Propositions going with the thesis *A system of types in the domain of residential buildings* (M. van Leusen)

Stellingen behorende bij het proefschrift *A system of types in the domain of residential buildings* (M. van Leusen)

1. In general, plans, sections, elevations and other kinds of drawings form a richer and less prejudiced source of knowledge about buildings than verbal descriptions.

2. Willingness to make intuitive decisions is an indispensable ingredient of the architectural designer's capacity to deal with complex and ill-defined problems.

3. The availability, in organic chemistry, of a well-defined representation of molecular structure has enabled retrieval facilities in computer databases of chemical compounds, which set a challenging example for databases of architectural precedents [Chemical Abstracts Service 1985 *CAS Online*; this thesis pp247-251].

4. When architectural plans are not strictly orthogonal they can be explained in many cases as the result either of local disturbances of orthogonality or of straightforward distortions.

5. Discussion with inhabitants of famous residential buildings often reveal dissatisfaction, on practical grounds, with characteristics which make the building special from an architectural point of view.

6. It is regrettable that Prof. Weeber's recent statements [*NRC Handelsblad* 2-2/94 p7] about the layman's inability to judge architecture have caused much controversy around his person, but little discussion about the apparent incompatibility between esthetic preferences of architects and those of the general public.

7. Its lack of visibility as well as the lack of view of its driver make the 'ligfiets' a dangerous means of transportation in
situations where motorized and non-motorized traffic are not strictly separated.

8. Allowing drivers a limited budget of traffic violations in a certain period of time before taking away their licence, as recently implemented in France, is fairer and probably more effective than fining.


10. The younger promovendi become, the less realistic it is to require that they demonstrate broad scientific knowledge by formulating propositions on a variety of subjects.
A SYSTEM OF TYPES IN THE DOMAIN OF RESIDENTIAL BUILDINGS

EEN TYPOLOGISCH SYSTEEM OP HET GEBIED VAN WOONGEBOUWEN

PROEFSCHRIFT

ter verkrijging van de graad van doctor aan de Technische Universiteit Delft,
op gezag van de Rector Magnificus prof. ir. K.F. Wakker,
in het openbaar te verdedigen ten overstaan van een commissie
door het College van Dekanen aangewezen,
op 29 maart 1994 te 14.00 uur
door Marc VAN LEUSEN,
bouwkundig ingenieur,
geboren te Utrecht.
Dit proefschrift is goedgekeurd door de promotoren:

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prof. A. Tzonis M.Sc

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1. Introduction

The work presented in following chapters should be seen in the perspective of contemporary architectural design. At the end of the study we will return to this perspective by discussing the relevance of the study's results to architectural design and the possibilities for their implementation. This chapter focuses on certain general ideas about architectural design and about the knowledge assumed to be seated in the mind of the architectural designer.

- The study intends to formulate architectural knowledge in order to support future design work. The domain of the complex residential building is thought to be a current one.
- The study adopts the view that architectural designers deal with complex and ill-defined problems. It is the a priori awareness and understanding of design options -often presenting themselves as *types*—which enables designers to solve such problems.
- Architectural systems of types may support decision-making in the design process through the education of architectural students, by facilitating retrieval of precedents, and by offering a framework for empirical research.
- The effectiveness of a system of types would benefit from its computerization. A relatively new CAAD approach is *precedent-based design*, in which retrieval and adaptation of architectural precedents are central issues. Architectural systems of types can play an important role in this model.
- The study has two major components. First, after reviewing several existing systems of types related to the domain, it formulates a particular need for improvement. Second, it develops a system of types which, within certain limitations, demonstrates that such an improvement is possible.
1.1. Character of the study

In *Architectural judgement* Peter Collins draws parallels between the theory of architecture and that of law. He describes a general distinction between two kinds of study of historical facts as follows [Collins 1971 p20]:

'Now it may be argued that the lawyer's attitude towards history, as described here, is no different from that of a number of distinguished and influential art-historians, such as the authors of *Pioneers of the Modern Movement* or of *Space, Time and Architecture*, who were also concerned with 'precedents', and with what seemed 'relevant', in the sense that their histories are chronologically arranged antecedents of contemporary architecture. But the similarity between the art-historian's approach to history, and the lawyer's approach to history ends here. No specialist in contract law would see any point in studying its evolution by reference to its 'pioneers'. No specialist in the law of Torts, however interested in its emergence from the feudal law of trespass, would think it worth his while to make a detailed study of wrongful pre-historic injuries, and then call it *The Eternal Present*. Nor would a specialist in international law, after having published the standard and most authoritative text-book on *Leading Cases of Nineteenth and Twentieth Centuries*, feel urged to write a monograph on *Rococo Ecclesiastical Law in Lower Franconia.*'

**Design-related character of the study** • Where architecture is concerned the present study considers Collins's distinction as one between studies that are explicitly related to contemporary design and those that are not. Many general 'architectural histories' deal primarily with stylistic characteristics of architectural form, or with the evolution of such characteristics within particular geographical boundaries and historical periods [Pevsner 1943; Fanelli 1978; Frampton 1980]. Frampton for example, when discussing the work of a particular architect, pays much attention to his sources of inspiration, to the degree to which his work exemplifies or renews a certain style, and to the developments in society that influenced it. A typical statement found in *Modern architecture*,
a critical history is the following [Frampton 1980 p161]: ‘Ludwig Mies van der Rohe was as much inspired by the work of the Dutch architect Berlage as by that Prussian school of Neo-Classicism to which he became the direct heir’.

Certainly much can be learned from these works and they usually form basic reading material in courses of architectural history. But only occasionally do they provide a specification of the practical and definable desires by which architectural form is to a considerable degree determined. Products of architectural design are primarily discussed as cultural or artistic events and no attention is paid to their possible relevance to the design of new products except in highly general terms. This study tries to show that detailed architectural knowledge can be specified with the explicit aim that this knowledge is implemented in contemporary design.

The complex residential building • There are many detailed studies which are limited to the work of a single architect or even to just one or a few of his designs. However, the domains of those studies are narrow and it is unclear to what degree their results can be generalized for larger architectural domains.

This study intends to deal with architectural knowledge in a wide and current domain: a particular kind of housing referred to as the complex residential building. There is a multitude of terms by means of which kinds of housing are distinguished and some of them, such as multi-storey housing and multi-family housing, include this domain. They are not sufficiently specific however. The complex residential building is defined in the present work by the following three characteristics:

1. It is primarily formed of a large number of dwellings. Other components, such as shops or communal facilities, may be present but they form only a modest fraction of the building.

2. Those dwellings are closely packed on top of one another. Close packing means the situation in which dwellings are positioned so close to one another, that their exposure in relation to view and natural light is seriously constrained.

3. Those dwellings are connected to a communal circulation system. The terms walk-up building and corridor building are in fact indications of a building’s circulation system.
Detailed definitions of the terms **dwelling**, close packing and **circulation system** are provided by chapter four. For the moment their conventional interpretation will do.

**Figure 1.1** The Unité d'Habitation in Marseilles (Le Corbusier 1952; source: Sherwood 1978). Dwellings are closely packed and connected to corridors. Communal facilities are gathered on the roof and at two intermediate storeys.

Complex residential buildings form a domain of architectural design which has received wide attention in a geographical as well as a historical sense. Residential buildings have been designed in large numbers during the 20th century and have been realized in many different places in the world.

There is no obvious reason to expect that the complex residential building becomes obsolete in the near future. Certainly new construction techniques will be developed and new materials will be introduced. The size and spatial organization of individual dwellings may undergo certain changes. Dwellings as such will be needed though and it is unlikely that the sort of considerations leading to their close
packing in large numbers will become less relevant. One may think of the need for high-density housing and the need to keep building costs within limits, which both tend to result in multi-storey solutions and minimization of external surface. As soon as dwellings are positioned at some distance from ground level—two or three storeys, say—a communal circulation system becomes a necessity.

Prior studies • Housing has been the topic of a multitude of studies of a widely different nature. A first, practical consequence is that this study does not start from scratch: much basic material about buildings, particularly drawings, has already been gathered and made accessible. Without the results of such labour being available this study would be an impossible task.

Second, there is the availability of studies that go beyond the level of gathering and presenting original material. Besides providing several significant leads, they form the state of the art, against which the significance of the present study can be evaluated. A number of studies which, in one way or another, describe the domain of housing in terms of types are discussed and compared by chapter two.

Practical needs and desires • In the design of housing desires and requirements of a practical and definable nature play a significant role. This is not meant to say that less definable desires and requirements are not important. It does mean however that certain considerations are more widely understood and acknowledged than others. The need for certain rooms to have view and natural light rather than others, or the idea that travelling distances within a dwelling should not exceed certain limits, are not only considered of importance by those trained and experienced in architectural design.

In the context of housing there has been a continuous effort by architects and architectural researchers to understand and to express those needs and desires, and to find ways in which they may principally be satisfied. This has led to a range of specialized handbooks on housing in which much practical knowledge is gathered [Sting 1979; Gieselmann 1979; Macsai et al 1982].
1.2. The architectural design process

In view of the intention of this study to make explicit architectural knowledge in support of design, it is important to understand at what point in the architectural design process such support would be most effective.

- The study conceives architectural design as a problem solving activity. The ill-definedness and complexity of architectural design problems have serious consequences for the design process.
- In the architectural design process architectural form is described by means of increasingly detailed graphical representations. Each of those representations facilitates the consideration of alternative design options at a particular level of spatial organization.
- By the time descriptions of architectural form have become sufficiently detailed for a reliable evaluation, the process has already consumed considerable time and money. At that point it is usually too late to reconsider options chosen at earlier stages.
- The designer's ability to handle this dilemma is largely dependent on his a priori awareness and understanding of design options. Much of that expertise is the result of becoming acquainted with large numbers of precedents and learning to distinguish them by type.

