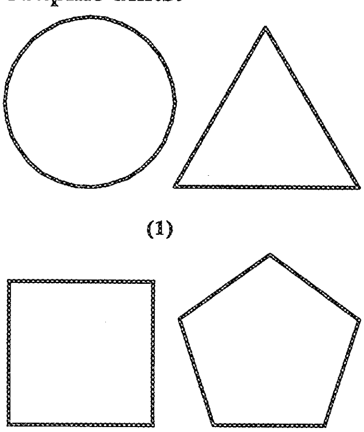
Sources:

Ching (1979), p. 54. Illustration of so-called 'primary shapes' that make up the basic shapes of geometry.

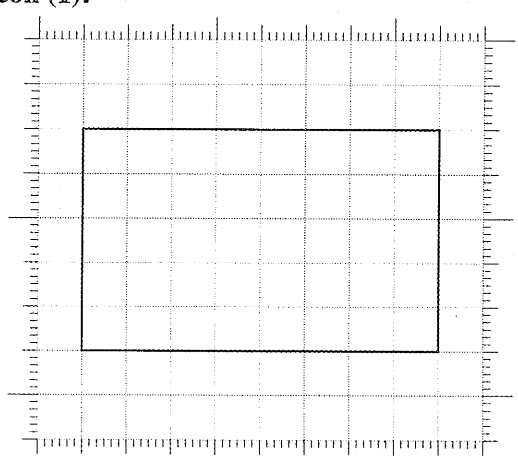
Description:

The simple contour consists of a single-line drawing which defines closed shapes. The line does not indicate any elaboration of the edge of the shape. Simple contours belong to the class of regular n-sides polygons (n=1,2,3,...) including the circle.
Decisions concern the restriction to a particular group of shapes. Simple contour defines the topological properties of a shape; its surface area, perimeter, and number of edges.
The graphic unit is the *simple contour*: a regular n-sides polygon, such as the circle, triangle, and square in the figure left (1).

Graphic units:

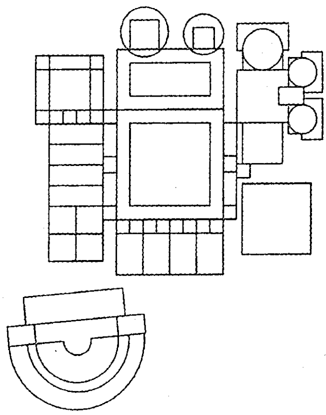


Icon (1):

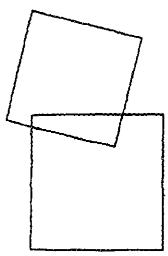


Combination of contours (2)

Graphic representations:



Mitchell and McCullough (1991), p. 136



Herdeg (1990b), p. 63 f. 7

Sources:

Ching (1979), p. 62, p. 88

Mitchell and McCullough (1991), p. 136. Illustration of composing a plan of polygons.

Herdeg (1990b), p. 63 figure 7, 8. Diagram of Turkistan house.

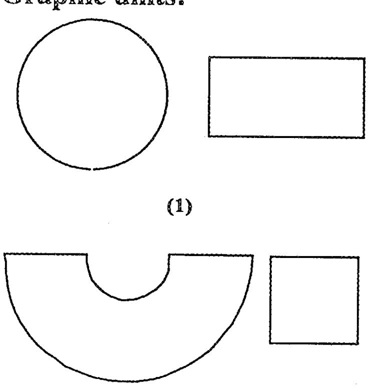
Description:

Combination of contours defines the composition of various simple contours put together. This can range from elaborate (top figure) to simple (bottom figure). It consists of a number of contours which do not have to be constrained to the class of simple contours.

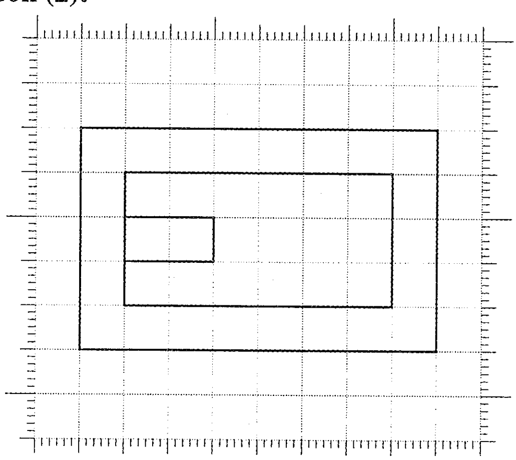
Decisions are made about relative positions, orientation, and proportion. Combination of contours provides conditions for functional assignment (function per contour), although in combination of contours this assignment is not provided. Combination of contours can lead to emergent shapes (*e.g.* the mutual area originating from both simple contours in the lower figure).

The graphic unit is the *contour*: closed shapes such as squares, rectangles, triangles, etc. (2).

Graphic units:

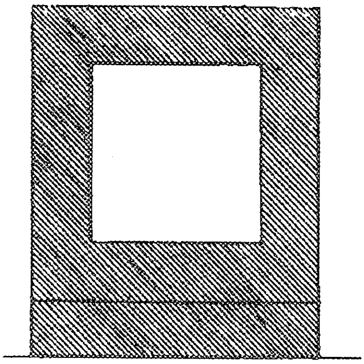


Icon (2):

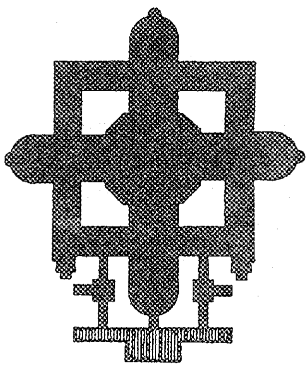


Complementary contours (3)

Graphic representations:



Durand (1804), Précis Second Volume Planche X



Zevi (1974), p. 51

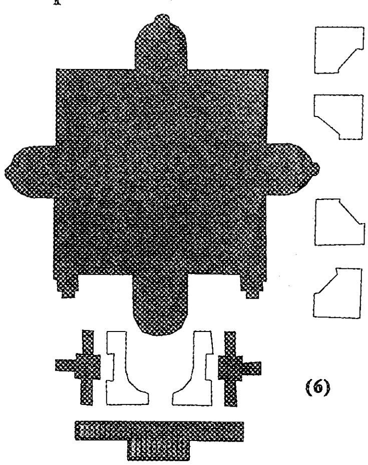
Sources:

Durand (1804), Précis, Second Volume Planche X, top and second row. Figure showing principle arrangement of building in lot.
Zevi (1974), p. 50, 51. Analysis of internal space of Michelangelo's design for St. Peter's, Rome.
Herdeg (1990a), p. 37 figure 5, p. 38 figure 1, 2
Herdeg (1990b), p. 19, figure H, p. 37, figure H

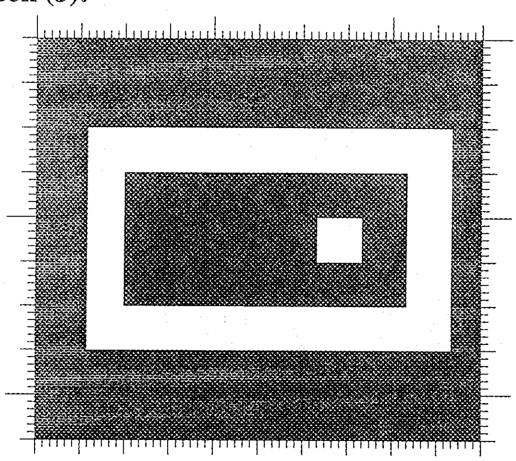
Description:

Complementary contours defines the interplay between mass and space in a building layout by figure/ground method. Particularly when space is represented black (see lower figure), it aids in understanding spatial continuity and the way spaces are defined. The linking of spaces is different in complementary contours than in for example a circulation system. It is more specific in the elaboration of the edge space-material.
Decisions involved are articulation of the edge between space and material, and the way spaces are connected.
The graphic unit is *complementary contours*: filled-in polygonal shapes (6).

Graphic units:

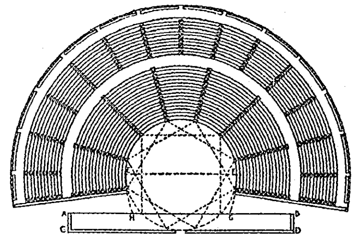


Icon (3):

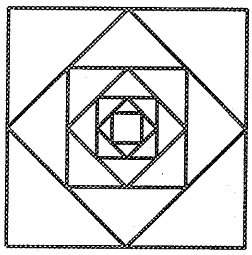


Proportion system (5)

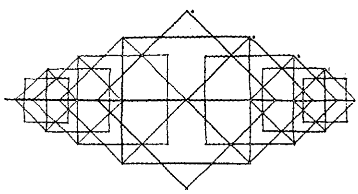
Graphic representations:



Vitruvius (33-14 BC), p. 152



Master WG (1560), p. 21 (redrawn)



Netsch in Schmertz (1980), p. 117

Sources:

Vitruvius (33-14 BC) in Morgan (1960), p. 152 figure B, C, p. 147. 'Roman theatre according to Vitruvius.'

Master WG (1560) in Bucher (1979), p. 21 (redrawn). 'Fundamental Gothic schema of the rotation of the square.'

Netsch in Schmertz (1980), p. 117 figure 2. Field development for north-east elevation Miami University Art Museum, Florida.

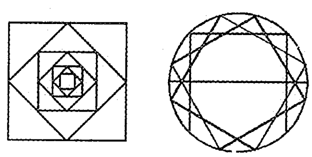
Description:

A proportion system defines the proportions between the key parts or the position of elements of the building. It provides a geometric structure which governs relations and positions. In the top figure the system is derived by rotating the square in a circle by 120 degrees. The middle figure shows rotation and nesting of the square by 45 degrees. The bottom figure shows a system of squares ordered on diagonals and axes that are placed on intersections.

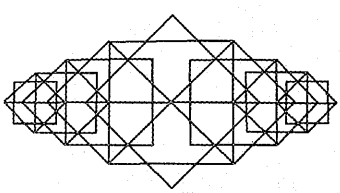
Decisions involve the measurement-sequence used in the design and the system of places established by the proportion system.

The graphic unit is the *proportion system*: lines (23).

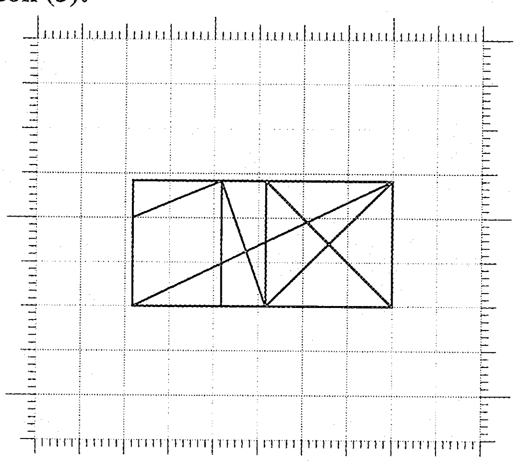
Graphic units:



(23)

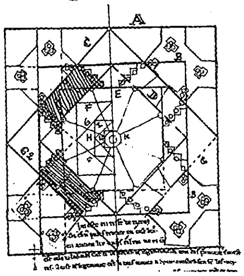


Icon (5):

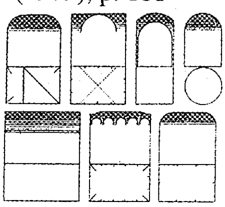


Proportion system in contour (14)

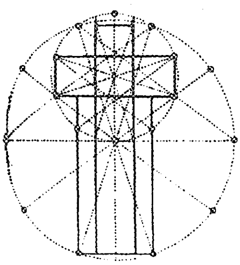
Graphic representations:



Bucher (1979), p. 181



Palladio (1738), Ch. 24, p. 30



Moessel in Ching (1979), p. 303

Sources:

Villard de Honnecourt (1215-1235) in Bucher (1979), p. 181. Diagram of gothic proportion system applied to plan of Tower of Laon cathedral.

Palladio (1738), Book 1 Chapter 24, p. 30. Room proportions related to vaulting systems.

Schmertz in Architectural Record 1980, p. 120, middle figure

Moessel in Ching (1979), p. 303 figure A, B, F. Standard Gothic plan.

Herdeg (1990a), p. 26 figure F, G, H

Clark and Pause (1985), p. 29 fig. J, p. 31 fig. J

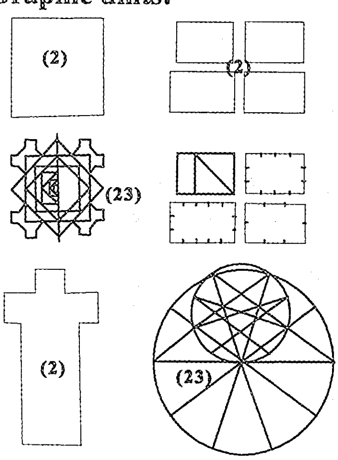
Description:

Combination of proportion system and contour results in determining the relative dimensions of the contour, and the placement of its parts or edges. This can be straightforward (see middle figure), or elaborate (bottom and top figures).

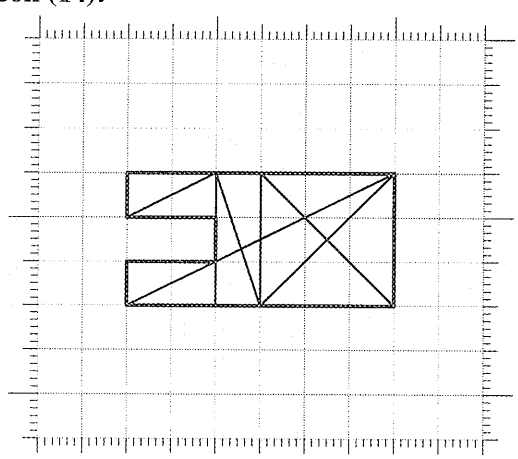
Decisions concern the interrelationship between the proportion system and the building design. The place and proportions of building parts are established.

Graphic units are *proportion system*: lines (23) and *contour*: closed polygonal shapes (2).

Graphic units:

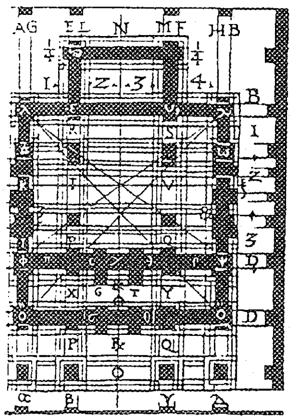


Icon (14):

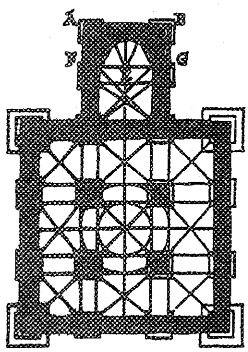


Proportion system in elaborated structural contour in tartan grid (35)

Graphic representations:



Cesariano (1521), p. 21



Cesariano (1521), p. 21

Sources:

Cesariano (1521) in Tzonis (1986), p. 21 figure 12 top left figure, bottom left figure. 'Grid patterns.'

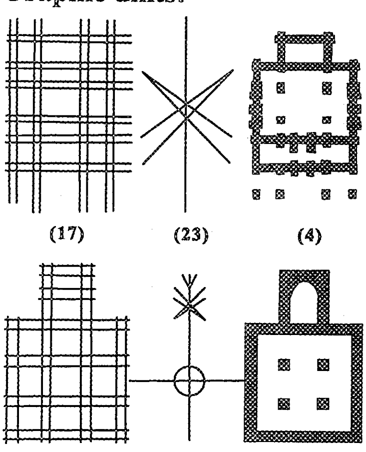
Description:

The combination of a proportion system and a grid is not common, since proportion systems often introduce fractions that are difficult to combine with the modular character of grids. A tartan grid is more flexible than a grid since it uses two modules at a time. A less strict defined tartan grid (changing modules) may adjust to a proportion system. The proportion systems in both figures are graphically inscribed through diagonals.

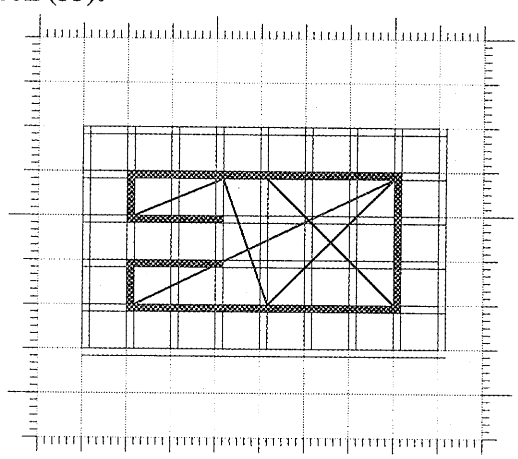
Decisions involve the place and shape of the contour in walls, columns, and such related to the tartan grid and proportions defined by the proportion system.

Graphic units are *proportion system*: lines (23), *tartan grid*: orthogonal set of lines (17), and *elaborated structural contour*: filled closed polygonal shapes (5).

Graphic units:

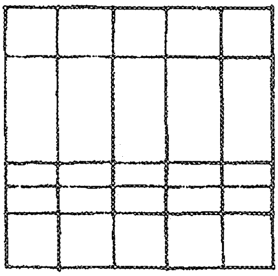


Icon (35):

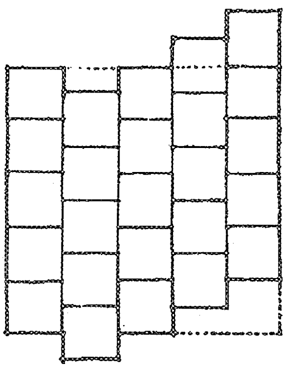


Modular field (4)

Graphic representations:



Ching (1979), p. 239 figure C



Ching (1979), p. 239 figure K

Sources:

Ching (1979), p. 205 figure 5

Ching (1979), p. 239 figure C. 'Irregular grid in one direction.'

Ching (1979), p. 239 figure K. Shifted 'bands' in a grid.

Ching (1979), p. 321

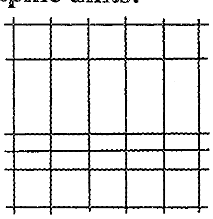
Description:

A modular field defines a system of lines that rule placing of elements in the plan. A modular field is different from a grid since the distances between the lines are not necessarily uniform in all directions, or within one direction. Thus different fields within the modular field may be established. The distances between lines have relevance for placing elements and as such are significant when stated explicitly in a graphic representation.

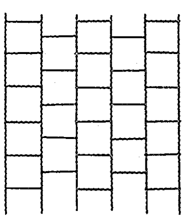
Decisions concern the structure where elements are to be placed, and the distance between lines.

The graphic unit is *modular field*: set of lines (11).

Graphic units:

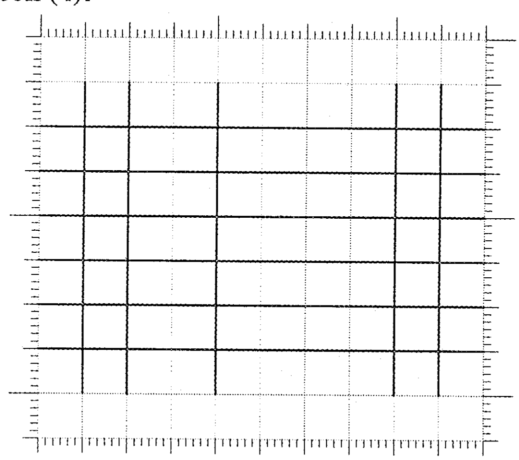


(11)



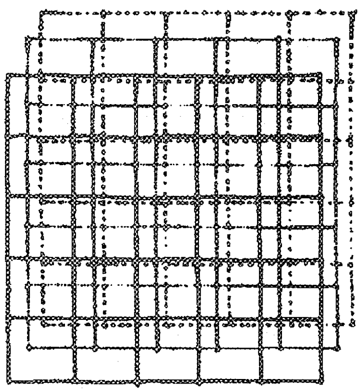
(11)

Icon (4):



Multiple grids (6)

Graphic representations:



Ching (1979), p. 239

Sources:

Ching (1979), p. 239 figure J. 'Layered grid.'

Description:

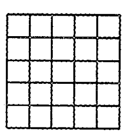
Multiple grids with the same or different module may be used in a shifted manner, thus introducing the same module for different purposes (*e.g.* spatial grid combined with a material grid and installations grid). In this way it is possible to resolve some conflicts of joint systems such as installations and room-partitioning.

The graphic unit of multiple grids is the single grid. A grid is a system of parallel lines (usually ordered in an orthogonal manner) that have a constant distance between them (module). Contrary to a modular field, a grid is regular in all directions. This property distinguishes it from the modular field and implies the decision to chose either one of them.

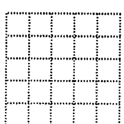
Decisions concern the relative positions of grids and the measure of the modules.

The graphic unit is the *grid*: orthogonal set of lines at specific distance (16).

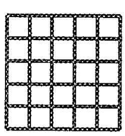
Graphic units:



(16)

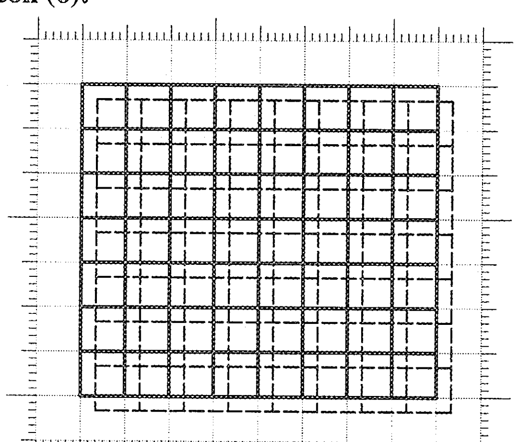


(16)



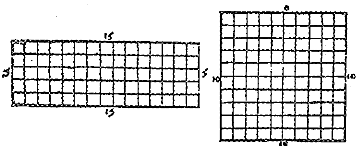
(16)

Icon (6):

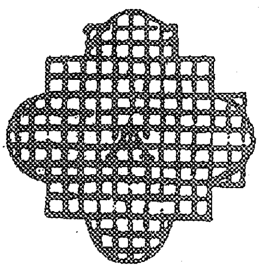


Contour in grid (15)

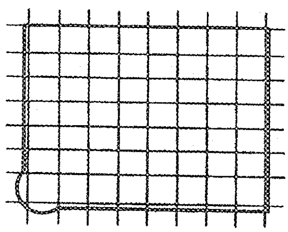
Graphic representations:



Serlio (1611), First Book First Chapter, Fol. 7



Cesariano (1521), p. 239



Sullivan in Clark and Pause (1985), p. 117

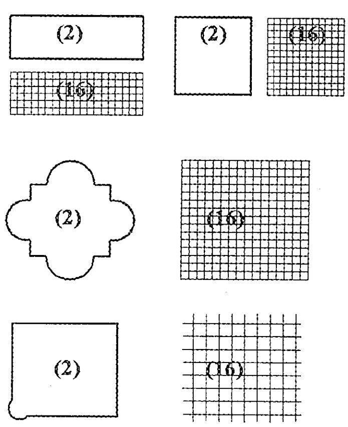
Sources:

Serlio (1611), First Book, First Chapter Fol. 7. Grid argument for demonstrating different surface areas with the same perimeter.
Cesariano (1521) in Tzonis (1986), p. 21 figure 10 top drawing. 'Grid pattern.'
Ching (1979), p. 239 figure B, D, H
Sullivan in Clark and Pause (1985), p. 117 figure F. Carson Pirie and Scott Store, Chicago, Illinois.

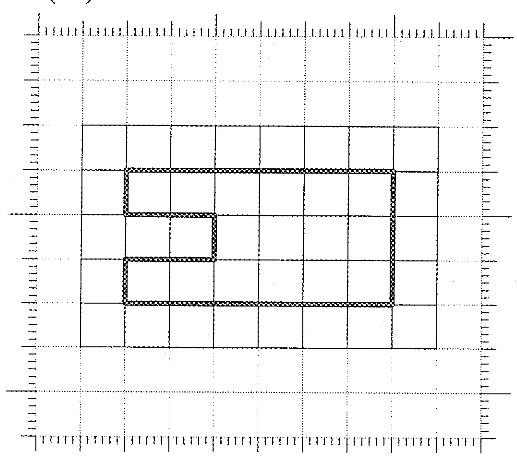
Description:

The grid structures the place of elements such as the perimeter (top), or columns (bottom). Not every part of the contour has to conform to the grid (middle). When the perimeter follows the grid, this establishes a surface area unit that can be used in the building to co-ordinate rooms and spaces. If the grid is used for a structural system (bottom) it is sometimes kept distant from the facade (contour) to resolve conflicts between columns and walls.
Decisions concern the relationship between contour and grid, in particular the dimension of the module with which the contour is measured.
Graphic units are the *grid*: orthogonal set of lines (16) and *contour*: closed polygonal shapes (2).

Graphic units:

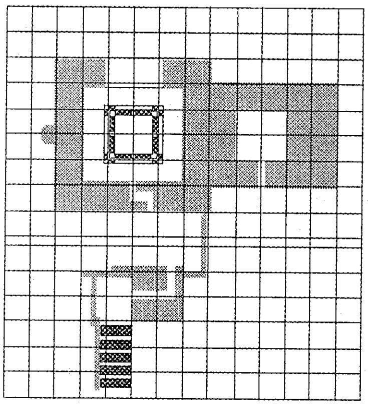


Icon (15):



Zone in contour in grid (36)

Graphic representations:



Herdeg (1990a), p. 43 (redrawn)

Sources:

Herdeg (1990a), p. 43 figure 3. Palace of sultan Baz Bahadur, Mandu, India.

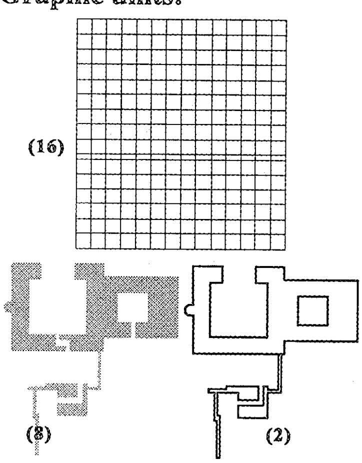
Description:

A zone can conform to the grid underlying the contours of the plan. In this manner, the dimensions and surface area of the zone relate to the unit of surface area established by the grid. A zone is an area with a particular attribution (such as functions, rooms, qualities, safety regulations). The zone within the contour indicates areas with specific properties such as function, circulation, meaning, etc. Elements placed in the zone have to comply with the attribution.

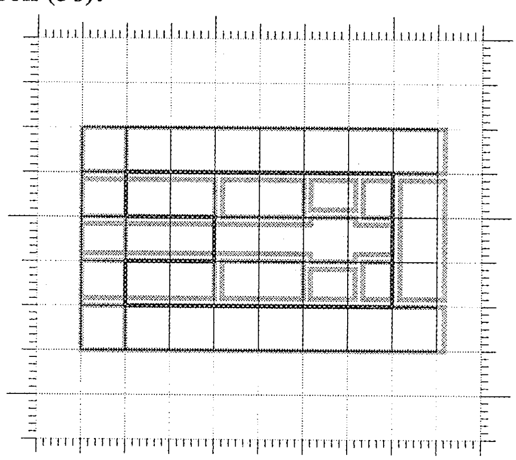
Decisions concern the organisation of the contour on the basis of the grid into zones. By zones, decisions on a general layout are made, which is constrained by choice to apply a grid. The contour indicates the building perimeters that is placed in the grid and relates to the zone.

Graphic units are the *grid*: set of orthogonal lines at specific distance (16), *zone*: (filled) closed polygonal shapes with different line-weights (8), and *contour*: closed polygonal shapes (2).

Graphic units:

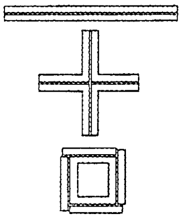


Icon (36):

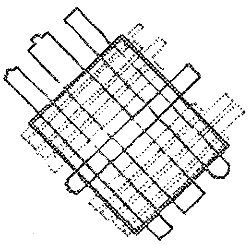


Zone in specified form (16)

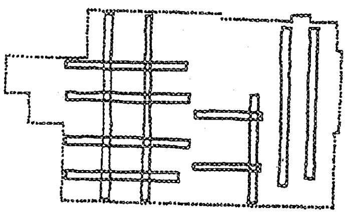
Graphic representations:



Tabor (1976), p. 370 .



Herdeg (1990b), p. 23



Herdeg (1990b), p. 43

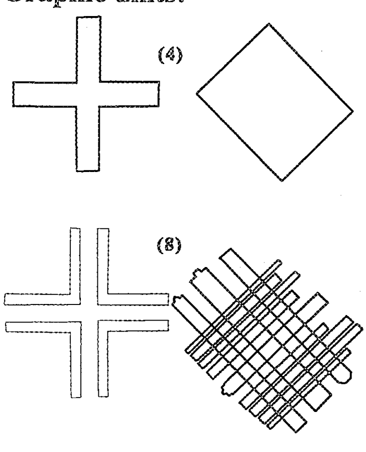
Sources:

Tabor in March (1976), p. 370 figure 10.21. Some principle layouts of circulation and office zones in basic office plan shapes.
Herdeg (1990a), p. 36 figure J, p. 18 figure 1,2
Herdeg (1990b), p. 23 figure 4. Grid of zones in courtyard of mosque Al-Hakim, Isfahan, Iran.
Herdeg (1990b), p. 43 figure E. Spatial zones of circulation linking spaces in house in Yazd, Iran.
Herdeg (1990b), p. 42 figure E, p. 46 figure C

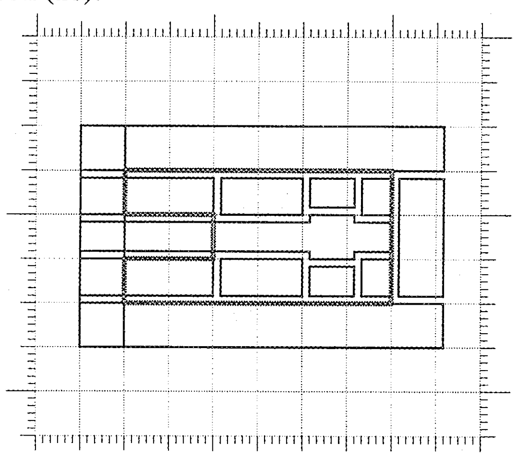
Description:

Zone in specified form defines areas within a specified form that have specific properties. A specified form is different from a contour. The particular shape and dimensions of the specified form are made specific. Clues for this distinction come from the source (plan of an existing building) or the appearance of a measurement device (reading the dimensions from the graphic representation).
Decisions concern where to allocate these particular properties within the overall shape of the building, and deciding upon their dimensions.
Graphic units are *specified form*: polygonal shapes (4), and *zone*: polygonal shapes (8).

Graphic units:

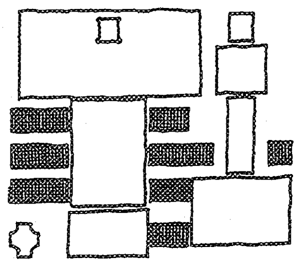


Icon (16):

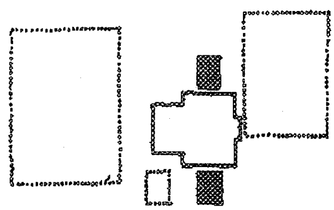


Functional spaces (7)

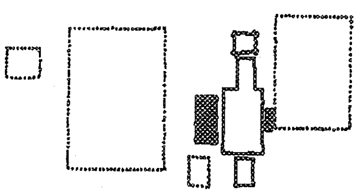
Graphic representations:



Herdeg (1990b), p. 42



Herdeg (1990b), p. 43



Herdeg (1990b), p. 43

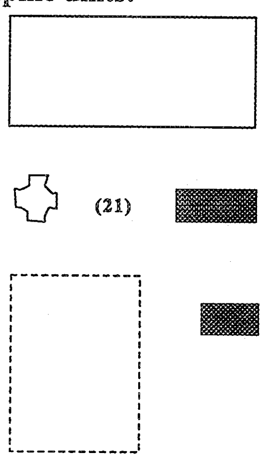
Sources:

Herdeg (1990b), p. 42 figures F, G, H. Razvian house, Yazd, Iran.
Herdeg (1990b), p. 43 figures F, G, H. Talaie House, Yazd, Iran.
Herdeg (1990b), p. 46 figures D, E

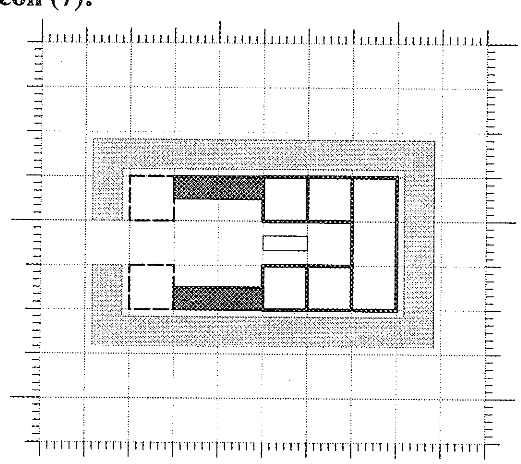
Description:

Functional spaces distinguishes between contours in a building layout. It is different from combination of contours (2) because the contours are represented different from contours (single lines) by hatching patterns, colours, and various linetypes. The differences between shapes aid in understanding the functional layout of the plan. A functional shape is related to zone. It is more specific since it links a function particularly to one contour, whereas a zone allows placing any number of contours.
Decisions concern spatial/functional relationships in the building layout. The different combinations of patterns, colours, and linetypes differentiate between functional assignments in the shapes.
The graphic unit is *functional space*: closed polygonal shapes of different colour, hatching, or linetype (21).

Graphic units:

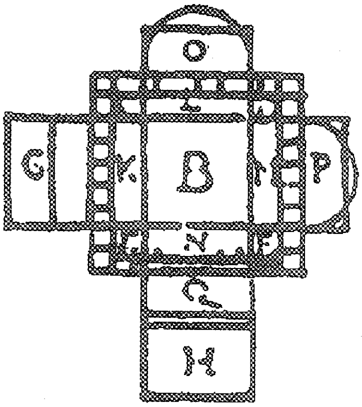


Icon (7):



Function symbols in combination of contours (17)

Graphic representations:



Cesariano (1521), p. 21

Sources:

Cesariano (1521) in Tzonis (1986), p. 21 figure 10. 'Grid pattern.'

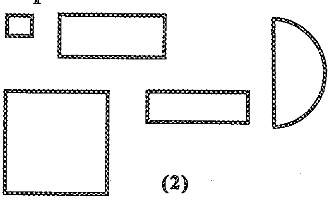
Description:

An assembly of contours can be assigned particular function by adding function symbols denoting specific purposes for the several shapes. In this way, the functional organisation of the brief is mapped on the spatial order of the plan layout. Function symbols state the relations between functions. They can be brief (letters in the figure) or long (codes or names), or in other symbols than letters. Function symbols can derive from the brief or adjacency requirements.

Decisions concern the assignment of functions to the building layout. The relation between contours and functions deals with the functional adjacency requirements of the brief, and the surface area requirements of the contours.

Graphic units are *contour*: closed polygonal shapes (2), and *function symbols*: letters indicating functions (7).

Graphic units:



(2)

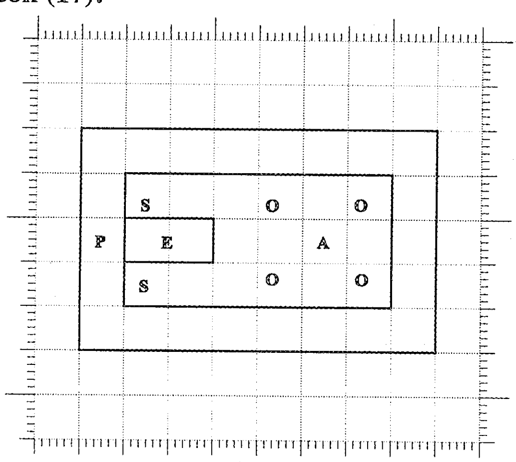
O G K B

M P N Q

L F H

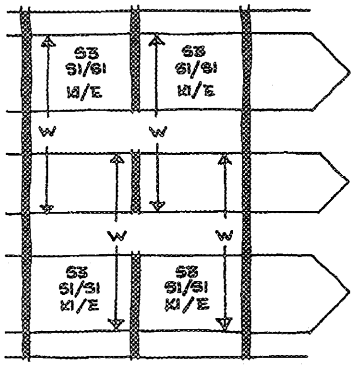
(7)

Icon (17):

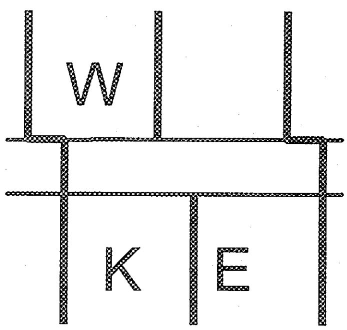


Schematic subdivision in zone in contour with function symbols (49)

Graphic representations:



Boekholt et al. (1982), p. 81



Carp and van Rooij (1974), p. 46 (redrawn)

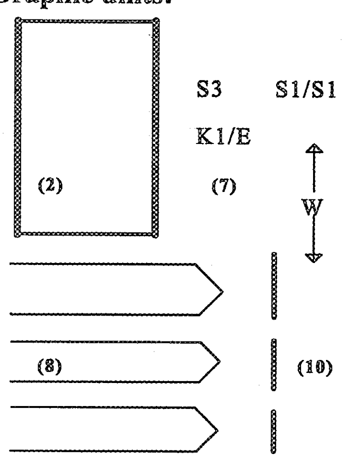
Sources:

Boekholt et al. (1974), p. 81. Sectors and possible functions in the basic variant of a house.
Carp and van Rooij in Plan 12 1974, p. 46 (redrawn). Basic types formed by functions in support structure.

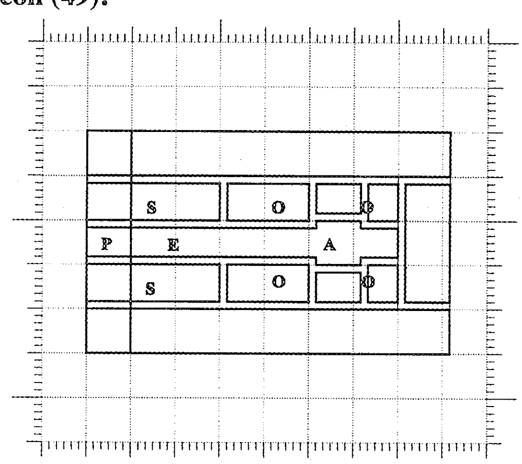
Description:

Zones in a contour (compare zone in specified form (16)) can be made more specific by assigning functions to particular parts that are defined by subdivisions (*e.g.* bedroom S3 and S1/S1 for "sleeping" in top figure; W, K, E in bottom figure). Since dimensions are not defined precisely, the drawing provides a schematic representation of the organisation underlying the layout.
Decisions concern the way the general organisation indicated by zoning is further elaborated into parts with particular functions.
Graphic units are *contour*: lines (2), *schematic subdivision*: lines (10), *zone*: polygonal shapes (8), and *function symbols*: letters and numbers indicating functions and spaces (7).

Graphic units:

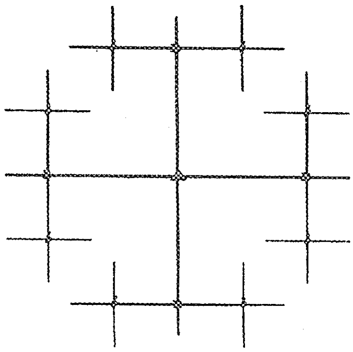


Icon (49):

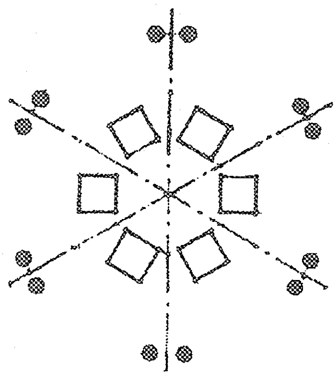


Schematic axial system (8)

Graphic representations:



Durand (1804), Précis Deuxième Partie Planche 20



Ching (1979), p. 342

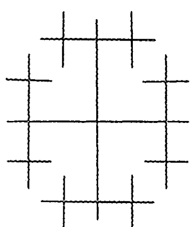
Sources:

Durand (1804), Précis, Deuxième Partie, Planche 20 schematic figures. Number and place of principal axes.
Durand (1804), Précis, Deuxième Partie, Planche 21 figures 1,2, Parties Planche 4, top middle figure, Parties Planche 5, top middle figure
Ching (1979), p. 342 figure A, C. Diagram of radial symmetry.

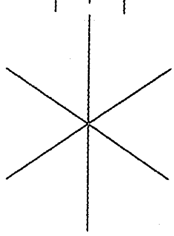
Description:

A schematic axial system introduces lines around which, or along which, elements of the plan are arranged. When the elements are arranged around the axes, they define a spatial system (corridors, circulation, visual orientation). When the elements are arranged on the axes, then they define a symmetrical material or spatial system. The axial system in the cases is schematic, indicating a principle of ordering unrelated to a layout.
Decisions concern the way of ordering the general layout of the building, either through the spatial layout or the material layout. The axes define orientation and relative position within the layout.
The graphic unit is the *schematic axial system*: lines (13).

Graphic units:

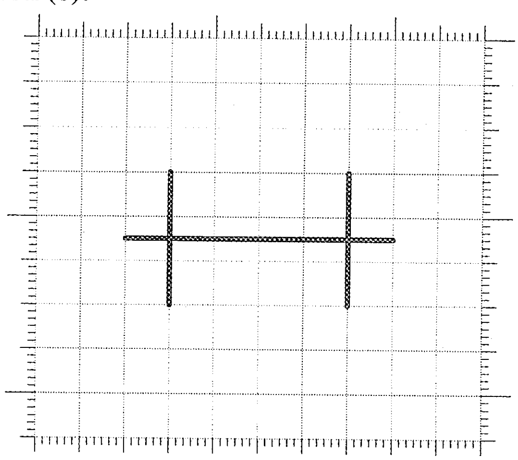


(13)



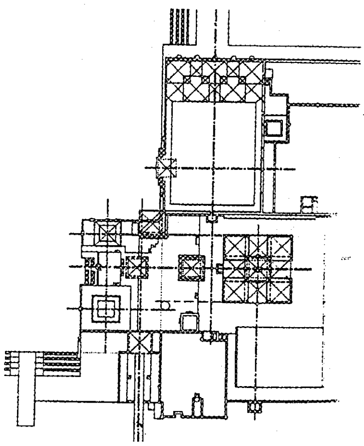
(13)

Icon (8):

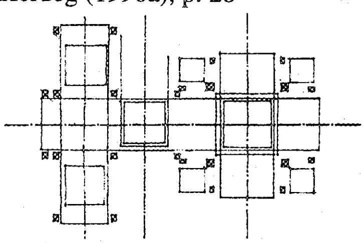


Axial system in specified form (18)

Graphic representations:



Herdeg (1990a), p. 28



Ching (1979), p. 343

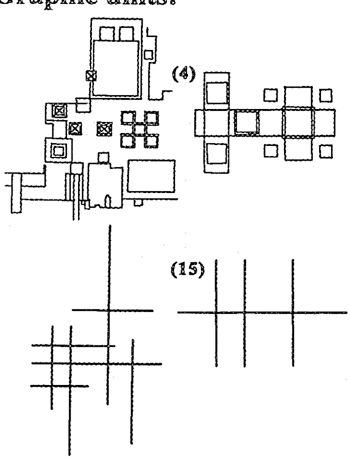
Sources:

Herdeg (1990a), p. 28 figure 6. Symmetry axes in building complex, Surkhej, India.
Herdeg (1990a), p. 49 figure 4, 5
Ching (1979), p. 343 figure 4. Symmetry axes in Unity Church Oak Park, Illinois, Frank Lloyd Wright.

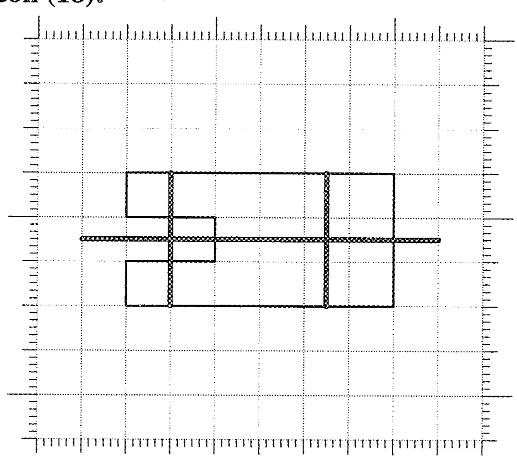
Description:

A plan layout can be developed according to a number of axes ordered in an axial system. The axes exert their influence on a number of spaces or elements arranged along their lines, and not to the whole building. Thus, local symmetries (see bottom figure) and spatial axes (see top figure) are created. The figures show specified forms because they are measured drawings of existing buildings. The axial system is more specific than a schematic axial system since it is related to a specified form and layout.
Decisions concern the spatial layout of the building design and the precise elaboration of the shape relative to the axial system.
Graphic units are *specified form*: closed polygonal shapes (4) and *axial system*: lines (15).

Graphic units:

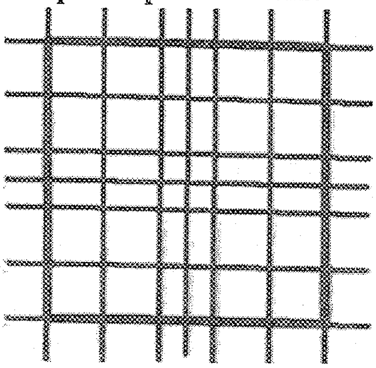


Icon (18):



Axial system in contour in grid (37)

Graphic representations:



Durand (1804), Parties Planche 3

Sources:

Durand (1804), Parties, Planche 3 figure A

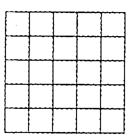
Description:

A grid in a contour defines where within the contour elements are to be placed. A grid does not impose a direction or hierarchy within the contour, other than by the direction of the lines of the grid. An axial system adds a hierarchy within the contour and hints at preferred directions in which to elaborate the contour.