1.2.1. Architectural design problems

In most general terms the present study conceives the architectural design process as a series of actions intended to lead towards a solution of a problem. This point of view is shared by many writers on architectural design [Simon 1981; Hamel 1990 pp4-7]. Design problems are straightforwardly characterized as follows [Alexander 1964 p93]:
The problem is defined by a set of requirements called $M$. The solution to this problem will be a form which successfully satisfies all of these requirements.

In these general terms architectural design problems are not essentially different from many other kinds of problems: an architectural design problem is formed of some combination of desires and requirements to be satisfied by a building or other product of architectural design. However, architectural design problems have certain more specific characteristics which have serious consequences for the process of finding a solution. Those characteristics are perhaps best introduced by discussing some points of criticism launched against the design method proposed by Alexander in Notes on the synthesis of form [1964].

Alexander's method starts with the listing of all requirements by which the problem is defined and the listing of which pairs of them interact. Interaction between requirements may be either positive in the sense that satisfaction of the one supports satisfaction of the other, or negative in the sense that satisfaction of the one contradicts the satisfaction of the other. Then a hierarchical clustering of requirements is determined so that within clusters interactions are relatively frequent, while in between clusters they are scarce. At the lowest level in the hierarchy a cluster defines a relatively simple and independent design problem, for which an appropriate solution is found and described straightforwardly. These basic solutions can then be combined into higher level ones and so on, until a complete solution is established.

Alexander's method has been tested in the design of a suburban housing scheme and that of an Indian agricultural village [Chermayeff and Alexander 1963; Alexander 1964]. Several objections have been raised against his approach, two of which are particularly relevant in the present context.\(^1\)

**Ill-defined character of design problems** • Alexander

---

\(^1\) Alexander himself was among the first to criticize the method [Alexander 1966]. His arguments are primarily to do with the hierarchical structure of both problem and solution being an oversimplification.
assumes that a design problem is explicitly defined in advance. For many actual design problems and certainly for architectural ones this is a practical impossibility. Various characteristics of *ill-defined* problems are mentioned in the literature [Mitchell 1977 pp60-62; Lawson 1990 pp88-89]. In short, ill-definedness implies that at the beginning of the process a complete, consistent and stable specification of the desires and requirements to be satisfied by the design product is not available. In fact the design process is not just one which produces a solution to a problem, but it is as much a process of understanding and specifying the problem itself. In the words of Lawson [1990 p88]:

'It is clear that many components of design problems cannot be expected to emerge until some attempt has been made at generating solutions. Indeed many features of design problems may never be fully uncovered and made explicit. Design problems are often full of uncertainties both about the objectives and their relative priorities. In fact both objectives and priorities are quite likely to change during the design process as the solution implications begin to emerge.'

In view of the design problem as one which never becomes entirely explicit, there cannot be such a thing as an optimal solution, that is, a solution which is the best among a set of alternatives [Lawson 1990 p90]. Akin argues that 'each designer applies his or her own specialized tests to determine whether or not a design is acceptable' and even that 'most designers are satisfied because of lack of time rather than anything else' [Akin 1986 pp21].

**Complexity of design problems** • Besides because a lack of well-definedness, straightforward 'calculation' of solutions for architectural design problems is unrealistic simply because of their immense complexity. According to Simon [1981 p139]:

'An earmark of all these situations where we satisfice for inability to optimize is that, although the set of available alternatives is 'given' in a certain abstract sense (...), it is not 'given' in the only sense that it is not practically relevant. We cannot within practicable computational limits generate all the admissible alternatives and compare their respective merits. Nor can we recognize the best alternative, even if we are fortunate enough to generate it early, until we have seen all of them. We satisfice by
looking for alternatives in such a way that we can generally find an acceptable one after only moderate search.'

In view of the complexity of actual design problems, Alexander's method fails to appreciate, to put it in Lawson's words, the fact that 'some requirements and interactions have much more profound implications for the form of the solution than do others'. Discussing the requirement interactions in Chermayeff and Alexander's 1963 housing experiment, he notices that in a normal design process the first kind would be given emphasis at an earlier stage in the process than the latter [Lawson 1990 p57]. The idea that all desires and requirements defining a problem are of equal importance and should be considered more or less simultaneously from the beginning of the process on is a serious misconception in the context of architectural design. In actual design processes a solution is first described only in very general terms. For many of the desires and requirements that form the problem it is simply not possible to evaluate their satisfaction on basis of such a description. One may think for example of requirements concerning individual rooms, such as floor areas or position of doors, the evaluation of which becomes possible only when a building is described by means of sufficiently detailed plans.

1.2.2. Representation of architectural form

Because of the ill-defined and complex nature of architectural design problems the immediate specification of a design product is a practical impossibility. In an actual design process the way towards material realization of a building is paved with various kinds of descriptions. As Habraken [1985 p11] puts it in *The appearance of the form*:

'The design is to instruct making, it must produce something that represents what is made. The designer's world is one of representations. We describe the object to be produced in a hundred ways; by means of drawings, words, and diagrams; in print, by scale models or on computer screens. In our descriptions we use a variety of formal languages tied to as many specialisations. In aid of the production of such diverse things as buildings, machines, automobiles, or ships there are often specifications of
all parts and drawings of all joints, all dimensions are stated, calculations and evaluations of numerous aspects are on record.\textsuperscript{1}

The terms description and representation are used frequently throughout this and following chapters. As defined by Winston [1984 p21] `a representation is a set of conventions about how to describe a class of things. A description makes use of the conventions of a representation to describe some particular thing'. Thus a description is an instance of a particular representation. Most commonly, and throughout the process, the design product is represented graphically. Drawings facilitate both the description and the evaluation of alternative options. Mitchell [1977 pp55] speaks of `graphical evaluation' as `an extremely common procedure in architectural design'. Akin [1986 pp112] considers graphical descriptions as part of the designer's personal tool-kit:

`Since design involves the manipulation of symbols that stand for realities, design is an excellent example of abstract problem-solving. Plans, sections, elevations, perspectives, axonometric and isometric drawings, models, and a host of other graphic representations are the abstract tools of the designer. Through these tools the designer can generate alternative solutions and test them before implementing them in real life and running the risk of costly errors. Representations afford the designer the luxury of testing ideas with little cost.'

Besides serving a designer's personal explorative purposes, many of the graphical descriptions produced during a design process play an important role in the communication between the parties involved. As Akin [1986 p58] points out, descriptions may be specifically intended for communication between certain parties rather than others:

`Designers communicate with the client using certain kinds of drawings and with the contractor using entirely different kinds of drawings. The information necessary for a preliminary cost estimate for the client is very different from that needed as part of the contractual agreement between client and contractor.'

For such communicative purposes it is significant that a communal understanding exists so that the relevant parties interpret a representation in the same way. Where highly
specific technical drawings are concerned, the interpretation of line-types, hatchings and various symbols is subject to explicit agreements. The communal understanding of more abstract representations is usually based upon implicit agreements.

**Design via intermediate representations** • The process of designing a complex product requires the production of several intermediate descriptions. The architectural design process typically starts with a (collection of) description(s) of desires and requirements to be satisfied by the building. It ends with a (collection of) description(s) sufficiently complete and detailed to instruct the building’s material realization. The process can be seen as a step by step production of more detailed descriptions on basis of earlier, more abstract ones. As proposed by Habraken [1985 p55] two representations may be related by the fact that the one enables the expression of constraints upon instances of the other. Reversely, the latter representation allows further specification of those constraints. We may speak, after Habraken, of a more general representation instructing a more specific one.

In architectural design representations are not necessarily all within the designer’s influence.\(^1\) Programmatic documents are often produced by specialized offices at the earlier stages of the process, just like certain detailed technical drawings and legal documents at the later stages.

**Design options** • During the design process representations may be revisited several times and, in principle, in any order. Every such visit may result in the production of one or more new descriptions, or in the adaptation of existing ones.\(^2\) At the end of the design process several descriptions may have become obsolete.

Every representation facilitates the expression of a particular

---

\(^1\) Where the present study speaks of ‘the designer’ this should be understood, in a wider sense, as the entire team working on a design within the architectural office.

\(^2\) Habraken stresses the unlikeliness of completing one description without, at the same time, working at others [Habraken 1985 p56].
category of design options. A design option is any (combination of) characteristic(s) of the design product which can be seen as one among a range of alternatives. In architectural design one might for example face the choice between a tower and a courtyard block, between single and double storey dwellings, between tiles or metal sheets as material for a pitched roof. Each of these choices requires a representation with a particular degree of abstraction. Where a building’s overall shape and size are concerned this might be a 1:2000 or 1:1000 axonometric projection, the distinction between single and double storey dwellings can be expressed in 1:500 plans and sections, and individual building parts, materials and joints are usually indicated in technical drawings at scales varying from 1:100 to 1:1.

Design options are considered within the constraints expressed by more general descriptions and, possibly, in relation to more specific descriptions already established. If a generated option is not in compliance with a constraining or a constrained description this may lead to rejection or revision of that description. This means reconsidering design options described earlier in the process. Ranges of alternative options can be described simultaneously or during separate visits to a representation.

The consideration of alternative options is not necessarily clearly visible in the process. This holds in particular when options are not subject to a collective evaluation so that, at least for communicative purposes, their explicit description is not needed. It may well occur that options are described and immediately evaluated by the designer during the process of editing a drawing. In this case descriptions of alternative options do emerge but are extremely short-lived. It frequently occurs that options are generated and evaluated entirely in the designer’s mind, without any explicit description of them being produced. ¹

¹ It is suggested by prof. Rijnboutt [personal communication] that the more experienced designers become, the less frequent do they need explicit descriptions to support the process of finding and evaluating alternative options.
**Figure 1.2** Three alternative options for a residential building in Amsterdam (after Rijnboutt 1988). The representation is an axonometric projection of building masses which ignores all details of the facades. The three descriptions were among a total of six, produced simultaneously and evaluated not only by the designer but by various parties involved in the process. The option to the right was chosen, described in increasingly more detail and, finally, materially realized.