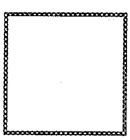
Decisions when imposing an axial system on a contour in grid concern the general organisation of the contour, primary directions and orientations.

Graphic units are *contour*: closed polygonal shape (2), *grid*: orthogonal set of lines at specific distance (16), and *axial system*: set of lines (15).

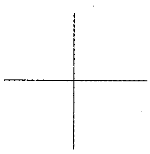
Graphic units:



(16)

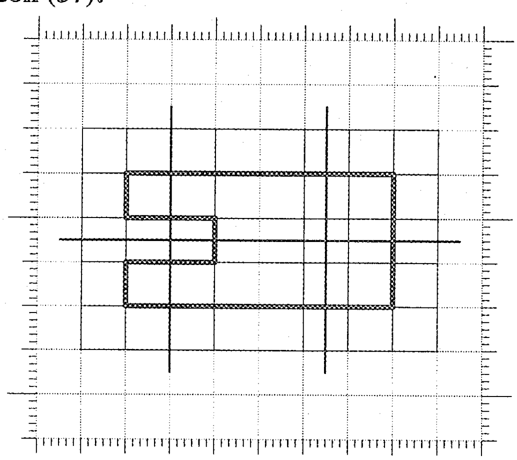


(2)



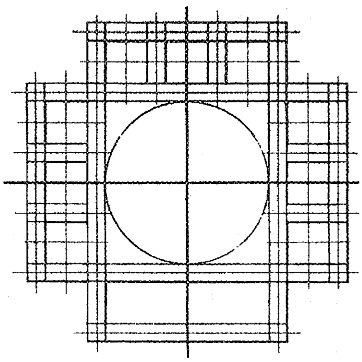
(15)

Icon (37):



Axial system in contour in tartan grid (38)

Graphic representations:



Durand (1804), Précis Deuxième Partie Planche 21

Sources:

Durand (1804), Précis, Deuxième Partie, Planche 21 figure C. 'Tracé des murs.'

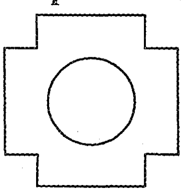
Description:

A tartan grid defines a field in which two different modules are used alternately in all directions of the grid. The 'bands' in the tartan grid may be used for different purposes. In the figure, the small bands define the place of wall elements. The axial system controls the hierarchy between the otherwise uniform spaces; the most important spaces are located around the axes.

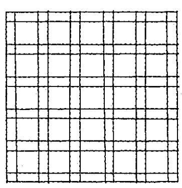
Decisions concern the modules of the tartan grid which establish basic dimensions of both spatial (wide bands) and material (small bands) elements, and the establishment of a spatial hierarchy by the axial system.

Graphic units are *contour*: closed polygonal shape (2), *axial system*: lines (15) and *tartan grid*: orthogonal set of lines with two modules (17).

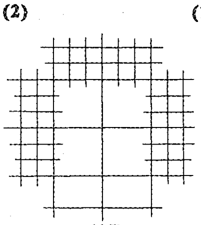
Graphic units:



(2)

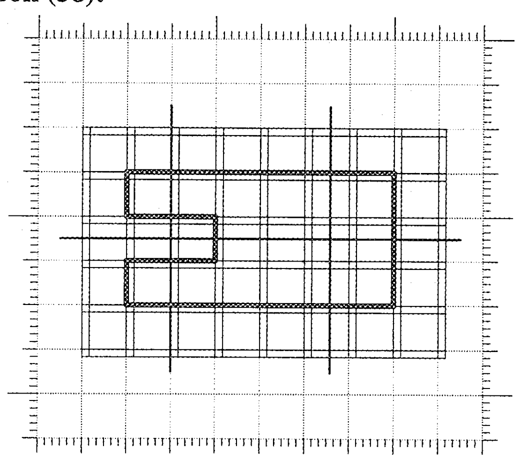


(17)



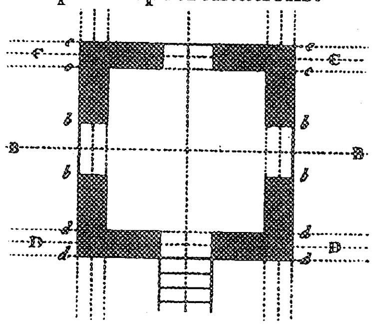
(15)

Icon (38):



Axial system in specified form in structural tartan grid (39)

Graphic representations:



Durand (1804), Précis Premier Volume Planche 2

Sources:

Durand (1804), Précis, Premier Volume, Planche 2 central figure. 'Maniere générale de dessiner.'

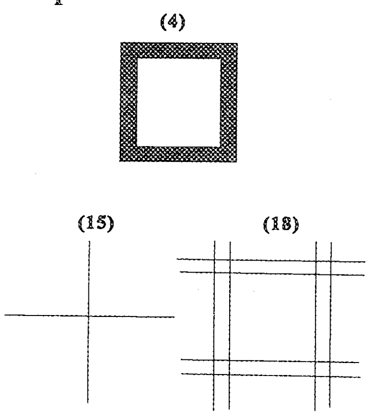
Description:

An axial system, combined with a structural tartan grid, gives the principles of spatial and structural development of the plan. The axial system imposes order on the otherwise non-distinct fields of the grid. The symbols in the graphic representation are used to show similar dimensions in the plan, rather than functions, and state explicitly its symmetrical properties. This makes the form a specified form.

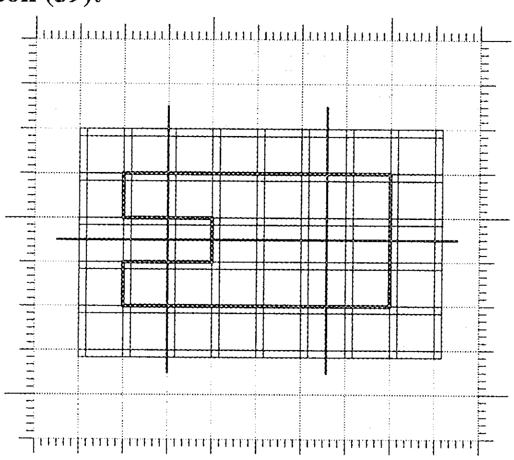
Decisions concern elaboration of both space and material in the tartan grid, and establishing the particular dimensions of the shape.

Graphic units are *axial system*: lines (15), *structural tartan grid*: orthogonal set of lines with two modules (18), and *specified form*: closed polygonal shapes (4).

Graphic units:

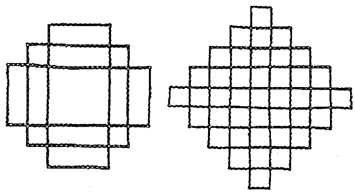


Icon (39):

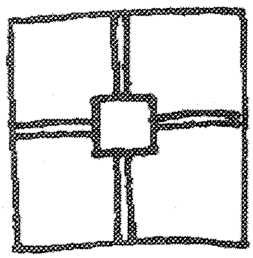


Schematic subdivision (9)

Graphic representations:



Herdeg (1990a), p. 10



Herdeg (1990b), p. 49

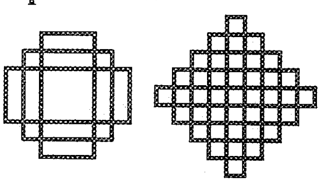
Sources:

Herdeg (1990a), p. 10 figure 4. Division principle of temple, Modhera, India.
Herdeg (1990b), p. 49 figure C. Principle subdivision of classical Iranian garden.

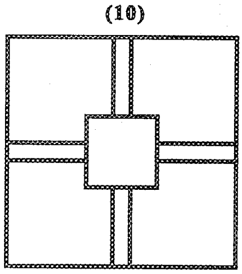
Description:

Schematic subdivision shows a principle of subdivision. The graphic representations show the principle without application to a particular shape, such as the division principle of a temple (top) and the division principle of classical gardens (bottom). The graphic representation makes clear which parts have to be distinguished when designing a form that obeys the rules of subdivision (*e.g.* the central and four quarters with pathways should be present in any classical Iranian garden, figure below).
Decisions concern the basic subdivision principles, the identification of major parts, and the relative proportions of the parts.
The graphic unit is *schematic subdivision*: single or double lines representing the subdivision (10).

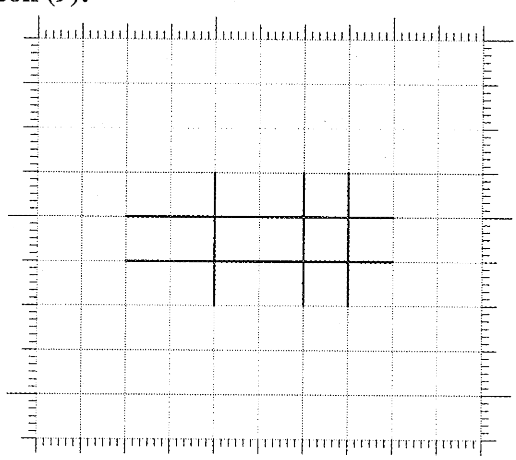
Graphic units:



(10)

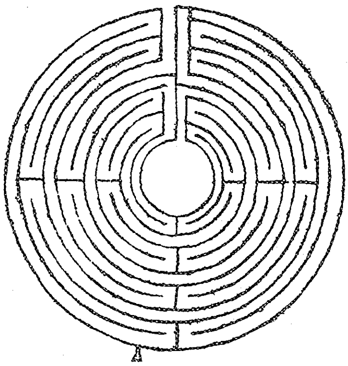


Icon (9):

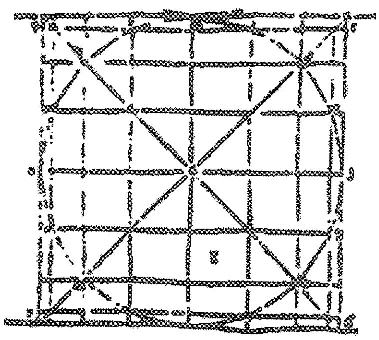


Schematic subdivision in grid (19)

Graphic representations:



Villard de Honnecourt (1215-1235), p. 14



Cousin (1560), p. 31

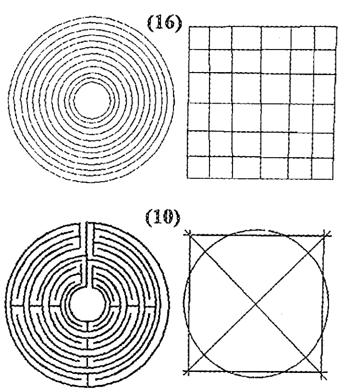
Sources:

Cousin (1560) in Tzonis (1986), p. 31 figure 16 first four figures. Taxis schemata partitioning plans by means of contour and axis.
Villard de Honnecourt (1215-1235) Bucher (1979), p. 14 figure 7. Drawing of labyrinth.

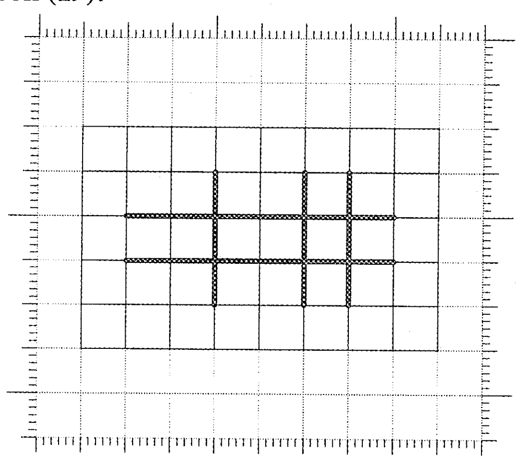
Description:

The schematic subdivision identifies major parts in a layout. In order to co-ordinate the place of minor elements such as spaces and walls, it is possible to combine the schematic subdivision with a grid. The grid can be concentric (see figure above) or orthogonal (bottom figure). The grid adds constraints to the possibilities of placing elements.
Decisions concern the way spaces are balanced in their dimensions relative to each other, the basic module of parts and spaces, and the internal composition of the building layout.
Graphic units are *schematic subdivision*: lines (10) and *grid*: concentric and orthogonal set of lines (16).

Graphic units:

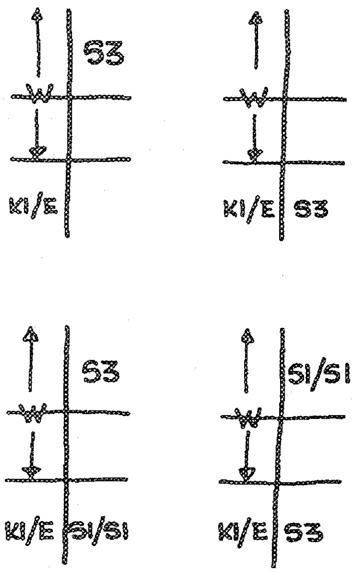


Icon (19):



Schematic subdivision with function symbols (20)

Graphic representations:



Boekholt et al. (1974), p. 82

Sources:

Boekholt et al. (1974), p. 82 figure 1 bottom figure. Sector analysis of a basic variant in housing.

Description:

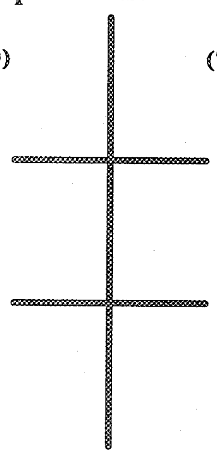
Schematic subdivision with function symbols demonstrates a general principle of subdivision in combination with the assignment of functions. In the figure, it shows a SAR-representation of a basic variant: different functional layouts within a particular subdivision (sectors).

Decisions in this graphic representation concern the principle relations between functions and a general subdivision of the layout.

Graphic units are *schematic subdivision*: lines (10) and *function symbols*: letters and numbers indicating functions (7).

Graphic units:

(10)

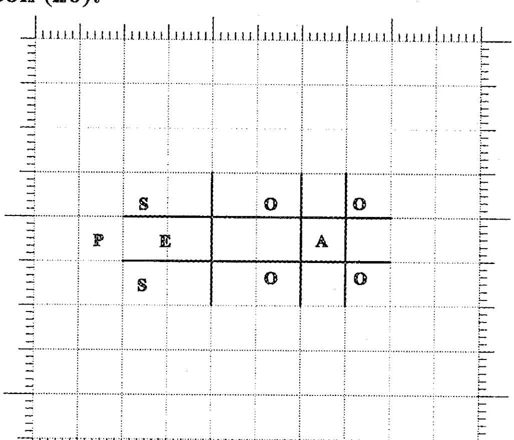


(7) S3

K1/E

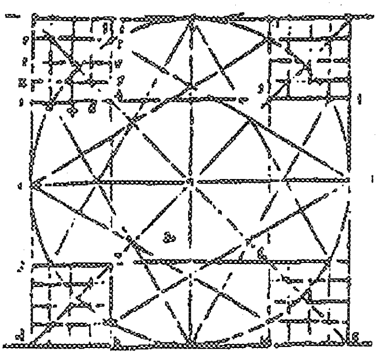
S1/S1

Icon (20):



Schematic subdivision in grid and refinement grid (40)

Graphic representations:



Cousin (1560), p. 31

Sources:

Cousin (1560) in Tzonis (1986), p. 31 figure 16 fifth figure. Taxis schemata partitioning plans by means of contour and axis.

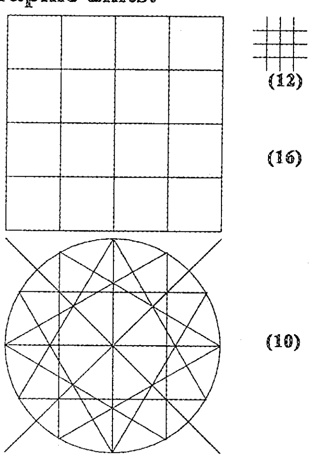
Description:

The grid provides a module with which elements placed in the grid are measured. If the extent of the grid is large, a small module is not advisable to measure large elements (a module of 30 cm does not make much sense on an urban scale, or even the building level). Therefore, the basic measure of the grid can be divided further so that another module is introduced (a whole multiple of the larger grid). The smaller grid is termed a refinement grid.

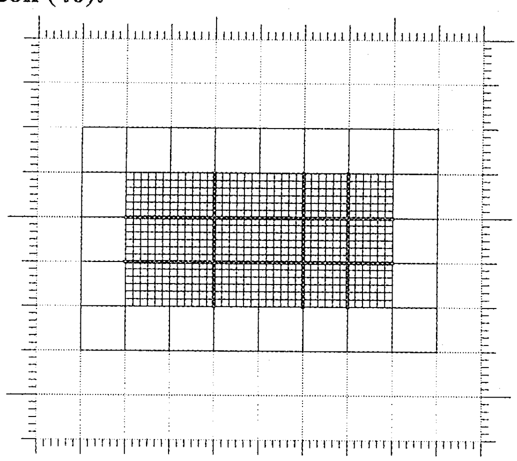
Decisions concern choosing the modules which influences the range of dimensions elements can have. This influences also basic surface areas, which have to fit elements of the brief. Both grids have to accommodate the schematic subdivision.

Graphic units are *grid*: orthogonal set of lines with particular distance (16), *schematic subdivision*: lines indicating rules of geometry (10), and *refinement grid*: orthogonal set of lines with smaller distance (12).

Graphic units:

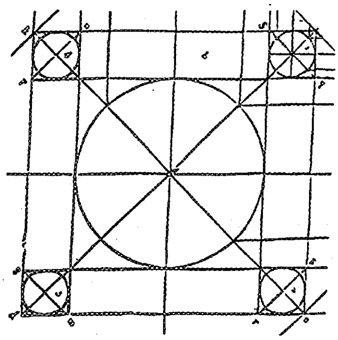


Icon (40):

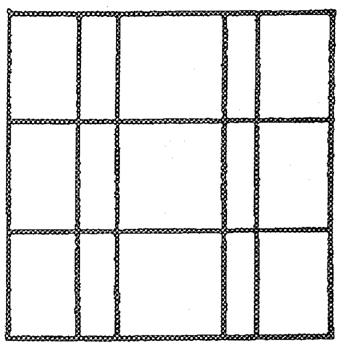


Schematic subdivision in contour (21)

Graphic representations:



Cousin (1560), p. 30



Wittkower (1973), p. 73

Sources:

Cousin (1560) in Tzonis (1986), p. 31, figure 16, p. 30, figure 16. Taxis schemata partitioning plans by means of contour and axis

Bentham (1797) in Vidler (1990), p. 114 middle figure. Organisation of Panopticon.

Durand (1804), Précis, Second Volume Planche X bottom figure; Parties, Planche 3 figure N, O.

Wittkower (1973), p. 73, bottom right figure. Principle subdivision of Palladian villa's.

Clark and Pause (1985), p. 29 figure F, M

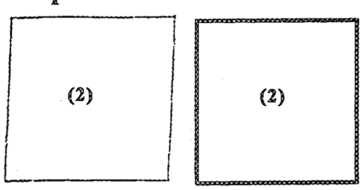
Description:

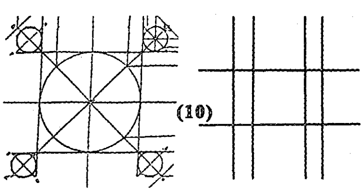
Applying the schematic subdivision to a contour results in major parts of the contour. It provides guidelines to order the contour, giving principles of subdivision rather than precise subdivision. The subdivision differs from a proportion system (5) as the goal is to establish parts rather than proportions. The proportions are not precisely defined.

Decisions are made on the formal organisation principles in the layout, establishing major parts in the contour.

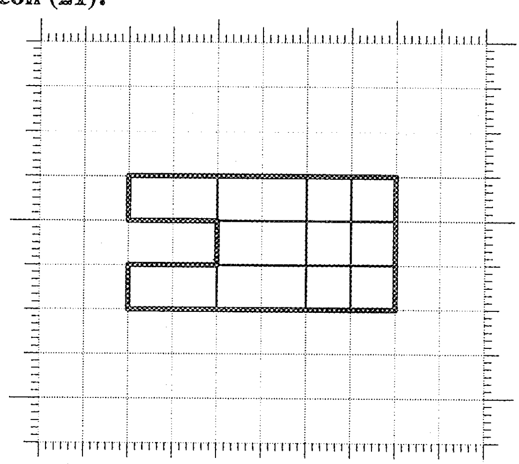
Graphic units are *schematic subdivision*: lines (10), and *contour*: closed polygonal shapes (2).

Graphic units:



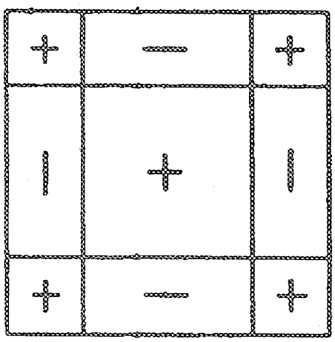


Icon (21):

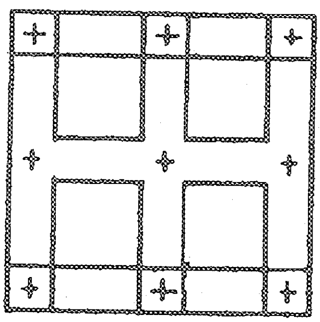


Schematic subdivision and schematic axial system in contour (41)

Graphic representations:



Durand (1804), ~~Parties~~ Planche 4



Durand (1804), Parties Planche 5

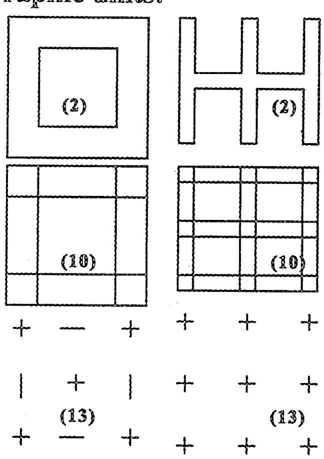
Sources:

Durand (1804), Parties, Planche 4 middle figure. 'Ensembles d'édifices formés par la combinaison de parties de cinq entr'-axes de largeur.'
Durand (1804), Parties, Planche 5 middle figure. Ibid.

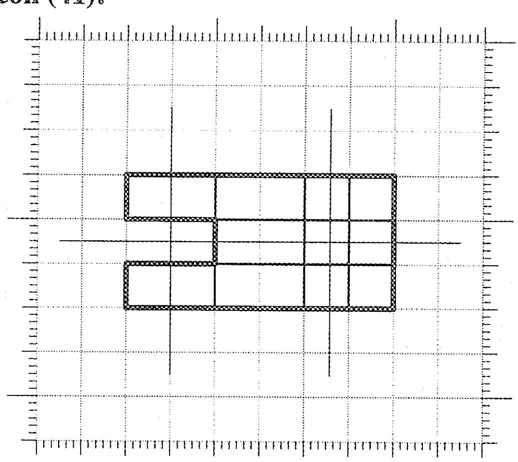
Description:

The schematic subdivision of a contour establishes major parts and a principle division into spaces. By adding a schematic axial system directions are imposed that differentiate among spaces. The axial system generates hierarchy in the organisation, mainly of spaces.
Decisions concern the main subdivision of the building layout and identification of the major spaces and specifics of internal organisation.
Graphic units are *contour*: closed polygonal shapes (2), and *schematic axial system*: short lines, '+' and '-' (13), and *schematic subdivision*: lines (10).

Graphic units:

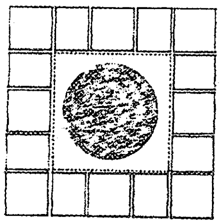


Icon (41):

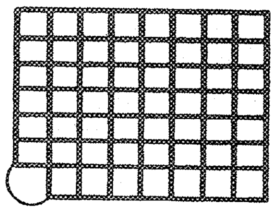


Partitioning system in contour (22)

Graphic representations:



Ching (1979), p. 173



Sullivan in Clark and Pause (1985), p. 117

Sources:

Tabor in March (1976), p. 370 figure 10.20. Two-storey slab, cross and court plans.

Ching (1979), p. 173 figure 2. Schematic representation of 'closure.'

Sullivan in Clark and Pause (1985), p. 117 figure D. Plan to section analysis of Carson Pirie and Scott Store, Chicago, Illinois.

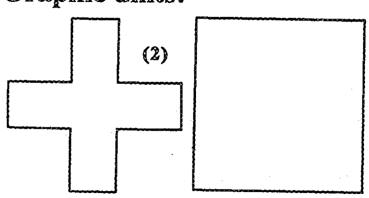
Description:

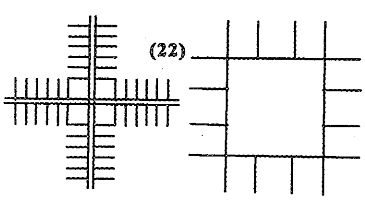
A partitioning system offers the possibilities of placing separations between spaces such as walls in order to distinguish them from each other. The system indicates where such separations can occur, but in the actual plan not all possible separations have to be realised. The partitioning system is often based on a spatial module that may be related to a grid system.

Decisions concern the size, place, and standard area unit, of partitions in the building design.

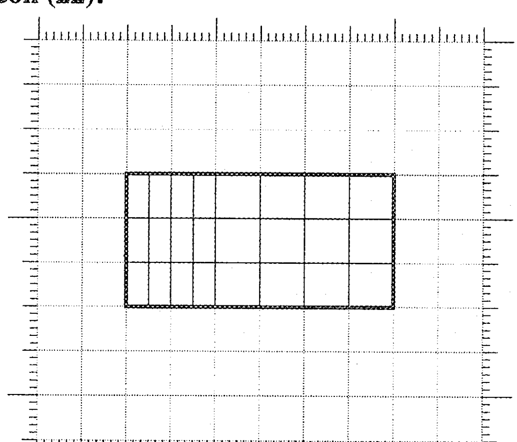
Graphic units are *contour*: closed polygonal shapes (2) and *partitioning system*: lines (22).

Graphic units:



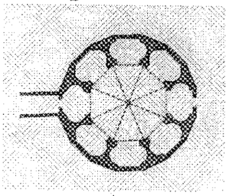


Icon (22):

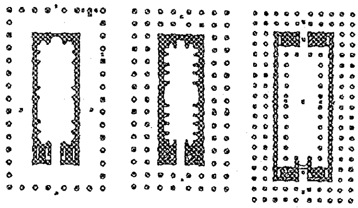


Elaborated structural contour (10)

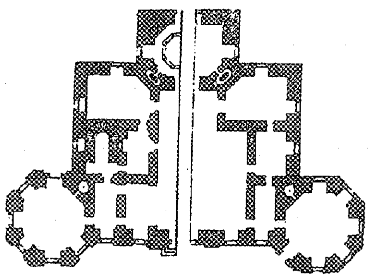
Graphic representations:



Brunelleschi (15th C.), p. 29



Rusconi (1590), p. 175



Milizia (1847), Tav IX, f. E

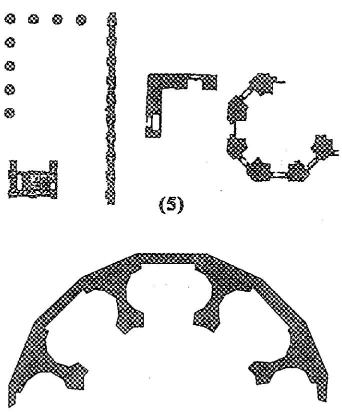
Sources:

Brunelleschi (15th C.) in Clark and Pause (1985), p. 29 figure A. Structure of church of San Maria Degli Angeli, Florence, Italy,.
Rusconi (1590) in Tzonis (1986), p. 175 figure 104
Gibbs (1728) in Tzonis (1986), p. 217 figure 152
Milizia (1847), Parte Seconda Tav. XII figures B, G, Parte Seconda Tav. IX, figures C, D, E
Durand (1804), Précis, Deuxième Partie, Planche 14 figure 4
Herdeg (1990a), p. 36 figure N
Herdeg (1990b), p. 37 figure 7

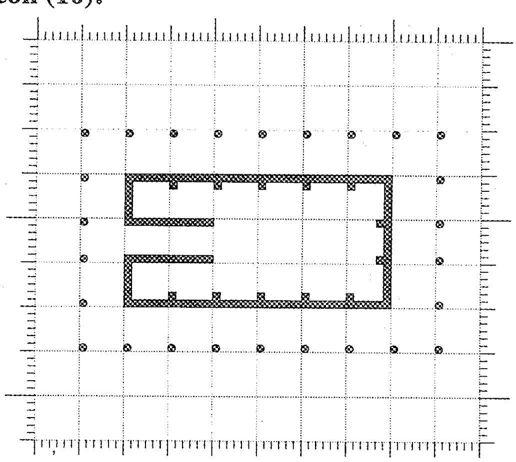
Description:

Elaborated structural contour defines the outline of spaces in a building according to the material and structural elements supporting the building. It defines how the structural contour is articulated and placed in the building layout. The elaborated structural contour is specific on the way partitions and the building envelope are realised.
Decisions concern the structural system (wall- and column dimensions and placement), and the shape of the envelope and partitions between spaces.
The graphic unit is the *elaborated structural contour*: dots, and filled polygons (5).

Graphic units:

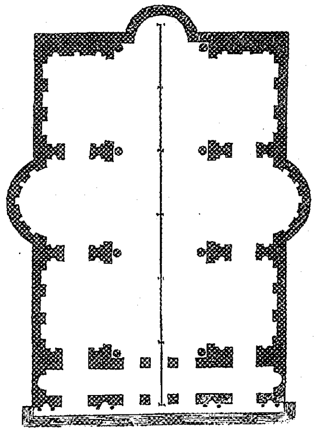


Icon (10):

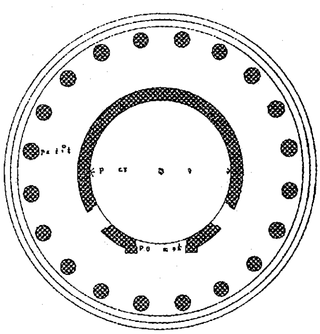


Specified elaborated structural contour (23)

Graphic representations:



Serlio (1611), 3rd Book, Fol. 9



Palladio (1738), Book 4, Pl. 34

Sources:

Serlio (1611), 3rd Book, 4th Chapter, Fol. 9. Plan of the Temple of Peace in Rome.
Palladio (1738), Book 4 Plate 34, Plate 87

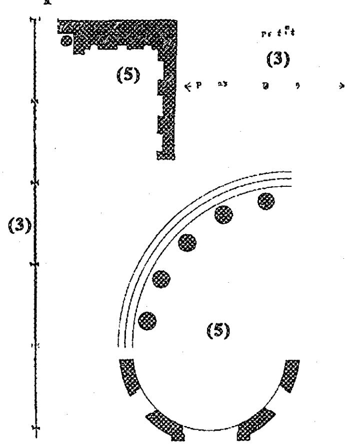
Description:

An elaborated structural contour (10) is indefinite concerning its dimensions through the lack of specific measures or a scale indication. Drawings with a measurement unit or dimensions add to this graphic representation by making the dimensions of the building explicit. The measurement device either gives the actual dimensions of parts of the building layout (with numbers) or by providing a scale with a measure. Although in the early phase of design this representation may occur, it is more likely to appear at the end of the design process (see figures) when most decisions about the building have been established.

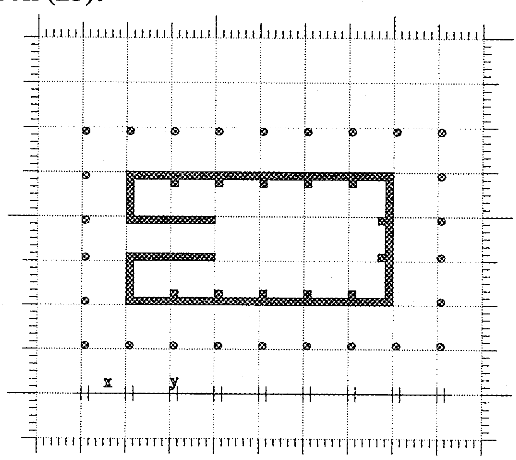
Decisions concern the precise dimensioning of the elaborated structural contour.

Graphic units are *elaborated structural contour* (5), and *measurement device*: subdivided line representing a measurement unit, and lines, arrows, and numbers for the dimensions of the building (3).

Graphic units:

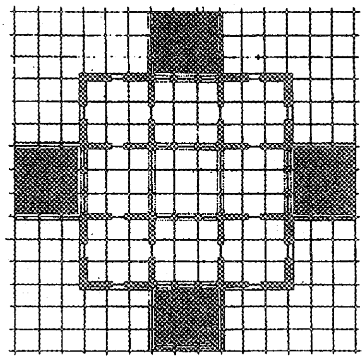


Icon (23):

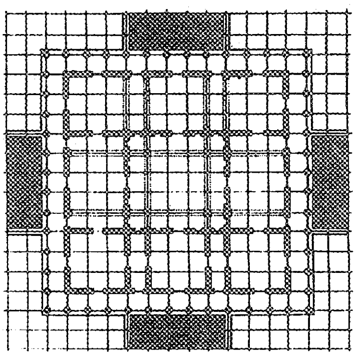


Elaborated structural contour in grid (24)

Graphic representations:



Durand (1804), Précis Deuxième Partie Planche 2



Durand (1804), Précis Deuxième Partie Planche 2

Sources:

Durand (1804), Précis, Deuxième Partie, Planche 2 figures A, B, C. 'Combinaisons horisontales, de Colonnes, de Pilastres, de Murs, de Portes et de Croisées.'

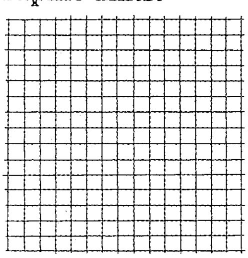
Description:

The elements that form the elaborated structural contour can be placed according to a grid, thus introducing a basic measure for building elements and spaces.

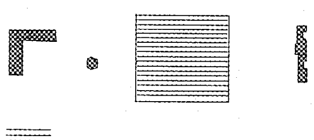
Decisions concern the placing of the building, building parts, and elements of the elaborated structural contour in the grid, the modules used, and articulation of the contour.

Graphic units are the *grid*: orthogonal set of lines at specific distance (16), and *elaborated structural contour*: dots, lines, and filled polygonal shapes (5).

Graphic units:

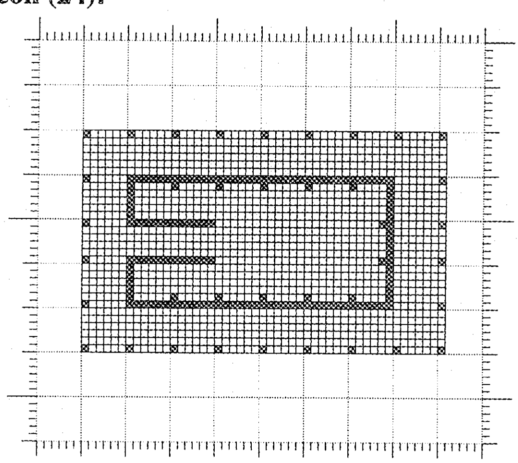


(16)



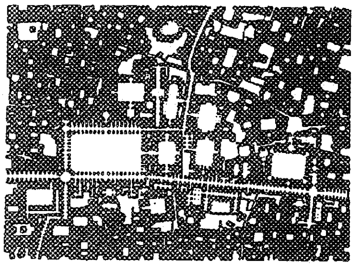
(5)

Icon (24):



Elaborated structural contour in complementary contours (25)

Graphic representations:



Herdeg (1990b), p. 37

Sources:

Herdeg (1990b), p. 37 figure E. Nolli-type plan of center area of Kerman, Iran.

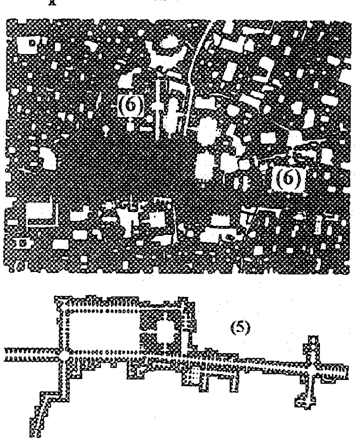
Description:

Elaborated structural contour in complementary contours shows how particular areas in a composition are worked out. Since elaborated structural contours apply to buildings, and complementary contours is often used in space-material analysis, this graphic representation is well suited for urban structures (see figure).

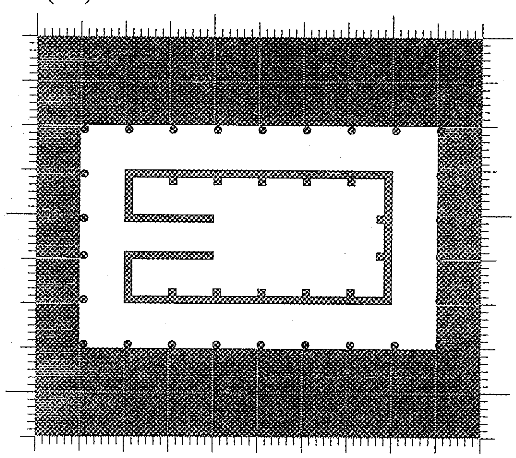
Decisions involved consider the way public-private relationships are elaborated materially.

Graphic units are *complementary contours*: black and white polygonal shapes indicating built and empty spaces at the urban level (6), and *elaborated structural contour*: lines, dots, and polygonal shapes indicating structural elements (5).

Graphic units:

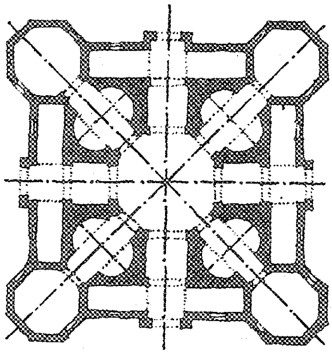


Icon (25):

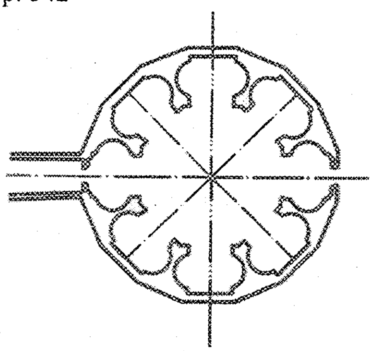


Elaborated structural contour and axial system (26)

Graphic representations:



Filarete (15th C.) in Ching (1979), p. 342



Brunelleschi (14th C.) in Clark and Pause (1985), p. 29

Sources:

Filarete (15th C.) in Ching (1979), p. 342 figure B. Ideal church.

Brunelleschi (14th C.) in Clark and Pause (1985), p. 29 figure L. Symmetry and balance analysis of Church of San Maria Degli Angeli, Florence, Italy.

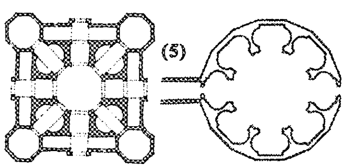
Description:

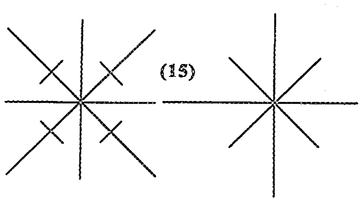
An axial system in concert with an elaborated structural contour directs the way spaces are articulated along or on axes. In this manner, principles of organisation are co-ordinated with spatial and material elements. The elaborated structural contour is more specified on the material realisation than the graphic representations in axial system in specified form (18).

Decisions concern the elaboration of the space-material elements in relation to the axial system. The axial system provides a hierarchy to which the shape of material elements must conform.

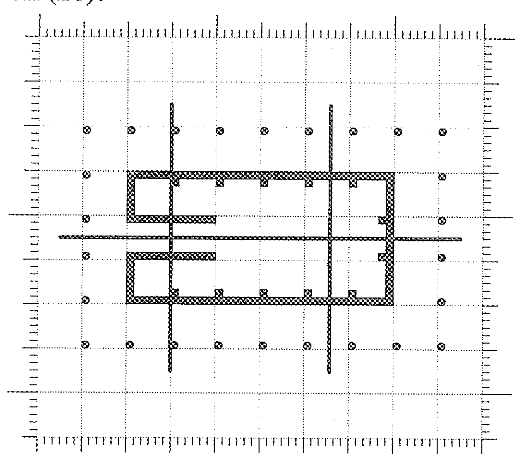
Graphic units are the *axial system*: lines (15), *elaborated structural contour*: dots and filled polygonal shapes representing columns, walls, and window- and door-entrances (5).

Graphic units:



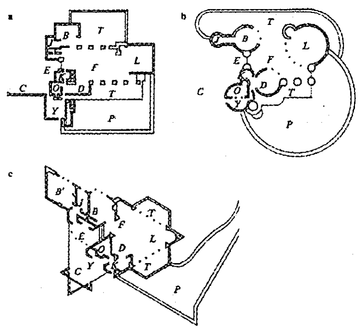


Icon (26):



Elaborated structural contour and function symbols (27)

Graphic representations:



March in March and Steadman (1971), p. 27

Sources:

March in March and Steadman (1971), p. 27 figure 1.13. Comparison of functional layout in houses by Frank Lloyd Wright.

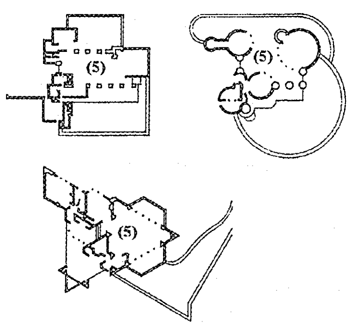
Description:

Elaborated structural contour with function symbols indicates the functional use of a building layout. The rooms are defined through the space-separating elements such as walls. Function symbols indicate the use or destination of a room or space. These graphic representations are different from function symbols in combination of contours (17) since the layout is specified by wall thickness and columns. Spaces are no more represented by closed contours but are defined indirectly by the elaborated structural contour and identified through the function symbols.

Decisions involved consider the functional layout of the building, and the way it is realised in the plan (adjacency requirements).

Graphic units are *elaborated structural contour*: double lines indicating walls, and squares or circles indicating columns (5), and *function symbol*: letter symbols indicating functions (7).

Graphic units:

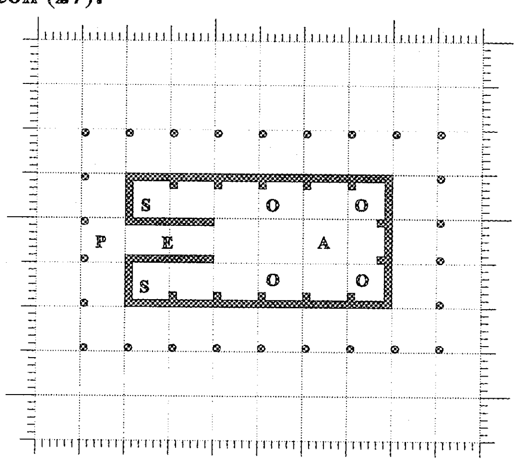


a b c (7)

B C D E F J

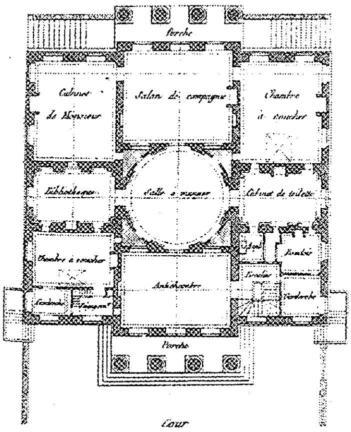
K L O P T Y

Icon (27):

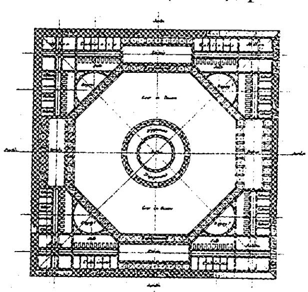


Elaborated structural contour and function symbols and axial system (42)

Graphic representations:



Ledoux in Vidler (1990), p. 37



Ledoux in Vidler (1990), p. 238

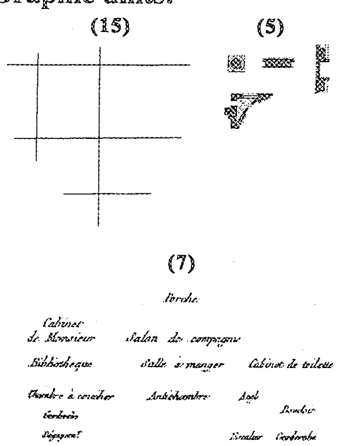
Sources:

Ledoux in Vidler (1990), p. 37 bottom figure.
Ledoux in Vidler (1990), p. 238 middle figure. 'Project for a *guinguette*.'

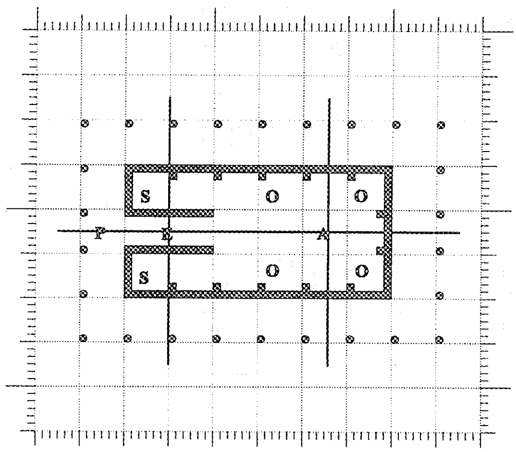
Description:

By assigning functions to spaces in a plan layout, the spaces of the brief are mapped on the spatial structure of the design. Combination with the axial system shows how spatial sequences or symmetry is worked out in the functional organisation. This graphic representation is worked out to a great extent: the level of detail and elaboration do not allow easy change or addition by the same means.
Decisions concern the way spaces and functions are sequences in the layout, ordered by the axial system. The elaborated structural contour implies a great number of design decisions on the structural system and circulation.
Graphic units are *axial system*: lines (15), *function symbols*: words indication functions (7), and *elaborated structural contour*: dots, lines, squares, and closed filled polygonal shapes (5).