**Form, operation and performance** • An important distinction is the one between representations which allow the expression of characteristics of the design product’s form, and representations which allow the expression of desired or anticipated characteristics of its behaviour.

When speaking of its formal characteristics the design product is considered as an isolated material object, irrespective of interactions with its environment [Tzonis and Oorschot 1987 pp52]. In case of a building such characteristics are for example the shape and size of rooms or the materials used in various building parts. Given its form and given its environment at a particular moment in time, the design product is said to behave in a certain way. **Behaviour** can be understood in general terms as a design product’s interaction with its environment. This study views the terms operation and performance as referring to behaviour from two different points of view.

Operational characteristics relate to details of the design product’s behaviour in a particular context. The patterns of
circulation by people within a building in a certain period of time form an operational characteristic in the context of human circulation. Similarly, the heat flows through the building's roof and facades form an operational characteristic in the context of its thermal behaviour. While the concept of operation does not involve any value judgement, the concept of performance does. When speaking of a design product's performance this implies a judgement about some aspect of its behaviour. A building can be said to perform well with respect to economy of human circulation or with respect to economy of energy use.¹

The desires and requirements in the building programme are commonly expressed in the form of statements. These may concern matters of performance straightforwardly, such as the desire that a building be economical on energy. They may also concern matters of form, such as the requirement of a certain minimal total floor area, motivated by implicit assumptions about the consequences for performance. Statements may hold maxima or minima to the value of quantifiable characteristics – such as an office building's maximal annual heat loss or the number of visitors to be minimally accommodated by a museum. Performances are not always easily quantified though: a building's performance with respect to beauty, privacy or security may simply be desired to be good. As discussed earlier the programme cannot be a complete description of the design problem: many characteristics of the building's form as well as its behaviour are tacitly or even unconsciously desired or assumed by the parties involved in the process.

The desires and requirements expressed or assumed at the beginning of the process with respect to a building's form and anticipated behaviour do not add up to a complete, coherent and sufficiently specific description of form. It is the designer's expertise to establish such a description and –as we have seen at the beginning of this section– in this respect a variety of graphical representations are indispensable tools.

Levels of organization • Buildings show a more or less

¹ This use of the terms form, operation and performance is largely based upon more elaborate definitions by Zandi-Nia (1992 chap.2 – pp9-11).
hierarchical spatial organization in which components can be identified at different levels [Habraken 1985 pp96-98]. In general it can be said that the degree of abstraction of a representation is related to the level of organization at which design options are considered. No designer will try to express details of a window-frame in a 1:500 plan and, reversely, no designer will use drawings at a 1:5 scale to express and evaluate alternative options of arranging building masses.

The more detailed descriptions are, the more fragmented they usually become. While the 1:500 axonometric is a single drawing, in order to enable the eventual material realization of the building a multitude of interrelated technical drawings is needed. At a 1:5 scale for example individual drawings zoom in on particular joints and the location of those joints is indicated by reference to drawings at a larger scale. These might be 1:20 plans and sections which are themselves blow-up's of certain fragments of 1:100 overall plans and sections.

1.2.3. A dilemma in the architectural design process

Theoretically alternative options at different levels of spatial organization may be described and reconsidered any number of times and at any moment in the process. There are however certain practical limitations to be taken into account:

(1) The process must lead to realization of the product within a limited period of time.

(2) The costs of the process, before material realization commences, are limited – in case of architectural design they usually form a small percentage of the costs of realization.

These limitations have serious consequences for the architectural design process. A first and rather straightforward consequence is the fact that, in almost all cases, the possibility is ruled out of the material realization of a prototype the performance which can be tested. A building is usually realized only once and, whatever its performance, the job cannot be done
all over again.

A second, more indirect consequence is due to the fact that the more specific the description of a building becomes, the more time and manpower its production tends to require. This is caused to some degree by the increasing accuracy and complexity of the drawings themselves. A more fundamental cause is the increasing number of choices among design options that present themselves at lower levels of the building's organization. While the description of a composition of building masses can produced by a single person in a limited period of time, production of the host of drawings and other documents needed for the eventual realization of the building involves a large segment of the office population for a large period of time.

A dilemma • This creates the following dilemma:

(1) On the one hand: the more detailed the description of a building is, the more reliable can be the expectations as to its compliance with explicit as well as tacit desires and requirements.

(2) On the other hand: the more detailed the description of a building is, the more costly and time-consuming—and thus the less likely to be acceptable— are serious adaptations to this description.

In other words: at the point where a complete, coherent and detailed description has been produced, poor performance is relatively easy to detect but difficult to avoid. Reversely, if a complete, coherent and detailed description has not yet been produced, poor performance is relatively easy to avoid but difficult to detect. During the process there is a shift in attention from more abstract representations towards more detailed ones. Frequently there are 'points of no return': a description in which particular design options are expressed satisfies the designer and is perhaps agreed upon by other parties, and from there on it serves as a basis for the production of more specific descriptions. Soon, reconsideration of those options is not affordable any more.

The higher the level of organization at which options are considered, the more urgent it is that the choice among them is based upon a reliable evaluation. If for example a residential
building is described by a 1:500 axonometric projection it is important to know whether the shape and size of building masses actually allows the number, type and size of dwellings as described by the programme. If it is discovered at a much later stage in the process that this is not the case, then either such violation of the programme must be accepted causing several parties to be dissatisfied, or the composition of building masses must be reconsidered. Such a reconsideration is inevitably followed by reconsideration of several design options at lower levels of spatial organization.

Much depends, in this respect, on the designer’s personal expertise. He is the one that must be aware of a variety of design options, and he is also the one who must have reliable expectations about their eventual compliance with the whole of desires and requirements forming the programme.

1.2.4. Knowledge of precedents

Many writers on architectural design recognize the fact that the design of complex products requires knowledge of previously designed and realized products. Colquhoun [1967 p73] points out that ‘even in a world of pure technology’ — he uses the example of airplane design — the area of free choice left by the application of physical laws, such as those of aerodynamics, is ‘invariably dealt with by adapting previous solutions’. According to Colquhoun:

ʻIn the world of architecture this problem becomes even more crucial, because general laws of physics and empirical facts are even less capable of fixing a final configuration than in the case of an airplane or bridge. Recourse to some kind of typological model is even more necessary.ʻ

As we have seen at the beginning of this chapter (subsection 1.1.1) Collins discusses certain parallels between the concept of precedent in the legal and in the architectural profession. He notices that the legal profession takes two distinct attitudes towards its own past: certain elements of this past are seen as ‘an integral part of the web of the current law’, while others are seen as ‘only remotely related to current practice’ [Collins 1971
pp20-21]. In the legal context the precedent is described as 'a judgement or decision of a court of law cited as an authority for deciding a similar state of facts in the same manner, or on the same principle by analogy'. In architectural design a precedent can be understood in a wide sense as any object known from the past, which is used as an example in the design of a new product. Such an object itself does not need to be a product of architectural design.

![Figure 1.3 Precedents related to the Unité d'Habitation by analogy indicated by Le Corbusier (source: Boesiger 1953). Above, from left to right: savage's hut, nomad's tent, bottle and apartment from the Unité. The bottle as an independent unit inserted in a bottlerack is analogous to the apartment inserted in the building's structural skeleton.]

Tzonis [1992 p144] says the following about the methods of architectural designers:

'Architects appear to use experience extensively. They exploit precedents, of theirs or others, solutions developed as answers to previous problems. They use knowledge, rules of thumb, general rules, theories and principles. The knowledge they use is transferred from one kind of problem to another, from one design domain, or even world domain, to another.'

Tzonis discusses at length the analogies between Le Corbusier's 'Unité d'Habitation' and several precedents indicated by Le Corbusier in his own writings. These are, among others, the native hut, the bottlerack and the ocean liner.
**Architectural precedents** • The present study deals only with architectural precedents. An architectural precedent is understood as a building or other product of architectural design, which materially exists or has existed in the past and which serves as an example in the context of the design of a new building.

According to Collins [1971 p25] ‘today, the selection and adaptation of precedents not only should fill, but clearly does fill, a far greater role than it ever filled in the architecture of the past’. Hancock [1986 pp70-71] distinguishes place-, type- and principle-grounded precedents. Place refers to ‘the historic continuity of settings’ and ‘the desirability of new work linking somehow to what has been accumulated in that continuity’. Type refers to ‘culturally rooted form-function analogues which have become formulas imbued by the general culture with a durable and important content’. According to Hancock, ‘we connect new work to type-grounded precedents when we believe that communicating the continuity of the institutional heritage or reflecting the long-standing value of an organizational format is one of the most important tasks that the work might fulfill’. Thus, Hancock uses the word type exclusively to indicate precedents which are relevant in a specific cultural context. Basing newly designed buildings upon type-grounded precedents means preserving stylistic continuity.

The relevance of principle-grounded precedents is not limited to a specific cultural or geographical context [Hancock 1986 p71]:

‘Principles may be defined as the accumulated insights and effective techniques that collectively form the established ways in which the language of the discipline operates. We do not choose principle-rooted precedents because of any overall intention to connect new works to previous works or to a particular geographical or cultural continuity. Instead the most important continuity is that of effective technique, and the most important precedents are those which together reveal a convincing continuity of that effectiveness under a variety of conditions.’

The differences between the place-, type- and the principle-grounded precedent can be argued to be gradual. A house designed in a particular vernacular style for example may be viewed as inspired by houses that exist or have existed in its vicinity. How distant a house must be located, or how long ago it
must have ceased to exist before we may speak of a type-grounded precedent is difficult to decide. And whether or not for example a certain arrangement of rooms shared by the new house and its precedents should be considered a principle is a matter of taste.