Graphic units:

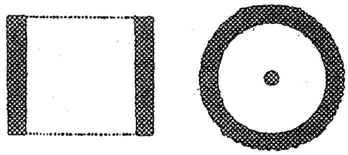


Icon (42):

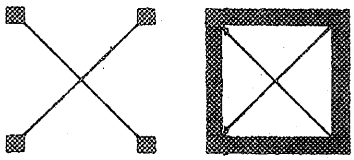


Element vocabulary (11)

Graphic representations:



Durand (1804), Parties Planche 1



Durand (1804), Parties Planche 1

Sources:

Durand (1804), Parties, Planche 1, 5e Leçon figure 2, 4, 6.

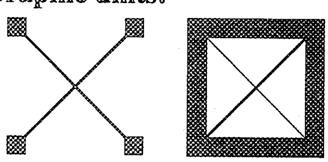
Description:

Element vocabulary defines the elements that constitute typical parts of a design. Elements are often related to each other (furniture elements for testing functional layouts, structural elements for elaborating the structure, etc.) They can be used on several levels of scale; at the urban level as building blocks or housing layouts in lots; at the building level as functional elements; at the infill level as furniture, equipment, or installation devices. An element vocabulary in itself is an unordered set of elements of a particular group. The graphic representation defines the elements, not size requirements, interrelationships, and position with respect to other elements. An element vocabulary rarely occurs isolated from a context.

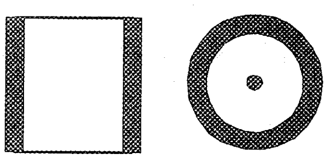
Decisions concern the identification of elements and the definition of their shapes and relative dimensions.

The graphic unit is *element vocabulary*: lines, dots, and filled closed polygonal shapes (19).

Graphic units:

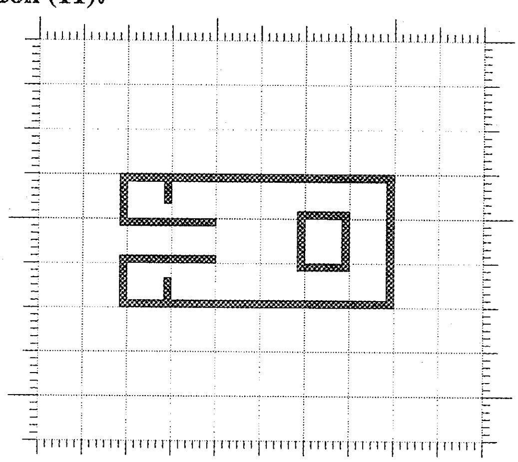


(19)



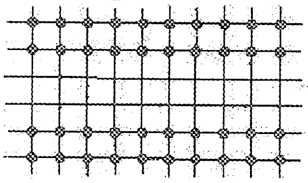
(19)

Icon (11):

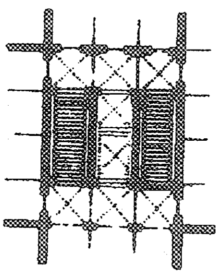


Element vocabulary in grid (28)

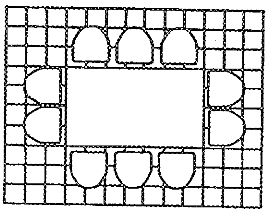
Graphic representations:



Durand (1804), Précis Deuxième Partie Planche 1



Durand (1804), Précis Deuxième Partie Planche 11



Bailey (1990), p. 82

Sources:

Durand (1804), Précis, Deuxième Partie, Planche 1 figures 9, 10

Durand (1804), Précis, Deuxième Partie, Planche 4 figures A, B, C, D, E, F. 'Combinaisons verticales d'Arcades.'

Durand (1804), Précis, Deuxième Partie, Planche 8 figures 1, 2

Durand (1804), Précis, Deuxième Partie, Planche 11 figures 5, 7, 11, 15

Bailey (1990), p. 82 figure 2.22

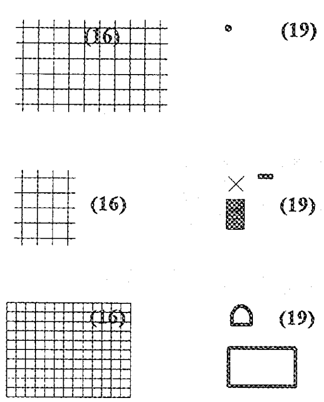
Description:

As a grid structures place and size of elements or building parts in the plan layout, an element vocabulary obviously conforms to a grid once a grid has been established.

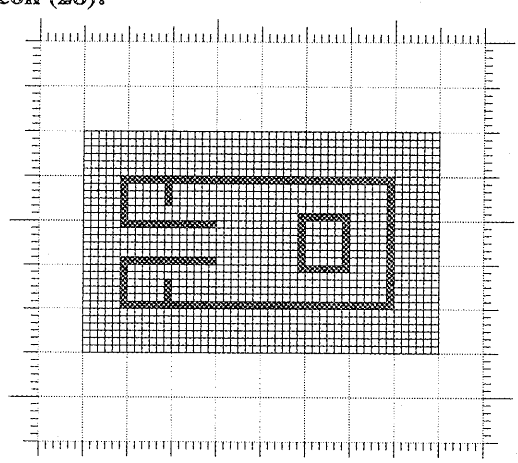
Decisions concern the placing rules of elements in the grid, the interrelationships between elements in the grid, and the module size of the grid.

Graphic units are the *grid*: orthogonal lines (16), and the *element vocabulary*: dots, lines, or combinations of lines representing columns, stairs, and vaults (19).

Graphic units:

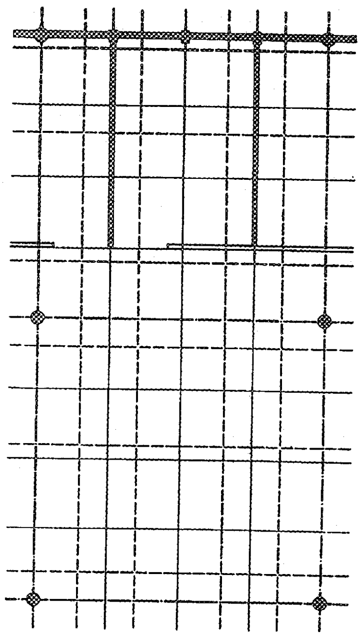


Icon (28):



Element vocabulary in multiple grids (29)

Graphic representations:



Bailey (1990), p. 52

Sources:

Bailey (1990), p. 52 figure 2.8A. 'Example of integration of structural, service and constructional grids.'

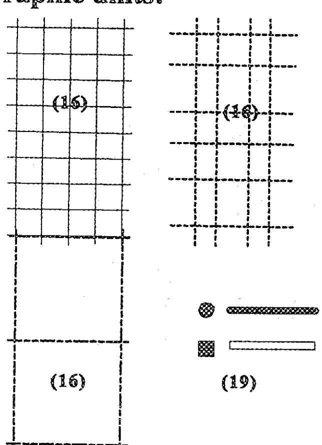
Description:

A grid can be chosen for accommodating one particular kind of element of the building design. When multiple grids are used, they often do not overlap in order to avoid conflicts between the elements or systems they accommodate. In the figure, grids are shown for structural elements (columns), services (water, light, electricity, HVAC), and construction (walls).

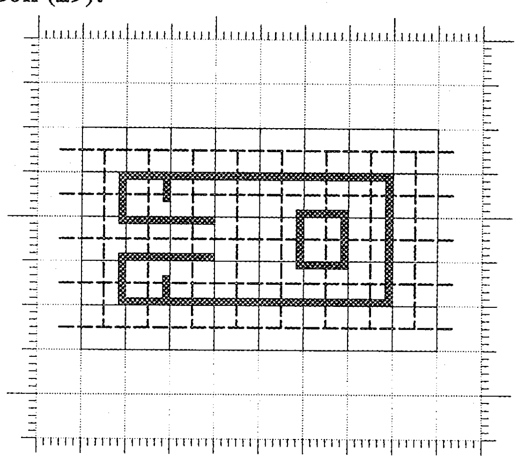
Decisions concern the assignment of elements to particular grids, co-ordination of the grids, and the dimensions of the modules of the grids.

Graphic units are *grid*: set of orthogonal lines at specific distance (16), and *element vocabulary*: dots, squares, and lines (19).

Graphic units:

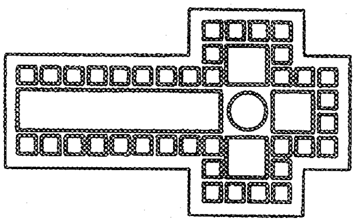


Icon (29):

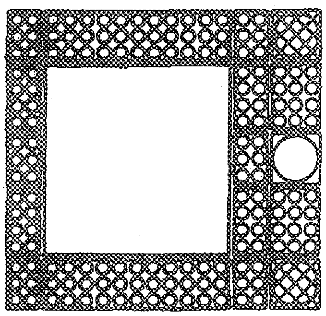


Element vocabulary in zone and contour (43)

Graphic representations:



Brunelleschi (15th C.) in Clark and Pause (1985), p. 31



Herdeg (1990a), p. 36

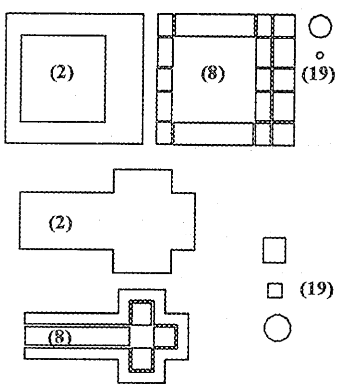
Sources:

Brunelleschi (15th C.) in Clark and Pause (1985), p. 31 figures F, H, M. Unit to whole analysis of church of San Spirito, Florence, Italy, Filippo.
Herdeg (1990a), p. 36 figures K, L. The great mosque of Mandu, India.

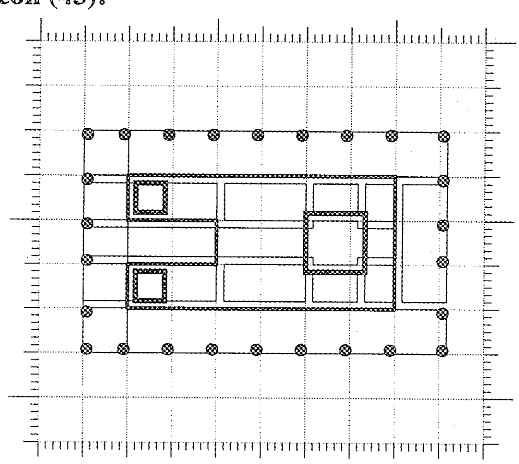
Description:

An element vocabulary can be restricted to specific zones within a building layout. This means that the zone, which identifies general properties of an area, is elaborated by means of the elements that are placed in it. In the figure above, the elements the spaces formed by the side aisles relative to the central space of the nave, and in the bottom figure they are domes above the spaces in the mosque. The elements are defined on a more general spatial level than for example furniture or walls.
Decisions concern the identification and place of elements within the organisation of a building layout.
Graphic units are the *zone*: closed polygons (8), *contour*: closed polygons (2), and *element vocabulary*: circles for the domes, squares and rectangles for the spatial elements (19).

Graphic units:

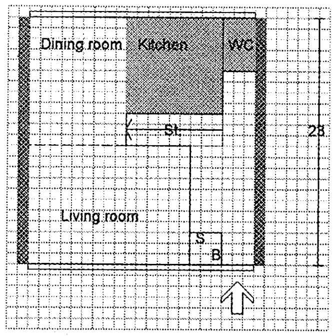


Icon (43):

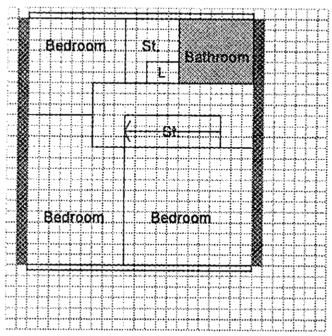


Element vocabulary and function symbols and grid in specified form (48)

Graphic representations:



National Building Agency (1965), p. 73 (redrawn)



National Building Agency (1965), p. 73 (redrawn)

Sources:

National Building Agency (1965), p. 73 top and bottom figure. Generic plan of two storey house for five persons.

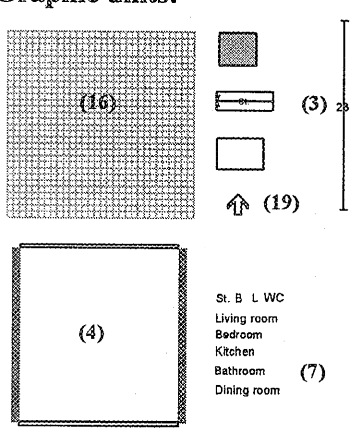
Description:

Contour and element vocabulary in grid establish a schematic plan layout of a building design. The figures on the left are 'generic plans,' a systematic survey of basic layouts of housing in England ordered on the composition of the household.

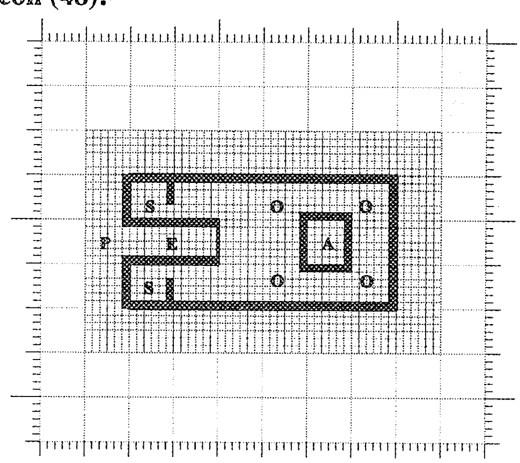
Decisions concern the overall functional-spatial organisation of the plan and their basic dimensions. It forms the least specified but most complete representation of a building layout. Therefore, it can form the starting point for more detailed working out.

Graphic units are *element vocabulary*: filled polygonal shapes indicating spaces (19), *function symbol*: words indicating spaces (7), *grid*: orthogonal set of lines at specific distance (16), *specified form*: lines indicating shape (4), and *measurement device*: line with numbers stating dimension (3).

Graphic units:

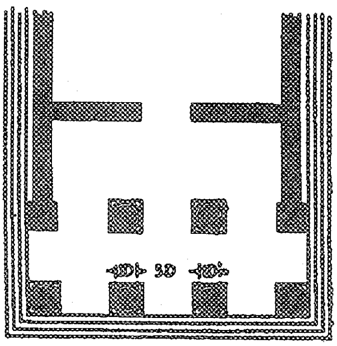


Icon (48):

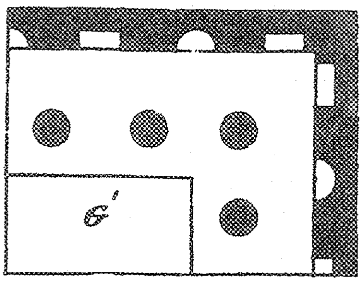


Combinatorial element vocabulary (12)

Graphic representations:



Vitruvius (33-14 BC), p. 79



Milizia (1847), Tav. I

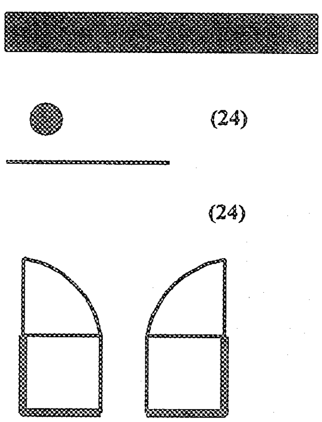
Sources:

Vitruvius (33-14 BC) in Morgan (1960), p. 76 figure A, B, C, D, p. 79 figures A, B, C, D.
Milizia (1847), Parte Seconda, Tav I, figure A, G'.
Bailey (1990), p. 84 figure 2.23
March in March and Steadman (1971), p. 119 figure 4.17. 'Combinations of pairs of Mark 8 telephone boxes.'

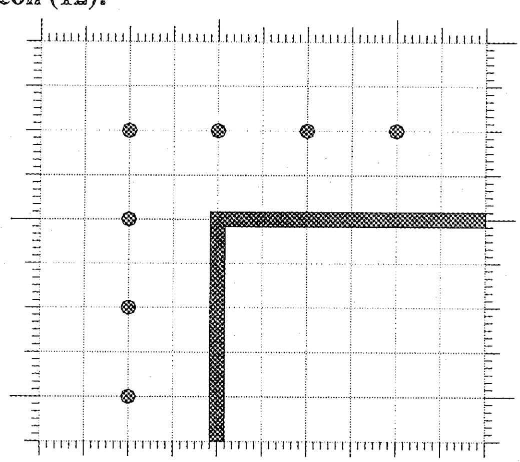
Description:

The elements of an element vocabulary are as a rule not placed randomly, but obey internal relationships. In a number of cases these relationships not specifically determine functional properties (eating, sleeping, working) but formal properties such as the precise place and internal proportions of columns and walls for a type of temple (top), or the proper treatment of an internal corner with columns and wall (bottom).
Decisions concern precise elaboration and interrelationships of elements in the building layout.
The graphic unit is *combinatorial element vocabulary*: dots, lines, and filled polygonal shapes (24).

Graphic units:

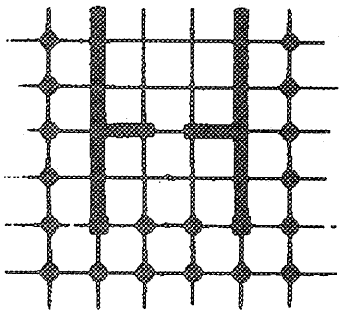


Icon (12):

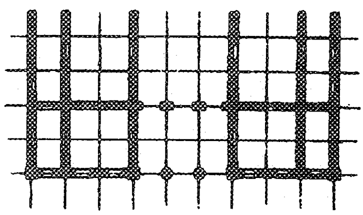


Combinatorial element vocabulary in grid (30)

Graphic representations:



Durand (1804), Précis Deuxième Partie Planche 8, figure 5



Durand (1804), Précis Deuxième Partie Planche 8, figure 14

Sources:

Durand (1804), Précis, Deuxième Partie, Planche 1 figure 2

Durand (1804), Précis, Deuxième Partie, Planche 8 figures 3-15. 'Porches ouverts par des entrecolonnements.'

Description:

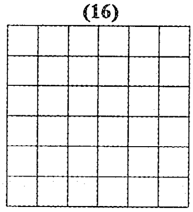
As stated in combinatorial element vocabulary (12), elements of an element vocabulary are combined in specific ways. The addition of a grid adds a structure which rules where elements can be placed. The graphic representations on the left show examples by Durand how elements are to be placed in a grid and relative to each other in order to reach particular solutions.

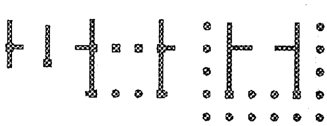
Decisions concern the elaboration of specific areas and rules governing the relations between elements.

Graphic units are the *grid*: orthogonal set of lines at particular distance (16), and *combinatorial element vocabulary*: lines, dots, and filled polygonal shapes (24).

Graphic units:

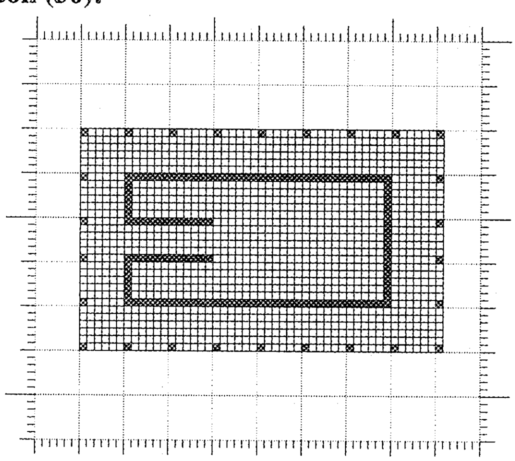
(16)





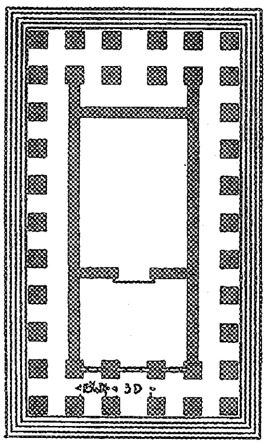
(24)

Icon (30):

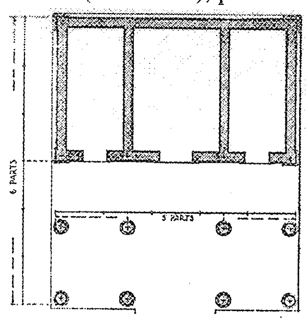


Combinatorial element vocabulary in specified form (31)

Graphic representations:



Vitruvius (33-14 BC), p. 81



Vitruvius (33-14 BC), p. 121

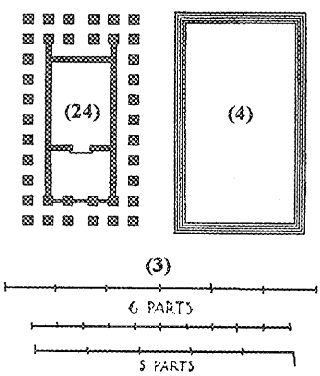
Sources:

Vitruvius (33-14 BC) in Morgan (1960), p. 81. 'The eustyle temple according to Vitruvius.'
Vitruvius (33-14 BC) in Morgan (1960), p. 121 top figure. 'The Tuscan temple according to Vitruvius.'

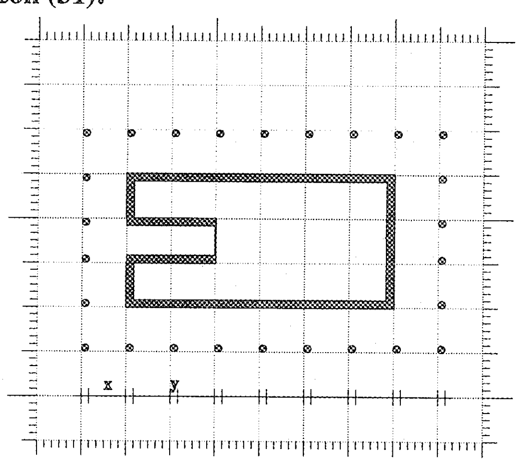
Description:

A number of types in classical architecture are defined by their constitutive elements and relative position and proportions (the figures show eustyle and Tuscan temples). Variations are possible in the unit dimension.
Decisions concern the relative positioning of elements and the elements required.
Graphic units are *combinatorial element vocabulary*: filled circle and square for columns, and filled polygonal shapes in specified combination (24), and *specified form*: lines indicating elevation (4), and *measurement device*: numbers and letters indicating intercolumnation (3).

Graphic units:

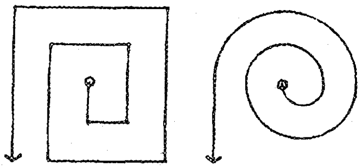


Icon (31):

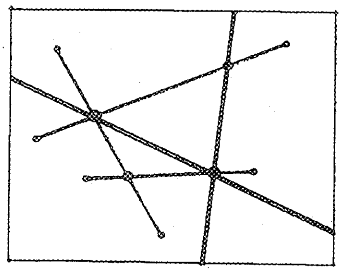


Circulation scheme (13)

Graphic representations:



Ching (1979), p. 271



Ching (1979), p. 271

Sources:

Ching (1979), p. 271 figures 1-5. 'Configuration of the path.'

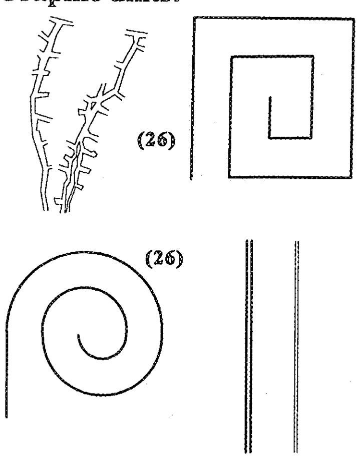
Description:

Circulation connects the spaces within a building and is very much related to the functional layout of the design. The top figure shows the principle of a spiral circulation system and the bottom figure shows a composite circulation system (which may act on an urban scale, e.g. the boulevards in Paris or the axes in Rome, or on the scale of the building or building part). In all cases, the circulation system is represented in schematic form, providing the principle rather than precise application.

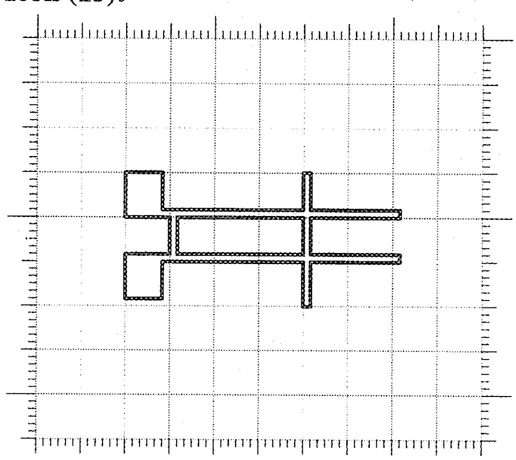
Decisions concern principle access to the major spaces of the design and the way circulation is organised.

The graphic unit is the *circulation scheme*: single or double lines (26).

Graphic units:

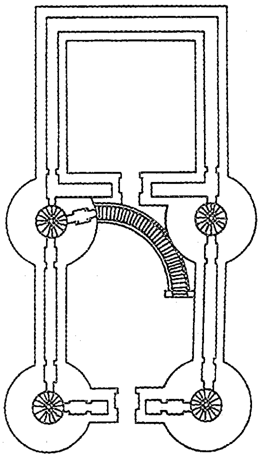


Icon (13):

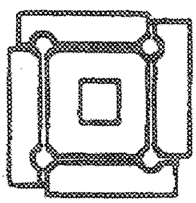


Circulation in contour (32)

Graphic representations:



Giovanni da Sangallo (1494-96), p. 197



Tabor (1976), p. 371

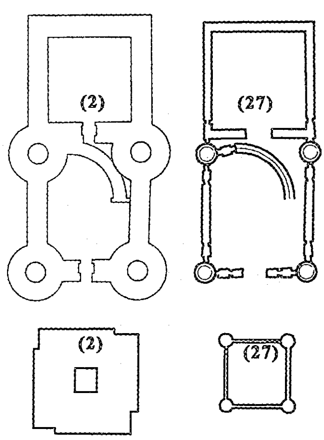
Sources:

Giovanni da Sangallo (1494-96) in Vidler (1990), p. 197. 'Plan of the old Palais de Justice or Palais Comtale.'
Ching (1979), p. 287 figures 3, 4, 8, 12
Tabor in March (1976), p. 371 figures A, B, C. 'Two storey slab, cross and court distributions.'

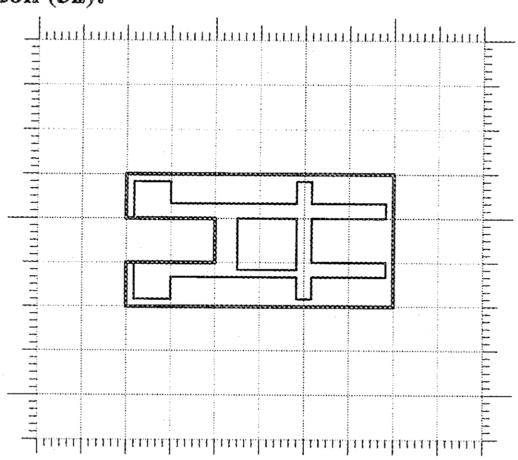
Description:

The circulation system in a building layout is required to link spaces to each other and to make them accessible for staff, visitors, and inhabitants. Therefore, in most cases the overall building shape and the circulation system are strongly related to each other (except where deep spaces are introduced). The circulation system is a more worked out instance of the circulation scheme. It shows how circulation is realised in the building layout.
Decisions concern the layout of the building, layout and dimensions of the circulation, place of elevators, etc.
Graphic units are *circulation*: double line (27) and *contour*: closed polygon shapes (2).

Graphic units:

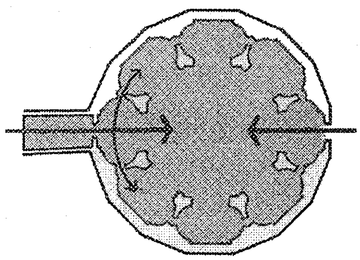


Icon (32):



Circulation scheme in elaborated structural contour (33)

Graphic representations:



Clark and Pause (1985), p. 29

Sources:

Clark and Pause (1985), p. 29 figure G. Circulation to use analysis of church of San Maria Degli Angeli, Florence, Italy, Filippo Brunelleschi.

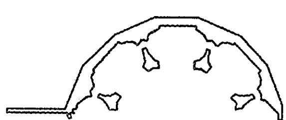
Description:

The circulation scheme (13) can be elaborated by its contour, or in other words, by elaboration of the structural contour, since circulation and walls/structural system are often complementary forms. In the graphic representation, the means of circulation is shown within the elaborated structural contour.

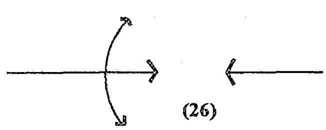
Decisions concern the way circulation (space) is elaborated by material elements. It shows where mainly circulation is expected and where other use of spaces is possible within the elaborated structural contour.

Graphic units are *elaborated structural contour*: closed polygonal shapes (5), and *circulation scheme*: arrows (26).

Graphic units:

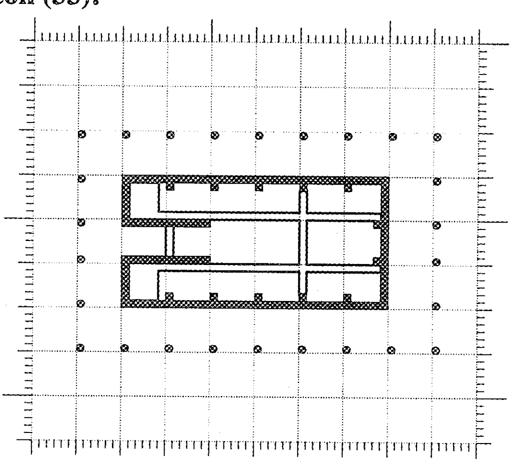


(5)



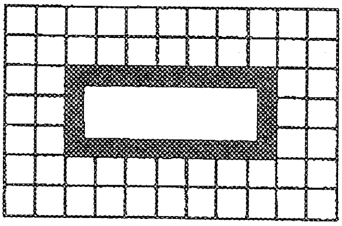
(26)

Icon (33):

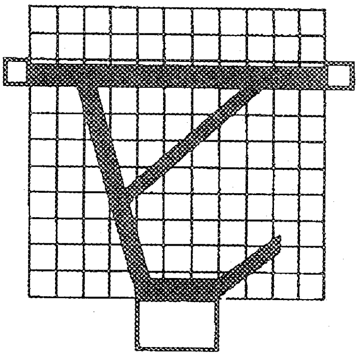


Circulation in contour in grid (44)

Graphic representations:



Bailey (1990), p. 69



Bailey (1990), p. 70

Sources:

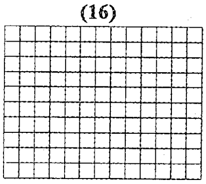
Bailey (1990), p. 69 figures 2.14. 'Effect of plan form, core positions and circulation routes on possible space arrangements.'

Description:

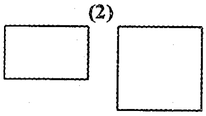
When a grid is chosen to order and co-ordinate the building design, the circulation system may conform to the grid (top figure) or deviate (bottom figure). In the case of deep space (bottom figure), circulation follows the internal functional use rather than a geometrical principle, be it a grid or otherwise. The circulation scheme (13) is made specific by dimensioning and positioning in the contour. Decisions concern the way spaces and places in the building layout are accessed through circulation and how it is related to the grid.
Graphic units are the *grid*: orthogonal set of lines as specific distance (16), *contour*: closed polygonal shape (2), and *circulation*: black lines representing circulation and rectangles representing cores (27).

Graphic units:

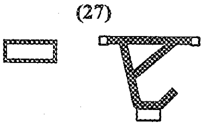
(16)



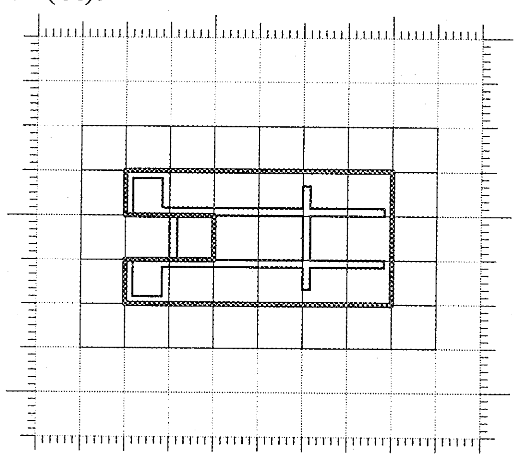
(2)



(27)

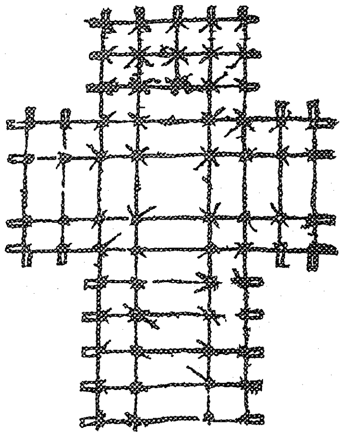


Icon (44):



Structural element vocabulary in contour in modular field (45)

Graphic representations:



Villard de Honnecourt (1215-1235), p. 28

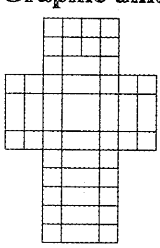
Sources:

Villard de Honnecourt in Bucher (1979), p. 28 figure 2. 'Ideal Cistercian plan.'

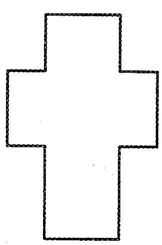
Description:

A contour which is ordered internally by a modular field, is further elaborated by applying an element vocabulary. In the case of a structural element vocabulary (columns, buttresses, and vaults: see figure) the graphic representation shows the build up of the structural system in the building layout. The modular field in this case provides the lines along which structural elements are placed. It corresponds with the spatial ordering of the contour. Decisions concern the relations between the structural system and the dimensions of the spaces.
Graphic units are *modular field*: set of lines (11), contour: *closed polygonal shape* (2), and *structural element vocabulary*: rectangles, crosses, and circles (20).

Graphic units:



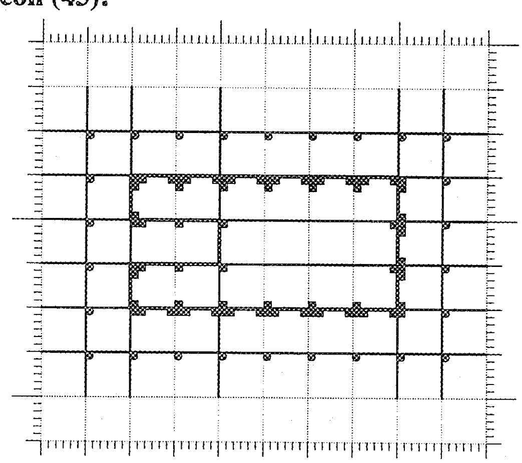
(11)



(2)

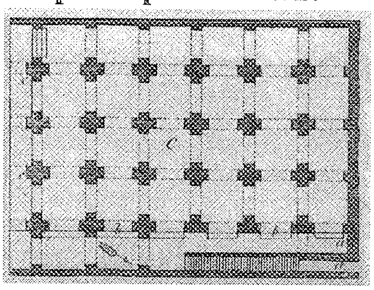
(20)

Icon (45):

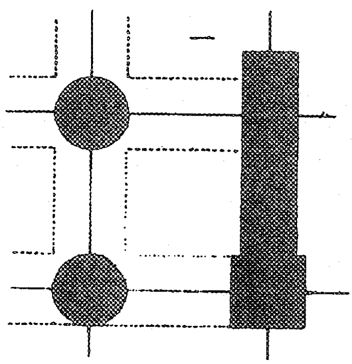


Structural element vocabulary in structural tartan grid (34)

Graphic representations:



Milizia (1847), Tav XI



Durand (1804), Précis Deuxième Partie Planche 1

Sources:

Vitruvius (33-14 BC) in Morgan (1960), p. 121 bottom left figure
Milizia (1847), Parte Seconda Tav XI, figure C
Durand (1804), Précis, Deuxième Partie, Planche 1 figure 11. 'Maniere de tracer les Pilastres.'
Ledoux in Vidler (1990), p. 102 middle figure

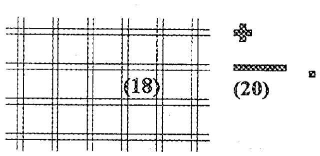
Description:

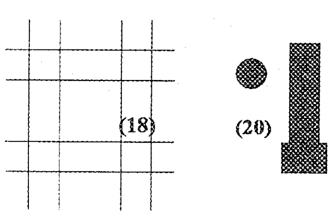
In the same way as an element vocabulary is placed in a grid, it can be placed in a tartan grid. The structural tartan grid, however, allows only structural elements in particular 'bands' of the grid (such as the cross-shaped column in the top figure). More specifically, it provides placement rules for elements (bottom). The modules of the tartan grid relate to structural features such as span. It is termed a structural tartan grid since it defines these features relative to structural elements.

Decisions concern place-agreements on the elements in the grid, and the dimensions of the modules.

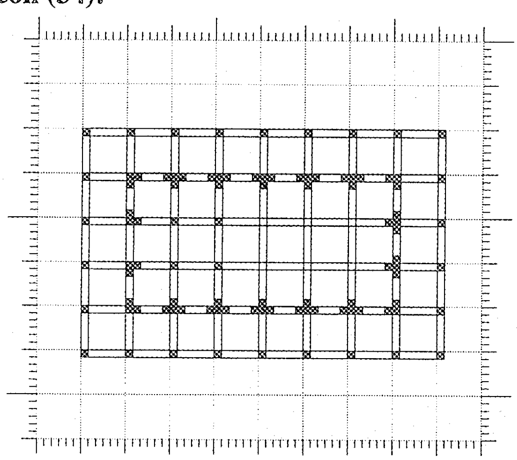
Graphic units are the *structural tartan grid*: lines (18) and the *structural element vocabulary*: filled polygonal shapes for columns and walls, and filled circles for columns (20).

Graphic units:



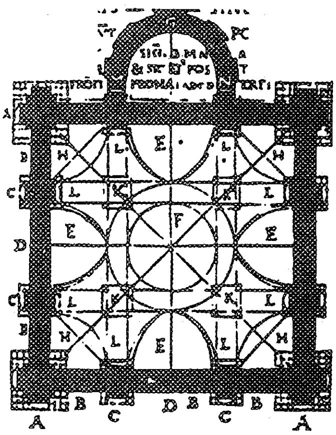


Icon (34):



Structural element vocabulary in structural tartan grid and refinement grid (46)

Graphic representations:



Cesariano (1521), p. 21

Sources:

Cesariano (1521) in Tzonis (1986), p. 21 figure 11. 'Grid pattern.'

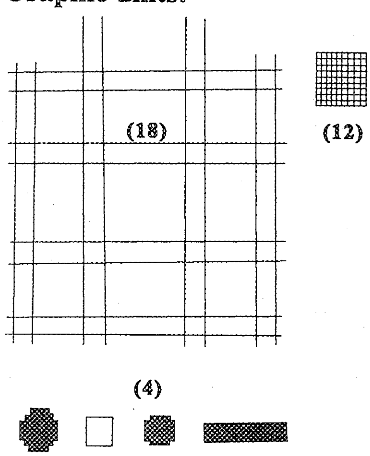
Description:

The structural tartan grid controls placement of structural elements. The modules of the tartan grid define the principle unit of measurement of elements placed in the bands of the grid. It is possible to establish a smaller unit of measurement by defining a refinement grid. The refinement grid controls the elaboration of the structural elements that make up the building. Since the graphic representation contains grids with specific modules, the form is specified (this can also be established through the symbols in the graphic representation which denote dimensions).

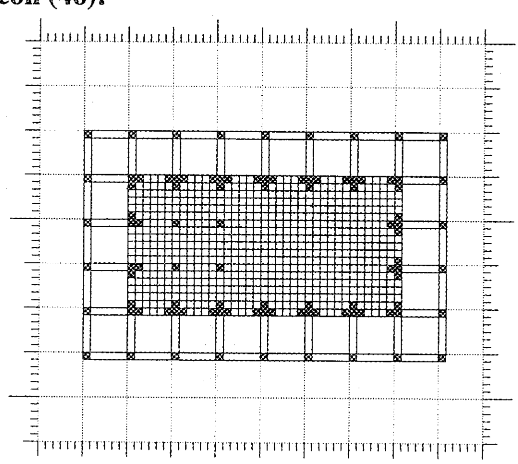
Decisions concern the modules and dimensions of the grids and shape of the building.

Graphic units are *structural tartan grid*: orthogonal set of lines with two modules (18), *refinement grid*: orthogonal set of lines with smaller distance (12), and *structural element vocabulary*: closed polygonal shapes representing walls and squares representing columns (4).

Graphic units:

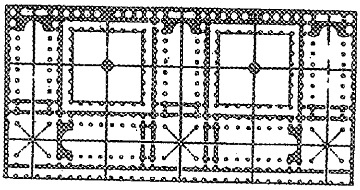


Icon (46):

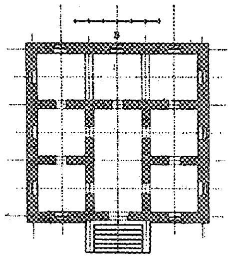


Structural element vocabulary in axial system in contour (47)

Graphic representations:



Durand (1804), Précis Deuxième Partie Planche 19



Durand (1804), Partie Planche 1

Sources:

Durand (1804), Précis, Deuxième Partie, Planche 19 figures G, H. 'Ensembles d'édifices résultants de la combinaisons horisontale de leurs parties.'

Durand (1804), Précis, Deuxième Partie, Planche 21 figure D

Durand (1804), Partie, Planche 1, 2^e Leçon

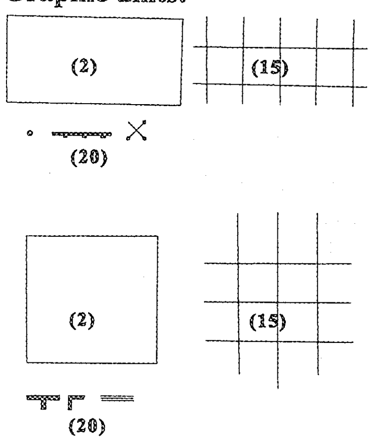
Description:

An axial system superimposed on contour provides direction and hierarchy within the building layout. The structural system is influenced by the axial system because it concerns the walls and columns and such that define the spaces.

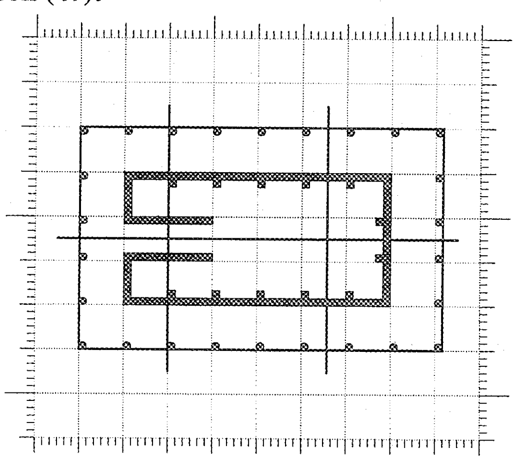
Decisions concern the structural system (distance between columns and span of spaces) and the articulation of the spaces defined by the contour.

Graphic units are *axial system*: lines (15), *structural element vocabulary*: dots, lines with different weights, and closed polygonal shapes (20), and *contour*: closed polygonal shape (2).

Graphic units:

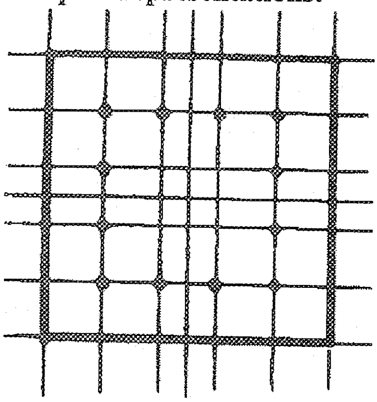


Icon (47):



Structural element vocabulary in axial system in contour in grid (50)

Graphic representations:



Durand (1804), Partie Planche 3

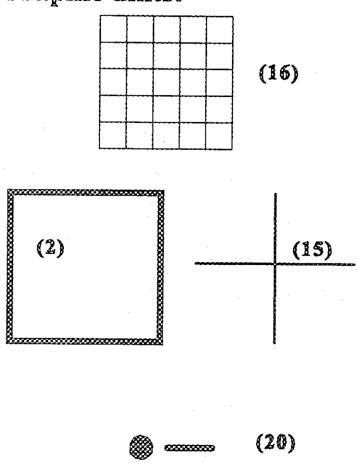
Sources:

Durand (1804), Partie, Planche 3, figure B, C, D

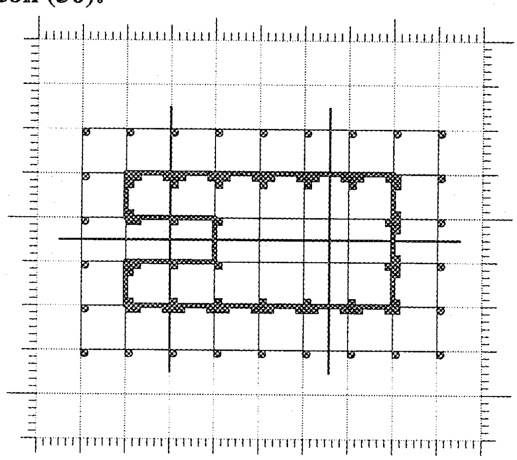
Description:

A grid in a contour defines where within the contour elements are to be placed. A grid does not impose a direction or hierarchy within the contour, other than by the direction of the lines of the grid. An axial system adds a hierarchy within the contour and hints at preferred directions in which to elaborate the contour. The elements of the vocabulary (walls and columns) are placed in the grid and in accordance with the axial system. The graphic representation in the figure left is the most schematic representation of a structural element vocabulary in an axial system imposed on a contour and a grid.
Decisions concern the organisation of the contour by axes, and the location of structural elements in the grid and building layout.
Graphic units are *contour*: closed polygonal shape (2), *grid*: orthogonal set of lines at specific distance (16), *axial system*: set of lines (15), and *structural element vocabulary*: dots representing columns and lines representing walls (20).