However, rather than with geographical or historical continuity the present study is preoccupied with architectural form motivated by desires and requirements which are relevant beyond the limitations of specific cultural contexts. Therefore this study considers precedents from the principle-grounded perspective and it assumes a more general meaning of the word type than advocated by Hancock.

A priori knowledge of types • Rarely are new buildings exact copies of precedents. The same holds for individual components of a building, although an exception must be made for certain standardized building parts provided by the building industry. There is only a certain combination of characteristics which the newly designed building shares with the precedent. Disregarding Hancock’s more narrow use of the term, it can be said that it is not the precedent as such which is preserved, but it is a type which is preserved in the new building. Often, choices between alternative design options present themselves as choices between types of buildings or building components. One may speak of types of buildings such as the perimeter block or the urban villa, of types of components such as the double oriented dwelling or the internal corridor, and of types building parts such as the spiral stair or the sliding window.

To a large degree the architectural designer’s expertise in dealing with the dilemma mentioned earlier (subsection 1.2.3) relies upon his a priori knowledge of types. It likely that acquiring such knowledge is largely dependent on one’s ‘intelligent consumption’ of large numbers of precedents over the years.
1.3. Architectural typology

The previous section advocated the assumption that a broad awareness and deep understanding of types is present in the minds of those, whose specialism it is to solve architectural design problems. This section discusses the tradition of describing architectural domains in terms of more or less coherent systems of types, commonly referred to as architectural typology.

- The architectural type is conceived as a class of buildings or components of buildings. A type is defined by a combination of essential characteristics, shared by all its instances. An important notion is that a type may be considered without any materially existing instances being known.
  - Durand’s 19th century handbook on the design of neoclassical buildings may be seen as an early example of a system of types which are described by diagrams and illustrated by detailed examples.
  - The approach exemplified by Durand’s handbook is by no means outdated: in different architectural domains and at various levels of spatial organization contemporary handbooks present systems of types described by means of a graphical representation and illustrated by detailed examples or precedents.
  - Where contemporary architectural design is concerned, three general environments for the implementation of a system of types can be distinguished: architectural education, design practice and empirical research.
1.3.1. Types and systems of types

The tradition of describing architectural domains in terms of more or less coherent systems of types is known as architectural typology. The concepts of type and typology did not enter the architectural debate recently. A 19th century writer who is frequently referred to in discussions about architectural typology is Quatremère de Quincy [Argan 1963; Vidler 1977; Moneo 1978]. Quatremère [1977 pp148-149, transl. Vidler] explains his notion of type as follows:

'"Thus we have achieved a thousand things in each genre, and one of the principal occupations of science and philosophy, in order to understand the reasons for them, is to discover their origin and primitive cause. This is what must be called 'type' in architecture, as in every other field of inventions and human institutions.'

Further on Quatremère circumscribes the type as the invariable 'original reason of the thing' which may well be founded –as he illustrates with the example of the vase and that of the chair– in 'the use that one makes of it and the natural habits for which one intends it'. For understandable reasons, his attitude has been qualified as a (neo)platonic one [Oechslin 1986 p43].

A type as a class of objects • Writers who discuss architectural typology in more mathematical terms usually consider a type as a class of objects. Those objects, to be understood as specific buildings or components of buildings, are instances of the type. ¹ These terms are adopted by the present study as well.

Mitchell [1990 pp86-87] distinguishes an object's essential characteristics from those which are accidental. The first are

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¹ Sometimes a specific instance is thought of as representing a type. Coyne et al [1990 pp30-35] for example speak of the archetype and the prototype as 'a representation of a class of designs' and as an 'exemplifying instance' of this class.
the ones ‘that it shares with others of its type’, the latter ‘may vary from instance to instance within a type’. Furthermore Mitchell [1990 p203] points out that types may be defined by form as well as function. A building’s function is to be understood as a general characterization of the accommodated activities. We call a certain building a church for example, not only because it has particular formal characteristics but also because it accommodates or is intended to accommodate a particular kind of activity.

![Diagram](image)

**Figure 1.4** T1 has subtypes T2 and T3, T2 has subtypes T4 and T5. T1 might be doors, T2 and T3 might be doors only for human passage and doors for vehicles, and T4 and T5 might be interior doors and exterior doors.

**Systems of types** - As we will see in chapter two, many writers present systems of interrelated types, loosely referred to as architectural typologies. According to Mitchell [1990 p87]:

‘Types may be divided into subtypes by specifying additional essential properties. Thus, for example, we might divide classical porticos into Doric, Ionic and Corinthian subtypes. Conversely, we may generalize type definitions by deleting properties, as when we generalize from squares to rectangles, and from rectangles to quadrilaterals. In general, then, we may construct hierarchies of subtypes within subtypes. Where such a hierarchy spans a universe of discourse, it provides a comprehensive classification scheme for elements in that universe. Such schemes are often referred to as typologies.’
Two aspects of such systems of types should be distinguished. There is, first, a realistic aspect: a system of types describes and orders a body of objects that exist or have existed — it is in principle irrelevant that these objects are products of design. Where types refer to design objects however there is also a constructivistic aspect involved: a system of types is understood as a system of design options.\footnote{The distinction between the realistic and the constructivistic aspect of typology is suggested by prof. Doorman [personal communication].} It is important that if a type is understood as a design option, it does not only include materially existing objects but objects which are possible in the sense that their past, present or future existence cannot, on reasonable grounds, be ruled out.

\begin{figure}
\centering
\includegraphics[width=0.3\textwidth]{figure1.5}
\caption{T1 and T2 are classes of possible objects. T2 does not include any materially existing objects.}
\end{figure}

An extreme notion following from the constructivistic point of view is the possibility that none of a type's instances are, or ever were, materially existent. When accepting this notion, as does the present study, a system of types acquires the methodological status of a hypothesis about which formal characteristics of artifacts in a particular domain are invariable and which are not. Considering a characteristic invariable means to assume that the considerations and circumstances which have implied it in the past will not change in the future. In this respect Panerai [1980 p75] speaks of the ahistorical analysis of architecture 'in terms of elements, operations, combinations,
variations and growth’.

It is the constructivistic and ahistorical conception of typology which underlies the work presented in following chapters. Chapter two discusses a number of studies which, tacitly or explicitly, take this point of view as well. Chapter four defines a type representation which is motivated by an explicit specification of the characteristics which are considered invariable. In order to prepare the ground, it will be useful to have a quick look at a system of types presented by J.N.L. Durand at the beginning of the 19th century. Durand’s work has a lot in common with contemporary systems of types.

1.3.2. Durand: a typological handbook

As mentioned by Panerai [1980 p78] Durand’s *Précis des leçons d’architecture donnée à l’Ecole Polytechnique* [Durand 1802-1819] ‘is not the work of an art historian: as an architect he is only interested in the past in order to retrieve examples for an operational theory upon which to base his teaching at the Ecole Polytechnique’. In contrast with Quatremère’s philosophical discussion (subsection 1.3.1) the approach of Durand is oriented more directly towards the design of new buildings.

In the first part of the book a basic vocabulary of building components is offered which are described in great detail by means of plans and sections. In the second part, which deals with aspects of composition, a set of initial schemes or diagrams is introduced. These can be understood as combinations of axes which are to coordinate the composition of building masses in plan view. No information about shape and size of building masses is represented, in fact the initial diagram deals with no more than their geometric configuration. Thereby it should not escape our attention that the initial diagram is more than just a sketch: Durand seems to have some notion about its primitives and the rules governing their configuration. In the earliest edition of the *Précis des leçons* an overview is presented in which the ordering of diagrams suggests a systematic listing of possible configurations.
Figure 1.6 A systematic ordering of initial diagrams
shown in Précis des leçons d'architecture donnée à l'Ecole
Polytechnique (source: Durand 1802).

Mitchell [1990 pp148-151] even goes so far as to consider the
Précis des leçons a naive grammar which could
straightforwardly be developed into a well defined one,
'providing a complete, consistent specification of a classical
architectural language'. This claim seems rather strong: such a
grammar would be seriously dependent on one's personal
interpretations of Durand's drawings and text. When
considering all the initial diagrams and not just the more
regular ones (as Mitchell does) it is not immediately clear, to
say the least, which are the primitives of these diagrams and
which are the rules governing their configuration.

A diagram is to serve as the starting point of a process of
refinement. This comes down to the selection and combination
of building components on basis of the diagram. The method of
refinement is not described explicitly but it is illustrated with an
example. Furthermore, in the third part of the Précis des leçons
a sequence of exemplary buildings –from which the initial
diagrams can be easily recognized– are depicted. Among these
are a library, a hospital, a prison and many other kinds of
Figure 1.7 Above: various initial diagrams in combination with detailed examples. Below: distinct stages in the process of elaboration of an initial diagram into a detailed plan. Illustrations from Précis des leçons d'architecture donnée à l'École Polytechnique (source: Durand 1817-1819).
buildings.

The *Précis des leçons* demonstrates two fundamentally different ways in which architectural types may be indicated. First, the initial diagrams describe essential characteristics directly. Though not explicitly defined, the overview of diagrams suggests a highly abstract type representation. Second, there is the use of fully detailed descriptions as a mere illustration of the diagrams. This is an indirect way of indicating types by means of paradigmatic instances. As we will see in chapter two, typologies commonly favour one of these ways more than the other. This study speaks of precedent-based versus representation-based typologies.