Graphic units:



Icon (50):



3.4 Identified graphic units

By means of the method outlined in Section *3.1.3* (p. 31-34) the graphic units of the previous cases are identified. The graphic unit is instrumental to understand the differences between graphic representations and to articulate the decisions involved when a graphic representation is established. The responsible mechanism is the distinction between the set of graphic entities and its assigned meaning. In the analysis, *24* graphic units are identified (graphic units are in *italic typeface* throughout the thesis):

- *Simple contour* (1). Set of graphic entities: regular n-sided (n=*3*, *4*, *5*, etc.) polygonal shapes, including the circle, represented by single lines. Meaning: on the level of scale of the building, the *simple contour* represents the building envelope.
- *Contour* (2). Set of graphic entities: closed polygonal shapes, represented by single lines. Meaning: on the level of scale of the building, the contour represents the building envelope.
  Contour is distinguished from *simple contour* because the topological features of a *contour* can be changed at will without changing the fact that it concerns a contour, whereas the same change in a *simple contour* most likely does not result in a regular n-sided polygonal shape.
- *Measurement device* (3). Set of graphic entities: subdivided line, arrows, and numbers. Meaning: a measurement device provides a unit of measurement of the drawing or the dimensions of parts of the drawing by stating them explicitly. A *measurement device* is an explicit means of establishing dimensions of elements in the drawing.
- *Specified form* (4). Set of graphic entities: closed polygonal shapes, represented by single lines. Meaning: on the level of scale of the building, the specified form represents the building envelope, in which the dimensions and shape of the envelope are determined.
  Specified form is distinguished from *contour* since in *specified form* the dimension and shape of the envelope is defined, which is not the case in *contour*. Establishing *specified form* in a graphic representation is based on either two clues: a measurement device, which provides dimensions of the graphic representation, or the context of the graphic representation (depiction of an existing building, drawing of a building design).
- *Elaborated structural contour* (5). Set of graphic entities: filled polygons. Meaning: an elaborated structural contour defines the outline of spaces in terms of their material form, for the complete building.

The *elaborated structural contour* is complex in its shape since it specifically describes how the material elements that make up the spaces are formed.

- *Complementary contours* (6). Set of graphic entities: interlocked surfaces, represented by filled-in (black, white, hatched, etc.) polygonal shapes. The boundaries of the shapes are represented by single lines. Meaning: all shapes that have the same colour represent either mass or space of the building.
  The shapes in *complementary contours* can vary considerably in complexity since they describe articulation of the edge between mass and space.
- *Function symbols* (7). Set of graphic entities: letters, symbols, or words. Meaning: a function symbols associates a function to the particular area or shape it is assigned to. The function can be defined by the function symbol itself ("living room," "bedroom," etc.), or by reference to a code.
- *Zone* (8). Set of graphic entities: (filled) closed polygonal shapes. The boundary is represented by single lines, which can be left out in the case of filled polygonal shapes. Meaning: a zone represents an area which has specific properties distinct from other parts in the plan.
  A *zone* is a specialised form of *functional space* since functional space is explicitly linked to *contours*. A *zone* designates areas that may accommodate numerous contours.
- *Schematic subdivision* (10). Set of graphic entities: lines. Meaning: a schematic subdivision provides a principle of distinguishing between parts. The lines represent boundaries between parts. The boundaries are often materialised by walls.
- *Modular field* (11). Set of graphic entities: parallel lines in one or more directions at three or more different distances. Meaning: the modular field defines a system of lines that rule placing of elements in the plan.
  The *modular field* is distinct from the *grid* since the *grid* has a module (distance between lines) that applies to all directions.
- *Refinement grid* (12). Set of graphic entities: the set of two sets of parallel lines in two or three directions in which the distance between lines for all directions is the smallest module. Meaning: a refinement grid defines how a grid can be further subdivided in a grid that has a smaller module. In this way, it is possible to use different sets of measures, or different levels of precision in the position of elements.
  A *refinement grid* can only occur in the presence of a *grid*. The *refinement grid* is always the grid with the smallest module.
- *Schematic axial system* (13). Set of graphic entities: lines. Meaning: the schematic axial system defines axes along or around which elements of the

plan are arranged. The lines represent the axes, which usually delineate the central line of spaces.

- *Axial system* (15). Set of graphic entities: lines. Meaning: the axial system is a more specific form of the schematic axial system. The axes are determined in more detail, and can also define local symmetries.
  Contrary to a *schematic axial system*, which only states a principle of axes, and can therefore be represented by itself, an *axial system* is specific and is used in combination with other shapes.
- *Grid* (16). Set of graphic entities: parallel lines in two or three directions in which the distance between lines is one module for all directions. Meaning: a grid defines a field which controls place and geometry of elements that are placed in the grid.
- *Tartan grid* (17). Set of graphic entities: parallel lines in a number of directions that have at least two modules in one direction. Meaning: a tartan grid defines a field in which bands are distinguished that accommodate particular elements.
- *Structural tartan grid* (18). Set of graphic entities: parallel lines in a number of directions that have at least two modules in one direction. Meaning: a structural tartan grid is a more specific form of a tartan grid, in which one of the bands is reserved for structural elements such as walls and columns.
- *Element vocabulary* (19). Set of graphic entities: a set of distinct complex shapes. Meaning: an element vocabulary defines a coherent set of matching elements. On the level of the building, element vocabulary consists of functional elements such as tables and chairs for eating, and elements beds, closets, and washbasins for the function sleeping, etc.
- *Structural element vocabulary* (20). Set of graphic entities: a set of distinct shapes. Meaning: a structural element vocabulary consists of shapes that represent structural elements such as columns, vaults, spans, walls, etc.
  A *structural element vocabulary* is distinguished from an *element vocabulary* since the structural system is an important aspect of the building design.
- *Functional space* (21). Set of graphic entities: (filled) closed polygonal shapes. The shapes can be filled with different colours or hatching. The boundaries are represented by single lines, which can have varying line weight, colour, or linetype. Meaning: functional spaces indicate different uses of contours in a combination of simple contours. The function is defined relative to the coding of the functional space.

- *Partitioning system* (22). Set of graphic entities: parallel or crossing lines. Meaning: a partitioning system determines where in a building layout spaces can be separated physically.
  A *partitioning system* is based on a *schematic subdivision* and makes more explicit where divisions can be established. It does not yet specify actual divisions in the building layout.
- *Proportion system* (23). Set of graphic entities: lines, simple contours, and geometric shapes that are placed at specific intersections or angles. Meaning: the proportion system defines a field in which specific points, proportions between lines, and particular angles have priority over other possible points, proportions, and angles.
- *Combinatorial element vocabulary* (24). Set of graphic entities: a set of distinct complex shapes. Meaning: a combinatorial element vocabulary determines precise relationships between elements of an element vocabulary which have a particular meaning.
  A *combinatorial element vocabulary* is distinguished from an *element vocabulary* since the relations determine particular properties (*e.g.*, distinct relations between columns and walls for styles of classical temples, or particular ways of solving edges).
- *Circulation scheme* (26). Set of graphic entities: one or more single or double polygonal lines, or arrows. Meaning: a circulation scheme defines the principle in which circulation is established in a building layout.
- *Circulation* (27). Set of graphic entities: one or more single or double polygonal lines or closed polygonal shapes. Meaning: circulation defines how the particular circulation is established in a building layout. *Circulation* is distinguished from *circulation scheme* since it is more specific on the precise place, form, and layout of the circulation.

3.5 Identified generic representations

The graphic units define *50* generic representations. The generic representations identified in the survey have no more than four distinct graphic units at the same time. The number of instances that belong to a graphic unit can differ (for example, the generic representation "combination of contours" has one graphic unit: the *contour*, but has a number of contours in a graphic representation; "multiple grids" has one graphic unit: the *grid*, but has at least two grids in a graphic representation). The following list of generic representations found in the survey is ordered on the basis of increasing number of graphic units (generic representations found in the survey are in underscored typeface throughout the thesis).

Generic representations with one graphic unit:

- Simple contour (1)
- Combination of contours (2)
- Complementary contours (3)
- Modular field (4)
- Proportion system (5)
- Multiple grids (6)
- Functional spaces (7)
- Schematic axial system (8)
- Schematic subdivision (9)
- Elaborated structural contour (10)
- Element vocabulary (11)
- Combinatorial element vocabulary (12)
- Circulation scheme (13)

Generic representations with two graphic units:

- Proportion system in contour (14)
- Contour in grid (15)
- Zone in specified form (16)
- Function symbols in combination of contours (17)
- Axial system in specified form (18)
- Schematic subdivision in grid (19)
- Schematic subdivision with function symbols (20)
- Schematic subdivision in contour (21)
- Partitioning system in contour (22)
- Specified elaborated structural contour (23)
- Elaborated structural contour in grid (24)
- Elaborated structural contour in complementary contours (25)
- Elaborated structural contour and axial system (26)
- Elaborated structural contour and function symbols (27)
- Element vocabulary in grid (28)
- Element vocabulary in multiple grids (29)
- Combinatorial element vocabulary in grid (30)
- Combinatorial element vocabulary in specified form (31)
- Circulation in contour (32)
- Circulation scheme in elaborated structural contour (33)
- Structural element vocabulary in structural tartan grid (34)

Generic representations with three graphic units:

- Proportion system in elaborated structural contour in tartan grid (35)
- Zone in contour in grid (36)
- Axial system in contour in grid (37)
- Axial system in contour in tartan grid (38)
- Axial system in specified form in structural tartan grid (39)
- Schematic subdivision in grid and refinement grid (40)
- Schematic subdivision and schematic axial system in contour (41)
- Elaborated structural contour and function symbols and axial system (42)
- Element vocabulary in zone and contour (43)
- Circulation in contour in grid (44)
- Structural element vocabulary in contour in modular field (45)

- Structural element vocabulary in structural tartan grid and refinement grid (46)
- Structural element vocabulary in axial system in contour (47)

Generic representations with four graphic units:

- Element vocabulary and function symbols and grid in specified form (48)
- Schematic subdivision in zone in contour with function symbols (49)
- Structural element vocabulary in axial system in contour in grid (50)

3.6 Relations between generic representations

The overview of generic representations in the list above is ordered only on increasing number of graphic units. Any further relations between generic representations are not provided. By means of the graphic unit, each single generic representation is described in terms of its design decisions. By determining the possible relations and their extent between generic representations, it should be possible to assess the completeness and scope of generic representations. Generic representations can be described in terms of their constituent graphic units (lower level), and in terms of groups of generic representations that deal with particular design decisions (higher level). The relation with respect to graphic units is *addition of graphic units*, which shows how new generic representations are established by adding graphic units to generic representations. The relation with respect to generic representations is *themes in generic representations*, which groups generic representations that deal with the same decisions.

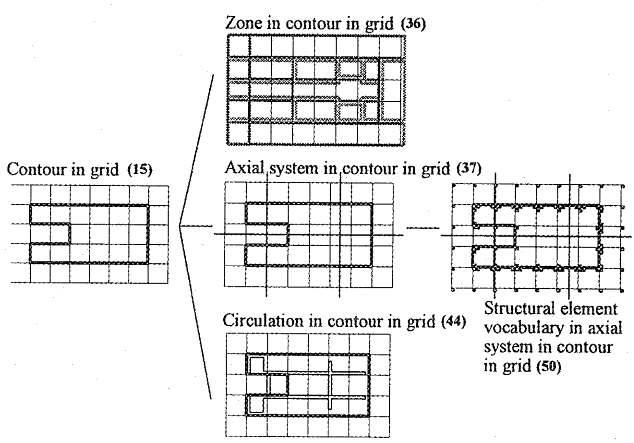


Figure III-7: Relation of addition of graphic units between generic representations.

3.6.1 Addition of graphic units

Addition of graphic units indicates how generic representations are related to each other in terms of their constituent graphic units. By analysing such relationships, it is possible to structure the otherwise unrelated graphic representations that constitute the basis of the survey. The relation shows how generic representations increase in complexity by adding graphic units. In this manner a sequence that moves top-down in the list above can be established. An addition of a graphic unit to a generic representation implies that the new graphic unit has to be matched with the existing graphic units of the previous generic representation. The generic representation becomes more complex in the sequence. Three examples illustrate this process.

Example one: "contour in grid."

Beginning with the generic representation contour in grid (15), the following relationships can be established by addition of graphic units:

- Contour in grid — zone in contour in grid (36: add *zone*).
- Contour in grid — axial system in contour in grid (37: add *axial system*) — structural element vocabulary in axial system in contour in grid (50: add *structural element vocabulary*)
- Contour in grid — circulation in contour in grid (add *circulation*)

The generic representation contour in grid can not be established by adding graphic units *contour* and *grid* because there is no generic representations contour and no generic representation grid[12] in the survey. This sequence of adding graphic units to generic representations is shown in Figure III-7.

Example two: "schematic subdivision."

This generic representation has the following relationships:

- Schematic subdivision — schematic subdivision in grid — schematic subdivision in grid and refinement grid
- Schematic subdivision — schematic subdivision with function symbols
- Schematic subdivision — schematic subdivision in contour — schematic subdivision and schematic axial system in contour

This sequence is shown in Figure III-8.

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[12] The generic representation multiple grids has one graphic unit: the *grid.* However, since there is a distinct difference between either one grid or multiple grids, the generic representation multiple grids is not a basis for adding *contour* in this case.

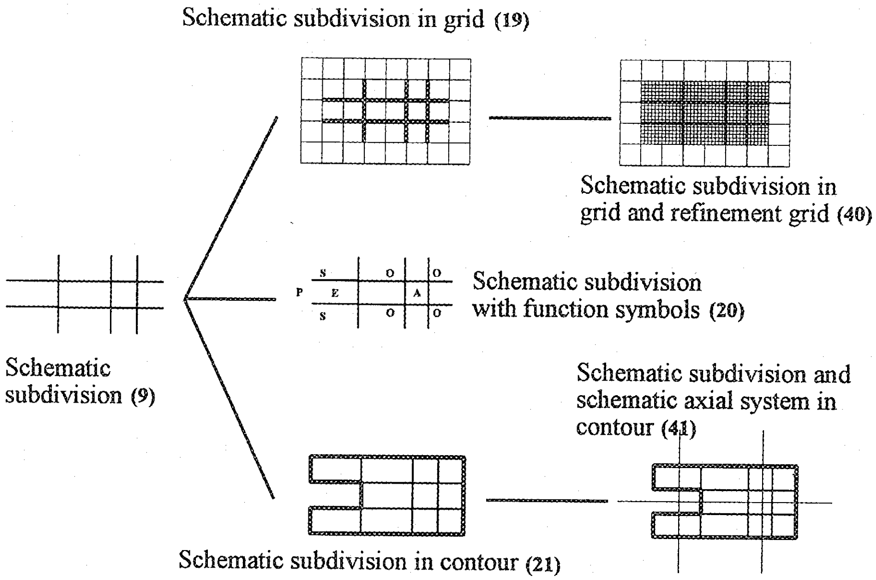

Figure III-8: Relation of additional graphic units between generic representations.

Example three: "Elaborated structural contour."

- Elaborated structural contour — specified elaborated structural contour
- Elaborated structural contour — elaborated structural contour in grid
- Elaborated structural contour — elaborated structural contour in complementary contours
- Elaborated structural contour — elaborated structural contour in axial system — elaborated structural contour and function symbols and axial system
- Elaborated structural contour — circulation scheme in elaborated structural contour

This sequence is shown in Figure III-9.

By analysing all relationships between generic representations in the same manner, a general structure of generic representations can be established (see Figure III-10). The structure demonstrates that on the basis of graphic units there is no obvious linear structure along which all generic representations are ordered.

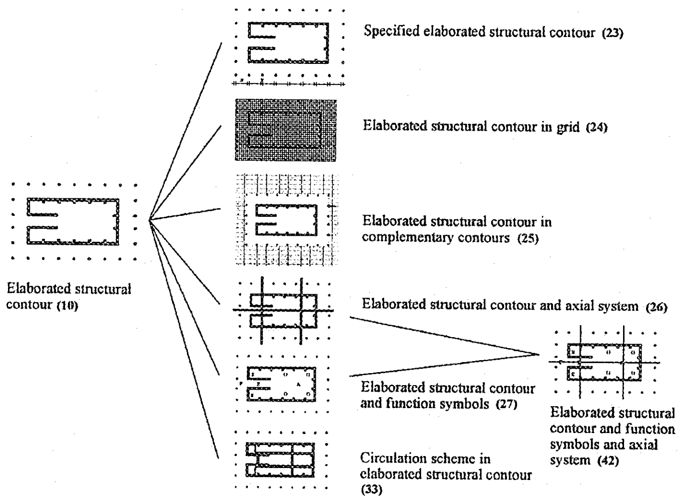

Figure III-9: Relation of additional graphic units between generic representations.

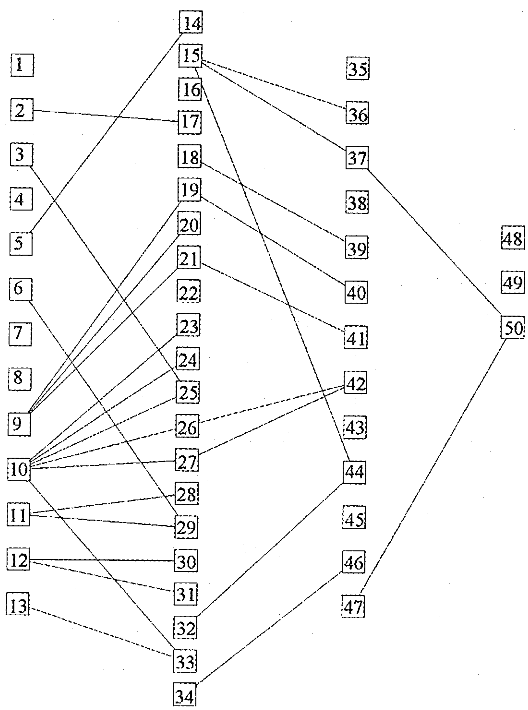

Figure III-10: Overview of generic representations. Numbers indicate generic representations (see Section *3.4.2*). Lines indicate addition of one graphic unit.

3.6.2 Missing generic representations

The relations above are all substantiated by the set of generic representations found in the survey. A number of generic representations is not related to each other by these relations. Formulated in general: given a generic representation X composed of *n* graphic units {*a*,*b*, …, *n*} there is no generic representation Y composed of *n-1* graphic units such that addition of graphic unit *a*, *b*, …, *n* results in generic representation X {*a*,*b*, …, *n*}.

For example, the generic representation schematic subdivision in zone in contour with function symbols (49) is not established by addition of either *function symbols*, *contour*, *zone*, or *schematic subdivision* to any generic representation *35 - 47* (see Figure III-10).

The fact that a number of generic representations are not related to each other by means of addition of graphic units, leads to the conclusion that there are 'missing links' between generic representations. Such missing links are significant because they indicate to which extent the survey is complete. It is possible to formulate hypothetical generic representations that provide links between generic representations by means of addition of graphic units. There are three different strategies of determining such hypothetical generic representations:

1. *Logical combination of graphic units.* Define 'primitive' generic representations that consist of one graphic unit. Since there are *24* graphic units, this yields *24* generic representations of which *13* are found in the survey (first column of Figure III-10). Hypothetical generic representations can be defined by establishing all possible combinations of two, three, or four generic representations. This gives a total of *12950* hypothetical generic representations[13], of which *50* are found in the survey.
2. *Subtraction of graphic units from existing generic representations.* Constrain the possible generic representations by the condition that any sequence of addition of graphic units must terminate in a generic representation that is part of the set found in the survey or in a hypothetical generic representation that is required for reaching a generic representation found in the survey. In terms of Figure III-10 this is a right-bound strategy. Because of the right-to-left direction of development, this strategy also identifies generic representations with one graphic unit that are not found in the survey (see Figure III-11). The strategy yields a total of *106* generic

[13] If any four graphic units of the total of *24* can be combined randomly, including combinations of three graphic units, two graphic units, and one graphic unit, this generates $24! / (4! \cdot 20!) + 24! / (3! \cdot 21!) + 24! / (2! \cdot 22!) + 24 = 10626 + 2024 + 276 + 24 = 12950$ combinations of graphic units.

representations of which *50* generic representations are found in the survey and *56* are hypothetical generic representations.

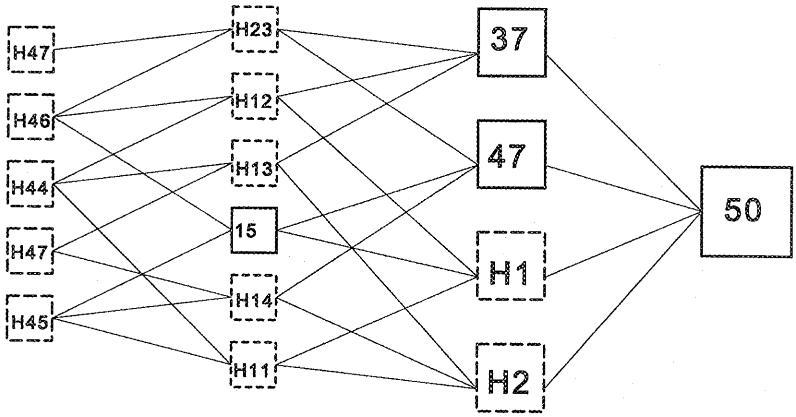

Figure III-11: Strategy (2). Establishing hypothetical generic representations by subtraction from generic representations found in the survey. Example of relations starting from structural element vocabulary in axial system in contour in grid (50)

3. *Subtraction from and addition to existing generic representations of graphic units.* Constrain the possible generic representations by the additional condition to (2) that any sequence of addition of graphic units to (hypothetical) generic representations must also start in a generic representation that is part of the set found in the survey (see Figure III-12). This gives a total of *59* generic representations of which *50* generic representations are found in the survey and *9* are hypothetical generic representations.

Strategy (3) provides hypothetical generic representations that fill in the 'blanks' between sequences of addition of graphic units in Figure III-10. This strategy poses the least amount of hypothetical generic representations and is maximally embedded in the current set since sequences both start and end in generic representations found in the survey.

Strategy (2) provides hypothetical generic representations that are constrained by the set through the requirement that sequences must end in an existing generic representation or a hypothetical generic representation that is required for an existing generic representation.

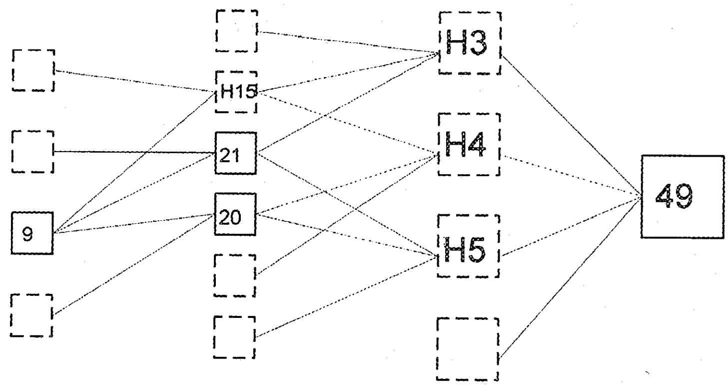

Figure III-12: Strategy (3). Establishing hypothetical generic representations by addition of graphic units that start and end in generic representations found in the survey. Example of relations starting from schematic subdivision in zone in contour with function symbols (49).

Strategy (1) provides all logically possible generic representations on the basis of unconstrained combination of graphic units. The large number of possible combinations renders an inventory on this basis practically meaningless.
Strategy (2) is chosen for identifying hypothetical generic representations. By the limitation that they must lead to existing generic representations, the set of possible generic representations is drastically reduced and related to the findings of the survey. It is only possible for this set of hypothetical generic representations to expand when new graphic units are identified on the basis of new generic representations.

Determining hypothetical generic representations with strategy (2)
The procedure of determining hypothetical generic representations starts with generic representation (50) structural element vocabulary in axial system in contour in grid (hypothetical generic representations are in *italic underscored typeface* throughout the thesis):

- For the generic representation, formulate all (hypothetical) generic representations that have one graphic unit less as formulated in Section *3.6.2*. In the case of generic representation (50), the resulting (hypothetical) generic representations are: axial system in contour in grid (37), structural element vocabulary in axial system in contour (47), *structural element vocabulary in contour in grid* (H1), and *structural element vocabulary in axial system in grid* (H2).

- Check whether any of these generic representations is identified in the survey, and number these accordingly. In this example, structural element vocabulary in axial system in contour is number (47), and axial system in contour in grid is number (37).
- The remaining generic representations are hypothetical. If they have not yet been identified in the list of hypothetical generic representations, give them a new number H#, where # is the next integer value (*1*,*2*,*3*,...). In this example *structural element vocabulary in contour in grid* is number (H1), and *structural element vocabulary in axial system in grid* is number (H2).
- Continue for the next generic representation in the list. Also perform this for all hypothetical generic representations that are identified in this manner, until all (hypothetical) generic representations have been analysed. In this example, the next generic representation is (49) schematic subdivision in zone in contour with function symbols.

In this manner, it is possible to identify all hypothetical generic representations that can be added to the survey. Appendix *B* provides an overview of these generic representations. For each hypothetical generic representation it is possible to formulate the properties on basis of the graphic units constituting the generic representations.

3.6.3 Themes of generic representations

The relations identified above are logical relations. They map all possible transitions from one generic representation to another by means of addition of graphic units. Because in each next 'step' in these relations a graphic unit is added, the transitions are by definition from simple to complex.

As has been outlined in the analysis, generic representations deal with design decisions. Similarity between generic representations can indicate if they deal with similar design decisions. Finding a number of such similar generic representations can give indications to which extent aspects are dealt with by generic representations. A large number of similar generic representations indicates that the kind of design decisions concerned are worked out in great detail.

The relationship of addition of graphic units can not identify such similarities. In order to identify groups of generic representations that deal with similar design decisions, it is necessary to find another relation. Similarity in the graphic units constituting generic representations can provide such a relation.

For example, the generic representations simple contour (1), combination of contours (2), and complementary contours (3) all deal with one single issue: the shape and place of the building edge. There are no other generic representations that focus only on the contour. Therefore, it is possible to state that these generic representations deal with the shape of the building (layout).

The generic representations proportion system (5), modular field (4), multiple grids (6), schematic axial system (8), schematic subdivision (9), schematic subdivision in grid (19), schematic subdivision with function symbols (20), and schematic subdivision in grid and refinement grid (40) all deal with one single issue: the structure underlying shapes. There are no other generic representations that focus only on the structure. Furthermore, within this theme it is possible to identify groups: proportion systems: (5), grids: (4) and (6), axial systems: (8), and schematic subdivisions: (9), (19), (20), and (40).

In this manner, groups of generic representations can be established that deal with similar issues. Such groups are termed "themes." The generic representations in a theme develop independent from generic representations in other themes. By combining generic representations from themes (addition of graphic units), it is possible to establish more complex generic representations that deal with more sophisticated design decisions.

In the following summary of themes, generic representations are grouped by theme. Included in the list are the hypothetical generic representations established above. Generic representations found in the survey are numbered as in the list of Section *3.5*. They are in underscored typeface, and numbered between brackets (#). Hypothetical generic representations are numbered as in Appendix *B*. They are in *italic underscored typeface* and numbered between brackets (H#). Themes are indicates by "quote-marks."

Theme: "shape"

The shape of the building is defined through establishing an outward contour. "Shape" concerns form, major building parts, their relative positions, (relative) dimensions, and their relation with the site. In this manner, "shape" provides important information about the general form of the building. The necessary decisions concern topology, orientation, and composition. These decisions are taken either on the urban tissue level or on the building level.

The generic representations that make up "shape" therefore, need to define contours of the design object and their relative positions and dimensions. The following generic representations contribute to "shape":

- Simple contour (1)
- Combination of contours (2)
- Complementary contours (3)
- *Contour* (H46)
- *Specified form* (H50)

Theme: "structure"

The manner in which any shape is organised depends on structure. Structure basically can be defined via a number of means such as proportion systems, grid-based fields, axial systems, and subdivisions. The means are not mutually exclusive (it is possible for example to establish an axial system in a grid).

"Structure" requires knowledge of organisation principles. These principles define on a high level of abstraction what rules apply in the actual placement of spaces, rooms, and systems. They generally do not emerge represented in the graphic representations at the end of the design. These decisions are generally taken on the building-level.

The generic representations that make up "structure" therefore, define the structure which provides rules for further elaboration of the building design. The following generic representations contribute to "structure":

- Proportion system (5)
- Modular field (4)
- Multiple grids (6)
- Schematic axial system (8)
- Schematic subdivision (9)
- Schematic subdivision in grid (19)
- Schematic subdivision with function symbols (20)
- Schematic subdivision in grid and refinement grid (40)
- *Grid* (H45)
- *Axial system* (H47)
- *Zone* (H48)
- *Function symbols* (H49)
- *Refinement grid* (H51)
- *Structural tartan grid* (H52)
- *Tartan grid* (H54)
- *Measurement device* (H55)
- *Axial system* in *grid* (H14)
- *Schematic subdivision* in *zone* (H15)
- *Function symbols* in *zone* (H17)
- *Function symbols* in *grid* (H20)
- *Function symbols* and *axial system* (H31)
- *Schematic subdivision* and *schematic axial system* (H32)
- *Schematic subdivision* in *refinement grid* (H34)
- *Schematic subdivision* in *zone* with *function symbols* (H4)
- *Refinement grid* in *grid* (H35)
- *Axial system* in *structural tartan grid* (H36)
- *Axial system* in *tartan grid* (H38)

- *Zone* in *grid* (H40)
- *Proportion system* in *tartan grid* (H42)
- *Structural tartan grid in refinement grid* (H25)

Theme: "systems"

The actual definition of the building design in physical parts such as rooms, structural cores, and furniture, takes place through positioning and dimensioning of elements. In order to do so, it is necessary to have an element vocabulary, and understanding how to use it. Such a whole can be conceived of as a system. A number of systems can be distinguished which have influence on the whole building design but that are worked out on infill- and detail level. Among those are circulation, structural system, HVAC, and electricity. These systems often are represented in highly specific ways. Although the influence of systems can reach up to "structure" on the building-level, it usually is fully worked out on the infill-level, and finally on the detail-level.

The definitive ordering into spaces is governed by the rules underlying where walls can be placed. A partitioning structure provides such rules. Functional properties of a space can be established by an element vocabulary that consists of a group of elements that define such functions (such as tables, chairs, closets, and other furniture for 'living room'). Two other kinds of systems are identified from the results in the survey: the circulation system and the structural system. The following generic representations contribute to systems:

- Element vocabulary (11)
- Circulation scheme (13)
- *Structural element vocabulary* (H44)
- *Circulation* (H53)
- *Partitioning system* (H56)

The themes "shape," "structure," and "systems" are independent of each other. The generic representations that are placed in these themes deal with separate issues. On the basis of these themes, it is possible to make the following combinations: "shape" and "structure," "structure" and "system," "shape" and "system," and "shape" and "structure" and "system" (see Figure III-13).

Combination of themes: "shape and structure"

"Shape and structure" results from the combination of generic representations that deal with structure and generic representations that deal with shape. The outward contour is refined under influence of the internal structure, brief, site conditions, and designer preferences. The major parts of the building are established and the actual subdivision of these major parts. These parts

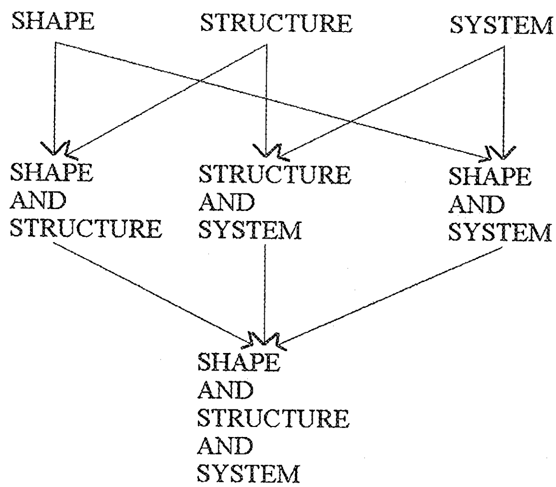

Figure III-13: Combinations of themes on the basis of "shape," "structure," and "system." Each theme has its specific set of generic representations.

generally establish separate areas, and tend to reflect groupings present in the brief. The decisions are taken on the building and support-level.

The generic representations that make up "shape and structure" therefore, apply the "structure" to the "shape" and provide the basic subdivision of the "shape."

The following generic representations contribute to "shape and structure":

- Proportion system in contour (14)
- Combinatorial element vocabulary (12)
- Combinatorial element vocabulary in grid (30)
- Combinatorial element vocabulary in specified form (31)
- Contour in grid (15)
- Axial system in specified form (18)
- Axial system in contour in grid (37)
- Axial system in contour in tartan grid (38)
- Axial system in specified form in structural tartan grid (39)
- Schematic subdivision in contour (21)
- Schematic subdivision and schematic axial system in contour (41)
- Zone in specified form (16)
- Zone in contour in grid (36)
- Functional spaces (7)
- Function symbols in combination of contours (17)
- Schematic subdivision in zone in contour with function symbols (49)
- *Zone* in *contour* (H16)
- *Function symbols* in *contour* (H18)
- *Function symbols* in *specified form* (H21)

- *Specified form* in *grid* (H22)
- *Axial system* in *contour* (H23)
- *Contour* in *modular field* (H27)
- *Schematic axial system* in *contour* (H33)
- *Specified form* in *structural tartan grid* (H37)
- *Contour* in *tartan grid* (H39)
- *Schematic subdivision* in *zone* in *contour* (H3)
- *Schematic subdivision* in *contour* with *function symbols* (H5)
- *Zone* in *contour* with *function symbols* (H6)
- *Function symbols in specified form in grid* (H10)

Combination of themes: "structure and system"

The combination of the themes "structure" and "system" results in co-ordinating the systems of the structure with the underlying structures of the building design by means of such devices as axes, grids, proportion systems, etc. "Structure and system" provides the basic rules governing place and organisation of systems such as partitioning, function, circulation, and structure. The following generic representations contribute to "structure and system":

- Element vocabulary in grid (28)
- Element vocabulary in multiple grids (29)
- Structural element vocabulary in structural tartan grid (34)
- Structural element vocabulary in structural tartan grid and refinement grid (46)
- *Structural element vocabulary* in *grid* (H11)
- *Structural element vocabulary* in *axial system* (H13)
- *Structural element vocabulary* in *refinement grid* (H24)
- *Structural element vocabulary* in *modular field* (H26)
- *Structural element vocabulary* in *axial system* in *grid* (H2)
- *Circulation* in *grid* (H28)
- *Element vocabulary* and *function symbols* (H19)
- *Element vocabulary* in *zone* (H29)
- *Element vocabulary and function symbols in grid* (H7)

Combination of themes: "shape and system"

The combination of generic representations from "shape" and "system" results in determining how systems such as circulation, partitioning, function, and structure are placed relative to the outline of the building design as established in "shape." The following generic representations contribute to "shape and system":

- Partitioning system in contour (22)
- Circulation in contour (32)

- *Structural element vocabulary* in *contour* (H12)
- *Element vocabulary in contour* (H30)

Combination of themes: "shape and system and structure"

The final partitioning of the building design establishes the definition of rooms and spaces, their place, and relative proportions on the basis of the requirements put forward by the brief, the principles established by the previous combinations of themes, site properties, and designer preferences. The actual partitioning is established and further elaborated into walls, columns, etc., resulting in a number of elaborated structural contours. The decisions are taken on the infill-level.

- Elaborated structural contour (10)
- Specified elaborated structural contour (23)
- Elaborated structural contour in grid (24)
- Elaborated structural contour in complementary contours (25)
- Elaborated structural contour and axial system (26)
- Elaborated structural contour and function symbols (27)
- Proportion system in elaborated structural contour in tartan grid (35)
- Elaborated structural contour and function symbols and axial system (42)
- Element vocabulary in zone and contour (43)
- Element vocabulary with functions and grid in specified form (48)
- Circulation scheme in elaborated structural contour (33)
- Circulation in contour in grid (44)
- Structural element vocabulary in contour in modular field (45)
- Structural element vocabulary in axial system in contour (47)
- Structural element vocabulary in axial system in contour in grid (50)
- *Proportion system* in *elaborated structural contour* (H41)
- *Elaborated structural contour* in *tartan grid* (H43)
- *Structural element vocabulary* in *contour* in *grid* (H1)
- *Element vocabulary* and *function symbols* in *specified form* (H8)
- *Element vocabulary in specified form in grid* (H9)

Themes versus addition of graphic units

In the themes generic representations occur that have different numbers of graphic units. "Shape" for example, has one generic representation with one graphic unit, six generic representations with two graphic units, and one generic representation with three graphic units. "Structure" has five generic representations with one graphic unit, two generic representations with two graphic units, and one generic representation with one graphic unit. The principle of ordering by themes establishes other relations than the relation of addition of graphic units discussed above.

Furthermore, the notion of themes seems to be a good categorisation of all generic representations. Generic representations can be categorised unambiguously in any theme "shape," "system," "structure," "shape and structure," "structure and system," "shape and system," and "shape and structure and system." There are no generic representations that fall in more than one category. The principle of themes therefore, seems complementary to the relation of additional graphic units.

Conclusion

The analysis of graphic representations from sources in architecture based on graphic units yields a set of generic representations. The multitude of graphic representations (over *220* cases) is identified as forming *50* generic representations, described by *24* graphic units. The graphic unit seems to be a suitable unit of analysis for describing graphic representations. Analysing graphic representations on the basis of graphic units brings forward the connection between drawing and decision-making. Description of graphic representations occurs in three levels: the graphic unit, generic representation, and themes of generic representations. Generic representations are analysed on a lower level in terms of graphic units, and on a higher level in terms of themes. The analysis in graphic units reveals that not all generic representations are related to each other by means of addition of graphic units. This leads to the proposition that it is possible to identify hypothetical generic representations on the basis of graphic units. These hypothetical generic representations are not found in the survey, but can be described in detail on the basis of the graphic unit. A number of *56* hypothetical generic representations are defined. The analysis in terms of themes reveals that generic representations can be grouped on the same kinds of decisions that they imply. The notions of 'additional graphic units' and 'themes' are instrumental for establishing design processes by means of generic representations. This will be discussed in the next Chapter.

4 A SEQUENCE OF GENERIC REPRESENTATIONS

Procedural Knowledge in the Sequence

In Chapter *3* generic representations are identified. The set of found generic representations is analysed on the basis of additional graphic units and themes. In order to establish a sequence of generic representations which can support the design process, it is necessary to understand how generic representations are related to each other. The generic representations within the themes are not related to each other by means of additional graphic units. In this Chapter another way of relating generic representations is identified and applied. This leads to general sequences of generic representations which provide the basis for a particular sequence of generic representations.

4.1 Six sequences of themes

The set of generic representations that results from the survey in Chapter *3*, is described on three levels: graphic units, generic representations, and themes. The analysis of the previous Chapter yields relations between generic representations on the basis of graphic units and groups generic representations in themes. The discussion is focused on single generic representations. The analysis up to now shows that the relationship of additional graphic units is insufficient for linking the generic representations found in a sequence. If hypothesis *3* ("it is possible to define the transitions between graphic representations and to establish a sequence") is true, this means that it is necessary to establish another way of defining transitions between generic representations on the basis of graphic units. First it is necessary to discuss in more detail how a sequence of generic representations is brought about.

The strategy for establishing sequences of generic representations is divided into two stages. First, sequences of themes are established. In Section *3.6.3* three basic themes are identified: "shape," "system," and "structure." Each of these themes has generic representations that deal specifically with that theme. They do not occur in other themes. More complex generic representations are identified in more complex themes: "shape and structure," "shape and system," and "structure and system." The generic representations of these more complex themes combine generic representations of the basic themes. The most complex generic representations occur in the theme "shape and structure and system." The generic representations of this theme combine generic representations of all themes.

Given the progression during a design process from simple to complex, general to particular, and ambiguous to specific, it seems logical that a sequence of themes starts with either one of the three basic themes: "shape," "system," or "structure." The next step in the sequence of themes are the more complex themes. The theme "shape" therefore, can be followed by either the theme "system" or "structure." The theme "system" can be followed by either "shape" or "structure," and the theme "structure" can be followed by either "shape" or "system." The third and last step in the sequence of themes then concludes by the most complex theme: "shape and structure and system."

In this manner, six general sequences of generic representations based on themes are established. The possible sequences of generic representations can be described as follows:

1. "Structure" → "shape and structure" → "shape and structure and system": the process starts with establishing the structure which governs internal

organisation of the building design. Structures identified in generic representations are proportion systems, grid-based fields, axial systems, and subdivisions (Section *3.6.3*). Via a sequence of generic representations in the theme "structure" it is possible to establish to some degree the structure without referring to the building design itself. The theme "shape and structure" defines in various degrees the way the building layout is organised with respect to the structure. After "shape and structure" is established, systems are added. This results in "shape and structure and system."

2. "Structure" → "structure and system" → "shape and structure and system": the process starts in the same way as described above. The sequence continues with elaborating the system with respect to the structure. At this point, the building layout is not dealt with but only the principle organisation by means of structures and systems. "Structure and system" provide the organisational principles to elaborate the building layout, by means of the generic representations of the theme "shape and structure and system."
3. "System" → "structure and system" → "shape and structure and system": the process starts with establishing the systems that define important properties of the building. Systems identified in generic representations are functional systems, circulation systems, and structural systems (Section *3.6.3*). The generic representations of "structure and system" deal with the same aspects as discussed in sequence *2*.
4. "System" → "shape and system" → "shape and structure and system": the process starts in the same way as described in sequence *3*. The generic representations of the theme "shape and system" co-ordinate the building layout with its systems. In the last step structures are added.
5. "Shape" → "shape and structure" → "shape and structure and system": the process starts with establishing the building layout. The building layout is defined through a variety of shapes that define the perimeter of spaces or the building (Section *3.6.3*). The generic representations of the theme "shape and structure" establish the structure implicitly defined by means of "shape" and co-ordinate the layout with the structure. The systems of the final step are ordered on the basis of the generic representations of "shape and structure."
6. "Shape" → "shape and system" → "shape and structure and system": the process starts in the same way as described above. The generic representations of the theme "shape and system" establish the systems

within the building layout. In the final step the structure of the building design is established.

In the first stage sequences of themes are established. These sequences generally define in which order the themes are established. The order of generic representations is as yet undefined in the themes. The second stage establishes sequences of generic representations in each theme.

By establishing sequence of themes and then sequences of generic representations within themes, it is possible to relate the found and hypothetical generic representations of the survey. The sequence of themes gives six general strategies of dealing with the design process by naming the order in which themes are dealt with. The sequences of generic representations in the themes determine all possible courses that can be taken in the themes.

4.2 Successive graphic units in sequences of generic representations

In the previous Chapter, analysis of the relationship of additional graphic units shows that not all generic representations can be put in a sequence (Section *3.6.1*, Figure III-10). Therefore, the relationship of additional graphic units is insufficient to establish sequences of generic representations. Another relation needs to be identified with which to establish sequences of generic representations.

Of the three levels of description of generic representations (graphic units, generic representations, and themes) the level of the graphic unit can provide clues for determining the order in which generic representations can be placed. The following assumption is made about identifying sequences of generic representations:

- A generic representation provides preconditions for more elaborate generic representations if one or more of its constituent graphic units provides such preconditions. It means there are generic representations that follow after the particular generic representation.
- A generic representation implies more schematic or less specific generic representations if one or more of its graphic units implies more schematic or less specific graphic units. It means there are generic representations that precede the particular generic representation.

Such sequences of graphic units that imply or provide preconditions are termed "successive graphic units." By identifying such relations between graphic units, it is possible to make statements about the order of generic representations in a sequence.

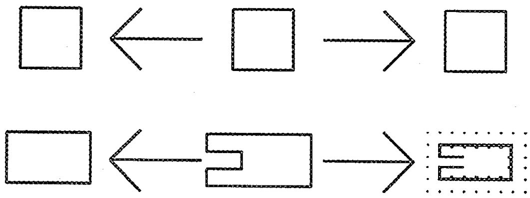

Figure IV-1: Top: precondition → and implication ← between generic representations. Bottom: *contour* ← *specified form* → elaborated structural contour.

The principle used for establishing successive graphic units is "general to specific." In this view, decisions are taken in a sequence, and decisions of a more global kind are take before decisions of a more specific nature. For example, before the particular length of a wing is decided upon, the decision has been taken that the shape of the building actually consists of a number of wings. In terms of graphic units this means that the *contour* (a shape with no particular dimensions) is established before the *specified form* (a contour with particular dimensions).

Successive graphic units therefore, are series of graphic units that imply or provide preconditions for other graphic units. In order to establish such a series, it is necessary to check for every graphic unit what other graphic units it provides preconditions for and what graphic units it implies. The relation *precondition* aims to identify graphic units that occur before the present generic representation in a process, and the relation *implication* aims to identify graphic units that occur after the present generic representation in a process. The relations precondition and implications are essentially the same, but point to different directions (Figure IV-1).

Implication and precondition are not the same as the relation of additional graphic units discussed in Section *3.6.1*. They deal with the conditions that graphic units provide for stating how one decision follows the next. For example, as has been noted above, *specified form* implies *contour*. This relation can not be identified via the relation of additional graphic units since it can not be discussed in terms of addition of graphic units. The number of graphic units remains the same (*contour* and *specified form* both have one graphic unit), but the kind of graphic units changes from one generic representation to the next. To distinguish between the relation additional graphic units and successive graphic units, the connecting symbol between (hypothetical) graphic units in terms of successive graphic units is "→".

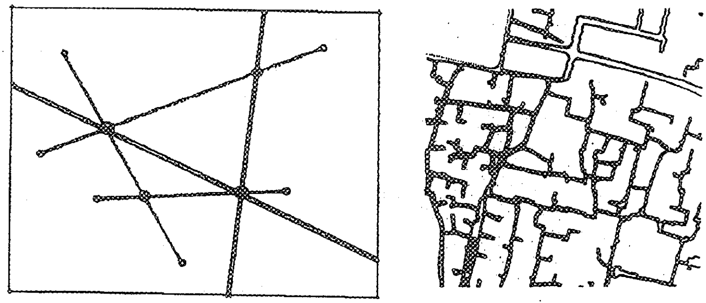

Figure IV-2: Graphic representations of circulation. Left: Ching (1979), p. 271. Right: Herdeg (1990b), p. 37.