1.3.3. The relevance of typology for contemporary design

Questions could be asked as to the relevance of Durand’s approach for contemporary architectural design. In motivation of this relevance it may be stressed that the architectural design process is—and it probably will remain for a long time to come—one in which the human designer plays an indispensable role. He is the specialist who has a wide and coherent knowledge of design options and their implications. So far, computers have not been successful in replacing him. Then, in view of our limited understanding of the strategies employed by human designers in solving the complex and ill-defined problems of architectural design [Lawson 1990 pp224-227] it seems wise to have a particularly modest attitude with respect to the possibility of improving those strategies.

Architectural typology offers a way of supporting the designer without significantly disturbing those strategies. The approach of informing about design options by means of examples—more specifically: by means of precedents—is certainly not outdated. This is perhaps best illustrated by the continuing success of Neufert’s *Bauentwurfslehre (Architect’s data)* [Neufert 1980, 1984, 1992]. Neufert’s handbook contains ranges of precedents in various architectural domains such as office buildings, housing, or sporting facilities.
Figure 1.8 Schematized plans presented in Planning office space (source: Duffy et al 1976). Service cores are indicated in dark grey, circulation zones in light grey; constraints upon overall depth are specified.

The technique of indicating types—in the style of Durand—by means of graphical representations is employed in several modern architectural handbooks and at various levels of spatial organization. In Planning office space [Duffy et al 1976 p42] for example we find schematized floor plans in which only service cores and circulation zones are indicated. Another example is the overview of door types presented in Bauentwurfslehre [Neufert 1992 p168]. Those types are described by schematized drawings, in which doors are reduced to single lines and locks and hinges are indicated by graphic symbols.

When, in chapter two, the state of the art in housing typology is discussed it will be seen that in addition to verbal type descriptions various kinds of drawings are used. Some of these are only the result of schematizing available plans or sections, while others are based upon more or less well-defined representations of architectural form. Where essential characteristics are formal, graphical representations are more

**Figure 1.9** Fragment of an overview of door types presented in Bauentwurflehre (source: Neufert 1992).

In the domain of housing the work of Alexander Klein, even though it dates from the 1920’s and 1930’s, sets the example for many postwar typological studies. In *Das Einfamilienhaus (The single-family house)* [Klein 1934] three general types of ground floor plans are illustrated by a modest number of paradigmatic instances described by detailed plans and short texts. These examples are clearly intended to convey as much as possible the degree of variation in the arrangement and the dimensions of rooms, as allowed by the type. In the earlier study *Beiträge zur Wohnungsfrage (Contributions to the issue of housing)* [Klein 1928] such variation had been demonstrated in a truly systematic way. For one particular type of dwelling plan an entire set of instances, every one of which with a unique combination of overall depth and width, is presented. In doing so Klein implicitly introduces the idea of the plan type as being dimensionless: sizes are accidental characteristics.
1.3.4. Three environments for implementation

An objection often raised against typological handbooks concerns their incompleteness: they only include types of which instances are known to be or to have been materially realized, thus possibly neglecting interesting but not yet realized ones. From the constructivistic point of view however this is not an inevitable shortcoming of a system of types, since types can be anticipated on reasonable grounds.

But even when admitting the above criticism where more traditional handbooks are concerned it can be argued that its relevance much depends on the degree to which the user of such a book expects to be informed about innovative design options. Coyne et al [1990] distinguish between innovative design and routine design. The latter is seen as a matter of 'prototype refinement' [Coyne et al 1990 p78] in the style of Durand: choosing a type, thus accepting the essential characteristics, and instantiating it, thus fixing the accidental characteristics. In most cases architectural design is largely routine. Even those
design products that are widely acknowledged as being innovative are usually to a certain degree based upon known design options. In Rietveld's Schröder House for example, floors and roof are formed of the traditional combination of wooden beams and floorboards [Brown 1958 pp53-55]. Reversely, in much contemporary housing technical innovations such as the use of new building materials or prefabricated parts go with a highly routine character of the room layout.

**Education, practice and research** • Particularly in those architectural domains and at those levels of organization where design options are relatively stable, systems of types may provide useful support for architectural education, practice and research.

A system of types may support the acquisition of basic architectural knowledge. This is most likely to be relevant in the context of the training and teaching of architectural students. In most schools of architecture, students are expected to expand there knowledge of architectural precedents in a short period of time and to learn to bring this knowledge into action in a simulated design process. Being introduced to precedents in the framework of a system of types may help to improve one's capacity, when engaged in design exercises, to adopt certain of a precedent's characteristics consciously instead of blindly copying it. Good examples of typological studies that are amenable to educational use are the ones by Sting [1975] and Sherwood [1978].

A system of types may improve the accessibility of a large body of precedents, that is, it may improve the possibilities of retrieving those precedents which are particularly relevant to design work being carried out. This is not a trivial matter, since information about architectural precedents in journals and books is usually scattered and difficult to find. Available reference works do not sufficiently support the retrieval of architectural precedents on basis of formal characteristics. In architectural practice as well as education it is often the case that one is interested in precedents on basis of certain preconceived ideas about architectural form.

Given a system of types superimposed on a large body of precedents, it becomes possible to discover constraints upon formal characteristics or performances which are shared by all
or most of the known instances of a particular type. All single storey dwellings for example may be found to have a large frontage width, or the majority of doors for the passage of vehicles may be found to be steel doors. Single storey dwellings with a small frontage width, or vehicle doors made of wood cannot be rejected in an absolute sense. Still, on the assumption that the available body of precedents sufficiently represents the actual variety of materially existing instances, knowledge of such apparent constraints is valuable to those involved in the design of new instances. If dwellings of a particular type are consistently found to have a frontage width larger than some minimal value, or if doors made of a particular material are found to be vulnerable to a certain kind of use, this should be taken as a warning. Empirical research can improve awareness of the indirect implications of essential characteristics for various accidental characteristics.

1.4. Computerization

Although this study itself is entirely precomputational, computerization is considered a relevant issue in relation with architectural typology. The effectiveness of a system of types in every one of the three environments of implementation distinguished in subsection 1.3.4 could be considerably improved through its computerization. Architectural systems of types offer the prospect of bringing the advantages of the computer into action in a much earlier stage of the design process than presently the case.

- Computer programs intended to solve architectural design problems or to support human designers in the process of solving them need to incorporate architectural knowledge. However, making explicit all the knowledge that plays a role in solving architectural design problems is a difficult matter.
- An alternative to incorporating explicit architectural knowledge in a CAAD system is to incorporate it implicitly, in the form of descriptions of precedents. A precedent-based design
system supports the retrieval of appropriate precedents from a precedent base and their adaptation to new design problems.

1.4.1. CAAD approaches

Computer programs for drawing and visualization, as they are by now used in almost any architectural office, are unable to support a designer in those stages of the process where the building is not yet described in detail and general decisions about its formal characteristics are still to be made. In his *Ten year assessment of the state of the art in Computer Aided Architectural Design* Eastman [1989 p291] concludes that 'a lack of consistent semantics results in systems that are effective in the manipulation of lines, arcs and graphic primitives, but are limited in usefulness and generality for higher level units of composition'. Koutamanis [1993 p49] speaks of 'the intellectual burden of having to structure his input and perform operations on it more or less impeccably' being imposed on the user.

However, computer programs intended to solve architectural design problems or to support human designers in the process of solving them have been developed from the 1960's on. Alexander’s program for the decomposition of large sets of requirements into subsets of strongly related requirements was among the first attempts to assist the designer at the programmatic stage of the process [Chermayeff and Alexander 1963; Alexander 1964]. This program did not support the translation of these clustered requirements into architectural form.

**Space allocation** • Soon after came various programs for the automated translation of sets of requirements into more or less abstract floor plans, an approach usually referred to as space allocation. Basically, programs for space allocation calculate a distribution of spaces or locations which are assumed to accommodate particular activities or actors, in such a way that some objective is optimized while certain constraints are satisfied. Often the intention is to minimize the total circulation cost to be understood loosely as the cost of time lost
on circulation by, for example, employees earning particular salaries. The earlier ones such as CRAFT and DOMINO [Mitchell 1977 pp426-474] produce layouts of spaces which are poor to the architectural eye, be it in ways which are not always easy to express. Tzonis [1992 p141] speaks of plans which ‘look more like patchwork than real buildings’. More recent space allocation programs try to get around this problem in various ways: by fixation of the plan’s overall shape and the introduction of a fixed circulation system beforehand [Willoughby 1975], by ‘local shape improvements’ on the initially produced plan [Liggett and Mitchell 1981a p285], by intensive interaction with the a human designer [Liggett and Mitchell 1981b], or by producing loose packings of rectangular spaces which need considerable ‘freehand interpretation’ [Shaviv 1987 p199-200].

The main shortcoming of the space allocation approach is that a straightforward optimization of, for example, travel cost is a gross oversimplification compared with the variety of desires and requirements and trade-offs between them, as considered by human designers. Space allocation programs do not incorporate the detailed and domain-specific knowledge possessed by the human expert [Tzonis 1992 pp141-142]. From the 1970’s on many systems have been developed which support human decision making in various architectural subdomains on basis of incorporated architectural knowledge. Such systems are knowledge-based. Two kinds of knowledge-based systems which have received much attention in relation to architecture are the shape grammar and the expert system.

**Shape grammars** • An approach which is very much concerned with aspects of form is that of the *shape grammar* [Gips 1975]. In most shape grammars shapes are defined as collections of finite lines in the horizontal plane. In architecture these two dimensional *line shapes* may represent components at various levels of spatial organization, from furniture to complete building plans. Basically, a shape grammar offers an initial shape and a set of rewriting rules which replace one subshape by another. By subsequent application of rules the initial shape can be transformed into a multitude of end shapes, which together form the language defined by the grammar. A computerized shape grammar allows the user to produce an
end shape by making choices among rules and subshapes to apply them on [Chase 1989; Mitchell et al 1990]. Typically, shape grammars have been developed for limited architectural domains in which there is a considerable stylistic uniformity both in the buildings’ overall composition and at the level of ornamentation. Examples of such domains are the Palladian villa [Stiny and Mitchell 1978], facades in the style of Terragni’s Casa Galliani Frigerio [Flemming 1981] and Frank Lloyd Wright’s prairie-style houses [Koning and Eizenberg 1981]. The main shortcoming of the shape grammar approach is that the architectural knowledge incorporated only concerns stylistic well-formedness, whereas interpretation of a shape’s implications for many commonsensical aspects of performance is left entirely to the user.