Examples of implication and precondition

In Figure IV-2, graphic representations depict circulation. The left picture is identified in the previous Chapter as a circulation scheme (13). The right figure represents "*Spaces on the ground usually denoting circulation,*" in the city of Kerman, Iran (Herdeg 1990b, p. 37). It depicts an existing situation and shows in detail the circulation system. It cannot therefore be considered a circulation scheme. It is an instance of the generic representation *circulation*[14] (H53). The circulation scheme is more general than *circulation*. *Circulation* therefore, implies circulation scheme: circulation scheme → *circulation*. In terms of a decision process, it means that general decisions on the kind of circulation (by means of circulation scheme) are established before a particular circulation (by means of *circulation*) is established.

The second example concerns the graphic units *function symbols, zone, functional space*, and *element vocabulary*. In order to establish *function symbols*, it is necessary to have some idea of the functions required in the building design. Such knowledge typically results from the brief. It is not possible to find a more schematic graphic representation in plan form that encompasses such knowledge[15]. *Function symbols* is the most schematic representation in this respect. In order to establish *zone*, the presence of a set of *function symbols* is required in order to determine the kinds of zones. Therefore, *function symbols* offers preconditions for *zone*. A *zone* defines an area with a particular function. In the area one or more elements can be placed that adhere to the function. A *functional space* is a contour with a particular function. A number of *functional spaces* can be placed in a *zone*. Therefore,

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[14] *Circulation* is identified in Chapter *3* as a hypothetical generic representation (see Appendix *B*).

[15] A graph representation is more specific since it contains vertices that denote relationships between nodes that are equivalent with function symbols. A bubble diagram is also more specific since it contains surface-area related elements associated with the required areas stated in the brief.

zone offers preconditions for *functional spaces* and vice versa, *functional spaces* imply a *zone*. In order to establish whether a *functional space* accommodates the functions it is assigned, an *element vocabulary* for that function can be employed to test functionality. By stating the function of a space, *functional space* provides preconditions for *element vocabulary*, and vice versa, an *element vocabulary* implies a *functional space*. This is represented as *function symbols* → *zone* → *functional space* → *element vocabulary*.

In the manner described above, sequences of successive graphic units are established. This results in the following list:

- *Contour* → *specified form* → *combinatorial element vocabulary* → *elaborated structural contour*: *specified form* is more specific than *contour* since dimensions are established. *Combinatorial element vocabulary* is more specific than *specified form* since it provides detailed ways to work out parts of the contour. *Elaborated structural contour* is more specific than *combinatorial element vocabulary* since the total contour in terms of material is established.
- *Simple contour* → *specified form*: a *simple contour* as such is not specific in its dimensions. In a *specified form* dimensions are established.
- *Contour* → *complementary contours*: *complementary contours* is more specific than *contour* since it implies contours and is establishes specific relations between contours.
- *Function symbols* → *zone* → *functional space* → *element vocabulary*: see discussion above.
- *Modular field* → *grid* → *refinement grid* → *tartan grid* → *structural tartan grid*: *grid* is more specific than *modular field* since the module is determined for all lines of the grid. *Refinement grid* is more specific than *grid* since it implies grid and also introduces a grid with a smaller module. *Tartan grid* is more specific than *grid* and *refinement grid* since it combines the *refinement grid* with the *grid* and introduces bands. *Structural tartan grid* is more specific than *tartan grid* since it specifically reserves bands in the grid for structural elements.
- *Structural tartan grid* → *structural element vocabulary*: a *structural tartan grid* provides preconditions for placing structural elements. *Structural element vocabulary* is more specific than a *structural tartan grid* since it also specifies the elements that are placed in the grid.

- *Measurement device* → *proportion system*: *proportion system* is more specific than *measurement device* since it defines a range of dimensions usually within a geometric system that can also be used for determining place.
- *Schematic subdivision* → *partitioning system*: *partitioning system* is more specific than *schematic subdivision* since it restricts the possible places where actual partitions between spaces can be realised.
- *Schematic axial system* → *axial system*: *axial system* is more specific than *schematic axial system* since it applies the axes to a concrete building layout.
- *Circulation scheme* → *circulation*: see discussion above.

All graphic units found in the survey (Section *3.4*) can be related to each other in terms of successive graphic units. Since graphic units are the building blocks of generic representations, this provides the relations to describe sequences of generic representations.

4.3 Sequences of generic representations in themes

By means of successive graphic units and additional graphic units it is possible to establish the sequences of generic representations in the themes. As discussed above, for each theme the sequences must be defined. The work starts with the basic themes "structure," "shape," and "system." The procedure is as follows:

1. List all generic representations of the themes ("structure," "shape," "system," "shape and structure," "shape and system," "structure and system," and "shape and structure and system."
2. Work on each single theme.
3. For each generic representation of the theme, note its graphic units.
4. Identify which other generic representations have graphic units that follow or precede one of the graphic units of the current generic representation by means of successive graphic units or additional graphic units.
5. Draw lines between this generic representation and the others that are found.
6. Repeat for all generic representations of the theme and all the themes.

This procedure is outlined for the theme "shape." The results are shown for the other themes.

4.3.1 Theme "shape"

The theme "shape" has five generic representations (simple contour (1), combination of contours (2), complementary contours (3), *contour* (H46), and *specified form* (H50); see Section *3.6.3* for the list of generic representations in themes). Each generic representation has one graphic unit (with the same

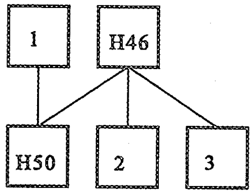

Figure IV-3: Successive generic representations in the theme "shape" established by means of successive graphic units.

name). Therefore, relations can only be established by means of successive graphic units. By means of the list established in Section *4.2.2*, the relation of successive graphic units determines the relations between generic representations:

- simple contour (1) → *specified form* (H50)
- combination of contours (2) ← *contour* (H46)
- complementary contours (3) ← *contour* (H46)
- *contour* (H46) → combination of contours (2)
  contour (H46) → complementary contours (3)
  contour (H46) → *specified form* (H50)
- *specified form* (H50) ← simple contour (1)
  specified form (H50) ← *contour* (H46)

Since the general order between generic representations is from simple to complex, the relations between the generic representations are drawn as lines, not as arrows. The order is top-down in the figures. This results in the following graphic representation of the relations of generic representations of the theme "shape" (Figure IV-3).

4.3.2 Theme "structure"

The theme "structure" has a substantial amount of generic representations.

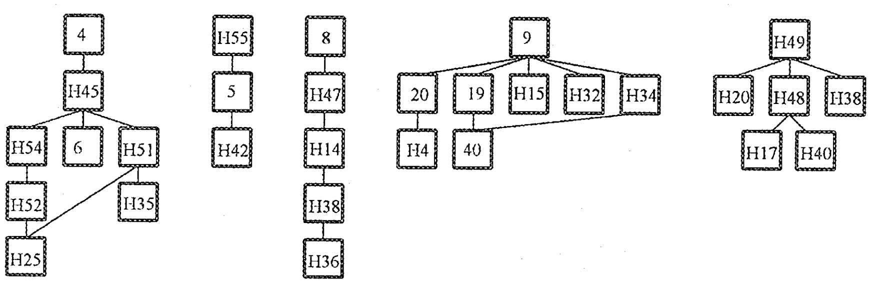

Figure IV-4: Successive generic representations in the theme "structure." From left to right: grid, proportion, axial system, subdivision, and zone.

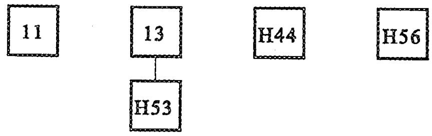

Figure IV-5: Successive generic representations in the theme "system." From left to right: element vocabulary, circulation, structural element vocabulary, and partitioning.

Figure IV-4 shows five groups of related generic representations which represent different means to structure a building layout. The subgroup "grid" for example, consists of eight generic representations that elaborate the grid. It starts with modular field (4) which is less specific than *grid* (H45). It is possible to structure *grid* in three manners: by defining a *tartan grid* (H54), establishing multiple grids (6), or defining a *refinement grid* (H51). The *tartan grid* is further elaborated by transforming it into a *structural tartan grid* (H52), and adding the graphic unit *refinement grid*: *structural tartan grid in refinement grid* (H25). Combining the refinement grid with the grid results in *refinement grid in grid* (H35). All relations are established by successive graphic units and additional graphic units. The relations in the other subgroups (proportion system, axial system, subdivision, and zone) are established in the same manner.

4.3.3 Theme "system"

The theme "system" has five (hypothetical) generic representations. Application of the procedure results in Figure IV-5. As in the case of the subgroups in "structure," the four kinds of systems are independent. Because the number of generic representations is limited, these systems are not very much worked out.

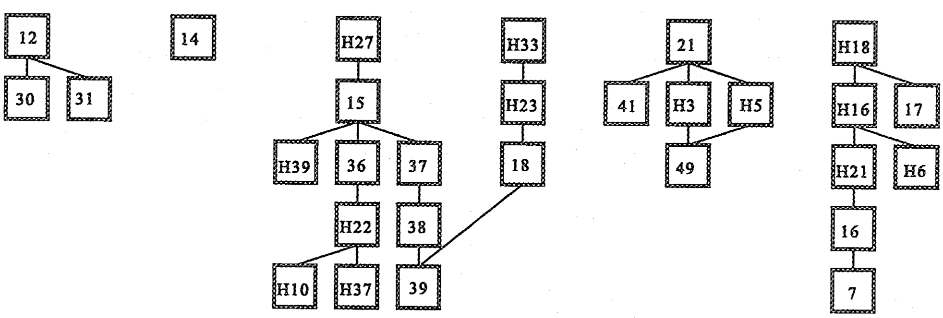

Figure IV-6: Successive generic representations in the theme "shape and structure." From left to right: combinatorial element vocabulary, proportion, grid, axial system, subdivision, and zone.

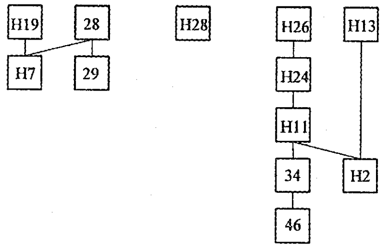

Figure IV-7: Successive generic representations in the theme "structure and system." From left to right: element vocabulary, circulation, and structural element vocabulary.

4.3.4 Theme "shape and structure"

As stated in Section *4.1.1*, for the second step of the general sequence of themes there are two ways to order the generic representations (in this case, ordering by shape or by structure). Here the generic representations are ordered by structure. In the theme "shape and structure," the relations between generic representations concerned with zone are established on the basis of the successive graphic units *contour* → *specified form* and *function symbols* → *zone* → *functional space*. This leads to the sequence of generic representations *function symbols in contour* (H18) → *zone in contour* (H16) → *function symbols in specified form* (H21) → zone in specified form (16) → functional spaces (7). *Zone in contour* has a second branch zone in *zone in contour* (H16) → *zone in contour with function symbols* (H6) by means of addition of graphic units. The application of successive graphic units in the set of generic representations that are part of "shape and structure," results in Figure IV-6.

4.3.5 Theme "structure and system"

In the theme "structure and system," precedence is given to the system as distinctive feature. This means that for each kind of system, successive graphic units for structures are applied. This results in Figure IV-7. The hypothetical generic representation *circulation in grid* (H28) is isolated in this theme, since the other generic representations of the theme "structure and system" have no graphic units in common with *circulation in grid*. This means that this generic representation can only be placed in a sequence when linked with generic representations from other themes.

Figure IV-9: Successive generic representations in the combination of themes "shape and system." From left to right: circulation, partitioning, structural element vocabulary, and element vocabulary.

4.3.6 Theme "shape and system"

In the combination "shape and system," precedence is given to the system as a distinctive feature. For each kind of system, successive graphic units for shapes are applied. This results in Figure IV-9. All generic representations are isolated from each other. This is a result of the small number of hypothetical and found generic representations in this combination of themes and because circulation in contour (32), partitioning system in contour (22), *structural element vocabulary in contour* (H12), and *element vocabulary in contour* (H30) are separated by using systems to order them.

4.3.7 Theme "shape and structure and system"

Application of successive and additional graphic units to the generic representations of the theme "shape and structure and system" results in Figure IV-8. The most frequent generic representation in this theme is the elaborated structural contour (10). It is the precise formulation of the material separations of the building layout. In this generic representation all decisions about the layout are combined. Therefore it is placed in the combination of all themes. The elaborated structured contour has seven relations to other generic representations. Added are the graphic units *proportion system* (leading to generic representation H41), *measurement device* (23), *grid* (24), *complementary contours* (25), *axial system* (26), *function symbols* (27), and *circulation scheme* (33).

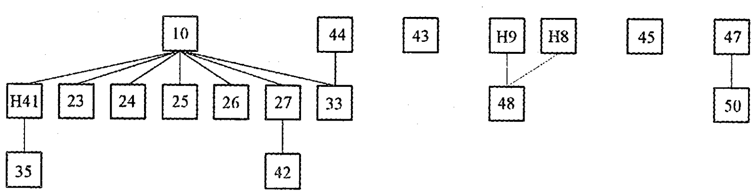

Figure IV-8: Successive generic representations in the combination of themes "shape and structure and system."

4.3.8 Order of generic representations in general sequences

The themes are ordered internally by successive generic representations. Each theme deals with specific issues: the "shape" of the building layout, the "structure" that governs organisation of the building, and the "system" that can be distinguished in a building design. Going from one theme to the next occurs by adding (additional graphic units) or changing graphic units (successive graphic units).

Each of the six possible sequences results in a different order of generic representations and associated design decisions. Consider for example the differences between the sequence "structure" → "shape and structure" and the sequence "shape" → "shape and structure." The first sequence starts with establishing a structure, such as a system of grids, or an axial system, etc. Such a structure is elaborated by a number of generic representations (Figure IV-4). After the structure is worked out, a building layout is established on the basis of the structure ("shape and structure"; Figure IV-6). The sequence "shape" → "shape and structure," starts with establishing the building layout (Figure IV-3). After the layout is worked out, a structure is defined on the basis of the layout. The generic representations of "shape and structure" following "shape" are ordered on the basis of "shape." This order is different from the one presented in Figure IV-6, which is based on structure.

Transitions from one theme to the next are accommodated by successive and additional graphic units. In the case of the transition "structure" → "shape and structure," it is possible to start in the theme "structure" with a grid. The grid is part of a sequence of generic representations that includes modular field, *tartan grid*, multiple grids, *refinement grid*, *structural tartan grid*, *structural tartan grid in refinement grid*, and *refinement grid in grid* (Section *4.3.2*). In this sequence the grid is defined in various degrees of specification, ranging from a global indication of grid-lines in modular field to combinations of kinds of grid such as in *structural tartan grid in refinement grid*.

After the structure is established, the building layout is realised on the basis of the structure. This can be done for example with building perimeter in a grid, or the spatial layout following an axial system, etc. For example, in the sequence of successive graphic units, the *grid* is followed by *refinement grid* (see Section *4.2.2*). This means that *grid* provides preconditions for the *refinement grid* and that generic representations which include the graphic unit *refinement grid* can follow generic representations which include *grid*. Furthermore, it is possible to add graphic units to generic representations with *grid*. "Shape and structure" has the following additional graphic units to generic representations with *grid*: combinatorial element vocabulary in grid (30), contour in grid (15), axial

system in contour in grid (37), zone in contour in grid (36), *specified form in grid* (H22), and *function symbols in specified form in grid* (H10).
The relations between generic representations in themes identified above establish all possible transitions between generic representations on the basis of successive and additional graphic units. In order to outline a sequence of decisions in a design process, it is necessary to make a choice of generic representations that are relevant for a design task and to establish a path that is relevant for the design task.

4.4 A particular sequence of generic representations

The sequences above proceed from general to specific with increasing complexity. Going from one theme to the next (for example "shape" to "shape and structure") implies that the focus is changed from the issues dealt with (for example issues from "shape" to issues in "shape and structure.") The approach outlined above assumes that design decisions taken in the previous theme are matched with design decisions taken in the next theme (for example matching building layout established in "shape" with structure in "shape and structure").
The relations identified above state all possible transitions between generic representations. Therefore, the sequences still are general. In a design process, steps are taken one after the other, and choices are made which generic representation follows the previous one. On the basis of the possible orders established above, it is possible to establish a particular sequence of generic representations. On the following pages one such sequence is presented. It consists of *23* generic representations. Seven of these are hypothetical generic representations. Since these are not dealt with in Section *3.3*, they are discussed here.
The particular sequence of generic representations results from choosing among the generic representations that are available in a theme and choosing a particular path of one generic representation to the next. The following sequence is establishing on the basis of the sequence of themes "shape" → "shape and structure" → "shape and structure and system." This means that for example no generic representations from either "structure" or "system" appear in the transition from "shape" to "shape and structure." The sequence is developed furthermore on the following working assumptions:

- A linear process of one generic representation at a time.
- No branches in the sequence.
- Each generic representation is dealt with only once.

◈ Decisions made in each generic representation have a continued effect in following generic representations.

The relations between generic representations have been outlined in the previous Sections *4.3.1* to *4.3.7*. In some themes, there is a clear linear progression from one generic representation to the next (Figure IV-3; Figure IV-4; Figure IV-6; Figure IV-7). Multiple sequences in a theme indicate different kinds of design decisions. In the cases of Figure IV-5; Figure IV-9 and Figure IV-8 this is not so obvious, which is due to the limited amount of generic representations in these themes. Therefore, establishing a sequence of generic representations means making choices between sequences and putting them in an order. The generic representations of the sequence are discussed with respect to the decisions they encode relative to a building type.

First step: basic theme "shape"

1. Simple contour (generic representation 1). The first generic representation of the theme "shape." Establish the building envelope (see Section *5.6* for application of knowledge; Chapter *3*, p. 39 for description of this generic representation).
2. Combination of contours (2). Tentatively define major parts of the building envelope (see Chapter *3*, p. 40 for description of this generic representation).
3. *Specified form* (hypothetical generic representation H50): At some point, a simple contour must change to a *specified form* when tentative decisions are taken about the dimensions of the shape. Up to that point, the shape is not determined with regard to the precise dimensions (see Section *5.6* for application of knowledge).
4. Complementary contours (3): Locating the building shape in the site (see Chapter *3*, p. 41 for description of this generic representation). Step *1* up to *4* deal with the building envelope exclusively. The next steps in the sequence deal with "shape and structure."

Second step: theme "shape and structure"

5. *Zone* (H48): As a hypothetical generic representation *zone* provides a principle often used in building. Zoning can be discussed independent from the *specified form* as a principle decision on organising the building. Therefore this generic representation of the theme "structure" is included in the sequence.
6. *Schematic subdivision in zone* (H15): A *zone* gives an abstract indication of specific properties of an area. There usually is not a one-to-one correspondence between zoning and spatial system. *Schematic subdivision in zone* indicates a general layout within the zone. This is an example of

combining two structuring principles in the theme "structure" by means of additional graphic units.

7. Schematic subdivision in zone in contour with function symbols (49): Checking a *schematic subdivision in zone* is done by testing whether it can accommodate the specifications indicated by the zone. In the case of a functional zoning, *function symbols* mark additional functions in the schematically subdivided zone. Such testing must take place in the contour in order to see whether surface requirements are met (see Chapter *3*, p. 52 for description of this generic representation).
8. Zone in specified form (16). After the zoning has been tested it can be established in the specified form of step *3*. By initiating the series H48 → H15 → 49 → 16 (step *5-8*), principle issues of functional organisation on the building level are dealt with (see Chapter *4*, p. 49 for description of this generic representation).
9. Schematic subdivision (9). The schematic subdivision can be discussed separately from the building envelope. Therefore, this generic representation is included in the sequence (see Chapter *3*, p. *58* for description of this generic representation).
10. Schematic subdivision in contour (21). Application of *schematic subdivision* to the building envelope is done in concert with combination of contours of step *2* (see Chapter *3*, p. 62 for description of this generic representation).
11. *Grid* (H45). The grid defines a field which orders place and measure by means of regulating lines. Establishing a grid gives a basic module for measuring elements that adhere to the grid.
12. Schematic subdivision in grid (19). Co-ordinating the basic subdivision with the grid (see Chapter *3*, p. 59 for description of this generic representation).
13. *Subdivision in specified form* (H57). At some point both the *contour* and the *schematic subdivision* have to be made more specific. This means that the *schematic subdivision* must become more specific, resulting in *subdivision*, and that *contour* results in *specified form*. The latter transition is accommodated by the successive graphic units *contour* → *specified form* (see Section *4.2.2*). According to the list of successive graphic units *specified form* is followed by *combinatorial element vocabulary* leading to *elaborated structural contour* (Section *4.2.2*), neither of which represents a subdivision. *Subdivision in specified form* is not identified in Section *3.6.2*. The series 2 → 9 → 21 → 11 → H45 → 19 → H57 (second step, *9-13*)

deals with the basic subdivision of the building envelope into distinctive areas.

14. Schematic axial system (8). The schematic axial system can be discussed separately from the building envelope. Therefore, this generic representation from the theme "structure" is included in the sequence (see Chapter *3*, p. 53 for description of this generic representation).
15. Axial system in specified form (18). Application of the schematic axial system in the building envelope establishes additional spatial order (see Chapter *3*, p. 54 for description of this generic representation). The series 8 → 18 (step *15-16*) establishes the axial system for the building shape.
16. Contour in grid (15). The *grid* of step *11* needs to be co-ordinated with the *contour* if it is to structure in which way the building envelope is developed according to the *grid* (see Chapter *3*, p. 47 for description of this generic representation).
17. Zone in contour in grid (36). Co-ordinating the results of the zone-sequence (step *5-8*) with the grid (see Chapter *3*, p. 48 for description of this generic representation).
18. Partitioning system in contour (22). The findings of subdivision, zone, grid, and axial system lead to a principle decision on partitioning the building (see Chapter *3*, p. 64 for description of this generic representation). This generic representation is the last of the theme "shape and structure."

Third step: theme "shape and structure and system"

19. Circulation scheme (13). The circulation scheme is a generic representation from the theme "system." It defines the principle manner of circulation (see Chapter *3*, p. 80 for description of this generic representation).
20. Circulation in contour (32). Co-ordinating circulation with the building layout (see Chapter *3*, p. 81 for description of this generic representation). Circulation provides preconditions for further elaboration of the work places.
21. Element vocabulary (11). Element vocabulary defines functional layout by placing elements that fulfil this function (see Chapter *3*, p. 72 for description of this generic representation).
22. *Element vocabulary in contour* (H30). By considering the element vocabulary in the contour, the functionality of the layout is worked out.
23. Element vocabulary and function symbols and grid in specified form (48). The first generic representation from "shape and structure and system" that combines all generic representations from the themes (see Chapter *3*, p. 76 for description of this generic representation). The series 11 → H30 → 48

(step 21-*23*) is based on the themes "system" (generic representation 11), "shape and system" (H30) which lead to "shape and system and structure" (48).

In the transition of "shape" to "shape and structure," the structuring devices zone, subdivision, axial system, and grid are applied to the shape. The generic representations that combine zone and shape, subdivision and shape, etc. are from the theme "shape and structure." However, before they are dealt with, the structures are defined separately (step *9*: schematic subdivision, step *11*: *grid* and *12*: schematic subdivision in grid, step *14*: schematic axial system, etc.) These generic representations are from the theme "structure." This means that generic representations from "structure" are only used if they occur in "shape and structure." The sequence in which they are embedded in "structure" is not copied in the particular sequence of generic representations. For example, in step *11* and *12* the generic representations *grid* and schematic subdivision are used before applying it in step *13* to the *subdivision in specified form*. Only the generic representations *grid* and schematic subdivision are used, not any other part of the sequence as identified in Section *4.3.2*. This means that the assertion that the particular sequence can be based on the general sequence of themes is not refuted by this finding.

4.5 Particularisation and the building type

During the design of a building belonging to a particular type, the design object develops from a general notion of the design task - the building type, brief, and site - to the specific design solution. At the beginning of the design process the notion of the solution is still very abstract. It becomes more defined throughout the design process. If the design task does not cause the design object to deviate very much from the building type, then during this process the design decisions refine rather than change the design with respect to the type. Such a process generally associated with building types is termed 'particularisation' or 'refinement.'

Both the general sequences of generic representations and the particular sequence of generic representations evolve from general to specific. Each subsequent step in the sequence is more complex than the previous and an increasing number of aspects is related to each other. The correspondence between both strategies - particularisation and the sequence of generic representations - indicates that the sequence of generic representations actually results in instances of the building type. It is proposed therefore, that the sequence of generic representations and the procedural and declarative

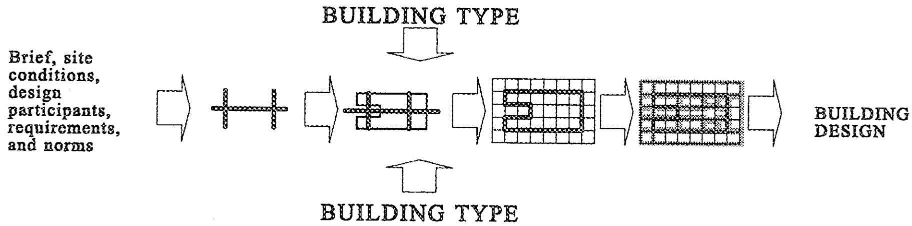

Figure IV-10: Relation between generic representations and procedural and declarative knowledge of building types.

knowledge embedded in the sequence models the building type (see Figure IV-10). If this is true, then this means that it should be possible to find a close map between the sequence of generic representations (combination of graphic representation and design decision) and the declarative knowledge of the building type. In order to test this proposition, it is necessary to apply the particular sequence of generic representations to a particular building type.

Conclusion

Transitions from one generic representation to the next can be identified on the basis of three relations: (1) additional graphic units, (2) themes of generic representations, and (3) successive graphic units. General sequences of generic representations can be established by sequences of themes. This leads to six general sequences of themes. Within each theme it is possible to establish the order of generic representations by means of additional graphic units and successive graphic units. This provides all possible transitions between generic representations. A particular sequence can be formulated based on the general sequences. By applying the particular sequence to a particular building type, it is possible to test whether a sequence of generic representations can encode a building type. In the next Chapter, the office building is analysed for its declarative knowledge content, and applied to the particular sequence of generic representations.

5 GENERIC REPRESENTATIONS OF THE OFFICE BUILDING TYPE

Application of generic representations

Introduction

The work developed up to this point must be applied to a concrete building type to test if generic representations can encode procedural and declarative knowledge of a building type. The office building type is subject for implementation. Knowledge acquisition of the office building type provides knowledge which is used during the design process. This knowledge is applied in a sequence of generic representations of the office building type. The work provides directives for implementation of generic representations in design aid systems. A preliminary application is presented and discussed. It provides a demonstration how generic representations can aid in making procedural and declarative knowledge accessible to design aid systems.

5.1 The office building

In the research work the office building type is chosen for application of the theory of generic representations. It is a building type that proliferated in the twentieth century, although its ancestry can be traced back as far as the 16th century in the case of the so-called 'Uffizi' administrative buildings in Florence of the de Medici family (Pevsner 1986, p. 47, 213; Staal 1987 Chapter *1*). A brief sketch of the development of the office building by some influential examples suffices to introduce the type. Staal (1987) distinguishes five periods in the modern history of the office building. For each period an example and some innovations are presented[16]:

- *First Leiter Building*, Chicago, USA, 1879, William Le Baron Jenny. In this building, the use of structural iron framing was introduced. Other innovations such as the revolving door, telephone, electrical light, and the elevator made possible both the monofunctional office building and the office building for anonymous users (a development which had started at about 1850; see Pevsner 1986, p. 214).
- *Larkin Building*, Buffalo, USA, 1904, Frank Lloyd Wright. The first office building with air-conditioning. The plan type was bull-pen like (office spaces overlooking open workspace; see Process Architecture nr. 60, 1985).
- *Rockefeller Centre*, New York, USA, 1931, John Todd. According to Staal (1987) it became the prototypical example of all later high-rise office buildings in urban contexts. Frank Lloyd Wright's Johnson Wax (Racine, 1939) exemplifies for Staal (1987) the major example for all later rural context office buildings.
- *Lever House*, New York, USA, 1952, Gordon Bunshaft of Skidmore, Owings & Merill. Together with Mies van der Rohe's *Seagram Building* (New York, 1958) it was a major influence on all subsequent office building architecture.
- *Centraal Beheer,* Apeldoorn, Netherlands, 1972, Herman Herzberger and the *Hongkong and Shanghai Bank,* Hongkong, China, 1986, Norman Foster Associates. Both buildings indicate a change towards other types of workplaces and corporate identity. Centraal Beheer provides a spatial articulation of office organisation, and the Hongkong and Shanghai Bank demonstrates how a building can express corporate identity.

Parallel to these more formal developments, changes in the office building type also occurred through developments in organisational forms, such as the transitions from the cellular type to the bull-pen type to the landscape office and several mixed forms. From the late 1980'ies and early 1990'ies onward, new changes may be noted that are most likely to alter general principles of office building design. Trends such as the 'deskless' office,[17] teleworking, advanced information technology, and increasing complexity of functional mixed use seem to be major factors.

5.2 Constraints on the office building

In order to acquire knowledge of the office building type, it is necessary to impose constraints on the extensive body of information available on office buildings. The constraints concern time-period, class of office buildings, and kinds of sources.

5.2.1 Time-period

Since the early 1990'ies developments are changing mainstream office building design. Establishing a coherent body of knowledge on this widely divergent set of movements is beyond the purpose of the research work. Since the building type is a form of generalised knowledge of a class of buildings, it is necessary to incorporate generally accepted knowledge in the knowledge base. This can be achieved when the office building type is restricted to mainstream office buildings. Therefore, the emphasis is on the mainstream office building such as is produced mainly in the period 1970-1990, and is still in currency during the late 1990'ies.

5.2.2 Class of office buildings

The notion of building type should offer a rationale how instances that are considered to belong to a class of buildings can be different in appearance. Acquired knowledge therefore, should not be confined to one particular architectural style. The work is restricted to single purpose office buildings. Mixed functions are not considered. Since there is no explicit brief, designing for an anonymous user will be assumed.

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[16] Overviews of the history of the office building type generally present the same list of exemplar cases (see for example: Peters 1973, Joedicke 1975, Process Architecture 1986, Pevsner 1986, and Staal 1987).

[17] See for example the deskless office which was experimentally implemented in Gehry's Main Street building for Chiat Day, Venice, 1986. The project was reported by Jeet Singh: *'Designing the Electronic Community'* in the Doors of Perception 1 Conference, October 30-31, 1993, Amsterdam.

The same reasoning applies to kinds of structural systems and HVAC types. In order to assure that the implementation of generic representations is not biased by one particular structural (such as concrete, steel, brickwork) or HVAC system, the knowledge base should encompass general knowledge of these subjects. This also has the consequence that there will be some adherence to general construction principles. Special cases of long-span construction, (innovative) facade techniques, exceptional briefs or sites are not dealt with. One way of incorporating these forms of knowledge, yet diminishing a dominant influence by any particular structural and HVAC technique, is by excluding high-rise office buildings. In the research work, high-rise will be defined according to Neufert (1992) as any building of which the highest floor is 22 meter above the site.

The knowledge acquisition is limited to the single-purpose, low- to medium-rise office building, which poses no special requirements on structural or installation features.

5.2.3 Sources of information

Knowledge of the office building type may be acquired from interviewing architects familiar with the design of offices, and from the extensive literature on office buildings.

Since the office building constitutes a test of the theoretical work, finding a way to minimise efforts on acquiring knowledge on office buildings is desirable. Knowledge acquisition from experts generally is labour-intensive. Several experts need to be interviewed in a structured manner, cross-checked for consistency, and represented in a way that is accessible for the research work. Knowledge acquisition from the literature generally is less labour-intensive if the condition that there is ample information available can be satisfied. For the office building this is the case. It is a type well-covered in publications. Therefore, the knowledge base is established on literature on office buildings.

5.3 Method of knowledge acquisition

The goal of knowledge acquisition in the research work is to establish a knowledge base which supports the implementation of declarative knowledge of the office building in generic representations. It must inform the decisions encoded in generic representations. Knowledge acquisition starts with analysing the most recent source, extracting the statements, and checking if there are any major items not covered. At the point where the acquired knowledge covers most aspects of the office building type as indicated by reference to generic representations, no more sources are consulted.

5.3.1 Selected sources

Sources are selected on the basis of a literature survey of publications on office buildings. The main requirement of selecting sources is that it must present to some extent a comprehensive account of office buildings in quantitative statements. It must be comprehensive to ensure some consistency in the knowledge extracted from the source. The statements must be quantitative to ensure unambiguous knowledge.

It is beyond the purpose of the implementation work for the knowledge base to be developed into great detail about certain subjects. For the application of generic representations the matter is not whether a specific design decision turns out a particular way, but rather that a design decision *is* taken. Therefore, it is more important to establish completeness in scope than in detail. For the purposes of the research, it suffices to use general information. The selected sources must cover most aspects of office building design.

The sources differ in year of publication, country, and kind of publication. The range in time is from *1973* to *1992*, and the countries are the Netherlands, Germany, United Kingdom, and the United States. Some sources are books, and others are articles in magazines. Since the subject is the mainstream office building of the period *1970-1990*, which in matter of style is context-independent, both range in time and country do not seem problematic for the mapping of knowledge on generic representations.

The sources used are, in chronological order from most recent to oldest:

- (1992) Neufert, E. and Neufert, P.: *Neufert Bauentwurfslehre.*
- (1991) Bovill, Carl: *Architectural Design.*
- (1990) Bailey, S.: *Offices - A briefing and design guide.*
- (1988) Hoke jr., J.R. (ed.): *Architects Room Design Data Handbook.*
- (1985) Stichting Bouwresearch: *Schachten als kern voor hoge gebouwen?*
- (1981) Architect's Journal, 11 nov.: *Buildings Update. Offices part 1.*
- (1980) Chiara, J. De and Callender, J.H. (eds.): *Time Saver Standards for Building Types.*
- (1973) Peters, P.: *Entwurf und Planung - Verwaltungsbauten.*

5.3.2 Extracting statements

In the sources selected, information is presented in text, graphics, diagrams, tables, nomograms, calculations, etc. These forms of presentation are related to the subject they are treating, and to the expected audience. Information for experts can be presented different than for lay-people or professionals unacquainted with the subject. Furthermore, presentation depends on the required level of detail; does it present rules of thumb for first estimates, or rather precise information for fine-tuning design decisions.

Knowledge from the sources is extracted when it can be formulated in a sentence stating some state of affairs or quantity. Such statements are instances of declarative knowledge. Example statements are: "*The conference rooms should be centrally located to the users,*" "*Office buildings typically have a Gross Area/Net Area ratio of 1.35,*" and "*The planning module and the exterior wall module must be reconciled with the structural module or column bay. If all these modules coincide, then the wall or window units adjacent to the column must be smaller than the intermediate units*". These statements aid the architect when making design decisions such as "where to position the conference room," "what total area can be expected from this brief," and "how to co-ordinate grids."

5.3.3 Structure of the knowledge base

Extracting knowledge from a number of sources provides a large set of unrelated statements. It is necessary to structure the set in order to make retrieval possible when knowledge is needed in the implementation. For this purpose, a categorisation of subjects is established. Each category defines a group of related statements that deal with a subject relevant to the design of office buildings. The main subdivision in categories is made on the basis of differentiation in levels of scale ('*Building*,' '*Building part*,' and '*Infill*'). The secondary subdivision is derived from the subjects as they are discussed in the literature. It is important to note that the categorisation into levels and subjects is not meant to present a comprehensive and consistent system of ordering knowledge. It covers the kind of statements found in the literature and orders them in an informal manner which is relatively easy to access by means of the names of the levels and subjects. The levels are further subdivided in the following sub categories: '*Building*,' '*Organisation*,' '*Spaces*,' '*Egress*,' '*Circulation*,' '*Structural system*,' '*HVAC*,' '*Core*,' '*Elevators*,' '*Stairs*,' *Workplace*,' '*Module*,' '*Furniture*,' and '*Toilets*.'

5.4 The knowledge base

At this point, structure and content of the knowledge base are established. Statements produced from the analysis of the sources can be inserted in any of the above categories. The knowledge base is presented on the following pages.

For each category, an example statement is given. The complete knowledge base is included in Appendix *C*.

Level of *Building*:

- Building: Statements about the building as a whole, such as orientation, classes of depth, feasible surface areas, etc.

  An example statement is: "*There are four basic depths of space: Shallow space (4-5 m), medium depth space (6-10 m), deep space (11-19 m), and very deep space (over 20 m).*" (Offices 2: for code see Appendix *C*)
- Organisation: Statements about the relationship between organisation and functional layout, such as the need for flexibility, function-integration, and positioning groups.

  An example statement is: "*Visitors should have a short, direct, and convenient route from the main entrance to the department sought.*" (Time 7C).

Level of *Building part*:

- Spaces: Statements about the kinds of spaces that are used in office building, such as single-person room, more-person room, group space, landscape space, etc., their typical dimensions, and how they are used or combined.

  An example statement is: "*The semiprivate office is a room, ranging in size from 150 to 400 sq. ft.* (37,2 m^2)[18], *occupied by two or more individuals.*" (Time 5B).
- Egress: Statements about requirements for safety, such as maximum distance to exit, number of stairs, and size of stairs.

  An example statement is: "*When more than one exit is required the occupant should be able to go toward either exit from any point in the corridor system.*" (Integration 3E).
- Circulation: Statements about dimension requirements, such as between workspaces, primary and secondary circulation, etc.

  An example statement is: "*Central circulation (primary) in corridors should be 2 m; secondary (linking groups to primary) 1,50 m, tertiary (within groups) 0,750 m.*" (Offices 3).
- Structural system: Statements about kinds of structural system, such as typical dimensions, and stability requirements.

  An example statement is: "*Column spacing most frequently used in multi-storey steel-framed office buildings is around 25 ft* (7,62 m), *center to*

[18] Any quantities from other standards are converted to the metric system.

center. Recent trend is toward larger spacing; 30 (9,14 m) *to 35 ft.* (10,67 m) *is not uncommon.*" (Time 10D).

- HVAC: Statements about HVAC-equipment, such as dimensions, location, and capacity.
  An example statement is: "*The major components of the HVAC (air-conditioning system) are the centrally located equipment - the chiller and the boiler, the cooling tower, and the air handlers - and the delivery equipment - the air duct and/or water pipe delivery system and the diffusers.*" (Integration 6A).

Level of *Infill*:

- Core: Statements about the core, such as distance from facade and other cores, dimensions, and location.
  An example statement is: "*Core location: - Interior central, - Interior off-center, - Interior split, - Exterior.*" (Time 1).
- Elevator: Statements about elevators, such as number and capacity.
  An example statement is: "*Offices using variable working hours require less elevators than offices with fixed working hours.*" (SBR 4A).
- Stairs: Statements about stairs, such as number, size, and location.
  An example statement is: "*Buildings with floors more than 18,3 m above ground level require at least one fire-fighting stair which must have direct access to open air at ground level, have openable windows at each landing level, have permanent ventilation at the top of the enclosure of 5 per cent of enclosed area minimum, have a protected and ventilated lobby at each floor and be continuous throughout the building.*" (Offices 4).
- Workplace: Statements about the space office employees require, such as typical surface areas, combinations, and location.
  An example statement is: "*The nominal range of open plan office sizes varies from 3000 sq. ft.* (279 m^2) *to 30000 sq. ft.* (2787 m^2)." (Data 1A).
- Module: Statements about prevailing dimension-units, such as modules for grids, distance between lights, and combination of grids.
  An example statement is: "*The spacing to mounting height ratio (S/MH) is used to calculate the appropriate space between light fixtures. For fluorescent fixtures the ratio is about 1,5; for medium-beam downlights, about 0,8; and for narrow-beam downlights, about 0,5.*" (Integration 11B).
- Furniture: Statements about dimensions of furniture, such as assembly rooms and their arrangements, and storage spaces.
  An example statement is: "*Conference rooms. Recommended standards for occupancies: 500 sq. ft.* (46,45 m^2) *per 15 people, 25 sq. ft.* (2,32 m^2) *per*

person for up to 8 people, 20 sq. ft. (1,86 m^2) *per person for 8 to 10 people, 18 sq. ft.* (1,67 m^2) *per person for 20 to 40 people.*" (Data 3A).

- Toilets: Statements about the required number of toilets related to number of employees.
  An example statement is: "Minimum required number of toilets for men: 1 (-15 persons), 2 (-35 p.), 3 (-55 p.), 4 (-80 p.), 5 (-110 p.), 6 (-150 p.); more every 40 person +1 toilet. Minimum required number of toilets for women: 1 (-15 persons), 2 (-35 p.), 3 (-55 p.), 4 (-80 p.), 5 (-110 p.), 6 (-150 p.)." (Integration 15).

5.5 Scope of the knowledge base

The knowledge base established contains declarative knowledge of the office building. The knowledge base has the following characteristics:

- Variables, terms, and units are informally used without explicit definition.
- The form of the statement is not fixed in a precise way.
- There is no explicit check on consistency.

Because of these characteristics, the knowledge base is informal. This however, is not problematic for the research. It is demonstrated that each statement of the knowledge base is an instance of declarative knowledge. There are no statements about procedural knowledge of a building type. The range of statements is broad and encompasses a large amount of aspects of office buildings.

Many statements depend on assumptions such as the nature of organisations, general requirements posed by employees, architectural style, economical relationships between structural span and flexible workplace, etc. Furthermore, general design issues such as composition and style are not covered in the knowledge base. Extending the knowledge base to include these assumptions does not seem feasible since it is difficult to impose a limit where such a knowledge base can be considered complete, and where a general reasoning facility will be able to handle all remaining inferences. It remains to be seen to which extent this limitation matters in a sequence of generic representations. It is necessary to keep in mind that the scope of the knowledge-base is related to these assumptions.

5.6 Knowledge in a sequence of generic representations

In order to establish a sequence of generic representations of the office building, the particular sequence of Section *4.5* is used. The sequence states a series of decisions that aids in designing an office building. Each single generic representation applies only statements of the knowledge base.

The knowledge base above contains knowledge of the office building type. By definition it does not include knowledge of the specific brief, the site, and the future owner, which is also knowledge required for designing. Therefore, some assumptions must be made about these matters. The office building concerned is a single-purpose, low- to medium-rise office building, which poses no special requirements on structural or installation features. The future tenants are anonymous. The site is a rectangular area measuring 75x75 m^2, the axis having a north-south orientation. Nearby buildings pose no special circumstances with respect to obstruction, shading, distance from site boundaries, etc. The useful floor area to be realised is 5500 m^2. The building is to be rented for office space, therefore, each floor is destined for office use.

The sequence of generic representations of the office building is established in the following way. The particular sequence of generic representations of Section *4.5* is used. For each generic representation, a drawing is made that follows the properties of the generic representation. The required decisions are noted and linked to the relevant statements of the knowledge base. The reasoning process of each generic representation is outlined. The sequence of generic representations is established, and the order is checked.

Two examples show how declarative knowledge is applied to a generic representation. The generic representations are simple contour (1) and *specified form* (H50).

Generic representation: Simple contour (1)

The simple contour starts with drawing the shape of the office building. In the example, the T-shape will be used. The shape implies the following design decisions:

1. Surface area of a floor. Knowledge required for establishing the surface area is:
   - The minimal economically feasible surface area of an office floor is 600 m^2 (Entwurf 2; see Appendix *C*[19]).

[19] The source Peters (1973) from which this statement is taken is in German. The original statements are included in Appendix *C*. In the examples they are translated.

- Office buildings typically have a Gross Area/Net Area ratio of 1.35 (Integration 1).
- Two percent of the building floor area served by the boiler and chiller will provide a room large enough for the chiller and boiler and their accompanying pumps (Integration 6D).
- A room large enough for the air handler will be provided by 4% of the building floor area served (Integration 8A).

The surface area of each floor of the T-shape must exceed 600 m^2. With concern to the gross area of the office building, the functional area stated in the brief can be multiplied by 1.35 which means 1.35x5500 m^2 = 7425 m^2. HVAC takes up 2% of this (148,5 m^2) for boiler and chiller and 4% of this (297 m^2) for air handling. The surface area of a floor is related to the number of floors and the maximum dimensions of the envelope within the site.

2. Number of floors. Knowledge required for establishing the number of floors is:
   - A high-rise office building is a building with the top floor 22 m above the site (Neufert 14).
   - Floor height usually has the dimension of 3.00 m, 3.10 m, 3.40 m, 3.70 m, or 4.20 m. (Neufert 17-20).
   - Buildings with floors more than 18.3 m above ground level require at least one fire-fighting stair which must have direct access to open air at ground level, have openable windows at each landing level, have permanent ventilation at the top of the enclosure of 5 per cent of enclosed area minimum, have a protected and ventilated lobby at each floor and be continuous throughout the building (Offices 4).
   - From a structural point of view, the following classes of number floors can be distinguished: (1) 1-4 floors, (2) 5-7 floors, and (3) 8-10 floors. For each class, a number of structural systems are advisable for stability[20] (SBR 2A-2C).

   Given the minimum requirement of 600 m^2 and the gross surface area of 7425 m^2 it is possible to establish a range of possible floor areas: 7 x 1061 m^2, 6 x 1238 m^2, 5 x 1485 m^2, 4 x 1856 m^2, 3 x 2475 m^2, 2 x 3713

[20] For class (1), a framework of columns and beams or slabs is sufficient for stability. So-called 'paddestoelvloeren' (mushroomfloors) are advisable, but not required (SBR 2A). For class (2), slabs are required for stability. Structural cores are also possible, but are less economical. There is a slight preference for 'mushroomfloors' (SBR 2B). For class (3), slabs combined with a 'mushroomfloors' are sufficient for stability. Structural cores for stability are generally recommended (SBR 2C).

m^2, en 1 x 7425 m^2. More than 7 floors are not possible given the low- to medium rise building constraint.

In simple contour the following characteristics of the building design are established: floor surface area (*e.g.* 1865 m^2), number of stories (*e.g.* 4 stories), and storey height (*e.g.* 3,70 m). The dimensions of the building envelope are not established, although the shape indicates a building with three wings (T-shape).

Generic representation: specified form (H50)

By specifying the form of the simple contour, a number of tentative dimensions are determined. Decisions implied by establishing a *specified form* are:

1. Orientation. Knowledge required for establishing orientation of the building is:
   - Orientation of the main axis usually is east-west in the USA and south-north in Europe (Neufert 4).
2. Length of the wings. Knowledge required for establishing the length of the wings is:
   - A circulation point (stairs) may be no further than 25 m from the end facade of a wing and no more than 50 m from another circulation point. Therefore, the maximum length relative to circulation points is 50 + (n-1)50 m; with n the number of circulation points (Neufert 7D).
   - Dead ends (no exit provision at the end) may be no deeper than 6.10 m (Integration 3D).
   - The maximum distance between workplace and egress is 30 m. (Neufert 7D).
   - An office space typically is 4.50-6.00 m deep (Neufert 9J).

   The positioning of circulation points (usually stairs and elevators in a multi-storey building) forms an important factor in determining the dimensions of the building. The length of the building is related to the number of circulation points (50+(n-1)50 m). If there is a dead end, the length may be no longer than 6.10 m. Given the typical depth of an office room of 4.50-6.00 m, such a wing will be some 12 m long.

   A first estimate of the length of the wings can be made by assuming equal dimensions for length and width of the wings. For the T-shape this means that given A=depth=length, then $4A^2$=1865 m^2, and A=21,6 m. In this estimate, the length of the building is 3A=64,8 m, and the depth is 43,2 m. Since one circulation point is always over 25 m distance from one end facade of a wing, at least two circulation points are required along the long side, and one circulation point in the short wing of the building.

3. Depth of the wings. Knowledge required for establishing the depth of wings is:
    - The floor space within 7.62-9.14 m of the facade provides premium rentals, resulting in slab-like office buildings, usually some 18.3-21.3 m wide and 46 m long (Time 13).
    - There are four basic depths of space: shallow space (4-5 m), medium depth space (6-10 m), deep space (11-19 m), and very deep space (over 20 m) (Offices 2).
    - From 1969-1980, the average area of floors in new offices starting construction, dropped from ca. 3500 m^2 to ca. 1000 m^2. The typical depth dropped from ca. 21 m to ca. 14 m with a highest peak of ca. 30 m in 1972 (Update 1).
    - The pressures from users, office electronics, energy conservers and in consequence the rate-paying tenant of office buildings, all point towards medium depth buildings (14-17 m across) as an attractive depth for both speculative and custom-designed developments (Update 3A).
    - Daylight can be used up to a space depth of 7 m (Neufert 6).

    Working at the facade is desirable with respect to daylight provision. The class of depth of the office building therefore relates to this factor. The estimate above of 21,6 m falls in the class of deep space. If wing depth is chosen smaller, the building becomes longer. Given the trends towards more shallow space, and the limitation of the site of 75 m, the most shallow depth of the wing can be 18,0 m[21]. This means therefore, that within the parameters of the building shape, the wing depth is 18,0 m or more, and the wing length is 28,5 m or less.

    If this class of wing depth is unsatisfactory it is necessary to either go back to <u>simple contour</u> and choose more floors with a lesser amount of surface area (5 x 1485 m^2, 6 x 1238 m^2, or 7 x 1061 m^2), or to chose another shape for establishing <u>simple contour</u>.

<u>*Specified form*</u> establishes the dimensions and orientation of the office building's perimeter. The interrelationships between wing length (*e.g.* 21 m),

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[21] The maximum length of the building equals the site dimensions. Therefore, 75 m = 2xwing length + 1xwing depth for a T-shape. Given x=wing length, and y=wing depth, and surface area=1865 m (chosen in previous generic representation), then y=75-2x. Furthermore, x follows from the equation $2x^2 + 75x - 3760 = 0$. This results in x=28,5 m and y=18 m.

wing depth (*e.g.* 22 m), and floor area (*e.g.* 1870 m^2) are constrained by statements and choices from the knowledge base.

5.7 A sequence of generic representations of the office building

In the manner described above, the particular sequence of generic representations of Section *4.5* is used for the office building. It is presented on the following pages. The tables are organised as follows (see Figure V-1).

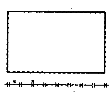
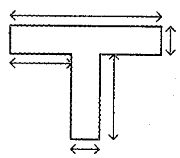
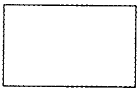
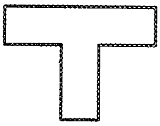
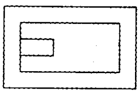
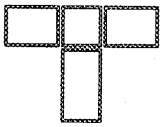
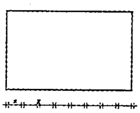
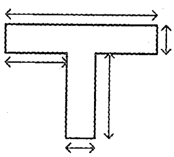
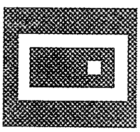
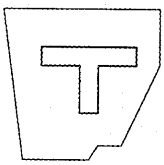
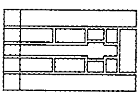
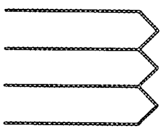
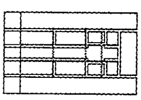
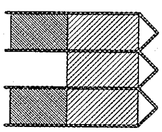
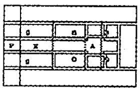
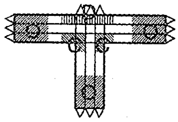
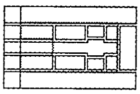
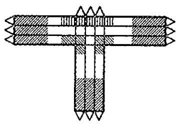
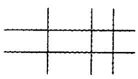
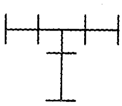
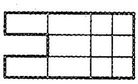
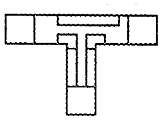
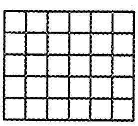
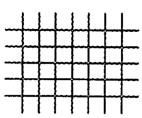
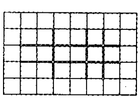
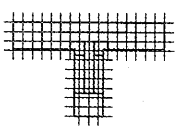
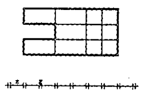
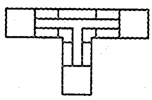
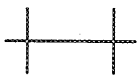
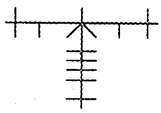
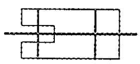
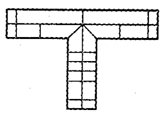
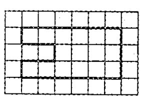
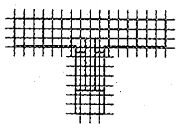
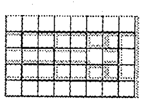
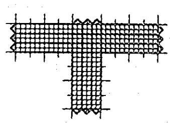
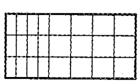
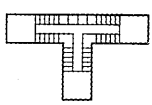
Icon	**Representation**	**Name and decisions**
previous	previous	previous generic representation
		***Specified form*** **(H50)** Establish tentative dimensions for wing length and depth, and orientation of the building. Neufert 6, 7D, 9J, Integration 3D, 6B, SBR 3A, Time 13, Offices 2, Update 1, 3A.
next	next	next generic representation

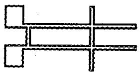
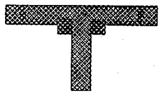
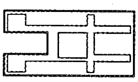
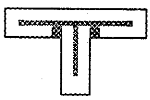
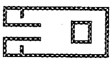
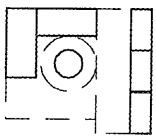
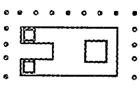
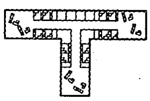
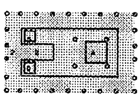
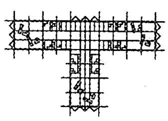
Figure V-1: Layout of table generic representations of the office building.

Each row of the table is a generic representation. The *Icon* column shows the iconic representation of the generic representation (see the survey of Chapter *3*). The *Representation* column shows the drawing based on the properties of the generic representation. This drawing only has the graphic units specified by the generic representation. Therefore, it conveys the design decisions relevant to this particular generic representation. This column presents the sequence of generic representations. The *Name and decisions* column gives the name of the generic representation and presents a brief account of the issues settled when this particular generic representation is used in the design process of an office building. The summary identifies the statements from the knowledge base that are required for making the design decisions.
Each single generic representation of the sequence (row in the table) encodes declarative knowledge of the office building type. The sequence of generic representations (column in the table) encodes procedural knowledge of the office building type. The office building design is worked out through the sequence of generic representations.

Icon	**Representation**	**Name and decisions**
		1. **Simple contour** (1) Defining the outward form of the building. Establishing the shape; triple-winged building. Surface area. Parametrise wing-length. Entwurf 2, Integration 1, 6D, 8A, Neufert 14, 17-20, Offices 4, SBR 2A-2C.
		2. **Combination of contours** (2) Composing ensemble of contours to establish overall shape. Define internal proportions and place of simple contours. Explore emergent forms. Neufert 1, 3, 5A, 5B, 5C, 6, 7C, 9J, Time 7, 13.
		3. ***Specified form*** (H50) Establish tentative dimensions for wing length and depth, and orientation of the building. Neufert 6, 7D, 9J, Integration 3D, 6B, SBR 3A, Time 13, Offices 2, Update 1, 3A.
		4. **Complementary contours** (3) Establish place of building mass in site. Relate to demands of distance from site, and other buildings. Neufert 4, Time 5K, 7C, Besluit 2C, Integration 4B.
		5. ***Zone*** (H48) Zoning structure establishes a principle of ordering the building. Establish a zoning principle for the wings, *e.g.* single, double, or triple zone with central circulation. Neufert 1, 3, 5A, 5B, 5C, 6, 7B, 7C, 9J, Offices 2, 3, Update 3A, Time 10D, 12B.
		6. ***Schematic subdivision in zone*** (H15) Along a zone, establish areas that have specific qualities such as lighting, circulation, accessibility, etc. This results in an inventory of possibilities. Time 5D, 7C, Update 2, Neufert 1, 3, 7C, 8.

Icon	Representation	Name and decisions
		**7. Schematic subdivision in zone in contour with function symbols (49)** Allocate tentative functions in specific areas along a zone, relative to its properties. This results in an inventory of possibilities. Integration 4B, 4C, 4D, Time 5D, 7C, Besluit 2C, 3, Neufert 1, 3, 8.
		**8. Zone in specified form (16)** Establish the zoning system in the building form. Define the dimensions of the zones, identify special places such as intersections, end of wing, internal/external corners, etc. Integration 4B, 4C, 4D, Time 5D, 7C, Besluit 2C, 3, Neufert 1, 3, 7C, 8.
		**9. Schematic subdivision (9)** Divide the building into sections that are independent from each other. For each section, establish a principle division into parts. Time 5B, 7C, Neufert 1, 3, 8, Besluit 2C, 3.
		**10. Schematic subdivision in contour (21)** Subdivide the contour of the building according to the schematic subdivision. Identify tentative surface areas to parts of the subdivision. Time 5B, 7C, Neufert 1, 3, 8, Besluit 2C, 3.
		**11. *Grid* (H45)** Establish grid of building according to modules and dimensions already available. Entwurf 4, Neufert 10A, 10B, Integration 11B, Offices 1, Data 1C, Time 10B, 10C.
		**12. Schematic subdivision in grid (19)** Co-ordinate the schematic subdivision in the specific form along a grid. Define major spaces within the subdivision. Time 5B, 7C, 10B, 10C, Neufert 1, 3, 8, 10A, 10B, Besluit 2C, 3, Entwurf 4, Integration 11B, Offices 1, Data 1C.

Icon	**Representation**	**Name and decisions**
		**13. *Subdivision in specified form*** (H57) Subdivision of the specified form. General organisation of the building layout of major spaces. Time 5B, 7C, Neufert 1, 3, 8, Besluit 2C, 3.
		**14. Schematic axial system** (8) Establish principle of axes that co-ordinate spaces. Axes of the system define lines of symmetry of spaces, in the case of cellular office type often equivalent to central circulation. Layout of major rooms and places. Time 1, Neufert 5C, 7B.
		**15. Axial system in specified form** (18) Place system of axes that define organisation of spaces in the specified form. Define general dimensions of spaces. Time 1, Neufert 5C, 7B.
		**16. Contour in grid** (15) Superimpose the grid on the specified form. Establish the module of the grid. Entwurf 4, Neufert 10A, 10B, Time 10A, 10B.
		**17. Zone in contour in grid** (36) Co-ordinate the zone structure according to the module of the grid. Entwurf 4, Neufert 1, 3, 7C, 8, 10A, 10B, Time 5D, 7C, 10A, 10B, Integration 4B, 4C, 4D, Besluit 2C, 3.
		**18. Partitioning system in contour** (22) Principle of partitioning along which future divisions may be placed. Establish module for rooms. Neufert 1, 3, 8, 9J, 10A, Data 3A, 3C, Time 5K, 9G, 10A, 10B.

Icon	Representation	Name and decisions
		**19. Circulation scheme (13)** Establish circulation principle according to zoning and schematic axial principle. Time 1, 12B, Neufert 5C, 7B, Offices 3.
		**20. Circulation in contour (32)** Dimension circulation in building design according to requirements and brief. Time 1, Neufert 5C, 7B, 7D, 15C, SBR 4A, 4B, 5, Besluit 1F, 1G.
		**21. Element vocabulary (11)** Establish sets of furnishing for parts of the building according to functional requirements, brief, and suppliers. Neufert 2, 9B, 11, Data 1A, 2A, 3B, 9C, Time 2A, 5A, Integration 15.
		**22. Element vocabulary in contour (H30)** For parts defined according to subdivision of specified form, determine usability and functionality by interior elements (furnishing). Neufert 1, 2, 3, 8, 9B, 11, Data 1A, 2A, Time 2A, 5A, 5B, 7C, Besluit 2C, 3.
		**23. Element vocabulary and function symbols and grid in specified form (48)** Determine general layout, furnishing, and zoning of the building design adhering to the grid. Neufert 1, 2, 3, 8, 9B, 11, Data 1A, 2A, Time 2A, 5A, 5B, 7C, 9F, 9G, Besluit 2C, 3.

5.8 A computational approach to generic representations

This section presents a brief overview of a computer implementation of generic representations of the office building type. The system is dealt with in depth in Achten *et al.* (1995a, 1995b). The goal of the implementation is to show to some extent the suitability of generic representations in design processes, demonstrate the difficulties in handling generic representations and point to practical limitations.

Knowledge-based systems offer a number of techniques to encode procedural and declarative knowledge. The concept of the frame is used for knowledge representation. The frame technique is a flexible approach to represent knowledge because the content of a frame is not fixed and depends on the use it is put to. It represents the general description of the office building type. The frame slots and the order in which they are evaluated constitute the procedural knowledge of the office building type. Each slot represents a generic representation. The values of the slots constitute the declarative knowledge of a particular office plan generated through use of the system. The structure of the frame is established on the basis of the sequence of generic representations of the office building presented above. By applying this structure to a specific case, such as the T-shaped office building, feedback-loops and recursions that occur when designing an instance are revealed.

The knowledge-based system is programmed in AutoLISP. The frame representation common to all subtypes of the office building is stored separately as a template-file in "`office.frm`" (see code in Figure V-2). From the template-file the instance frames are constructed in the process of designing an office plan. The slots are ordered in sections. The first section "`Office:`" contains slots that hold general information: the subtype ("`Is_a:`"), the required area in the brief ("`Area:`"), the number of stories ("`No_stories:`"), and the storey-height ("`Height_storey:`"). In order to obtain a value, the slot calls AutoLISP-programs ("`officetype`", "`def_area`", "`def_no_stories`", and "`def_height_story`" respectively). When a new subtype is added to the system, for example the L-type, the appropriate slots are placed in the template-file under the section called "`LShape`". In this way, the system can extend gradually its command over various subtypes.

```
'(
 (Office: (myoffice)
   (Is_a: (officetype))
   (Area: (def_area))
   (No_stories: (def_no_stories))
   (Height_storey: (def_height_story))
 )
 ("TShape"
   (Orientation: (def_T_orient))
   (Dimensions: (def_T_dim))
   (Insertpoint: (def_insert))
 )
 ("LShape"
      ....
 )
)
```

Figure V-2: Sample code of template file "`office.frm`."

The implementation applies the first seven generic representations of the sequence of generic representations of the office building: simple contour → combination of contours → specified form → complementary contours → *zone* → *schematic subdivision in zone* → schematic subdivision in zone in contour with function symbols. Although the implementation has drawbacks (*e.g.* the frame as it is used has limited functionality, the implementation cannot support different sequences, AutoLISP lacks an inference engine which makes it a poor environment for developing), it is possible to conclude that structuring the frame by means of generic representations proves helpful in understanding the reasoning sequence which leads to a specific design. It also shows how frames can support a modular approach in developing subtypes of the office building. The static structure of the frame can be defined on the basis of generic representations. Furthermore, the work shows the significance of understanding and supporting the design process by means of generic representations. It demonstrates that design aid systems still lack the graphic support that is embedded in generic representations and that these systems would benefit much from implementation of these instruments.

The seven generic representations that are implemented constitute an aid for developing a subdivided zoning system in a preliminary office building layout. Although the implementation is limited, it demonstrates the applicability of the work. In the design system, one sequence is programmed via the order of slots in the frame representation, although the sequence can be put in at least one different feasible order ("structure" → "shape and structure"): *zone* (H48) → *schematic subdivision in zone* (H15) → schematic subdivision in zone in contour with function symbols (49) → simple contour (1) → *specified form* (H50) → complementary contours (3).

The system is useful in that it allows a quick survey of different shapes of the office building with a number of zoning principles. These are activities that occur in the early phase of the design process, of which it is easy to conceive that they are performed by sketches. The design system therefore, addresses two aspects of architectural design - the role of graphic representations and the role of knowledge of building types - that are important aspects of a CAAD system.

5.9 Discussion

The sequence of generic representations of the office building presented in the tables of Section *5.7* shows a series of graphic representations that conform to the definition of generic representations. Each drawing is different from the others. It appears that each drawing encodes different aspects of the building design.

As has been demonstrated in the two examples of Section *5.6*, each generic representation involves design decisions that can be made specific for the office building type. The knowledge required for establishing graphic representations that comply with the properties of generic representations can be derived from the knowledge base.

Separate generic representations encode declarative knowledge.

The knowledge base of the office building ranges from high level to low level (urban level to infill level) and includes building organisation, structural design, and HVAC. The generic representations of the office building range from high level to low level, and incorporate knowledge relevant to those levels. They also include features from structural design, in particular notions of structural span, stability (cores and slabs) and column grid. The application to HVAC is limited. The structuring device axial system (step *14-15*) is not very well supported by the knowledge base. Large spatial elements such as coolers, chillers, and installation rooms are not represented in the generic representations.

Generic representations incorporate most aspects of the knowledge base of office buildings. However, they are limited with respect to HVAC.

The sequence shown in the tables above leads to a conceptual design which determines important features of a building design: dimensioning, internal organisation, circulation, modular co-ordination, and functional brief. It is yet far from being a complete design. On the basis of the result of the sequence it is possible to work out in further detail the design of an office building.

Generic representations lead to a conceptual design of an office building.

The order in the sequence of generic representations is established on basis of one of the six general sequences of generic representations. Depending on the context of the design, it may start with "structure" or "system" rather than "shape." Within each theme or combination of themes, the exact order can be changed to some degree. For example, in the theme "shape and structure" a sequence may start with the structure subdivision rather than zone.

The precise order of generic representations in a concrete design process is not predefined. It may be changed depending on the design strategy taken.

By allocating design decisions to specific generic representations, it is possible to decompose the lengthy and complex sequence of design decisions involved in a building type. In each generic representation the design decisions are identified. It is possible to allocate knowledge of the knowledge base for each generic representation. Conflicts in design decisions occur when by means of additional or successive graphic units the new graphic units of the generic representation are incompatible with decisions taken by means of a previous generic representation. In such a case it is necessary to go back to the previous generic representation and reconsider the design decision given the problem of the current generic representation.
Feedback loops of design decisions can be identified and occur on the level of generic representations.

Conclusion

It is possible to apply declarative knowledge of the office building type on a particular sequence of generic representations. The application results in a set of graphic representations each of which is different with respect to the other. It shows a sequence of design decisions that makes small steps from one instance to the next. The work demonstrates that generic representations encode declarative and procedural knowledge of a building type. Seven generic representations are implemented in AutoLISP in an AutoCAD environment using approaches from the field of knowledge-based systems. The implementation shows that it is possible to create a design aid system based on generic representations, and that it supports a flow of design decisions resulting in a conceptual design.

6 CONCLUSIONS

By further figuring, it appeared that between New York and Rochester the Erie ran eight passenger trains each way every day - sixteen altogether; and carried a daily average of 6,000 persons. That is about a million in six months - the population of New York city. Well, the Erie kills from thirteen to twenty-three persons out of its million in six months; and in the same time 13,000 of New York's million die in their beds! My flesh crept, my hair stood on end. "This is appalling!" I said. "The danger isn't in travelling by rail, but in trusting to those deadly beds. I will never sleep in a bed again."

Mark Twain, The Danger of Lying in Bed

6.1 Research hypotheses

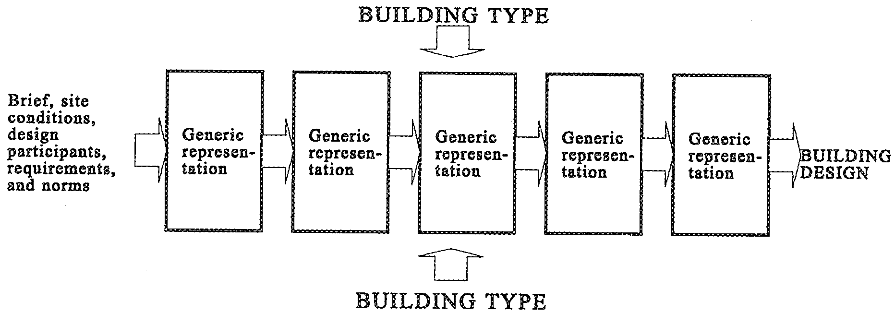


Figure VI-1: The model of Section *1.3* (Figure I-2) with generic representations incorporated in the sequence.

Based on the introduction in Chapter *1*, the role of knowledge associated with the building type in the design has been investigated by means of the medium of graphic representations. As stated in the introductory Chapter, the building type can be conceived of as a form of knowledge which comprises form, process, and function. The form aspect is addressed by graphic representations. This is studied in more detail in Chapters *2* and *3*. The process aspect of building type is established in sequences of generic representations. Chapter *4* identifies possible sequences on the basis of graphic units, generic representations, and themes. The function aspect of building type determines that a building actually belongs to a type. This aspect is addressed in Chapter *5*. At this point, it is possible to address the hypotheses posed in Chapter *1*.

1. Graphic representations consistently encode design decisions.

In Chapter *2* it is demonstrated that graphic representations consistently represent the things they depict. In order to answer whether design decisions can be derived from graphic representations the concepts of the *graphic unit* and the *generic representation* are defined. The graphic unit is the unit of analysis of graphic representations. With this concept it is possible to derive which elements are subject of the design decisions taken in a particular graphic representation. The generic representation is the specified form of a graphic representation in terms of its constituent graphic units. For each generic representation it is possible to state the associated design decisions. The 'encoding' of design decisions therefore, is by means of graphic units and therefore indirect.

2. *It is possible to identify sufficiently diverse graphic representations which encode specific design decisions.*

   In Chapter *3* the survey on the basis of the notions of the graphic unit and the generic representation is presented. It demonstrates that there exists a variety of graphic units which define a number of generic representations. Graphic units which represent architectural elements such as structural system, walls, etc. are actually in minority. Graphic units such as grids, axial systems, zones, etc. are more numerous. These establish in a graphic format a variety of design decisions with respect to organisation and order of the building design. The various generic representations found indicate that it can be possible to represent the large amount of design decisions that occur in a design process.

   This finding is informative about the role of graphic representations in the design process. It shows that architects have at their disposal a large set of graphic representations with which they can develop the design. In the research, these specific graphic representations - graphic units and generic representations - are identified and described.

3. *It is possible to define the transitions between graphic representations and to establish a sequence.*

   In Chapter *3* and *4* three kinds of relationships between generic representations are defined: additional graphic units, themes of generic representations, and successive graphic units. The relation of additional graphic units defines how generic representations become more complex by adding graphic units (Section *3.6*). The relation of themes of generic representations defines how groups of generic representations deal with the same kind of design decisions. Seven themes are identified in Section *3.6.3*. The relation of successive graphic units defines how graphic units provide preconditions for different graphic units. A number of sequences of successive graphic units are defined in Section *4.2.2*. By means of these relations it is possible to define six general sequences of generic representations on the level of themes (Section *4.4*), and to articulate particular sequences on the level of generic representations by means of additional and successive graphic units (Section *4.5*).

   Transitions between generic representations are defined and described. It appears that the relations of additional graphic units, themes of generic representations, and successive graphic units are instrumental in describing such transitions, but that establishing a sequence of generic representations on this basis does not follow automatically. Rather, the transitions state the possible sequences of generic representations.

4. *It is possible to map procedural and declarative knowledge of a building type on the sequence of graphic representations.*
In Chapter *5* declarative knowledge of the office building type is acquired and applied to the particular sequence of generic representations established in Chapter *4*. It is demonstrated how each generic representation of the sequence results in a different graphic representation of the design and how each generic representation calls for different design decisions. The term 'map' can now be more accurately described. Design reasoning is associated with particular generic representations. The outcome of this reasoning process is established in the drawing. This is clearly demonstrated in Section *5.6* where the application of declarative knowledge of the office building type requires additional reasoning. Therefore, it is appropriate to state that a sequence of generic representations leads to the structuring of the process of decision-making, but does not in itself handle the inference process. The order of the inference process however, can be defined in accord with the sequence of generic representations. This means that parallel to a sequence of generic representations it is also necessary to have a computational structure that can deal with the inference aspects of the decision-making. The prototype as discussed in the introductory Chapter and the frame-technology as discussed in the application of Section *5.8* can provide such a structure.

6.2 Declarative and procedural knowledge and the building type

In terms of the research work, procedural and declarative knowledge can now be more clearly defined, as well as the building type. The building type is the whole of generic representations that are required for instantiating building designs that belong to the type. It has a procedural and declarative component. The procedural component of the building type is defined in the sequence of generic representations. The sequence establishes the sequence of design decisions that is relevant for the type. It determines which issues to solve first, how to proceed from one issue to the next, and how to develop the building design. The declarative component is defined in each single generic representation that is relevant for the type. It determines the outcome of the design decisions and constraints the possible outcomes of the design decisions to the building type.

In order to establish a sequence of design decisions for a building type, it is necessary to have procedural knowledge. Since the sequence of design decisions is encoded in the sequence of generic representations, procedural knowledge is encoded in the sequence of generic representations. More precisely, procedural knowledge is formulated by means of additional graphic units, successive graphic units, and successive themes of generic representations (Chapter *4*). This knowledge determines the place of generic representations in a sequence. Therefore, the generic representation encompasses procedural knowledge.

In order to establish design decisions for a building type, it is necessary to have declarative knowledge. Since each generic representation encodes the outcome of design decisions - which requires declarative knowledge - declarative knowledge is encoded in single generic representations. More precisely, declarative knowledge is formulated by means of the graphic units of generic representations (Chapter *3*). The graphic unit determines which design decisions have to be taken. Therefore, the generic representation encompasses declarative knowledge.

It is demonstrated in the work that procedural knowledge and declarative knowledge can be treated quite distinct[22], and that generic representations are capable of incorporating both forms of knowledge. Furthermore, generic representations link the building type to the cultural and historical tradition and body of knowledge established in the architectural design community through graphic representations.

6.3 Constraints on the results of the research work

At a number of places in the research work, constraints have been applied to limit the work. It is necessary to focus on these constraints and see what their influence is on the scope of the conclusions. The constraints are:

Restriction to plan-based representations

The basic claim of generic representations is that drawing in the design process means making design decisions. This assertion applies in principle to all forms of graphic representations such as sections of a building design. However, in

[22] Akin (1986, p. 32-33) states about procedural and declarative knowledge: "*Although the distinctions between the two categories of knowledge are tautologically obvious, it is not immediately clear why they are needed.*" The work at hand demonstrates that making a strict division between the sequence of generic representations (procedural knowledge) and the application of knowledge associated with a building type (declarative knowledge) is productive.

the research work other conventions of depiction than the plan are not investigated. Therefore it is not known whether for the conventions there exist graphic representations that are saliently different and diverse enough to accommodate design decisions. A cursory glance at sections, perspectives, and iso/axonometric projections does not indicate that these conventions are as diverse as the plan. It seems therefore that the work is restricted to plan-based graphic representations.

Restriction to drawings

The graphic representations that are analysed in the research work are drawings rather than sketches. The goal of the analysis of graphic representations is to identify graphic units and generic representations. Since at the outset these are unknown, it is necessary to analyse cases that offer as less problems of ambiguity as possible. Sketches, due to the limited amount of time in which they are produced, and the specific intended personal use, are less precise and specific than drawings found in architectural sources. Therefore drawings are used as material for analysis. There is no principled distinction between sketches and graphic representations with respect to the claim that establishing either of them means making design decisions. Now that a set of graphic units and generic representations has been identified in the research, it is possible to apply these notions to sketches. However, this has not been done in the current work. Therefore, although it is quite plausible, it is not possible to state on the basis of the research work that in sketching architects also extensively use graphic units and generic representations to develop the design.

Restriction to procedural and declarative knowledge of building types

Generic representations encode procedural and declarative knowledge of building types. Both forms of knowledge are subsets of procedural and declarative knowledge. Since both larger classes of knowledge are required for design (think for example about matters of style, composition, etc.), it follows that generic representations are insufficient for encoding all knowledge required for designing. Part of this lack seems to be compensated by the fact that additional knowledge is implicitly used when establishing 'correct' graphic representations that make sense within the architectural design process (Section 2.2).

Restriction to linear sequence of generic representations

The particular sequence of generic representations of the office building is an ideal case. It presupposes that all design decisions are made correct in one go. However, this is not the way real design processes develop. There is no principled objection as to the number of times a generic representation is used in a sequence. The implementation work in the computer (Section *5.8*) shows that it is possible to deal with a generic representation more than once in a sequence. The notion of generic representations only states that if a generic representation is used, a particular set of design decisions is being considered.

Set of graphic representations

Although the set of graphic representations that makes up the body of cases of Chapter *3* is large, it is undetermined to which extent this set is exhaustive. The matter is difficult to establish, since there is no systematic way of describing all graphic representations. It is possible to conclude however, that it is more likely that a new combination of already identified graphic units will be found, than that a new graphic unit will be found. This is due to the large amount of possible combinations (*12950*; see note *12*, p. *98*) relative to the number of graphic units (*24*).

Another issue concerns the notion that if there are more than four different graphic units in a generic representation[23], this does not seem to aid in furthering the design. This means that generic representations are limited basically to the early stages of design where the design object is represented most often in a schematic fashion.

Although it is not clear to what extent the set of graphic units found is complete, it is at least reasonable to assert that not every possible combination of graphic units is used, and that only a restricted set of generic representations is used in architectural design.

Completeness of the set of graphic units

The identification of graphic units in graphic representations is based on the constituent graphic entities (lines, shapes, colours, hatching patterns, etc.), the context (assumptions of architectural plan, scale, relations among elements), and conventions (how do graphic entities encode salient characteristics of the building plan). The definition of the graphic unit reflects this interrelationship by distinguishing between graphic entities and their meaning. This definition proves useful to articulate design decisions in graphic representations. However, the definition is problematic in two respects: (1) there is no simple 'neutral' or 'automatic' way with which to decide whether for example a set of graphic entities such as a square represents either the graphic unit wall, zone, column, or ramp. (2) It does not seem possible to define all conceivable graphic units. The fact that graphic units are convention-based for some part, makes it

[23] This maximum number of graphic units found in graphic representations is for some part the result of the selection process as discussed in Section *3.1.2*. Therefore, it cannot be conclusively established to which phase of the design process generic representations are limited.

difficult to assess to which extent any derived set of graphic units can be complete. In all cases, such an inventory is open-ended, since it is possible to establish new conventions which may lead to new graphic units. It seems plausible however, to state that the graphic units identified in the research work form a substantial part of any inventory of graphic units.

6.4 Context of the research

The context of the research is about the basic assumptions and belief systems that inform the approach of the research work. Some of these have been identified in Sections *1.2.1* and *1.2.2*. The results of the research have an impact on the context. A number of points emerge.

The relationship between type and its instances.
The current work on generic representations shows a particular approach towards the issue of building types. Instead of assuming an abstract knowledge object 'type' to which instances - building designs - are related, the work focuses on the role of procedural and declarative knowledge derived from building types in the design process. As has been stated in the introductory Chapter, one of the difficult issues about type is the question how related-yet-different buildings can be designed that belong to a particular building type. It is now possible to provide a tentative account on the basis of generic representations.
In the theory of generic representations, there is a strict division between procedural and declarative knowledge. Procedural knowledge is encoded in the sequence of generic representations and declarative knowledge is encoded in single generic representations. The knowledge base of the building type is established independent of the generic representations[24].
The distinction between procedural and declarative knowledge allows to consider the following. Suppose, for instance, that in the statements of the knowledge base subsequently all values are altered (*e.g.* smaller values for daylight use within the facade area, larger values for personal floor area, smaller values for circulation area, etc.) Although the items of the knowledge base do not change (optimal light use, floor area, and circulation space are still

[24] Obviously, there is some interaction between establishing both the knowledge base and the sequence. For example, should it appear during the treatment of a generic representation that some knowledge is lacking, this can be searched for on the basis of the characteristics of the generic representation. This means that structuring the decision-process by means of generic representations also implies structuring the need for knowledge during the design process.

discussed) this has an impact on the design decisions taken. This change in the knowledge base is equivalent to changing the range of parameters in the data structure of a prototype (this is also known as parametric design or routine design).

Another possibility is to delete statements from the knowledge base. As long as this does not result in gaps of the remaining knowledge base (deleting for example data on a particular kind of office space while still insisting on using it) this does not affect the sequence of generic representations. This change in the knowledge base is equivalent to constraining the range of options that is available in the building type (less variation in functional spaces, for example).

Third, under condition of consistency it is possible to add new statements to the knowledge base. This is more labour-intensive, since existing statements of the knowledge base that are related to the new statement have to include these new statements (as has been stated in Section *5.5*, there is no implicit consistency check in the knowledge base)[25]. In this manner, new elements from a brief may be inserted. This change is equivalent to expanding the possibilities of the type (adding new functions or requirements).

Also, it is possible to interchange for example two knowledge bases (*e.g.* changing an office building knowledge base for a hospital knowledge base) and apply them to the same sequence[26]. The sequence may not be optimal for the other building type, but the change has only effects on declarative knowledge. The generic representations are independent of the statements of the knowledge base. This change is equivalent to choosing another building type.

Procedural approach versus idealistic position

In a number of research disciplines building type is discussed in terms such as 'nucleus,' 'model,' 'design generator,' 'schema,' and 'prototype.'[27] As has been stated in Section *1.2.1*, there is a difference between type as a theoretical construct structuring or influencing its instances (building designs), and type as

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[25] Changing the values of the statements, deleting statements, adding new statements, and changing knowledge bases is not implemented in the research work. Therefore, this discussion is tentative. It may appear for example that the claim 'under condition of consistency' is too hard to comply with.

[26] The hospital type has many similarities with the office building. Both types have large numbers of specifically sized functional rooms often in a double-loaded corridor system. They are typically multi-storey buildings. Salient differences with the single-purpose office building type occur in the number of specialised areas with special requirements, the compartmentalisation of departments, the role and treatment of public access, and additional services such as restaurants, hairdressers, shops, chapels, etc.

[27] The term 'nucleus' derives from de Quincy (1825), 'model' from the approach by Durand (1804), 'design generator' from Lawson (1980), 'schema' from Hamel (1990), and 'prototype' from Gero (1990).

a cognitive knowledge structure of groups of objects with the same properties. The first point of perspective is connected with theories of design, and the second is connected with theories of knowledge concepts. In an ideal case, both perspectives should support each other (it is not very likely that design proceeds without using cognitive structures such as schemas, nor that cognitive structures are not informed by knowledge generated through design). It is advisable therefore, to differentiate between type as derived knowledge from observing instances (resulting into schemas or other cognitive structures) and type as an object resulting from study and which can be used as a prescriptive and descriptive device in supporting and analysing architectural design processes.

In the research work it is demonstrates that an approach which is not based on the notion of an idealistic type also leads to support of design of buildings belonging to a type. 'Typical designs' result from applying a particular knowledge base in a particular sequence of design decisions. Although this conclusion is not substantiated in the research work by altering knowledge bases and applying these to a sequence of generic representations, it seems plausible enough to warrant caution on the idealistic position. It seems that at least an alternative for explaining the diverse instances of a building type is available in the procedural approach. This alternative is reminiscent of developments in biology which proceeded from essences of animals and plants to an evolutionary theory of species.

Architectural design research is multidisciplinary.

The activity of architectural design is a complex phenomenon to study. Many aspects can be distinguished:

- The process of designing is a cognitive process in the sense that the architect is problem solving, creating, learning, exploring, etc.
- Architectural design is a social process in the sense that the architect has contact with many design participants in a variety of relationships.
- Architectural design is a cultural and technical phenomenon situated in a specific cultural context.
- Architectural design is a process of dealing with uncertainty and establishing useful artefacts.

It is clear that no single research discipline will cover the complete array of phenomena of architectural design. Even within the design discipline of architectural design, its study must be interdisciplinary.

More specifically, on the subject of the building type it is demonstrated that from neither architectural theory, design theory, cognitive science, or computer science the subject can be treated comprehensively. The proposition in architectural theory and design theory that a concept such as type exists can only be corroborated via research in cognitive science. Application in design aid systems can only occur through use of expertise from computer science. This dependence seems to occur with subjects that both are part of architectural discourse and that can be considered as elements of human thought.

In the current work the focus of the research is on the role of the *knowledge structure* building type, considered in its aspects of *procedural and declarative knowledge* in the *architectural design process* related to the *medium of graphic representations*. The research disciplines of architectural theory, design theory, cognitive psychology, and computer science have proven informative in establishing both the theoretical work and the implementation work.

Figure VI-2 shows the relations between the research disciplines and the subject of the research. Design theory and architectural theory are disciplinary and provide notions about the role and meaning of building type from the point of view of architectural design. Computer science and cognitive psychology provide the means to support such notions in design aid systems and the understanding of the building type in design reasoning respectively. In general, these research disciplines contribute to design research. Design theory and computer science provide tools for architectural design that relate to architectural design processes and structures. Design theory and cognitive psychology provide insight in the thought processes that occur in designing. Architectural theory and computer science provide architectural concepts that can be used in design aid systems. Architectural theory and cognitive psychology provide the general constituent elements of architectural thinking.

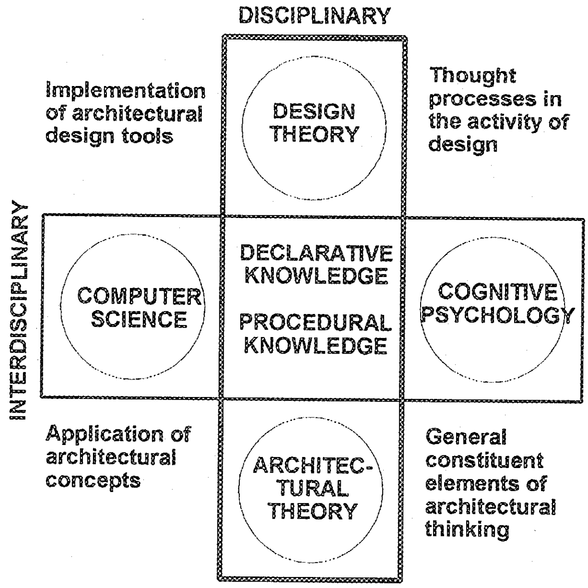

Figure VI-2: The relationship between research disciplines with respect to declarative and procedural knowledge of building types and design research.

6.5 Future work

The results of the research work discussed above provide feedback for the research disciplines with respect to future work.

6.5.1 Architectural theory

In the research work it is demonstrated that a procedural approach to building types is productive. This approach is quite different from the usual notion of type in architectural theory. Both 'ambiguity approach' and 'explicitness approach' assume that there is a type object which governs the nature of instances. This position has been termed 'idealistic' in Section *1.2.2*.

Future work in the discipline of architectural theory can test the impact of the idea that building types can be approached from a procedural point of point. The building type used in the research (the office building) is generally conceived of as a well constrained type. Questions that can be posed in architectural theory are:

- *Is it feasible to model other building types in the same way as the office building?* In order to be able to do this, it is necessary to establish knowledge bases from other building types, and applied them to sequences of generic representations.
- *What are the implications of a procedural approach to building types in architectural theory?* It seems that a general shift of focus from an idealistic

position to a procedural position will put emphasis on the way objects in architecture are created. Thus, there can be more attention for such issues as the design process, conceptualisation, visualisation, and design reasoning in architectural theory. It might imply a more dynamic notion than is usual today. This is a general discussion rather than an elaboration of the theory of generic representations alone.

6.5.2 Design theory

The work on generic representations has an emphasis on the procedural aspects of building types. It states that a sequence of generic representations encodes a series of design decisions which are informed by declarative knowledge. In this manner, building designs belonging to a particular building type can be realised. The general argument therefore, is that the architect has knowledge of the process related to buildings types, and inserts knowledge of the building type in the process. This process is carried out and articulated through the sequence of graphic representations.

On the basis of the current work, it is possible to formulate the following questions in the field of design theory:

- *Is it possible to describe design strategies in terms of a sequence of generic representations?* The design strategy applied in the sequence of generic representations is very much related to 'refinement.' Other strategies are termed 'adaptation' and 'creation.' As has been discussed in Section *6.3.1*, adaptation seems to lie within the scope of the theoretical work. Creation on the other hand, is not so obvious. The data required for establishing a building type is based on analysis of an existing building type. 'Creation' implies that there is no such type at hand to analyse. This raises the question if it possible to support a design process with an 'empty' knowledge base, that is, to support design only on the use of the graphic part of generic representations.
- *Do the notions of graphic unit and generic representation also apply to sketches made during the design process?* The work up to this point derives from analysis of drawings. This yields the set of graphic units and generic representations found in the current work. Although it is plausible that sketches can also be analysed in terms of graphic units, this is not been established in the research. It is necessary to further refine the notion of the graphic unit in order to be able to deal with the ambiguities of sketches produced during design. If it appears to be the case that graphic units are a relevant notion to analyse sketches, then this provides an approach for automated design support through sketches.

- *Is it possible to describe and support the role of design participants in the design process by means of generic representations?* A particular feature of graphic representations is the communication between the architect and the design participants (principal, contractor, advisors, etc.). As is demonstrated in Section 5.6, generic representations constrain the design decisions that need to be taken in each step of the design process. The generic representations can give cause to incorporate expert knowledge in the design process.
- *Are there graphic representations for other domains than the utility-domain?* In domain theory (Bax 1979, 1989) building designs are described in terms of three domains: utility (how is the building used), durability (how is the building sustained), and manufacturability (how is the building realised). At this point, generic representations are derived from graphic representations that predominantly deal with the utility-domain. This is the case because they are taken from sources on architectural design which specifically deals with issues such as the layout and composition of the building design. However, it seems reasonable to assume that design disciplines in architecture that deal with other domains (such as structural engineers, HVAC engineers, contractors, etc.) also may have generic representations that apply to their field. If this is the case, then it may be possible to address these disciplines also by means of generic representations.

6.5.3 Computer science

The implementation work on generic representations uses approaches from the field of knowledge-based systems. As has been stated in Section *5.8*, the implementation lacks interactive graphics, is not programmed to deal with varied site-forms, lacks a powerful frame-notation, and is not flexible with respect to the order of generic representations taken. Obviously, future work should focus on these issues. Particularly the restrained order of generic representations is something that needs to be solved, before it is possible to support a variety of design styles. The order of generic representations in the knowledge-based systems approach is fixed in the frame structure. However, the frame itself does not require one specific order of evaluation. Making generic representations modular enables a less strict order of processing them.

There are a number of other issues that the research work brings to bear on the discipline of computer science.

- *Can the work apply to the prototype approach?* The prototype approach, discussed in Section *1.2.2*, requires two aspects to be solved before it can be used in supporting design. The first is formulation of the prototype structure: defining the variables, their interrelationships, ranges of values, etc. The second is the way a prototype is used to produce an instance: which variables to start with, what are the reasoning mechanisms, how to solve conflicts, etc. In Section *6.1*, point *4*, it is proposed that a computational structure such as the prototype can be used for the inference strategy and the data structure in which to record the state of the design. The research work has addressed specifically the procedural side of building types. It may inform the instantiation process of prototypes. Also, it may show how knowledge of the prototype can be encoded in graphic representations.

- *Does the notion of the graphic unit aid in automated plan recognition systems?* One particular issue that is difficult in plan recognition, is the interpretation of the drawing. When it is possible to identify graphic units, then high level design knowledge can be added to the system. However, this requires working out subroutines that can interpret the formal part of the graphic unit. There has to be developed a way to describe the graphic unit such that it can aid in identification. This is not only a matter of matching a pattern found in the graphic representation, but also of relating graphic units among themselves.
- *Can the graphic tools embodied in graphic units be implemented in design aid systems?* It appears from the research that architects have at their disposal a variety of graphic tools with which to elaborate and work out the building design. This wide variety of graphic tools is in contrast with the rather limited graphic tools available in design aid systems. It is recommendable to implement tools such as zones, axial systems, proportion systems, tartan grids, etc. in design aid systems.
- *Is an automated approach of generic representations feasible in design aid systems?* When it is possible to automate recognition of graphic units in graphic representations, then knowledge embedded in the knowledge base can aid in the design process. At this point in the research work the designer is offered a particular set and sequence of generic representations. The other way around would be when the design aid system can analyse plan-based drawings produced in the design process, recognise graphic units and infer which generic representation(s) are dealt with. The design aid system can then suggest to the architect useful knowledge relative to the building type. Such a system could be realised in a blackboard architecture[28], by the use of

[28] Yoon (1992) discusses the blackboard architecture relative to design systems: "*The blackboard architecture consists of a kind of global database (or context) termed a 'blackboard', which*

agents (Minsky 1986), or possibly with the use of neural networks trained for recognition of graphic units. In all cases, it deals with structures that are programmed to recognise a particular generic representation. In this manner, it is very well possible that multiple processes, agents, or neural nets react to a graphic representation. Since the goal of the system is support of the design process in the early stage the resulting ambiguity may be exploited positively in the design aid system. Furthermore, generic representations offer a way to support the architect in a natural manner - that is, through the use of graphic representations. This seems specifically appropriate for systems that combine high-speed graphics with fast user feedback. A case in point is the VR-DIS system[29] in development at the Eindhoven University of Technology.