**Expert systems** • Systems which do incorporate knowledge of the relation between form and performance have been developed for a variety of architectural subdomains. Typically, these systems either evaluate the performance of formal descriptions proposed by the user or they allow the human expert to describe a design problem and then suggest one or more possible solutions. This means that they emulate certain capacities of human experts and therefore they are often referred to as expert systems. Examples are the HI-RISE system for the structural design of high rise buildings [Maher 1985], the expert system shell BUILD – implemented in the context of the design of retaining walls and of kitchens [Rosenman et al 1986], and BEADS – supporting the selection of materials and constructional systems for a building’s envelope [Fazio et al 1989].

These systems are limited, not by stylistic uniformity of the domain, but by the fact that they perform architectural reasoning only in areas where a relatively large portion of the requirements to be satisfied are definable and quantifiable. This is understandable when realizing that the system must incorporate a sufficiently complete and detailed body of architectural principles in order to produce reliable evaluations or realistic solution proposals. These are often stated in the form of rules, such as ‘if climate is moderate then apply double glazing’. The knowledge base of the experimental BUILD system for example includes approximately 500 rules in relation
to retaining wall design. It is this obligation to make explicit all
the knowledge that plays a role in human problem solving
which is problematic, particularly where problems are complex
shortcomings of the rule-based approach in general, that is,
irrespective of the particular domain. First, there is the
difficulty of acquiring detailed and reliable knowledge from
human experts. Second, rule-based systems do not remember
problems they have dealt with earlier and as a result they do
not learn from their mistakes. Third, they are not robust: when
presented with a problem which does not match any of the rules
they fail to respond.

1.4.2. Precedent-based design

A promising new alternative to incorporating expert
knowledge in the form of explicit rules is to incorporate it,
implicitly, in the form of episodes or cases which are to be
understood as descriptions of earlier experiences in the domain.
Referring to the three shortcomings mentioned above, Slade
[1991 p49] argues:

'The technology of case-based systems directly addresses problems
found in rule-based systems. First is knowledge acquisition. The unit of
knowledge is the case, not the rule. It is easier to articulate, examine, and
evaluate cases than rules. Second is performance experience. A case-
based system can remember its own performance and modify its
behaviour to avoid repeating prior mistakes. Third are adaptive solutions.
By reasoning from analogy with past cases, a case-based system should be
able to construct solutions to novel problems.'

The behaviour of a case-based system is similar to that of the
human expert 'who has a vast specialized experience, has
witnessed numerous cases in the domain, and has generalized
this experience to apply it to new situations' [Slade 1991 p49].
The legal practice of passing judgement on basis of earlier
verdicts and the medical practice of establishing a diagnosis on
basis of experience with previous patients are favourite
examples. This view is consistent with the ideas about the
capacity of human designers to solve the complex and ill-defined problems of architectural design, as expressed in section 1.2.

In recent years the case-based approach has received some attention in relation to architectural design, sometimes under the name of design prototypes or prototype refinement and adaptation [Oxman and Gero 1988; Gero 1990; Oxman and Oxman 1992]. Schmitt [1993] speaks of case-based design systems. Since in the terminology of the present study cases or episodes concern architectural precedents the following discussion will speak of precedent-based design systems.

The central component of a precedent-based design system is a reservoir of precedent descriptions, or precedent base. According to Schmitt [1993 p15] these may be structured as well as unstructured. Structured are for example metric descriptions produced in a specialized drawing editor 'which requests room labels, material descriptions and structural design specifications'. Unstructured are for example scanned images or verbal descriptions of aspects of the building's form and performance. The metric editor allows the input of structured descriptions in the precedent base and it allows the user to adapt such a description in relation to a new design problem after it has been retrieved from the precedent base.

A high expectation about a precedent-based design system is that the user's role is reduced to the specification of the design problem: the selection of a precedent and its adaptation are carried out automatically. A more realistic expectation is that it is the user who selects and adapts precedents, while the system offers support wherever this is possible and useful. Two issues seem to be crucial to such a precedent-based design system:

(1) A sufficiently wide variety of precedents must be available and the system must offer ways of finding the most appropriate one(s).

(2) The system must be able to determine the implications of adapting a precedent for its appropriateness to the design problem which motivated its selection.

Inherent in precedent-based design is the idea that a precedent represents a type – precedents are frequently referred to as prototypes. The adaptation of a precedent may or
may not affect its type. Architectural systems of types seem indispensable in relation to issues (1) and (2).

1.5. Approach of the study

The global methodology of the study can be understood as follows:

**Problem formulation** • The main function of chapter two is to formulate a problem in housing typology. The chapter starts with a review of various existing typological studies, followed by a comparative evaluation. Both the review and the evaluation are focused on the graphical type representations presented in those studies. The problem emerging from the comparative evaluation is the apparent lack of success in defining a type representation which combines the following three qualities: (1) a properly defined syntax and interpretation, (2) a high degree of abstraction and (3) representation of components at a higher level of spatial organization than that of the individual dwelling.

The study intends to demonstrate that it is in principle possible to combine (1), (2) and (3).

**Scaling down the problem** • Chapter three reduces the general problem down to a manageable size. To be able to do this it first develops the basic terminology needed for the discussion of several aspects of the spatial organization of complex residential buildings. Some concepts which are usual in writing about housing such as dwelling or corridor are defined more accurately, new concepts such as storey system and opening are introduced. Next, this terminology allows the specification of several limitations to the discussion in chapters four and five, the most significant one being the limitation to a single level of spatial organization – the basic arrangement of dwellings repeated along a corridor or a vertical circulation axis. The scaled-down problem is that of developing a type representation of such arrangements.
**Figure 1.11** Methodology of the study. The two major components are chapter two which formulates the problem, and the combination of chapters four and five which respectively define a type representation and explore the system of types implicit in it.

**Proposal of a system of types** • Chapter four defines and motivates a type representation of dwelling arrangements. The representation's primitives and their possible relations are specified, and so is the interpretation of those primitives and relations. Given certain reasonable grounds on which arrangements are considered possible, the chapter specifies conditions of well-formedness to be satisfied by any configuration of primitives. These conditions implicitly define a system of types.

Chapter five makes two fragments of this system explicit by enumerating, within certain limitations, types of vertically repeated arrangements and types of horizontally repeated arrangements. Then it carries out two experiments. First, it matches the two ranges of types against a sample of arrangements presented by Sting and several other writers on housing design. This gives us an idea as to which types are apparently considered more relevant than others, and it also reveals the incompleteness of existing systems of types such as the one presented by Sting. Second, the chapter defines certain formal characteristics which can be derived from a type description, and which may have significant implications for the performance of its instances. An attempt is made to explain the apparent popularity of certain types rather than others in
terms of those characteristics.

*Figure 1.12* A type description as proposed by this study. Left: an arrangement of two dwellings which is repeated along the corridors in the Unité d'Habitation. Right: the same arrangement represented with a high degree of abstraction.

**Evaluation** • Chapter six refers to earlier chapters in two ways. First, after summarizing the results of chapters four and five, it speculates on the possibilities of extending those results by developing similar systems of types beyond the limitations specified at the end of chapter three, and beyond the domain of this study. Second, it proposes implementation of the system of basic arrangement types in the framework of *precedent-based design*. This proposal intends to suggest a way in which the type representation's usefulness to architectural education, practice and research—and particularly the advantages of its well-definedness—could be tested.
At several points in chapters three and four characteristics of the spatial organization of residential buildings are assumed to be invariable. Such knowledge originates largely from reviewing vast ranges of precedents as a preparation for this study. However, being able not only to observe a precedent's characteristics but also to understand their motivation requires much domain knowledge to be already present in the mind of the observer. To a certain degree of course one acquires this kind of knowledge in architectural education. Several specialized books on housing design which are mentioned in the following chapters have contributed much as well. Besides containing basic information about precedents, these books express a writer's personal knowledge of design options in the domain – often those writers are experienced designers themselves. Even when criticising some of them the present study frequently benefits from their insights and ideas.

**Six exemplary buildings** • It is a practical impossibility to give a complete and reliable account of the precedents that played a role in forming the ideas presented by this work. No such account is attempted. At those points in the text where it seemed of importance, explicit references to precedents are given.

Six exemplary buildings are used more continuously though, for the purpose of illustrating the various concepts introduced and discussed by chapter three and in order to demonstrate the representation developed by chapter four. These buildings are, in the order of their age:

• A complex city block in the Spangen district in Rotterdam, The Netherlands. This block was designed by *Brinkman* and realized in 1922 [Fanelli 1978 pp43-49].

• The Narkomfin building in Moscow, Russia. The building was designed by *Ginzburg* and *Milinis* and realized in 1928. It is one of the very few housing designs from the period of Russian Constructivism that were actually realized [Palmboom 1979 pp53-55; Kopp 1985 pp71-75].

• A U-shaped city block alongside the Vroeselaan in Rotterdam, designed by *Van den Broek* and realized in 1934 [Van den Broek 1936 pp225-232; Stroink 1981 pp85-90].
• Immeuble Clarté in Geneva, Switzerland. This was the first large residential building by Le Corbusier—in cooperation with Jeanneret—which is actually realized. This was in 1932 [Boesiger 1935 pp66-71; Sumi 1989].