6.5.4 Cognitive psychology

The notions of the schema and the prototype point to approaches in cognitive science and Artificial Intelligence to implement the research work. The discussion in Section *6.3.2* urges to distinguish between the cognitive structure of type and the descriptive and prescriptive use of type in the design process. The relationship between the two interpretations of building types needs to be investigated. However, the main contribution from the field of cognitive psychology lies in the emphasis on the process of instantiation and the role knowledge has in this process, as well as in stating the main characteristics of graphic representations. The research work poses the following questions in the field of cognitive psychology:

- *Are graphic units 'chunks' and are generic representations 'templates'?* Cognitive psychology states that short term memory can hold a limited number of seven or eight pieces of information. A piece of information is called a 'chunk' (see Simon 1996, p. 63-74). The question rises what the chunks are when an architects views a plan-based drawing[30] (see Akin 1986,

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stores the information about the design, and a set of knowledge sources, which updates the blackboard [...] *In addition, the system has a control mechanism which chooses one of the most appropriate knowledge sources and executes it.*" (Yoon 1992, Section *6.2.1.* [...] by HA)

[29] VR DIS: Virtual Reality Distributed Interactive Simulations / Design Information System. See Smeltzer and Mantelers and Roelen (1994), Achten (1996), Achten *et al.* (1996), Coomans (1996), Dijkstra (1996), Leeuwen *et al.* (1996), de Vries (1997).

[30] Akin states about the relation between graphic representations and chunks: "*Chunks also support the hierarchic and multirelational organizations of information. By nesting chunks within other chunks, one can achieve multilayered hierarchies. This is critical in spatial representations* [...] *Similarly, designers recalling drawings of floor plans use multiple and alternative groupings between lines drawn, often assigning a building element or a wall segment to more than one chunk simultaneously. It is this redundancy of association inherent in spatial*

p. *119-130* for research on the subject). If the chunks of a graphic representation are in some way related to graphic units, this might aid in understanding knowledge transfer from drawings. If the first question is answered affirmative, then the question might be studied whether generic representations form 'templates' into which chunks are stored.

- *To what extent do graphic representations resemble cognitive structures?* The research work proposes that graphic representations are basic to understanding the way architects deal with the design process through graphic representations. One way of testing this idea is to have architects perform small design tasks on paper and ask them to say aloud what they are drawing and what they are intending to solve with that particular drawing. On the basis of the theoretical work, there should be a large correspondence between the design decisions identified verbally and the design decisions analysed in the graphic representations with help of generic representations.
- *Can the theory of generic representations form a basis for further analysing documents produced in protocol-analysis?* If there is a large correspondence between stated design issues and the graphic representation worked on during the design process, then the theory of generic representations may aid in analysing graphic documents produced in protocol-analysis.

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relationships that makes chunks a suitable memory organization for modeling visual knowledge." (Akin 1986, p. 117-118. [...] by HA)

A APPENDIX
Literature of the Case Studies

The case studies are limited to plan-based graphic representations which are found in literature on architecture. In the research work, it has not always been possible to acquire original sources, or reprints of original sources. Therefore, a number of sources in the list contain graphic representations from one or more original sources. The sources are listed in chronological order, starting with the oldest ones. Some bibliographical remarks add information about the context and kind of work with respect to the graphic representations.

Villard de Honnecourt, 1215-1235. *Sketchbook.*
From Bucher, F. 1979. *Architector. The Lodge Books and Sketchbooks of Medieval Architects.* Abaris Books, New York. First part of a series of books with annotated plates from the medieval sketchbooks of Villard de Honnecourt (ca. 1175-1240; book ca. 1215-1235), Master WG (active 1560-1572; book 1560), and Hans Boeblinger (ca. 1412-1482; book 1435). The first two books concern architecture and are included in the analysis.

Cesariano, C. di Lorenzo, 1521. *De architectura.*
From Tzonis, A. and Lefaivre, L. 1986. *Classical Architecture. The Poetics of Order.* MIT Press, Cambridge, Massachusetts. An overview of classicist theory and its applications. The book has a great number of illustrations from 16th to 18th century architectural sources. From this book graphic representations were used from Cousin (1560), Cesariano (1521), and Rusconi (1590).

Master WG, 1560. *Lodge book.*
See Villard de Honnecourt.

Cousin, J., 1560. Livre de perspective.
See Cesariano.

Rusconi, G., 1590. *Dell'architettura.*
See Cesariano.

Serlio, Sebastiano, 1611. *The Five Books of Architecture.*
Reprint 1982 Dover, New York. The book was first published in 1537 (Tzonis and Lefaivre 1990, p. 112). The edition referred to here, is a facsimile of the first English translation of 1611, printed by Simon Stafford for Robert Peake, London. *The Five Books of Architecture* is a handbook, showing principles of geometry and perspective as well as plans and drawings of existing structures and buildings.

Palladio, Andrea, 1738. *The Four Books of Architecture.*
Facsimile 1965, Dover, New York. Facsimile of 1738 print, originally published by Isaac Ware, London. According to the Introduction to Dover Edition, *The Four Books of Architecture* were first published in Venice in 1570. The first complete English translation was published in 1715, however, not with original illustrations. The edition drawn from here was published in 1738. *The Four Books of Architecture* is a handbook of architectural rules and building projects in the classicist tradition, depicting designs by Palladio and predecessors.

Ramée, Daniel, 1847. *L'Architecture de C.-N. Ledoux.*
Illustrations taken from Vidler, A. 1990. *Claude-Nicolas Ledoux - Architecture and Social Reform at the End of the Ancien Régime*, MIT Press, London. Monograph on the work of Ledoux. It has numerous illustrations from Daniel Ramée's *L'Architecture de C.-N. Ledoux.* Ramée published plates that were not used in Ledoux's *L'Architecture considerée sous le rapport de l'art, des moeurs et de la législation.* Graphic

representations also used from Vidler are Giovanni da Sangallo's "plan of the old Palais de Justice or Palais Comtale" (1494-1496) and Bentham's "plan of the Panopticon" (1797).

Durand, J.N.L., 1804. ***Préçis des Leçons d'Architecture donnees a l'Ecole Royale Polytechnique*****, Paris.**
Three-volume set of instruction books for architecture students: Précis des Leçons d'Architecture Premier Volume, Précis des Leçons d'Architecture Second Volume, and Partie Graphique des Cours d'Architecture. The books contain a wealth of graphic representations.

Milizia, Francesco, 1847. ***Principi di Architecttura Civile.***
Facsimile print, 1973 by Johnson Reprint Corporation. Facsimile of 1847, Majocchi, Milano. A general overview of architecture, aiming to establish principles based on functionalist and rationalist grounds (Tzonis and Lefaivre 1990, p. 364).

National Building Agency, 1965. ***Generic Plans.***
A survey of general housing solutions based on a systematic approach towards organisation of the main spatial elements that constitute a house. The study aims to present design solutions that emerge time and again in housing. For this purpose, a specific set of graphic representations was developed.

Zevi, Bruno, 1948. ***Architecture as Space - How to look at architecture.***
Revised edition, Da Capo Press, New York. The book presents a history of architecture from the perspective of the notion of space. Graphic representations used are figure-ground analyses of mass-space distribution in buildings. *Architecture as Space* was first published in 1948 in Italian. The first English translation is from 1957.

Vitruvius, 33-14 BC. ***The Ten Books of Architecture.***
Translated by Morgan (1960). Dover Publications Inc., New York. Vitruvius presumably wrote the books between 33 and 14 BC (Kruft 1994, p. 21). Although there seem to be old copies with illustrations (Kruft mentions the existence of an illustrated Vitruvius manuscript of the ninth or tenth Century) of the original *Ten Books of Architecture* only the text is preserved (Kruft 1994, p. 31). However, many illustrations of the genera and kinds of temples that are used in other sources are based on the descriptions in Vitruvius' text. The translated version by Morgan provides an illustrated edition of the *Ten Books of Architecture*.

Herdeg, K. 1967. ***Formal Structure in Indian Architecture.***
Reprint Rizzoli, New York. A survey, analysis, and presentation of existing urban and architectural structures in India. Analysis and presentation are executed in a diverse body of graphic representations. Originally published in 1967.

March, L. and Steadman, P., 1971. ***The Geometry of Environment.***
RIBA. A number of articles offering a résumé of computational, theoretical, and mathematical research work in architecture.

Wittkower, R., 1973. *Architectural Principles in the Age of Humanism.*
Academy Editions, London. Study on the basic principles of Renaissance art and architecture. Contains an overview and analysis of the general ordering principle of Palladian villa's.

Boekholt et al. 1974. *Denken in Varianten.*
Samson Uitgeverij, Alphen aan den Rijn. Together with Carp and van Rooij (1974) a publication on SAR methodology. The SAR developed new graphic representations that were used to support their design methods. The book contains an overview of the theory applied to the design of housing structures.

Carp, John and van Rooij, Ton, 1974. De ontwikkeling van een taal; het gebruik van een taal.
From: *Plan* 12, 1974, p. 25-55. Review of the state of the art of the use of SAR methodology in building practice. Contains graphic representations developed by SAR and applied to housing design.

March, L. (ed.), 1976. *The Architecture of Form.*
Cambridge University Press, Cambridge. A number of papers offering a résumé of computational, theoretical, and mathematical research work in architecture.

Ching, Francis D.K. 1979. *Architecture: Form, Space and Order.*
Van Nostrand Reinhold, New York. A primarily graphic handbook on basic principles of architectural design, concentrating on the constitutive elements, systems, and orders that inform composition and organisation.

Clark, R.H. and Pause, M. 1985. *Precedents in Architecture.*
Van Nostrand Reinhold, New York. A survey on a large body of buildings analysed and presented in a graphic manner in order to convey general formal characteristics.

Schmertz, M.F., 1980. A New Museum by Walter Netsch of SOM Given Order by his Field Theory.
From: *Architectural Record*, January 1980. Article on a building project and underlying theoretical work that generates building designs in a graphic manner.

Bailey, S., 1990. *Offices. A Briefing and Design Guide.*
Butterworth Architecture, London. A handbook on the early stages of design, including the briefing process of office buildings. Includes a number of graphic representations that illustrate principles in office buildings.

Herdeg, K. 1990. *Formal Structure in Islamic Architecture of Iran and Turkistan*
Rizzoli, New York. A survey, analysis, and presentation of existing urban and architectural structures in Iran and Turkistan. Analysis and presentation are executed in a diverse body of graphic representations.

Mitchell, W.J. and McCullough, M., 1991. ***Digital Design Media.***
Van Nostrand Reinhold, New York. An overview of the state of the art in design aid systems based on the distinction between vertices, lines, planes, volumes, and hypermedia.

B APPENDIX

Hypothetical Generic Representations

With the notion of the graphic unit it is possible to formulate generic representations that are not found in the survey of the research work, but that can be described as linking generic representations by means of addition of graphic units. These *56* hypothetical generic representations lead in a sequence of additional graphic units to generic representations that are found in the survey.

Hypothetical generic representations with one graphic unit

- H44. *Structural element vocabulary*
  Graphic units: *structural element vocabulary* (20)
- H45. *Grid*
  Graphic units: *grid* (16).
- H46. *Contour*
  Graphic units: *contour* (2).
- H47. *Axial system*
  Graphic units: *axial system* (15).
- H48. *Zone*
  Graphic units: *zone* (8).
- H49. *Function symbols*
  Graphic units: *function symbols* (7).
- H50. *Specified form*
  Graphic units: *specified form* (4).
- H51. *Refinement grid*
  Graphic units: *refinement grid* (12).
- H52. *Structural tartan grid*
  Graphic units: *structural tartan grid* (18).
- H53. *Circulation*
  Graphic units: *circulation* (27).
- H54. *Tartan grid*
  Graphic units: *tartan grid* (17).
- H55. *Measurement device*
  Graphic units: *measurement device* (3).
- H56. *Partitioning system*
  Graphic units: *partitioning system* (22).

Hypothetical generic representations with two graphic units

- H11. *Structural element vocabulary in grid*
  Graphic units: *structural element vocabulary* (20), *grid* (16).
- H12. *Structural element vocabulary in contour*
  Graphic units: *structural element vocabulary* (20), *contour* (2).
- H13. *Structural element vocabulary in axial system*
  Graphic units: *Structural element vocabulary* (20), *axial system* (15).

- H14. <u>*Axial system in grid*</u>
  Graphic units: *axial system* (15), *grid* (16).
- H15. <u>*Schematic subdivision in zone*</u>
  Graphic units: *schematic subdivision* (10), *zone* (8).
- H16. <u>*Zone in contour*</u>
  Graphic units: *zone* (8), *contour* (2).
- H17. <u>*Function symbols in zone*</u>
  Graphic units: *function symbols* (7), *zone* (8).
- H18. <u>*Function symbols in contour*</u>
  Graphic units: *function symbols* (7), *contour* (2).
- H19. <u>*Element vocabulary and function symbols*</u>
  Graphic units: *element vocabulary* (19), *function symbols* (7).
- H20. <u>*Function symbols in grid*</u>
  Graphic units: *function symbols* (7), *grid* (16).
- H21. <u>*Function symbols in specified form*</u>
  Graphic units: *function symbols* (7), *specified form* (4).
- H22. <u>*Specified form in grid*</u>
  Graphic units: *specified form* (4), *grid* (16).
- H23. <u>*Axial system in contour*</u>
  Graphic units: *axial system* (15), *contour* (2).
- H24. <u>*Structural element vocabulary in refinement grid*</u>
  Graphic units: *structural element vocabulary* (20), *refinement grid* (12).
- H25. <u>*Structural tartan grid in refinement grid*</u>
  Graphic units: *structural tartan grid* (18), *refinement grid* (12).
- H26. <u>*Structural element vocabulary in modular field*</u>
  Graphic units: *structural element vocabulary* (20), *modular field* (11).
- H27. <u>*Contour in modular field*</u>
  Graphic units: *contour* (2), *modular field* (11).
- H28. <u>*Circulation in grid*</u>
  Graphic units: *circulation* (27), *grid* (16).
- H29. <u>*Element vocabulary in zone*</u>
  Graphic units: *element vocabulary* (19), *zone* (8).
- H30. <u>*Element vocabulary in contour*</u>
  Graphic units: *element vocabulary* (19), *contour* (2).
- H31. <u>*Function symbols and axial system*</u>
  Graphic units: *function symbols* (7), *axial system* (15).

- H32. *Schematic subdivision and schematic axial system*
  Graphic units: *schematic subdivision* (10), *schematic axial system* (13).
- H33. *Schematic axial system in contour*
  Graphic units: *schematic axial system* (13), *contour* (2).
- H34. *Schematic subdivision in refinement grid*
  Graphic units: *schematic subdivision* (10), *refinement grid* (12).
- H35. *Grid in refinement grid*
  Graphic units: *grid* (16), *refinement grid* (12).
- H36. *Axial system in structural tartan grid*
  Graphic units: *axial system* (15), *structural tartan grid* (18).
- H37. *Specified form in structural tartan grid*
  Graphic units: (4), *structural tartan grid* (18).
- H38. *Axial system in tartan grid*
  Graphic units: *axial system* (15), *tartan grid* (17).
- H39. *Contour in tartan grid*
  Graphic units: *contour* (2), *tartan grid* (17).
- H40. *Zone in grid*
  Graphic units: *zone* (8), *grid* (16).
- H41. *Proportion system in elaborated structural contour*
  Graphic units: *proportion system* (23), *elaborated structural contour* (5).
- H42. *Proportion system in tartan grid*
  Graphic units: *proportion system* (23), *tartan grid* (17).
- H43. *Elaborated structural contour in tartan grid*
  Graphic units: *elaborated structural contour* (5), *tartan grid* (17).

Hypothetical generic representations with three graphic units

- H1. *Structural element vocabulary in contour in grid*
  Graphic units: *structural element vocabulary* (20), *contour* (2), *grid* (16).
- H2. *Structural element vocabulary in axial system in grid*
  Graphic units: *structural element vocabulary* (20), *axial system* (15), *grid* (16).
- H3. *Schematic subdivision in zone in contour*
  Graphic units: *schematic subdivision* (10), *zone* (8), *contour* (2).
- H4. *Schematic subdivision in zone with function functions*
  Graphic units: *schematic subdivision* (10), *zone* (8), *function symbols* (7).

- H5. <u>*Schematic subdivision in contour with function symbols*</u>
  Graphic units: *schematic subdivision* (10), *contour* (2), *function symbols* (7).
- H6. <u>*Zone in contour with function symbols*</u>
  Graphic units: *zone* (8), *contour* (2), *function symbols* (7).
- H7. <u>*Element vocabulary and function symbols in grid*</u>
  Graphic units: *element vocabulary* (19), *function symbols* (7), *grid* (16).
- H8. <u>*Element vocabulary and function symbols in specified form*</u>
  Graphic units: *element vocabulary* (19), *function symbols* (7), *specified form* (4).
- H9. <u>*Element vocabulary in specified form in grid*</u>
  Graphic units: *element vocabulary* (19), *specified form* (4), *grid* (16).
- H10. <u>*Function symbols in specified form in grid*</u>
  Graphic units: *function symbols* (7), *specified form* (4), *grid* (16).

C APPENDIX

Knowledge Base of the Office Building Type

The knowledge base holds declarative knowledge of the office building type. It is ordered in levels (*Building*, *Building part*, and *Infill*) and subjects (*Building*, *Organisation*, *Spaces*, *Egress*, *Circulation*, *Structural system*, *HVAC*, *Core*, *Elevators*, *Stairs*, *Workplace*, *Module*, *Furniture*, and *Toilets*) dealing with relevant aspects of office building design. Statements are identified by an abbreviation and number. The statements are used in their original formulation. Long statements and text in other languages than English are briefly summarised (*in italics*). Units are converted to the metric system. The abbreviations used are:

Besluit: Bouwbesluit, *Neufert*: Neufert Bauentwurfslehre (Neufert and Neufert 1992), *Integration*: Architectural Design: Integration of structural and environmental systems (Bovill 1991), *Offices*: Offices - A briefing and design guide (Bailey 1990), *Data*: Architect's Room Design Data Handbook (Hoke 1988), *SBR*: Schachten als kern voor hoge gebouwen? (Stichting Bouwresearch 1985), *Update*: Buildings Update - Offices Part I (Architect's Journal, 11 nov. 1981), *Time*: Time Saver Standards for Building Types (De Chiara and Callender 1980), *Entwurf*: Entwurf und Planung - Verwaltungsbauten (Peters 1973).

Level: Building

Subject: Building

Neufert 4. *In the USA, most office buildings have an east-west orientation. In Europe, most office buildings have a south-north orientation.* Nach Rosenauer bei 90% aller Burobauten in USA Hauptachse O/W, da tief eindringende Morgen- und Abendsonne stört. Südsonne is durch Sonnenblenden leicht abzuschirmen. Nach Joedicke Hauptachse S/N-Lage, damit Durchsonnung aller Räume gewährleistet ist. Nordräume nur bei flurfreien Anlagen vertretbar.

Neufert 6. *Daylight can be used up to 7,00 m from the facade.* Das Tageslicht läßt sich bis zu einer Raumtiefe von ca. 7,00 m noch weitgehend nutzen.

Neufert 7C. *Daylight can be allowed in a variety of ways in the building layout.* Wirtschaftliche unmittelbare Flurbeleuchtung durch Kopflicht bei kurzen Bauten, Flügelbauten, Winkelbauten, T-Bauten, U-Bauten, in versetzten Langbauten mit abschließendem Kreuzbau mit Fahrstuhlschacht inmitten. Seitliche Flurbeleuchtung durch Rücksprünge unwirtschaftlicher raum. Auf tiefen, teuren Grundstücken Flure und Nebenräume, Registeien, Aborte und Kleiderabgabe zweckmäßig an Lichthöfen. In den Innenecken Treppenhäuser, Fahrstühle und Abortanlagen; in den dunklen Teilen Dunkelkammern, Tresore und Abstellräume.

Neufert 9J. *Typical office room is 4,50-6,00 m deep, which can still utilise some daylight. A rule of thumb is T=1,5 H_f (T = depth of daylight; H_f = height of window). More remote workplaces require artificial light.* Durchschnittliche Tiefe von Büroraum 4,50-6,00 m. Tageslichtausleuchtung bis Arbeitsplatztiefe von ca 4,50 m (abhängig von Lage des Bürohauses, wie enge Straße oder freie Umgebung). Faustregel T = Tiefe des Lichteinfalls = 1,5 H_f, Höhe Fenstersturz (H_f=3,00m, T=4,50m). Bei Tieferliegenden Arbeitsplätzen Kunstlicht im letzten Drittel der Raumtiefe. Arbeitsgruppen vielfach unabhängig von Tageslichteinfall, da tiefere Räume notwendig.

Neufert 14. *Highrise buildings have the upper floor above 22 m of the site.* Hochhäuser sind Gebäude mit Räumen, die dem dauernden Aufenthalt von Menschen dienen und deren Fußboden im obersten geschoß an einer Gebäudeseite mehr als 22 m über Gelände liegen.

Neufert 17. *With a floor height of 3,00/3,10 m, the building typically does not have extensive installations.* Geschoßhohe 3,00/3,10 m: Gebaude mit geringem Installationsgrad. Keine abgehangten Decken. Heizungsrohre an Aubenwand. Elektroversorgung über Fensterbankkanal oder Bodenkanale. Deckenleuchten uber Leerrohre oder Stander-Trennwande versorgt. Flurbereiche fur Installationstrassen.

Neufert 18. *With a floor height of 3,40 m, the building utilises installations, although no airconditioning.* Geschoßhohe 3,40 m: Gebäude mit Installationsanforderungen, ohne Luftungstechnik. Unter der Decke (h=22 cm) Leitungen für Heizung, Elektro und Wasser. Im Flurbereich Installationstrassen.

Neufert 19. *With a floor height of 3,70 m, the building can accommodate airconditioning (minimal space for installations 50 cm).* Geschoßhohe 3,70 m: Gebäude

mit lüftungstechnisch versorgten Büroraumen. Für klimatisierte Büroraumen Installationsraum von min. 50 cm zu empfehlen. Laengsgeführte Trassen im Flurbereich.
Neufert 20. *With a floor height of 4,20 m, usually landscape office.* Geschoßhohe 4,20 m: Bürogroßraum, lichte Raumhohe n. ASTV 3,00 m. Durch kreuzende Lüftungskanale Geschoßhohen von ca. 4,20 m. Alle hohenabhangigen Gebäudeelemente beeinflussen die Gebäudekosten in Relation zur Büronutzflache.
Integration 1. Office buildings typically have a Gross Area/Net Area ratio of 1.35
Offices 2. There are four basic depths of space: Shallow space (4-5 m), medium depth space (6-10 m), deep space (11-19 m), and very deep space (over 20 m).
Update 1. *There is a trend towards smaller office floors.* From 1969-1980, the average area of floors in new offices starting construction, dropped from ±3500 m^2 to ±1000 m^2. The typical depth dropped from ±21 m to ±14 m with a highest peak of ±30 m in 1972. Energy resource problems reduced the percentage of air-conditioned office floorspace from ±88% to ±40 %. The highest amount of air-conditioned building was in 1974: ±98 %.
Update 3A. *There is a trend towards medium depth (14-17 m).* The pressures from users, office electronics, energy conservers and in consequence the rate-paying tenant of office buildings, all point towards medium depth buildings (14-17 m across) as an attractive depth for both speculative and custom-designed developments. The medium depth building allows: •A hybrid system of environmental control, where opportunities for natural light and ventilation can be maximised and a central zone established with extract for equipment and heat generating devices; •User demand for proximity to external views, and personal control over their environment; •Flexibility of layout types, allowing for a high proportion of enclosed offices, group spaces and open-plan areas.
Time 13. *Office buildings tend to have slab-like shapes.* Since the floor space within 7,6 m to 9,1 m from the exterior wall brings premium rentals, office buildings (site or zoning considerations aside) tend to assume a slablike shape, 18,3 m to 21,3 m wide by 45,7 m or more long, with the service core in the center. For greater flexibility in the rental space, the service core may be moved completely outside the office space. When this scheme is combined with clear span framing, the ultimate in flexibility is achieved.
Entwurf 2. *In terms of economical feasibility, the minimal surface area is 600 m^2.* Das absolute Minimum eines Wirtschaftlich vertretbaren Geschoßgrundrisses liegt bei einer Größenordnung von 600 m^2.

Subject: Organisation

Update 2. *Only 25% move regularly from place. Only 30% opts for an individual office.* Tentative conclusions of a 1980 study are that: 75% of all white collar never move their offices while the remaining 25% move an average of four times per year, which suggests a great deal of the flexibility built schemes may be redundant; and that only 30% of the office population would opt for an individual office, although the majority of staff tend to complain about noise and lack of privacy.
Time 7B. Relatively minor activities are better placed around the major office activities rather than integrated with them.

Time 7C. *Visitors should have short and direct access. Group together departments that work closest together. Do not group departments that are cumbersome to change. Group centralised services. Isolate departments with confidential status. Conference rooms close to most intensive users. Facilities on the lower floors to reduce vertical transport.* Here are ten guides for determining what proper locations should be. •Convenience to the public: Visitors should have a short, direct, and convenient route from the main entrance to the department sought. The sales, purchasing, and employment or personnel departments usually have the most visitors. •Flow of work: Departments having the closest working connections should be placed closest together. Sales and advertising departments normally work together; so do the sales and credit departments, cost and payroll departments. •Equipment used: Moving department requiring extensive wiring, plumbing, or ventilation equipment requires expensive alterations. Obviously, two such departments should not be located together because of the difficulty of later expansion. •Centralized functions: Sections and facilities that serve the entire office should be centrally located and easily accessible to all who use them. •Confidential areas: Central files, the paymaster, the controller, and legal offices are examples of functions that require them to be isolated from others in the office and from the general public. •Conference rooms: Conference and training rooms should be reasonably near those departments that use them the most. If the office is air-conditioned, the room can be in the interior of the space to eliminate the distraction of windows and to provide more wall display area. •Freight elevators: Departments receiving and delivering large quantities of materials should be located near the freight area for ease of handling, less time and labor, and less distraction of other workers. Mail, stockroom, and machine departments are in this category. •Shipping dock: Near the point of entrance and exit of material. •Service facilities: Eating, medical, and lounge facilities are generally on the lower floors to reduce elevator traffic. The number and type of employees in a particular department might be considered in locating it near these facilities. •Passenger elevators: When an office occupies more than one floor, elevator service will be more effective when the departments with large clerical forces are on the lower floors.

Level of building part

Subject: spaces

Neufert 1. *Kinds of spaces: Office room: 1-3 people, group space: -20 people, landscape office: -200 people. "Kombi" office: mix of office rooms and collective spaces.* Raumgruppen: Bürobereich: Zellen büros 1-3 Personen mit AZUBI-Arbeits plätzen. Gruppenbüros bis 20 Personen mit AZUBI-Arbeits plätzen. Großräume bis 200 Personen auf einer Ebene. Kombibüros mit Einzelarbeits plätzen und gemeinschaftlich nutzbaren Gruppenbereichen.

Neufert 3. *A mix of kinds of spaces is required.* 75% der täglichen Arbeit findet am Engeren und Erweiterten Arbeitsplatz statt... Notwendige Arbeitskontakte, sowie kollektiv genutzte Einrichtungen sind von Bedeutung. Daher die Forderung einer

Nutzungsmischung aus Einzel- und Gruppenräumen, "Persönliche" und "Kollektive" Arbeitsplätze.

Neufert 8. *The landscape office only has application for a limited number of organisations.* Der Großraum scheint, trots weit verbreiteter "Trend-Anwendung" nur bei wenigen Organisationsformen und Arbeitsinhalten sinnvoll und die Idee des durchrationalisierten Büros nicht für alle Betriebsorganisationen gleich geeignet.

Neufert 9J. See *subject: building* (p. 182) on typical room size.

Data 3A. Conference rooms. Recommended standards for occupancies: •46 m^2 per 15 people; •2,3 m^2 per person for up to 8 people; •1,9 m^2 per person for 8 to 10 people; •1,7 m^2 per person for 20 to 40 people.

Data 3C. Conference rooms. Minimum standards: •As per program; •18,6 m^2 for conference space.

Data 3D. Plan features of conference rooms: interior rooms are preferred, without distraction of views and heat gain of windows.

Update 2. See *subject: organisation* (p. 183) on numbers of staff that require flexibility.

Time 5B. Semiprivate offices: The semiprivate office is a room, ranging in size from 14 to 37 m^2, occupied by two or more individuals.

Time 5D. *Open space for more than 50 people should be subdivided.* 'General office space' refers to an open area occupied by a number of employees, supervisors, furnishings, equipment, and circulation area. In many cases open-space housing for more than 50 people should be subdivided either by use of file cabinets, shelving, railing, or low bank-type partitions.

Time 5G. Conference space should not be provided in private offices. In lieu of large offices, it is desirable to provide a conference room adjoining the office of a top official who holds a large number of conferences and nearby conference rooms for officials with more limited requirements.

Time 5H. The conference rooms should be centrally located to the users. Access to conference rooms should be through corridors or reception areas.

Time 5I. Conference rooms should be designed to accommodate average but not maximum attendance.

Time 5K. Reception areas and visitor control: An allowance of 0,9 m^2 for each visitor to be served may be used for space allocation. The receptionist should be placed so as to command a clear view of those entering and be easily accessible to visitors.

Time 7C. See *subject: organisation* (p. 184) on conference rooms.

Time 9B. The following typical allowances include space for departmental aisles, space to move about, space for occasional visitors and consultation, rest rooms, fountains, special files, general office equipment, bookcases, and coat racks. It does not include main aisles, corridors, or the space covered by the other four space categories. •Top executive: 37,2 - 55,8 m^2; •Junior executives: 9,3 - 18,6 m^2; •Supervisors 7,4 - 9,3 m^2. •Operator at 1,52 m desk: 5,12 m^2; •Operator at 1,40 m desk: 4,65 m^2; •Operator at 1,27 m desk: 4,19 m^2.

Time 9F. *Additional spaces usually part of the programme of demands.* Depending on the type of business, offices will require rooms of a size matched to their use. These will include: Reception room, waiting room, interviewing room, examination room, conference room, exhibition room, medical room, lunchroom, employee lounge, rest room, mail room.

Time 9G. The more common rooms will have the following typical space allotments, based on their use by 15 people: •Reception room 37,2 m^2; •Waiting or interviewing room 18,6 m^2; •Conference room 46,5 m^2. Add approximately 0,9 m^2 for each additional person to be provided for.

Subject: Egress

Besluit 2C. *There should be at least two possibilities of egress.* Een toegang van een rookcompartiment als bedoeld in artikel 234, vierde tot en met zevende lid moet zijn gelegen aan het aansluitende terrein of aan een ruimte waardoor twee onafhankelijke vluchtmogelijkheden voeren.

Besluit 3. *There is a maximum distance from workplace to point of egress of 30 m.* De afstand tussen een toegang van een rookcompartiment en een toegang van het kantoorgebouw mag, gemeten langs de kortste route, ten hoogste 30 m zijn.

Integration 3C. Corridor width is to be less than 1,12 m for an occupant load of 10 or more people. It can be 0,91 m for less than 10 people.

Integration 3D. Dead end corridors are limited to 6,10 m.

Integration 3E. When more than one exit is required the occupant should be able to go toward either exit from any point in the corridor system.

Integration 3G. Handrails or fully open doors cannot extend more than 0,2 m into the corridor.

Integration 3H. Doors at their worst extension into the corridor cannot obstruct the required width by more than a half.

Integration 4B. Almost all buildings will need at least 2 exits.

Integration 4C. An occupant load of "number of people of floor" + 0.5 x "number of people floor below" + 0,25 x "number of people floor above" = 501-1000 people requires three exits.

Integration 4D. An occupant load of "number of people of floor" + 0.5 x "number of people floor below" + 0,25 x "number of people floor above" > 1001 people requires four exits.

Integration 4I. Minimum exit door width is 0,9 m with 0,8 m clear opening.

Integration 4J. The width of exit stairs, and the width of landings between flights of stairs, must all be the same and must meet the minimum exit stair width requirements as calculated above or: 1,1 m minimum width for an occupant load of 50 or more people, or 0,9 m minimum width for 49 or fewer people, whichever is greater.

Subject: circulation

Neufert 11. *Place requirements circulation between furniture*[31]*: •standing workplace 2,46 m^2 (0,8 m free space) •single table 2,25 m^2 (0,7-0,75 m free space); •single table*

[31] The dimensions are stated on p. 294 of Neufert (1992) in graphic form. The numbers between brackets refer to the graphics. The English text is in the same order, giving an indication of the graphics.

with shelf behind back 2,90 m² (0,75-0,8 m free space); •U-shaped table 2,90 m² (0,5-0,55 m free space); •table with passage at back 2,60 m² (0,85-0,95 m free space); •table with magazine-stand in back 3,70 m² (0,90-1 m free space); •face-to-face tables 1,90 m² (1 m free space); •2x2 tables 2,25 m² (1,4 m). Short archives require 1,40 m free space. Longer archives requires 1,75 m free space. At the window, there must be a free space of 0,55 m from the heating. Platzbedarf je Platz ohne seitliche Verbindungsflure: (5) 2,46 m², (6) 2,25 m², (7) 2,90 m², (8) 2,90 m², (9) 2,60 m², (10) 3,70 m², (11) 1,90 m², (12) 2,25 m². Für kurze Registreischrankreihen genügt (13), für längere (14), denn hier muß wie bei den Tischen (8-12) ein Durchgang möglich sein. Am Fenster muß bei Heizkörper-Anordnung ein Abstand sein, der bei 55 cm Breite auch als Durchgang dienen kann (17).

Offices 3. Central circulation (primary) in corridors should be 2 m; secondary (linking groups to primary) 1,50 m, tertiary (within groups) 0,750 m.

Time 1. There are a number of core locations: •Interior central, •Interior off-centre, •Interior split (two or more cores), •Exterior.

Time 12B. Corridors are usually 1,5 m to 1,8 m wide, wider if very long, narrower if very short.

Subject: structural system

Neufert 5A. *Single loaded plans are only economical in deep office space.* Einbündige Anlagen unwirtschaftlich, nur bei tiefen Büroräumen vertretbar.

Neufert 5B. *Double loaded plans are frequently used.* Zweibündige Anlagen bisher mehrzahl der Verwaltungsbauten, Einzelräume und kleine Bürosäle mit Tageslichtausleuchtung möglich.

Neufert 5C. *Double corridor system (two exterior/one middle zone) typical for highrise office buildings.* Dreibündige Anlagen Typ des Bürohochhauses.

Neufert 7B. *Single central row of columns enables different treatment of left- and right side. Double central row of columns enables similar treatment of left- and right side.* Einfache Mittelstützereihe gestattet Fluranlage rechts oder links der Stützen den Raumbedürfnissen entsprechend. Eine Doppelstützenreihe ermöglicht gleich tiefe Büroräume. Die Flure haben hierbei mittelbare Belichtung durch hochliegende Fenster und Glasthren in der Flurwand.

SBR 2A. *There is no need for structural cores in terms of stability for buildings between 2 and 4 floors. A frame of beams and columns or slabs is sufficient. 'Mushroomfloors' may be used.* Bij 2 t/m 4 bouwlagen zijn kernen niet nodig voor het stabiliteitssysteem. Men kan volstaan met een raamwerk van balken en kolommen of met schijven. Aanbevolen worden voor het vloersysteem paddestoelvloeren, maar balkenvloeren zijn ook goed mogelijk.

SBR 2B. *Buildings between 5 and 7 floors require at least slabs for stability. Structural cores are possible but less economical. 'Mushroomfloors' are recommended, but a beam-system suffices.* Bij 5 t/m 7 bouwlagen moeten op zijn minst schijven toegepast worden voor de stabiliteit. Kernen zijn ook mogelijk, maar ongunstig in kostenopzicht. Voor het vloersysteem heeft de paddestoelvloer een lichte voorkeur ten opzichte van de balkenvloer.

SBR 2C. *Buildings between 8 and 10 floors can use slabs and 'mushroomfloors' for stability. Generally, the structural core is recommended*[32] . Bij 8 t/m 10 bouwlagen kan met schijven volstaan worden (mits er een paddestoelvloer toegepast wordt). De kern als stabiliteitssysteem wordt in het algemeen aanbevolen.
SBR 1J. *An opening of 2,5 x 4,5 m^2 for a shaft can be realised in a 'mushroomfloor' of module 7,2 m without further strengthening of the concrete structure.* Een schachtsparing van 2,5 x 4,5 m^2 is bijna altijd in een paddestoelvloerkonstruktie met een stramienmaat van 7,2 m aan te brengen zonder de betonkonstruktie te verzwaren.
Time 10D. *Typical spans in steel.* Column spacing most frequently used in multistory steel-framed office buildings is around 7,6 m, center to center. Recent trend is toward larger spacing; 9,1 m to 10,7 m is not uncommon. Flexibility of interior space is so important in office building design that the extra cost of clear span framing with the elimination of all interior columns is sometimes considered worthwhile; clear spans of 18,3 m to 21,34 m have been used.
Entwurf 4. *The structural grid module depends on space dimensions, furnishing, and installations. It usually is between 1,40 and 1,80 m. The infill grid is often shifted to avoid conflicts of structural system and interior walls.* Sachbezogen [in die Entscheidung über dass Maß des Konstuktionsrasters] ist das Konstruktionsrastermaß ein Mehrfaches des gewählten Ausbaumoduls, dessen maß in Abhängigkeit von gewünschten Einzelraumgrößen, Möblierungen und haustechnischen Zubehör, wie Leuchtstofflampen und Klimakonvektoren marktgängiger Fabrikationsgrößen, in der Regel zwischen 1,40 und 1,80 m liegt. Die Lage des Ausbaumoduls wird übrigens dabei zur Vermeidung schwieriger Trennwandanschlüsse oftmals verschoben.

Subject: HVAC

Integration 6A. The major components of the HVAC (air-conditioning system) are the centrally located equipment - the chiller and the boiler, the cooling tower, and the air handlers - and the delivery equipment - the air duct and/or water pipe delivery system and the diffusers.
Integration 6B. *Group chiller, boiler, and air handlers together.* The chiller, boiler, and air handlers are large pieces of equipment that serve the whole building and are often grouped together into a mechanical room located for convenient distribution of HVAC services to the building.
Integration 6C. *Boiler and chiller can placed freely.* The boiler and chiller with their accompanying hot and chilled water pumps are often grouped together in a room. The outputs from this room are the hot and chilled water supply and return isolated pipes (0,15 - 0,25 m) in diameter including the insulation). Because these pipes take up very little room and can extend long distances, the room containing the chiller and boiler can be located fairly freely.
Integration 6D. *Add 2% of building floor area for space for boiler and chiller.* Two percent of the building floor area served by the boiler and chiller will provide a room

[32] The SBR-report has brought together a number of diagrams and rules of thumb with which one can determine measures of stability, dimensions of the structural system, combination with the

large enough for the chiller and boiler and their accompanying pumps. The room must be 3,7 m high with a minimum width of 9,1 to 12,2 m. It should be located away from critical noise areas.

Integration 6E. Boiler sizes vary but can be approximated as: •650.000 Btu/hr (1,5 x 2,4 x 1,5 m^3); •1.650.000 Btu/hr (1,8 x 3,1 x 1,8 m^3); •3.350.000 Btu/hr (1,8 x 4,6 x 1,8 m^3)

Integration 6F. Chiller sizes also vary: •50 tons (3,1 x 0,9 x 1,5 m^3); •100 tons (4,6 x 1,8 x 1,8 m^3); •500 tons (4,6 x 2,4 x 2,1 m^3); •1000 tons (8,2 x 2,4 x 3,7 m^3)

Integration 6G. Commercial buildings need approximately 1 ton of refrigeration for every 27,9 m^2 of floor area.

Integration 8A. *Add 4% of building floor for space for air handler.* A room large enough for the air handler will be provided by 4% of the building floor area served. The room should have a minimum ceiling height of 3,7 m (less if only one air handler is in the room), and a minimum width of 2,4 to 3,7 m depending on the equipment.

Integration 8B. *Position of air handlers.* Air handlers can be grouped together in one room or spread around the building in separate rooms. In a multistory building, they are often stacked above each other. They are best located near the center of the area they serve so that the main supply duct can be divided into two branches, thus reducing the diameter of the ducting.

Integration 8C. Air handler sizes vary but can be approximated as: •2000 cfm (1,5 x 4,6 x 1,2 m^3); •10000 cfm (2,4 x 6,1 x 1,5 m^3); •20000 cfm (3,7 x 7,6 x 2,1 m^3)

Integration 8D. Return fan sizes also vary: •2000 cfm (1,2 m^3); •10.000 cfm (1,5 m^3); •20.000 cfm (2,1 m^3).

Integration 8E. Commercial buildings require approximately 1 cubic foot per minute (cfm) of air flow into the space for every 0,1 m^2 of floor area.

Integration 9A. *Spacing between diffusers is approximately equal to ceiling height.* The diffusers are the interface between the HVAC system and the design of the interior of the building. From a thermal standpoint the diffusers should be located in a uniformly distributed pattern over the ceiling to spread the tempered air over the entire space. The spacing between diffusers should be approximately equal to the ceiling height.

SBR 3A. *The maximum distance between central HVAC and diffusers is 50 m*[33] . Maximale afstand centrale voorziening van de installaties tot verste in- en uitblaas-opening 50 m.

Data 1E. Fire sprinklers as per code, generally one or more to cover every 18,6 m^2.

HVAC system, etc. These rules are not described here in the knowledge base.

[33] The SBR-report (step *2* and *3* of Page *2*) gives tables for tentative determining of horizontal and vertical ducts (m^2 and number).

Level of infill

Subject: core

Neufert 7A. *The core may not be further than 25 m from the end of the wing, or 50 m from another core. It can be placed on the outside, in corners, at the end of wings, and along internal courts.* Größere Bürobauten sind Geschoßbauten mit veränderlichen Zwischenwände, die von den Decken getragen werden. Festpukte, wie Abortanlagen, Treppenhäuser, Fahrsthhle usw. sitzen entweder •in bauaufsichtlich vorgeschriebenen Abständen vor dem Bau, •einseitig im Bau, •in Innenecken, •am Ende einer Raumflucht oder •in mitten der Flure am Lichtschacht, so daß möglichts lange, zusammenhängende Arbeitsflächen verbleiben.

SBR 6. The SBR report shows a number of nomograms (Page 5) to determine dimensions of cores and slabs.

Time 1. See *subject: circulation* (p. 187) for places of core relative to floor.

Subject: elevator

SBR 4A. *Offices with variable work hours require less elevators than offices with fixed work hours.* Kantoren met variabele werktijden hebben minder liften nodig dan kantoren met vaste werktijden.

SBR 4B. The SBR report shows on Page 3 number, configuration, and surface areas of elevators relative to number of occupants, number of stops, and varying/fixed work hours.

Subject: stairs

Besluit 1F. *For an area larger than 500 m^2, stairs should be: •width > 1,1 m; •vertical free space on top > 2,1 m; •maximum height 4 m; •thread > 0,23 m at the line of ascent; •riser < 0,21 m; •line of ascent to side > 0,3 m; •connect at the top to a free surface area of at least 1,1 x 1,1 m^2.* De afmetingen van een trap (indien de trap is bestemd voor het ontsluiten van een woning met een gebruiksoppervlakte van meer dan 500 m^2) moeten ten minste voldoen aan: •minimum breedte van de trap 1,1 m; •minimum vrije hoogte boven de trap 2,1 m; •maximum hoogte van de trap 4 m; •minimum aantrede ter plaatse van de klimlijn gemeten loodrecht op de voorkant van de trede 0,21 m; •maximum afmeting van een optrede 0,21 m; •minimum breedte van het tredevlak, gemeten loodrecht op de voorkant van dat vlak 0,17 m; •minimum breedte van het tredevlak ter plaatse van de klimlijn gemeten loodrecht op de voorkant van dat vlak 0,23 m; •minimum afstand van de klimlijn tot de zijkanten van de trap 0,3 m; •De trap moet ter plaatse van de bovenste trede over de ten minste vereiste breedte aansluiten op een vrije vloeroppervlakte van ten minste 1,1 m x 1,1 m.

Besluit 1G. *0,57 < thread + 2 x riser < 0,70 m at the line of ascent.* De som van een aantrede en twee optreden, gemeten ter plaatse van de klimlijn mag ten hoogste 0,7 m, doch niet minder dan 0,57 m zijn.

Neufert 7D. *The length of going from any place to a point of egress may not be longer than 30 m. Therefore, cores are at 25 m maximum distance from the end of the wing* *and 50 m from each other.* Nach der Bauordnung muß von jedem Punkt eines Aufenthaltsraumes eine Treppe auf ±30 m Entfernung erreichbar sein. Man rechnet daher zweckmaßig den Abstand der Treppenhäuser von der Geländegrenze mit 25 und untereinander mit 50 m.

Neufert 15A. *In high-rise buildings there must be at least two points of egress.* Hochhäuser sollen in Brandabschnitte von L=30m durch feuerbeständige Wände unterteilt werden. Von jedem Raum jedes Geschoß müssen Fluchtwege über mindestens zwei voneiander unabhängige Treppenhäuser vorh. sein. Die eine Treppe muß als notwendige Treppe im Sinne der Bauverordnung, die andere kann, wenn es sich niet um eine notwendige Treppe handelt, bei Hochhäuser bis 12 Geschoß als Nottreppe ausgebildet sein.