• The Unité d’Habitation in Marseilles, France. The huge building contains more than 300 dwellings and was designed by a large team supervised by Le Corbusier and realized in 1952 [Boesiger 1953 pp189-223; Fondation Le Corbusier 1983]. It served as a prototype for a series of similar buildings realized in France and Germany.

• A tower in the Hansa district in Berlin, Germany. The building, with its characteristic split-level section, was designed by Stokla, Van den Broek and Bakema and realized in 1960 [Joedicke 1963 pp106-110]. Similar towers have been realized in Delft and Kampen, The Netherlands.

\[\text{Figure 1.13 Six residential buildings (building masses highly schematized).}\]

Rather than by geographical and historical diversity, the choice for these six is motivated by the fact that they exemplify
the diversity of spatial organization to be found in the domain. Five of them are among Sherwood’s selection of thirty-two prototypes of modern housing [Sherwood 1978]. The buildings show a variety of circulation systems and many different kinds of dwellings and dwelling arrangements. They also show a wide variety in overall size and external shape, ranging from simple rectangular boxes like the Narkomfin building and the Immeuble Clarté, to the highly complex composition of building masses in the Spangen block.
2. Approaches in housing typology

This chapter reviews six studies which develop systems of types in the domain of housing. Some of them do not explicitly present themselves as typological studies but, for example, as a design or programming method. The intention of the chapter is not to indulge in the diversity and complexity of any of these studies, but to highlight a number of aspects which are thought to be of great importance for a typology's effectiveness as a design supporting tool. The studies have been selected because they give a representative picture of the state of the art in housing typology. They represent two fundamentally different approaches towards housing typology, which allows several useful comparisons.

- The typological handbooks of Sting and Sherwood represent a number of precedent-based typologies. In these handbooks systems of types at various levels of spatial organization are implicit in the ordering of paradigmatic precedents. Occasionally types are described by means of schematized plans and sections.

- The SAR design method, the system of basic types proposed by the SEW, and the so-called programming method are Dutch studies which implicitly develop a system of types— at the level of the individual dwelling or its single storey components— by defining type representations.

- Rectangular arrangements and plan-related graphs, as discussed in a number of closely related British studies, are well-defined type representations. These representations apply at the level of the single storey component of a dwelling.

- In the precedent-based typologies the differences between
types are significant: schematized plans and sections suggest a high degree of abstraction. Most of the representation-based types are not sufficiently abstract and apply at lower levels of spatial organization.

2.1. Precedent-based typologies

This section discusses two housing typologies which represent a large number of similar studies produced mainly during the 1960's and 1970's. Those studies present systems of types which are largely implicit in the ordering of a sample of precedents. What distinguishes these precedent-based typologies from the studies discussed by following sections is that a type's essential characteristics are not systematically described but are largely to be interpreted from the paradigmatic precedents supporting it. This interpretation is often supported by verbal descriptions, or by schematized plans and sections.

- Hellmuth Sting's Grundriss Wohnungsbau introduces the concept of the access unit which is an aggregation of dwellings around a vertical circulation axis or a corridor. At this particular level of spatial organization Sting presents an elaborate system of types and subtypes.
- Roger Sherwood's Modern housing prototypes presents systems of types at three different levels of spatial organization: the building as a whole, the access unit, and the individual dwelling.

2.1.1. Sting's typology of multi-storey housing

Grundriss Wohnungsbau [Sting 1975] consists of two largely independent parts titled 'the floor plan in multi storey housing' and 'the floor plan of the single family dwelling as element of integrated dwelling complexes'. Since the latter of the two is
outside the domain of this study this review only considers the first.

**Access units •** In this first part Sting presents a system of types at one particular particular level of the spatial organization of the complex residential building. He recognizes that residential buildings can be efficiently described in terms of repetitions of *access units*, rather than in terms of repetitions of dwellings. These access units are organized around corridors and vertical circulation axes [Sting 1975 pp10-11, transl. by the author]:

> 'For a closer determination of the elementary forms of housing unambiguous leads present themselves in the type of access. This on the one hand influences the floor plan layout of the individual dwelling and on the other hand determines the mutual connections between dwellings. If one follows the access principle, it can be seen that close neighbourhood relations between dwellings exist, which —solely based on the routing— embody individual arrangements. Those are combinations of similar or mixed dwelling types and should, as a result of the possibility of repeating them, be viewed as the actual basic systems of multi-storey housing.'

The basis of Sting's typology is formed by a large sample of existing access units. The sample is divided according to a distinction between three general categories which are indicated by roman numerals I, II and III. Under category I one finds the access units that are organized around stair-and elevator cores, under category II the units that are organized along corridors, and under category III the units found in buildings with a mixed circulation system [Sting pp11-12, transl. by the author]:

> 'Units with vertical access — so-called walk-up types — are characterized by the stacking of similar groups of dwellings around a communal vertical circulation axis, which may have either a central or a peripheral position. The number of dwellings is limited within a single storey and not in the vertical direction. (...) Units with horizontal access — so-called corridor types — are based on the concatenation of similar dwellings or groups of dwellings along a communal landing, which may have either an internal or a peripheral position. The number of dwellings is limited in the vertical and not in the horizontal direction. (...) Units with vertical and horizontal access are based on an access principle which combines the characteristics of basically vertically and
basically horizontally structured systems and thereby leads to a stronger interweaving of both vertical and horizontal neighbourhood relations."

Access units are presented by means of floor plans, drawn at a standard scale (1:200) which allows the indication of individual rooms and their furnishing. Under type II transversal sections are occasionally added. The graphic presentation is combined with a short verbal description which typically includes the designer's name, the buildings geographical location and occasionally some remarks about aspects of performance, such as flexibility of use or efficiency of internal routing.

**Figure 2.1** Two vertical access units under subtype I-1.2.2 (source: Sting 1975).

**Ordering and codification** • Under types I, II and III access units are ordered hierarchically and codified by means of a numbering system. The first digit indicates a general subtype, the second digit indicates a more specific subtype, and so on. Usually the final digit indicates the particular unit itself. Thus the most specific subtypes are illustrated with at least one, but often with several paradigmatic access units.

The implicit classification features of these codes are occasionally confirmed and complemented by verbal
I. Units with vertical access

1. Sections facing two directions, extensible along one axis
   1.1. Internal staircase
       1.1.2. Access by stair and lift, in groups of two
       1.1.3. Access by stair and lift, in groups of three
       1.1.4. Access by stair and lift, in groups of four
       1.1.5. Access by stair and lift, in groups of five
   1.2. External staircase
       1.2.1. Access by stair and lift
       1.2.2. Access by stair and lift, in groups of two
       1.2.3. Access by stair and lift, in groups of three
       1.2.4. Access by stair and lift, in groups of four
   1.3. Staggered sections

2. Sections facing all directions, extensible along two or more axes

3. Detached units
   3.1. Circular buildings and derivatives
   3.2. Square and rectangular units and derivatives
   3.3. Triangular units and derivatives
   3.4. Y-shaped, T-shaped, cross-shaped and star-shaped units
   3.5. Freely shaped units

II. Units with horizontal access

1. Single storey units
   1.1. Lateral corridor
   1.2. Central corridor
   1.3. Double corridor, central core plan

2. Units of two or more storeys (so-called maisonettes)
   2.1. Units with external corridor
       2.1.1. Longitudinal stairs
       2.1.2. Transversal stairs
       2.1.3. Landing and spiral stairs
   2.2. Units with internal corridor

3. Split-level units
   3.1. Units with external corridor
   3.2. Units with internal corridor

III. Units with vertical and horizontal access

1. Units with external corridor
2. Units with internal corridor

Figure 2.2 Types and subtypes in the first part of Grundriss Wohnungsbau (after Sting 1975).
descriptions such as ‘I-1 Sections facing two directions, extensible along one axis’ or ‘I-1.1.2 Access by stair and lift, in groups of two’. In addition the more general types are often described by means of an abstract graphic schematization [Sting 1975 pp11-12].

**Schematized plans and sections** • The schematized plans corresponding to the general types under I indicate the access unit’s orientations and possible directions of repetition, as well as the position of the circulation core. The schematized sections corresponding to the general types under II indicate the unit’s orientations, the position of the corridor and the storeys occupied by individual dwellings. No schematizations are offered under III.

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**Figure 2.3** Six schematic split level sections under type II-3 (after Sting 1975). Corridors are indicated in black, the internal routing of dwellings is indicated by arrows. Individual access units are identified by means of an independent coding system.

In general the choice as to which types are described by a schematic plan or section and what information is expressed in those drawings seems to have been a rather opportunistic one. On two occasions however Sting presents a more systematic
range of schematic sections: three distinct ways of positioning double storey dwellings (commonly referred to as duplexes or maisonettes) on top of each other, and six distinct split level sections [Sting 1975 p46, p52].

In these schematized sections the internal routing of dwellings is shown as well. Distinct arrangements of dwellings around a corridor and distinct vertical repetitions of those arrangements can be observed. Rather than being merely the product of a schematization of certain available cases, the sections—just like Durand’s diagrams—suggest a systematic combination of basic elements. This impression is supported by the presence of an additional coding which identifies individual access units, and which is entirely independent from the one mentioned earlier. Every number or character in a code is the value of a particular parameter. The first parameter indicates the total number of storeys in the access unit. The second one indicates the number of dwellings present in the section. Several combinations of those values are shown.

2.1.2. Sherwood’s housing typology

Where Grundriss Wohnungsbau presents a system of types at one particular level of spatial organization, Sherwood’s Modern housing prototypes presents three separate systems of types at distinct levels of spatial organization:

(1) A system of types which is implicit in the ordering of thirty-two prototypical precedents in the second part of the book. Types are indicated by the terms detached and semidetached housing, rowhousing, party-wall housing, block housing, slabs and towers. Since the distinctions between them are of a very general nature and since their illustration with paradigmatic precedents seems to be rather opportunistic, this system will not concern us any further.