Neufert 15B. *At least one of two stairs must be at the outside wall and have openable windows at each floor.* Von je 2 Treppenhäuser muß mindestens 1 an einer Außenwand liegen und in jeder Geschoß Fenster ins Freie haben, die geöffnet werden können.

Neufert 15C. *Width of required stairs and elevations depends on the use of the building. It should not be less than 1,25 m. Emergency stairs are at least 0,80 m wide, with maximum 20/20 cm rise in the line of ascent.* Laufbreite notwendige Treppen und ihrer Podeste richtet sich nach Ausnutzungsart des Hochhauses, muß aber mindestens 1,25 m betragen. Nottreppen müssen eine Laufbreite von mindestens 0,80 m, max. Steigungsverhältnis von 20/20 cm in der Lauflinie haben.

Offices 4. Buildings with floors more than 18.3 m above ground level require at least one fire-fighting stair which must have direct access to open air at ground level, have openable windows at each landing level, have permanent ventilation at the top of the enclosure of 5 per cent of enclosed area minimum, have a protected and ventilated lobby at each floor and be continuous throughout the building.

SBR 5. *The SBR report provides for a number of floors en thread-riser proportion the projected horizontal length for a number of stair-configurations.*

Entwurf 7. *In buildings up to twelve floors and intensive transport between floors, escalators have been proven efficient.* So haben sich in Gebäuden mit Großflächigen Grundrissen und bedeutetem Verkehr zwischen den einzelnen Geschossen Fahrtreppen bis zu einer Höhe von zwölf Geschossen als außerordentlich leistungsfähig erwiesen.

Subject: workplace

Neufert 2. *Because of terminal work and additional equipment, typical surface area for workplace increases with 2-3 m^2 to 15-18 m^2.* Durch Bildschirmarbeitsplätze und damit Computerterminals und Zusatzgeräte, steigt der Flächenbedarf für den Büroarbeitsplatz zunächts additiv um ca. 2-3 m^2 auf ca. 15-18 m^2 an.

Neufert 9B. *Required surface area including equipment: ◦secretary ≥ 10 m^2; ◦clerk 6-9 m^2; ◦clerk in landscape office 5 m^2; ◦general space in landscape office 3,8-4,8 m^2; ◦conference room per person 2,50 m^2; ◦department manager without visitors from outside 15,00-25,00 m^2.* Raumbedarf einschließlich Bürohilfsmittel und deren Bedienungsflächen: ◦Sekretärin ≥ 10,00 m^2; ◦Selbstständiger Sachbearbeiter 6,00-9,00 m^2; ◦Selbstständiger Sachbearbeiter im Mehrplatzraum 5,00 m^2; ◦Selbiger im

Arbeitssaal 3,80-4,80 m^2; •Konferenzzimmer je Person 2,50 m^2; •Abteilungsleiter ohne Besuchverkehr von Außen 15,00-25,00 m^2

Neufert 11. See *subject: circulation* (p. 186) for data on furniture arrangements.

Data 1A. Office building, open plan: recommended standards of occupancies. The nominal range of open plan office sizes varies from ± 279 m^2 to ± 2787 m^2; •18,6-32,5 m^2 for top executives; •12,1 m^2 average floor space per employee; •9,3-23,2 m^2 for middle managers & junior executives; •8,4-11,1 m^2 for supervisors; •9,3-13,9 m^2 for secretaries; •7,4-9,3 m^2 for clerical workers.

Data 2A. Managerial offices. Recommended standards for occupancies: •27,9 m^2 and up for top executives; •9,3-27,9 m^2 for middle managers & junior executives; •8,4-11,1 m^2 for supervisors; •9,3-13,9 m^2 for executive secretaries; •7,4-9,3 m^2 for clerical workers.

Time 2A. General rules in positioning desks: •Desks should face the same direction, •In open areas, desks in rows of two, •Desks 1,8 m from the front of a desk to the desk behind it, or 2,1 m when more than one desk in a row, or confined on one side, •In private offices, position the desk in a way that the occupant can view the door, •In open areas, locate supervisor adjacent to receptionist or secretary. Access to supervisory area not through work area, •Desks of employees having considerable visitor contact should be located near the office entrance. •Conversely, desks of employees doing classified work should be away from entrances.

Time 5A. Sizes of private offices: It is desirable that private offices be a minimum of 9,3 m^2 and a maximum of 27,9 m^2 each in size, depending upon the requirements of the occupant. Only in cases where it is necessary for the occupant to meet with delegations of 10 or more people at least once a day should the size approach 27,9 m^2. For the average government function, the private office should not exceed 18,6 m^2.

Time 8. In the general office area, allotment of 9,3 m^2 per clerical worker is generally considered a liberal standard; 6,05 m^2 is an economical standard. 7,44 m^2 would be a reasonable average.

Time 9B. See also *subject: spaces* (p. 185) for indication of surface areas.

Subject: module

Neufert 10A. •*Module 1,20 m: gives room of 3,50 m which is too small for standard workplace for two people.* •*Module 1,30 m: gives room of 3,80 m which can accommodate two workplaces.* • *Module 1,40 m: gives room of 4,10 m which has the best possibilities for furnishing.* •Achsmaß 1,20 m: Die Standardgröße von 18 m^2 (3x1,20 m abzügl. 0,10 m Trennwand) entrsprechend 3,50 m Raumbreite ist mit Standardmöblierung für 2 Mitarbeiter, bei DIN-gerechter Auslegung (2x1,00 m Abstandsfläche und 2x0,80 m Schreibtischtiefe=3,60 m) zu schmall. Tiefere Bildschirmarbeitsplätze und Sonderausstattungen setzen den nächtsgrößeren Raum (4,70) voraus. Zusätzliche Nutzfläche kann nicht ausgeschöpft werden. •Achsmaß 1,30 m: Raumbreite von 3,80 entspr. 18 m^2 Nutzfläche ermöglichen:—zusätzliche Registraturmöbel;—2 Bildschirmarbeitsplätze mit berufsgenossenschaftl. empfohlener Tiefe von 0,90 m;—1 Zeichentisch bzw Zeichenmaschine u. 1 Schreibtisch;—1

Schreibtisch und Besprechungstisch für 4 Personen. Alle übliche Büroarbeitsplatz möglich, hohe Nutzungsflexibilität ohne Umsetzen von Wänden. ●Achsmaß 1,40 m: Raumbreite 4,10 mit sehr günstigen Möblierungsmöglichkeiten und hoher Nutzungsflexibilität. Raumtiefe von 4,40 m bei 18 m^2-Raum ausreichend, sofern nicht durch Sondernutzungen o. höheren Raumanspruch größere Raumtiefe erwünscht ist. Bei 4,75 m Raumtiefe erwünscht ist. Bei 4,75 m Raumtiefe, Erhöhung der Nutzläche des 3-achsigen Standardraums auf 19,5 m^2.

Neufert 10B. *Facade modules of 1,25m and 1,875 m are common.* ●Achsmaß 1,25m. Kleinster Fenster- oder Fensterpfeiler-Achsenabstand, den Regelmaßen entsprechend, der dem vielfältigsten Bürohausplatzbedarf entspricht. Die so gegebenen Zwischenwandabstände von 2,5; 3,75; 5,0 m usw. ●1,875 m = 1 ½ Uba das größere Achsenabstandsmaß für Bürohausbauten. Kann ebenfalls um viele Beispiele zweckmäßiger Möbelstellung vermehrt werden. Für diesen Achsenabstand paßt ebenfalls die Balkenentfernung nach Regelmaßen von 625 mm oder 1,25 m, von denen jeder dritte Balken mit einer Frontstütze zusammentrifft.

Integration 11B. *Distance between light fixtures = (S/MH) x mounting height.* The spacing to mounting height ratio (S/MH) is used to calculate the appropriate space between light fixtures. For fluorescent fixtures the ratio is about 1,5; for medium-beam downlights, about 0,8; and for narrow-beam downlights, about 0,5. The mounting height is the height from the working plane (0,76 m) above the floor to the level of the light fixtures. (The light fixtures are often on the ceiling but they can be mounted below the ceiling on pendants.) Proper spacing is then calculated as: Spacing = (S/MH) x (Mounting Height)

Offices 1. Final selection of modules for integration of structural, service, and constructional grids should be assessed against detailed knowledge of usage to ensure, for example, that the service grid suits possible furniture layouts and maintenance requirements.

Data 1C. Common modules are: ●1,52 x 1,52 m^2 module (cubicle dimensions of 3,05 x 3,05 m^2, 3,05 x 4,57 m^2, 3,05 x 6,10 m^2, 4,57 x 4,5 m^2, 4,57 x 6,10 m^2, 4,57 x 7,6 m^2 etc. ●Other common modules are 0,76 m, 1,22 m and 1,83 m. ●Modules and dimensions may be determined by partition systems, ceiling system, electrical power grid - preferably an integration of all

Time 10A. *Module of 1,52 x 1,83 m2 can apply for office areas.* Office layout is often based upon a module derived from standard furniture and equipment and the necessary clearances. For large general offices, the planning unit or module is based upon one desk and chair and is thus about 1,52 m by 1,83 m. Since this dimension is also satisfactory for aisles between rows of desks the module can be used to form a regular grid for the planning of large office areas.

Time 10B. *Module of 1,22 m - 1,52 m can apply for private offices.* In the layout of private offices the controlling factors are the minimum practical office layout with the wall and window design. A planning module of 1,22 m to 1,52 m works reasonably well for this purpose. With this module the smallest office (2 modules) would be 1,24 m to 3,04 m wide, and a convenient range of office sizes is provided in increments of one module. If the exterior wall consists of continuous windows, one module in width, then the office widths are limited to even modules. If windows alternate with solid walls, then office widths do not have to be in even modules but may vary widely. This type of wall design permits greater flexibility in office layout at the expense of less natural light in the offices.

Time 10C. *Co-ordinate planning module (office space), facade module, and structural module.* The planning module and the exterior wall module must be reconciled with the structural module or column bay. If all these modules coincide, then the wall or window units adjacent to the column must be smaller than the intermediate units. If the wall units are kept uniform in size, then the planning module is interrupted by the column width. If the columns are set inside the walls, they do not interfere with the wall module but they create a serious limitation on the layout of private offices. If the columns are set outside the walls, then the planning module and the wall module are not affecting them.

Entwurf 4. See *subject: structural system* (p. 188) for modules in office buildings.

Subject: furniture

Data 3B. *In Architect's room design data handbook (1988), a number of graphics show dimensions and configurations of furniture.*

Time 9C. *In Time saver standards for building types (1980), a number of graphics show dimensions and configurations of several types of furniture.*

Subject: toilets

Integration 15. •Minimum number of toilets for men: 1 toilet (-15 persons), 2 (-35), 3 (-65), 4 (-100); •minimum number of urinals: 0 (-6), 1 (-20), 2 (-45), 3 (-70), 4 (-100); •minimum number of washbasins: 1 (-5), 2 (-30), 3 (-50), 4 (-75), 5 (-100). •Minimum number of toilets for women: 1 (-12p), 2 (-25), 3 (-40), 4 (-57), 5 (-77), 6 (-100); •minimum number of washbasins: 1 (-12p), 2 (-25), 3 (-40), 4 (-57), 5 (-77), 6 (-100).

LITERATURE

Achten, H.H. (1996a). Generic Representations: Intermediate Structures in Computer Aided Architectural Composition. Asanowicz, A. and Jakimowicz, A. (eds.) 1996. *Approaches to Computer Aided Architectural Composition*, Technical University of Bialystok, Bialystok

Achten, H.H. (1997). Generic Representations - Typical Design Without the Use of Types (1997). Proceedings CAAD Futures 1997, 3-7 August, München

Achten, H.H. and Bax, M.F.Th. and Oxman, R.M. (1996). Generic Representations and the Generic Grid: Knowledge Interface, Organisation and Support of the (Early) Design Process. Timmermans, H. (ed.), 1996. *Proceedings of the 3rd Design & Decision Support Systems in Architecture & Urban Planning Conference*, Spa, Belgium

Achten, H.H. and Dijkstra, J. and Oxman, R. and Bax, M.F.Th. (1995a). Knowledge-Based Systems Programming for Knowledge Intensive Teaching. Colajanni, B. and Pellitteri, G. (eds.) 1995. *Multimedia and Architectural Disciplines - Selected Proceedings of the 13th European Conference on Multimedia and Architectural Disciplines*, Palermo

Achten, H.H. and Dijkstra, J. and Oxman, R. and Bax, M.F.Th. (1995b). *Knowledge-Based Systems Programming for Knowledge Intensive Teaching*. BIT-Note Publication 1995/3. Department of Architecture, Eindhoven University of Technology

Akin, Ö. (1986). *Psychology of Architectural Design*. Pion Limited, London.

Alberti, L.B. (1988). *On the Art of Building in Ten Books (De re aedificatoria)*. Translated by J. Rykwert, N. Leach, R. Tavernor. The MIT Press, Cambridge, Massachusetts

Argan, G.C. (1963). On The Typology Of Architecture. Papadakis, A. and Watson, H. (eds.) 1990. *New Classicism - Omnibus Volume*, SDU Publishers, The Hague

Bailey, S. (1990). *Offices - A Briefing and Design Guide*. Butterworth Architecture, London

Bax, M.F.Th. (1976). *Meten Met Twee Maten - Ontwikkeling van een maatstelsel als kader voor een besluitvormingsproces op het gebied van ruimtelijk ordenen*. Proefschrift. Technische Hogeschool Eindhoven, Eindhoven

Bax, M.F.Th. (1979). Domain Theory, the Scope and Structure of Building Science. *Open House International* vol. 3, no. 2, p. 30-43

Bax, M.F.Th. (1985). The Design of a Generic Grid. Beheshti, R.M. (ed.), 1985. *Proceedings of International Design Participation Conference*, Design Coalition Team, Vol. 2, Eindhoven

Bax, M.F.Th. (1989). Structuring Architectural Design Processes. *Open House International* vol. 14, no. 3, p. 20-27

Bax, M.F.Th. (1992). Het Ordonnantie-concept - Het Concept van Schaal en Ritme van het Bouwwerk; Generic Grid als Notatiewijze. Bax, M.F.Th. and Trum, H.M.G.J. (eds.), 1992. *Concepten van de Bouwkunde*, Faculteit Bouwkunde, Technische Universiteit Eindhoven

Bax, M.F.Th. and Trum, H.M.G.J. (1995). Voorwaarden voor Concurrent Engineering. *Symposium over Concurrent Engineering*, Enschede, Netherlands

Boekholt, J.T. & Thijsen, A.P. & Dinjens, P.J.M. & Habraken, N.J. (1974). *Denken in Varianten - Het Methodisch Ontwerpen van Dragers*. Samson Uitgeverij Alphen aan den Rijn, Brussel

Boekholt, J.T. (1984). Bouwkundig Ontwerpen - Een Beschrijving van de Structuur van Bouwkundige Ontwerpprocessen. Proefschrift. Technische Hogeschool Eindhoven, Eindhoven

Bovill, C. (1991). *Architectural Design - Integration of Structural and Environmental Systems*. Van Nostrand Reinhold, New York.

Bucher, F. (1979). *Architector. The Lodge Books and Sketchbooks of Medieval Architects*. Abaris Books, New York.

Buildings Update (1981). Offices part 2. *Architect's Journal*, 18 nov. 1981, p. 997-1010

Carp, J. and van Rooij, T., 1974. De ontwikkeling van een taal; het gebruik van een taal. *Plan* 12, 1974, p. 25-55

Chiara, J. De and Callender, J.H. (eds.) (1980), *Time Saver Standards for Building Types*. MacGraw-Hill (2nd edit.)

Ching, F.D.K. (1979). *Architecture: Form, Space and Order*. Van Nostrand Reinhold, New York

Churchland, P.M. (1993). *Matter and Consciousness - Revised Edition*. The MIT-Press, Cambridge, Massachusetts

Clark, R.H. and Pause, M. (1985). *Precedents in Architecture*. Van Nostrand Reinhold, New York

Colquhoun, A. (1988). Postmodernism and Structuralism: A Retrospective Glance. *Modernity and the Classical Tradition: Architectural Essays 1980-1987*. The MIT Press, Cambridge, Massachusetts, 1989, p. 243-255

Colquhoun, A. (1976). Alvar Aalto: Type versus Function. *Essays in Architectural Criticism: Modern Architecture and Historical Change*. The MIT Press, Cambridge, Massachusetts, 1981, p. 75-81

Colquhoun, A. (1967). Typology and Design Method. *Essays in Architectural Criticism: Modern Architecture and Historical Change*. The MIT Press, Cambridge, Massachusetts, 1981, p. 43-50

Colquhoun, A. (1981). *Essays in Architectural Criticism: Modern Architecture and Historical Change*. The MIT Press, Cambridge, Massachusetts

Coomans, M. and Oxman, R.M. (1996). Prototyping of Designs in Virtual Reality. Timmermans, H. (ed.), 1996. *Proceedings of the 3rd Design & Decision Support Systems in Architecture & Urban Planning Conference*, Spa, Belgium

Coyne, R.D. and Rosenman, M.A. and Radford, A.D. and Balachandran, M. and Gero, J.S. (1990). *Knowledge-Based Design Systems.* Addison-Wesley Publishing Company, Reading, Massachusetts

Cross, N. (ed.) (1984). *Developments in Design Methodology.* John Wiley & Son Ltd., Chichester

Dennett, D.C. (1995). *Darwin's Dangerous Idea.* Allen Lane/Penguin Press, London

Dijkstra, J. and Timmermans, H. (1996). Conjoint Measurement in Virtual Environments. Timmermans, H. (ed.), 1996. *Proceedings of the 3rd Design & Decision Support Systems in Architecture & Urban Planning Conference*, Spa, Belgium

Duffy, F. and Cave, C., and Williams, B., and Worthington, J. (1981). Buildings Update - Offices Part I. *Architect's Journal*, 11 November 1981, p. 951-964

Durand, J.-N.-L. (1804). *Préçis des Leçons d'Architecture.* Paris

Eckardt, B. von (1993). *What is Cognitive Science?* The MIT Press, Cambridge, Massachusetts

Ervin, S.M. (1990). Designing with Diagrams: A Role for Computing in Design Education and Exploration. McCullough, M. and Mitchell, W.J. and Purcell, P. (eds.) 1990. *The Electronic Design Studio - Architectural Knowledge and Media in the Computer Era.* The MIT Press, Cambridge, Massachusetts

Flanagan, O.J. (1984). *The Science of the Mind.* The MIT-Press, Cambridge, Massachusetts

Gero, J.S. (1990). Design Prototypes: A Knowledge Representation Schema for Design. *AI Magazine*, Winter 1990, p. 26-36.

Rosenman, M.A. and Gero, J.S. (1993). Creativity in Design Using a Design Prototype Approach. Gero, J.S. and Maher, M.L. (eds.), 1993. *Modeling Creativity and Knowledge-Based Creative Design.* Lawrence Erlbaum Associates, Hillsdale, p. 111-138

Gross, M.D. (1990). Relational Modeling: A Basis for Computer-Assisted Design. McCullough, M. and Mitchell, W.J. and Purcell, P. (eds.) 1990. *The Electronic Design Studio - Architectural Knowledge and Media in the Computer Era.* The MIT Press, Cambridge, Massachusetts

Gross, M.D. and Ervin, S.M. and Anderson, J.A. and Fleisher, A. (1988). Constraints: Knowledge Representation in Design. *Design Studies*, vol. 9, no. 3, july 1988, p. 133-143

Habraken, N.J. (1985). *The Appearance of the Form.* Awater Press, Cambridge, Massachusetts

Hamel, R. (1990). *Over het Denken van de Architect - Een Cognitief Psychologische Beschrijving van het Ontwerpproces bij Architecten.* AHA Books, Amsterdam

Heath, T. (1984). *Method in Architecture.* John Wiley & Sons Ltd., Chichester

Herdeg, K. (1967). *Formal Structure in Indian Architecture.* Reprint 1990. Rizzoli, New York

Herdeg, K. (1990). *Formal Structure in Islamic Architecture of Iran and Turkistan.* Rizzoli, New York

Hoke, J.R. (ed.) (1988). *Architects Room Design Data Handbook.* John Wiley & Son Ltd., Chichester

Joedicke, J. (1975). *Büro und Verwaltungsbauten.* Krämer, Stuttgart

Koutamanis, A. (1990). *Development of a Computerized Handbook of Architectural Plans.* Proefschrift. Technische Universiteit Delft, Delft

Kruft, H.-W. (1994). *A History of Architectural Theory - From Vitruvius to the Present.* Zwemmer, an imprint of Philip Wilson Publishers Ltd., London and Princeton Architectural Press, New York

Lakoff, G. (1987). *Women, Fire, and Dangerous Things - What Categories Reveal about the Mind.* The University of Chicago Press, Chicago

Lavin, S. (1992). *Quatremère de Quincy and the Invention of a Modern Language of Architecture.* The MIT Press, Cambridge, Massachusetts

Lawson, B. (1980). *How Designers Think.* The Architectural Press Ltd, London

Leeuwen, J.P. van and Wagter, H. and Oxman, R.M. (1996). Information Modelling for Design Support - A Feature-Based Approach. Timmermans, H. (ed.), 1996. *Proceedings of the 3rd Design and Decision Support Systems in Architecture and Urban Planning Conference*, August 18-21, Spa, Belgium

Leusen, M. van (1994). *A System of Types in the Domain of Residential Buildings.* Proefschrift. Technische Universiteit Delft, Delft

March, L. (ed.) (1976). *The Architecture of Form.* Cambridge University Press, Cambridge

March, L. and Steadman, P. (1971). *The Geometry of Environment.* RIBA.

McCullough, M. and Mitchell, W.J. and Purcell, P. (eds.) 1990. *The Electronic Design Studio - Architectural Knowledge and Media in the Computer Era.* The MIT Press, Cambridge, Massachusetts

Milizia, F. (1847). *Principi di Architecttura Civile.* Facsimile 1973 of 1847 facsimile, Majocchi, Milano by Johnson Reprint Corporation.

Minsky, M. (1986). *The Society of Mind.* Simon & Schuster, New York

Mitchell, W.J. (1990). *The Logic of Architecture - Design, Computation, and Cognition.* The MIT Press, Cambridge, Massachusetts

Mitchell, W.J. and McCullough, M. (1991). *Digital Design Media.* Van Nostrand Reinhold, New York.

Nagakura, T. (1990). Shape Recognition and Transformation: A Script-Based Approach. McCullough, M. and Mitchell, W.J. and Purcell, P. (eds.) 1990. *The Electronic Design Studio - Architectural Knowledge and Media in the Computer Era*. The MIT Press, Cambridge, Massachusetts

Neufert, E. (1992). *Neufert Bauentwurfslehre.* Vieweg, Braunschweig

National Building Agency (1965). *Generic Plans*

Oxman, R. (1990). Architectural Knowledge Structures as "Design Shells": A Knowledge-Based View of Design and CAAD Education. McCullough, M. and Mitchell, W.J. and Purcell, P. (eds.) 1990. *The Electronic Design Studio - Architectural Knowledge and Media in the Computer Era*. The MIT Press, Cambridge, Massachusetts

Oxman, R.M. and Oxman, R. (1990). The Computability of Architectural Knowledge. McCullough, M. and Mitchell, W.J. and Purcell, P. (eds.) 1990. *The Electronic Design Studio - Architectural Knowledge and Media in the Computer Era.* The MIT Press, Cambridge, Massachusetts

Oxman, R.E. and Oxman, R.M. (1992). Refinement and Adaptation in Design Cognition. *Design Studies*, vol. 13, no. 2, april 1992

Oxman, R.M. and Oxman, R.E. (1994). *Cognitive Models in Design Case Libraries.*

Oxman, R.M. (1994). *The Reflective Eye: Visual Reasoning in Design.*

Oxman, R.M. and Bax, M.F.Th. and Achten, H.H. (1995). Design Research in the Netherlands. (Bouwstenen 37) Faculteit Bouwkunde, Technische Universiteit Eindhoven

Palladio, A. (1738). *The Four Books of Architecture.* Facsimile 1965, Dover, New York

Perez-Gomez (1983). *Architecture and the Crisis of Modern Science.* The MIT Press, Cambridge, Massachusetts

Peters, Paulhans (1973). *Entwurf und Planung - Verwaltungsbauten.* Callwey

Pevsner, N. (1979). *A History of Building Types.* Thames and Hudson, London

Polyzoides, S. and Sherwood, R. and Tice, J. and Shulman, J. (1982). *Courtyard Housing in Los Angeles - A Typological Analysis.* University of California Press, London

Powell, J.A. (1987). Is Architectural Design a Trivial Pursuit? *Design Studies,* Vol 8, No 4, October 1987, p. 187-206

Prins, M. (1992). *Flexibiliteit en Kosten in het Ontwerpproces: een Besluitvormings Ondersteunend Model*, Ph.D. Thesis, Department of Architecture, Building, and Planning, Eindhoven University of Technology, Eindhoven

Process Architecture nr. 60. (1985). *Office Style Book - A Presentation by the Institute of Office Environment*

Quincy, Q. de (1825). Type. Translated by Anthony Vidler. *Oppositions 8*, 1977, p. 147-150

Rogers, R.E. (1969) *Max Weber's Ideal Type Theory*. Philosophical Library, New York

Ronner, H. and Jhaveri, S. and Vasella, A. (1977). *Louis Kahn - Complete work 1935-74*. Birkhäuser Verlag, Basel und Stuttgart

Rossi, A. (1982). *The Architecture of the City*. The MIT Press, Cambridge, Massachusetts

Rowe, P.G. (1987). *Design Thinking*. The MIT Press, Cambridge, Massachusetts, London, England

Russell, B. (1961). *History of Western Philosophy*. George Allen & Unwin Ltd., London

Schmertz, M.F., 1980. A New Museum by Walter Netsch of SOM Given Order by his Field Theory. *Architectural Record*, January 1980

Schön, D.A. (1988). Designing: Rules, Types and Worlds. *Design Studies*, Vol 9 No 3, July 1988, p. 181-190

Serlio, S. (1611). *The Five Books of Architecture*. Reprint 1982 Dover, New York

Sherwood, R. (1979). *Modern Housing Prototypes*. Harvard University Press, London

Simon, H.A. (1973). The Structure of Ill-Structured Problems. Cross, N. (ed.). *Developments in Design Methodology*. John Wiley & Son Ltd., Chichester

Simon, H.A. (1996). *The Sciences of the artificial*. The MIT Press, Cambridge, Massachusetts

Smeltzer, G. and Mantelers, J. and Roelen, W. (1994). *The Application of Virtual Reality Systems in Architectural Design Processes*. BIT Note 1994/3. Faculty of Architecture, Building and Planning. Eindhoven University of Technology.

Sowa, J.F. (1984). *Conceptual Structures: Information Processing in Mind and Machine*. Addison-Wesley Publishing Company, Inc., Reading, Massachusetts

Staal, G. (1987). *Bouwheer en Meester - De Architectuur van Kantoorgebouwen*. Uitgeverij 010, Rotterdam

Steadman, J.P. (1983). *Architectural Morphology - An Introduction to the Geometry of Buildings*. Pion Limited, London

Stichting Bouwresearch (1985). *Schachten als Kern voor Hoge Gebouwen? - Vuistregels voor de onderlinge Afstemming van Bouwtechniek en Installatietechniek in de Fase van het Voorlopig Ontwerp van Kantoorachtige Gebouwen*. Publicatie 120.

Stiny, G. (1990). What Designers do That Computers Should. McCullough, M. and Mitchell, W.J. and Purcell, P. (eds.) 1990. *The Electronic Design Studio - Architectural Knowledge and Media in the Computer Era*. The MIT Press, Cambridge, Massachusetts

Stitt, F.A. 1992. *Architect's Room Design Data Handbook*. Van Nostrand Reinhold, New York

Trum, H.M.G.J. (1979). Over het Normbegrip in de Bouwkunde. Proefschrift. Technische Hogeschool Eindhoven, Eindhoven

Tzonis, A. and Lefaivre, L., (1986). *Classical Architecture. The Poetics of Order*. MIT Press, Cambridge, Massachusetts

Tzonis, A. and Lefaivre, L. (1990). *De Oorsprong van de Moderne Architectuur*. Uitgeverij SUN, Nijmegen

Verstijnen, I.M. (1997). *Sketches of Creative Discovery - A Psychological Inquiry into the Role of Imagery and Sketching in Creative Discovery*. Proefschrift. Technische Universiteit Delft, Delft

Vidler, A. (1987). From the Hut to the Temple - Quatremère de Quincy and the Idea of Type. *The Writing of the Walls*. Princeton Architectural Press, Princeton. 1987

Vidler, A. (1977a). The Idea of Type: The Transformation of the Academic Ideal, 1750-1830. *Oppositions* 8, 1977, p. 93-115

Vidler, A. (1977b). The Production of Types. *Oppositions* 8, 1977, p. 93-115

Vries, B. de and Leeuwen, J.P. van and Achten, H. (1997). Design Studio of the Future. *Proceedings CIB W78*, 9-11 july 1997, Cairns.

Vidler, A. (1990). *Claude-Nicholas Ledoux - Architecture and Social Reform at the End of the Ancien Régime*, MIT Press, London

Vitruvius, (33-14 BC). *The Ten Books of Architecture*. Translated by Morgan (1960). Dover Publications Inc., New York

Westfall, C.W. and Pelt, R.J. van (1991). *Architectural Principles in the Age of Historicism*. Yale University Press, New Haven/London

Wigginton, M. (1973). Offices. *Architectural Design*, no. 8, 1973, p. 512-519

Wittkower, R. (1973). *Architectural Principles in the Age of Humanism*. Academy Editions, London

Yoon, K.B. (1992). *A Constraint Model of Space Planning*. Brebbia, C.A. and Connor, J.J. (eds), Topics in Engineering vol 9, Computational Mechanics Publications, Southampton UK and Boston USA

Zevi, B. (1974). *Architecture as Space - How to Look at Architecture*, revised edition. Da Capo Press, New York

GLOSSARY

Additional graphic unit
A relation between two *generic representations* in a design process. A *generic representation* has an additional graphic unit is it has the same *graphic units* as the other *generic representation* plus one different *graphic unit.*

Architectural theory
Architectural theory comprises any written system of architecture, whether comprehensive or partial, that is based on aesthetic categories (after Kruft 1994).

Building type
A building type is a form of generalised knowledge of a group of buildings that have distinct common properties. Building types often are defined on a functional basis (for example hospitals, houses, office buildings, etc.). Another influential basis for defining building types in architectural design is form (courtyard, slab, block, etc.).
In the research work, the building type is defined as the whole of generic representations required for making instances that belong to the type. The sequence of generic representations determines the *procedural knowledge* of the building type, and the generic representations determine the *declarative knowledge* of the building type.

Cognitive psychology
The psychological study of human thought. Cognitive psychology constitutes a specific approach in psychology. It aims to understand human psychology through making models of human thinking. These models have to meet three criteria: their outcomes should resemble human activity; the 'mechanisms' used should be similar to human 'mechanisms'; and the means must not exceed human capabilities (after Churchland 1993).

Convention of depiction
A particular way, generally agreed upon in the architectural design community, to graphically represent the state of a building (part). Examples are: section, isometric, axonometric, perspective, plan, etc.

Convention of encoding
A particular way, generally agreed upon in the architectural design community, to graphically indicate properties of represented building (parts). Examples are: hatching, line weight, symbols, icons, etc.

Declarative knowledge

The class of knowledge that contains facts and principles in a discipline, *e.g.* construction techniques, structure, ergonomics, installations, dimensioning, materials, cost calculation, history, norms, etc. (after Hamel 1990).

In the research work, declarative knowledge is the knowledge encoded in *generic representations* by means of *graphic units*. The *graphic unit* determines which *design decisions* are taken in the *generic representation*. *Declarative knowledge* is required for taking the *design decision*.

Design cognition

The psychological study of the designer at work. Design cognition aims to investigate the mental processes of the designer that take place when designing. It draws from the *research framework* of *cognitive psychology*.

Design decision

A design decision is an action taken by the designer or other *design participants* which establishes a different state of affairs of the *design object* from the previous state of affairs. A design decision usually makes a choice among many possible different states of affairs.

Design discipline

The (professional) daily practice, reference to, and application of theory where a specific kind of design takes place. Design disciplines are usually identified through their names which indicate the specific area: *e.g.* architectural design, graphic design, industrial design, mechanical design, and aircraft design.

Design methodology

The study of the principles, practises and procedures of design in a rather broad and general sense. Its central concern is how designing both is and might be conducted. This concern therefore includes the study of how designers work and think; the establishment of appropriate structures for the *design process*; the development and application of new design methods, techniques, and procedures; and reflection on the nature and extent of design knowledge and its application to design problems (after Cross 1984).

Design object

The complete representation (both *external* and *internal*) of the design in the *design process*. The design object constitutes everything the designer(s) knows about the solution to the design problem at hand.

Design participant

Any person who is authorised in a particular project to contribute to the *design task* in the *design process*.

Design process

The activity through time in which *design decisions* are taken in order to produce a design solution to a design task.

Design theory
The theory that aims to investigate, model, and explain the activity of design in general. Design theory brings together two major areas of inquiry: *design cognition* which investigates the psychological processes of the designer, and *design methodology* which investigates the activity of the designer in one or more design disciplines.

Design thinking
The study of general cognitive aspects in design. Design thinking is a less restricted term than *design cognition* or *cognitive psychology* as it might also include computational models and general inquiry into architectural thought, whereas *design cognition* strictly adheres to psychological studies.

External representation
A physical expression of an object with respect to a person (after Eckardt 1993). An external representation is not a mental — *internal* — representation, since the physical expression can be shared by others.

Generic representation
A schematic graphic representation denoting a particular state of the *design object*. A generic representation consists of *graphic units* through which knowledge of the design object is encoded. A single generic representation encodes *declarative knowledge* and by means of transitions to other generic representations it encodes *procedural knowledge*.

Graphic entity
A primitive used in graphic representations. Graphic entities are points, lines, and letters.

Graphic unit
A specified set of *graphic entities* that has a general accepted meaning within the design community. Examples are: black circles denoting columns, closed polygonal shapes with letters denoting functional zones, and line-drawings denoting furniture.

Instantiation
The process of defining an instance of a *building type*. An instance is specific whereas a *building type* is general.

Internal representation
A mental expression of an object with respect to a person (after Eckardt 1993). Internal representations constitute in what way a person conceives and reasons about the world.

Level of scale
A concept of proportion that groups objects according to magnitude. In the theory of generic grids, a level of scale is associated with one grid in the system of grids. To that level of scale specific *design participants* and elements may be assigned. Levels distinguished in the research are: urban tissue, building, support, and infill level.

Procedural knowledge

The class of knowledge that contains information about actions and how to proceed in a discipline, *e.g.* kinds of design goals, information sources, aspects of assignments, means to comply to norms and their limitations, structure of subproblems, etc. (after Hamel 1990).

In the research work, procedural knowledge is the knowledge encoded in the state transitions of generic representations defined by the relations of *additional graphic units*, *successive graphic units*, and *successive themes of generic representations*.

Schemata

A psychological concept of knowledge-structure. A schemata is a complex structure in memory that holds information. A schemata represents a concept, which is specified through attributes. These can be general or specific. Schemata are organised hierarchically. Schemata can hold both *declarative* and *procedural knowledge* (after Hamel 1990).

Successive graphic unit

A relation between two *graphic units* in the *design process*. A successive *graphic unit* is a *graphic unit* that is more specific than a preceding *graphic unit*.

Successive themes of generic representations

Themes of generic representations group generic representations that deal with the same issues. Successive themes is the principle that in a *design process* all themes have to be dealt with once before all relevant generic representations have been dealt with.

SUMMARY

Generic Representations: An Approach for Modelling Procedural and Declarative knowledge of Building Types in Architectural Design

Summary

The building type is a knowledge structure that is recognised as an important element in the architectural design process. For an architect, the type provides information about norms, layout, appearance, etc. of the kind of building that is being designed. Questions that seem unresolved about (computational) approaches to building types are the relationship between the many kinds of instances that are generally recognised as belonging to a particular building type, the way a type can deal with varying briefs (or with mixed use), and how a type can accommodate different sites. Approaches that aim to model building types as data structures of interrelated variables (so-called 'prototypes') face problems clarifying these questions. The research work at hand proposes to investigate the role of knowledge associated with building types in the design process.

Knowledge of the building type must be represented during the design process. Therefore, it is necessary to find a representation which supports design decisions, supports the changes and transformations of the design during the design process, encompasses knowledge of the design task, and which relates to the way architects design. It is proposed in the research work that graphic representations can be used as a medium to encode knowledge of the building type. This is possible if they consistently encode the things they represent; if their knowledge content can be derived, and if they are versatile enough to support a design process of a building belonging to a type.

A graphic representation consists of graphic entities such as vertices, lines, planes, shapes, symbols, etc. Establishing a graphic representation implies making design decisions with respect to these entities. Therefore it is necessary to identify the elements of the graphic representation that play a role in decision making. An approach based on the concept of 'graphic units' is developed. A graphic unit is a particular set of graphic entities that has some constant meaning. Examples are: *zone*, *circulation scheme*, *axial system*, and *contour*. Each graphic unit implies a particular kind of design decision (*e.g.* functional areas, system of circulation, spatial organisation, and layout of the building). By differentiating between appearance and meaning, it is possible to define the graphic unit relatively shape-independent.

If a number of graphic representations have the same graphic units, they deal with the same kind of design decisions. Graphic representations that have such a specifically defined knowledge content are called '*generic representations*.' An analysis of over *220* graphic representations in the literature on architecture results in *24* graphic units and *50* generic representations. For each generic representation the design decisions are identified. These decisions are informed by the nature of the design task at hand. If the design task is a building belonging

to a building type, then knowledge of the building type is required. In a single generic representation knowledge of norms, rules, and principles associated with the building type are used. Therefore, a single generic representation encodes declarative knowledge of the building type. A sequence of generic representations encodes a series of design decisions which are informed by the design task. If the design task is a building type, then procedural knowledge of the building type is used.

By means of the graphic unit and generic representation, it is possible to identify a number of relations that determine sequences of generic representations. These relations are: additional graphic units, themes of generic representations, and successive graphic units. Additional graphic units defines subsequent generic representations by adding a new graphic unit. Themes of generic representations defines groups of generic representations that deal with the same kind of design decisions. Successive graphic units defines preconditions for subsequent or previous generic representations. On the basis of themes it is possible to define six general sequences of generic representations. On the basis of additional and successive graphic units it is possible to define sequences of generic representations in themes. On the basis of these sequences, one particular sequence of *23* generic representations is defined.

The particular sequence of generic representations structures the decision process of a building type. In order to test this assertion, the particular sequence is applied to the office building type. For each generic representation, it is possible to establish a graphic representation that follows the definition of the graphic units and to apply the required statements from the office building knowledge base. The application results in a sequence of graphic representations that particularises an office building design.

Implementation of seven generic representations in a computer aided design system demonstrates the use of generic representations for design support. The set is large enough to provide additional weight to the conclusion that generic representations map declarative and procedural knowledge of the building type.

From the research work the following relevant results can be derived:

- An approach for analysing graphic representations on their implied design decisions by means of the concepts of graphic unit and generic representation.
- Survey and structured analysis of plan-based graphic representations in architecture.
- An inventory of graphic tools - the graphic unit - with which the architect elaborates the design object.
- A structured approach to describing sequences of graphic representations.
- A procedural approach to the notion of building type.

Samenvatting

Het gebouwtype is een belangrijke vorm van kennis in het architectonisch ontwerp proces. Het geeft de architect informatie over normen, organisatie, verschijning, etc. die horen bij het soort gebouw dat ontworpen wordt. Vraagstukken met betrekking tot het gebouwtype zijn de relatie tussen type en de verscheidenheid aan gebouwen die tot een type behoren en de relatie tussen type en gevarieerde programma's van eisen en locaties. Bestaande benaderingen die het type modelleren als een datastructuur met onderling gerelateerde variabelen - zogenaamde 'prototypen' - kunnen deze vragen niet goed beantwoorden. In het onderzoek wordt voorgesteld om de rol van kennis van gebouwtypen in het ontwerp proces te onderzoeken.
Om kennis van het gebouwtype te kunnen representeren in het ontwerpproces is het noodzakelijk te beschikken over een representatie dat het nemen van ontwerpbeslissingen ondersteunt, de veranderingen van het ontwerp vastlegt, kennis van de opgave omvat, en dat gerelateerd is aan de wijze van ontwerpen van architecten. In het onderzoek wordt aangenomen dat grafische representaties zo een medium zijn. Dit is alleen mogelijk als zij op een consistente wijze dingen vastleggen; als hun kennisinhoud geanalyseerd kan worden, en als de verscheidenheid groot genoeg is om het ontwerpproces van een gebouw te ondersteunen.
Een grafische representatie bestaat uit grafische elementen zoals punten, lijnen, vlakken, vormen, symbolen, etc. Het maken van een grafische representatie impliceert het nemen van ontwerpbeslissingen met betrekking tot deze elementen. Het is dus noodzakelijk de elementen te kunnen identificeren die een rol spelen in het beslissingsproces. Hiervoor wordt een benadering ontwikkeld gebaseerd op het concept van 'grafische eenheden.' Een grafische eenheid is een gedefinieerde set van grafische elementen die een bepaalde betekenis hebben. Voorbeelden zijn: *zone*, *circulatie schema*, *assen systeem* en *contour*. Elke grafische eenheid impliceert een bepaalde ontwerpbeslissingen (bijv. functioneel gebied, wijze van circuleren, ruimtelijke organisatie, en vorm van het gebouw). Door onderscheid te maken tussen vorm en betekenis is de grafische eenheid onafhankelijk gedefinieerd van de verschijningsvorm.
Als een aantal grafische representaties dezelfde grafische eenheden hebben, leggen ze dezelfde ontwerpbeslissingen vast. Een grafische representatie met op deze wijze een specifiek gedefinieerde kennisinhoud wordt een 'generieke representatie' genoemd. Analyse van ongeveer *220* grafische representaties in de bouwkundige literatuur resulteert in de definitie van *24* grafische eenheden en *50* generieke representaties. Voor iedere generieke representatie zijn de ontwerpbeslissingen vastgesteld. Om deze beslissingen te nemen is kennis van de

ontwerpopgave nodig. Als de ontwerpopgave een gebouw is behorende tot een bepaald type, dan is kennis van het gebouwtype nodig. In één generieke representatie wordt kennis van normen, regels en principes die verband houden met het gebouwtype gebruikt. Men mag dus concluderen dat één generieke representatie declaratieve kennis van het gebouwtype vastlegt. Een reeks generieke representaties legt een reeks ontwerpbeslissingen vast. Hiervoor is procedurele kennis nodig. Als de ontwerpopgave een gebouw is behorende tot een bepaald type, dan legt een reeks generieke representaties dus procedurele kennis van het gebouwtype vast.

Met behulp van de begrippen grafische eenheid en generieke representatie is het mogelijk een aantal relaties te definiëren waarmee reeksen van generieke representaties geformuleerd kunnen worden. Deze relaties zijn: toegevoegde grafische eenheden, thema's in generieke representaties en opeenvolgende grafische eenheden. Toegevoegde grafische eenheden definieert de opeenvolging van generieke representaties door toevoegen van grafische eenheden. Thema's in generieke representaties definieert groepen van generieke representaties met dezelfde soort ontwerpbeslissingen. Opeenvolgende grafische eenheden definieert voorwaarden voor opeenvolgende en voorgaande generieke representaties. Op basis van de thema's kunnen zes algemene reeksen van generieke representaties gedefinieerd worden. Op basis van toegevoegde en opeenvolgende grafische eenheden kunnen reeksen generieke representaties binnen thema's gedefinieerd worden. Op basis van de mogelijke reeksen wordt een specifieke reeks opgesteld bestaande uit *23* generieke representaties.

De specifieke reeks legt het ontwerpproces vast van een gebouwtype. Teneinde dit te toetsen wordt het type van het kantoorgebouw toegepast op de reeks. Hiervoor is het noodzakelijk declaratieve kennis van het kantoorgebouw te vergaren. Van iedere generieke representatie in de reeks is het mogelijk de bijbehorende grafische representatie te maken en de benodigde kennis van het kantoorgebouw te identificeren. De toepassing laat zien dat er een reeks grafische representaties ontstaat die steeds meer gespecificeerd het ontwerp van een kantoorgebouw weergeven.

Toepassing van zeven generieke representaties van de reeks in een CAD systeem demonstreert de mogelijkheid generieke representaties in een ontwerp ondersteunend systeem te implementeren. De implementatie maakt plausibel dat generieke representaties procedurele en declaratieve kennis van gebouwtypen vastleggen.

Uit het onderzoek komen de volgende relevante resultaten:

- Een benadering voor het analyseren van grafische representaties op impliciete ontwerpbeslissingen met behulp van de grafische eenheid en de generieke representatie.

- Overzicht en gestructureerde analyse van plattegrond-gebaseerde grafische representaties in het architectonisch ontwerpen.
- Een inventarisatie van grafische hulpmiddelen - de grafische eenheid - waarmee architecten het ontwerp realiseren.
- Een gestructureerde benadering van het beschrijven van reeksen van grafische representaties.
- Een procedurele benadering van het begrip gebouwtype.

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Henri Achten (1967, Venlo) completed secondary school (HAVO and VWO) at the Rijksscholengemeenschap Den Hulster in 1986 in Venlo. He studied architecture at Eindhoven University of Technology from 1986 onward and graduated in 1992 in the Design Methods Group on the design of a museum. During this period he has been assistant with the FAGO group (Physical Aspects of the Built Environment) for four months and participated in the Bouwkundewinkel (students consultancy shop) for one and a half year. In 1991 he worked three months in Thailand on a waste-logistics project.

In the period 1993-1997 he was employed as AiO in the Design Methods Group working on his Ph.D. thesis on generic representations. During this period he was involved in teaching (projects and class), the organisation of two symposia on design research and design education, and realisation and administration of the "Design Methods Group" and the "Design Research in the Netherlands" internet-sites, and the joint administration of the "LAVA" internet-site. He was involved with formulation of the VR-DIS research project of the Design Systems Group that resulted from the merge of the Design Methods Group and the Building Information Technology group. In 1997 he accepted a post as researcher with the Design Systems Group.

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