(2) A system of building types, apparently at the level of access units, as defined by Sting. Three general types are distinguished: private access, multiple vertical access and corridor buildings. Under this last type a hierarchy of subtypes
are described by phrases like 'double-loaded corridor systems' or 'corridor every second floor' and by schematized sections similar to the ones presented by Sting. Among those sections many of the possible combinations of an external or internal corridor with a package of one, two or three storeys can be found [Sherwood 1978 pp17-24].

![Diagram](image)

**Figure 2.4** Three subtypes of 'double-loaded corridor systems' (after Sherwood 1978). Left: 'corridor every floor', middle: 'corridor every second floor', right: 'corridor every third floor'.

(3) A system of unit types, apparently at the level of the individual dwelling [Sherwood 1978 pp2-16]. Just like the building types, these unit types are described by short phrases, such as 'double-orientation unit, open ended' or 'interior kitchen, transverse stair', and by a graphic schematization. Three general types are distinguished by their directions of orientation – these are described by schematized plans in which directions of orientation are indicated by arrows. The term orientation is not explicitly defined. Sherwood speaks of a unit having an orientation towards one of its sides when it 'opens' or 'faces' to this side [Sherwood 1978 p3]. A number of subtypes are distinguished by the position of core elements such as stairs, kitchens and bathrooms. These subtypes are described by simplified but at certain points highly detailed floor plans showing complete room layouts. In fact this schematization is almost at the level of abstraction at which precedents themselves are described.

Building types as well as unit types are not explicitly related to the sample of thirty-two prototypical precedents mentioned earlier. They are illustrated with a variety of other precedents which are given in the form of original plans and sections. Most
of the subtypes are only illustrated with a single precedent.

**Figure 2.5** Unit types (after Sherwood 1978). Above: three general types, distinguished on basis of their directions of orientation. Below: subtypes distinguished on basis of the position of the stair, bathroom and kitchen.

2.2. Representation-based typologies

This section discusses three Dutch studies proposing systems of types which are implicit in more or less abstract representations of architectural form. The syntax and interpretation of type descriptions is specified in general terms, independently from any particular instances of these types. These representation-based typologies are developed with the
intention to support architectural design in a much more direct way than the more conventional typologies discussed by the previous section. Two of them are presented in the form of a method by which types are to be generated, evaluated and refined into more detailed descriptions.

- The 'SAR method' intends to support the design and evaluation of support structures in the domain of housing. A support structure is understood as a building structure which allows the realization, alteration and removal of dwellings independent from one another.
- The sector group is metric representation of a support structure. It is defined by a distribution of longitudinal zones which coordinate the depth and transversal position of spaces, and by the specification of which parts of those zones may be occupied by spaces.
- The basic variation is a representation of the layout of a dwelling's more important spaces in relation to a particular sector group. However, its highly simplified visualization suggests that the basic variation can be seen as a type representation.
- 'Basic types for housing' is a system of types defined by two independent and highly abstract representations of dwellings. In the WK pattern the position of the living room and the kitchen is represented in very general terms. A graph is defined which represents access relations between only four of the dwelling's components.
- The 'programming method' presents several modest systems of types at higher levels of spatial organization. The differentiated dwelling types describe dwellings as combinations of several single storey components.
- The basic pattern is a dimensionless representation of the spatial organization within such single storey components. A basic pattern can be refined into a class of fully dimensioned layouts of functional regions. These are referred to as basic layouts.
2.2.1. The SAR method

In 1965 the Stichting Architecten Research (Foundation for Architect’s Research) introduced a method for the design of supports widely known as the ‘SAR method’. The concept of the support or support structure was introduced by Habraken – one of the founders of the SAR [Habraken 1961 p84]:

'I propose this definition: A support structure is a construction which allows the provision of dwellings which can be built, altered and taken down, independently of the others.'

The main concern of the SAR method is to enable the evaluation of support structures – which are determined by the size and position of physical components such as structural walls – with respect to the degree of freedom they allow in choosing layouts of spaces for individual dwellings. The method is not only meant to serve a designer’s personal explorations but it is expected to provide a means of communication between various partners involved in the design process. It offers representations at different levels of spatial organization. The present review concentrates on two of these:

- The **sector group** which is a representation of support structures.
- The **basic variation** which is a representation of space layouts.

The sector group is a metric description of a support structure. A basic variation describes the position of a dwelling’s more significant spaces in relation to a dimensionless version of a particular sector group. Thus a basic variation can be

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1 Instead of rooms the SAR speaks of *spaces*. A space is a rectangular region minimally needed to accommodate furniture layouts appropriate to certain activities – the sides of this rectangle do not necessarily coincide with physical boundaries such as walls.
understood as describing a class of space layouts. The user of the method is presented with various strategies to explore the system of types implicit in those representations. An elaborate presentation and illustration of the SAR method is found in *Variations: the systematic design of supports* [Habraken et al 1976] – the following discussion refers to this work.

In the following subsections the sector group and the basic variation are discussed more thoroughly. Judging from published experiments with the SAR method [SAR 1967; Habraken et al 1976; Habraken 1981] the scope of these representations seems to be limited to linear and orthogonally organized support structures. The sector group describes a certain length of such a linear structure, to be occupied by an individual dwelling. It is significant that the assumption of linearity defines a situation in which view and natural light are only continuously available at two opposite sides of a building. The limitation to orthogonality is sometimes denied but little evidence is shown as to how non-orthogonal cases would actually be dealt with.

2.2.2. The sector group

The constraints imposed by the support structure upon a dwelling’s layout of spaces are described by the sector group. For a proper explanation two more fundamental concepts must be introduced first.

**Zone distribution** • Constraints upon the transversal size and position of spaces are embodied by a combination of longitudinal zones called a zoning or zone distribution. In relation to a particular zone distribution additional constraints upon the longitudinal size and position of spaces define sectors, which are longitudinal portions of zones. In spite of frequent and elaborate attempts to clarify them these concepts remain somewhat obscure. Perhaps the easiest way to understand them is through an example which is constantly used in *Variations: the systematic design of supports*. In the example there are
altogether five zones the middle three of which are labelled $\alpha$, $\beta$ and $\alpha$ respectively.

![Diagram of zones and margins](image)

**Figure 2.6** A zone distribution in which one $\beta$-zone is positioned in between two $\alpha$-zones (after Habraken et al 1976). The depth of zones and margins is given in meters.

In fact a total of four types of zones are defined: the $\alpha$-zone, the $\beta$-zone, the $\gamma$-zone and the $\delta$-zone. The latter two are reserved respectively for spaces for public circulation such as corridors, and for exterior private spaces such as gardens. The size and position of interior private spaces is coordinated by the $\alpha$- and $\beta$-zones. Zones are always at a certain distance from one another. The in between distance is referred to as a margin. A margin is named after the two zones that it separates: in between an $\alpha$-zone and a $\beta$-zone lies an $\alpha\beta$-margin. There is one general rule with respect to the position of spaces in relation to the zoning:

- In the transversal direction every space begins and ends in a margin [Habraken et al 1976 p56]. In other words, spaces may not partially but only fully intersect with zones.

Spaces are treated as simple rectangles. The SAR method
offers a technique of determining which arrangements of furniture are appropriate to particular activities and, consequently, what is the minimal depth and width of a space accommodating them [Habraken et al 1976 pp60-61]. The method offers an elaborate system of labels indicating the activities which a space accommodates [Habraken et al 1976 pp62-64].

A general distinction is the one between general purpose spaces (living rooms), special purpose spaces (bedrooms, dining rooms) and service spaces (bathrooms, toilets). The original Dutch text qualifies the first two as habitable spaces [Boekholt et al 1974 p56]. The constraints imposed by the zone distribution upon the size and position of habitable spaces and of service spaces are the following:

- Habitable spaces intersect with at least one $\alpha$-zone.
- Service spaces intersect with at most one zone – either $\alpha$ or $\beta$.

![Diagram of zone distribution](image)

**Figure 2.7** The most current positions of private spaces in the $\alpha\beta\alpha$ zone distribution (after Habraken 1976). Habitable spaces are light grey, service spaces are dark grey.

Since habitable spaces need view and natural light an $\alpha$-zone is positioned close to the facade. A $\beta$-zone may be positioned at any depth from the facades.

**Sectors** • A sector is a certain length of a zone, in which no
non-removable physical obstacles are present. In the majority of the examples a sector corresponds to the free length between transversal structural walls. However, the scope of the SAR representations is not limited to cases where structural walls are transversal, as demonstrated in the example ‘The longitudinal support system’ [Habraken et al 1976 pp156-168].

In the previously introduced $\alpha\beta\alpha$ zone distribution three structural walls intersect with all zones. This produces a total of six sectors: four $\alpha$-sectors and two $\beta$-sectors. If these sectors are to be occupied by spaces of one and the same dwelling they form a sector group.

![Diagram of sector groups]

**Figure 2.8** A sector group (after Habraken et al 1976). Six sectors are bounded by three structural walls.

### 2.2.3. The basic variation

Once the minimal depths and widths of spaces with particular labels have been determined the SAR method suggests that the user investigates, for a particular sector group, the possible layouts of spaces which occupy an $\alpha$-zone.
With the occasional exception of an entrance these are habitable spaces. A layout must satisfy the following conditions:

- Spaces do not overlap. As a result the sum of minimal widths of the spaces that occupy one and the same sector may not exceed the sector's width.
- The depth of a space may not exceed the total depth of the zones that it occupies, together with their margins. Such an excess would be in conflict with the general positioning rule presented earlier (subsection 2.2.2).

![Diagram of a layout with labels](image)

**Figure 2.9 A basic variation (after Habraken et al 1976). Left:** a distribution of spaces in a sector group. **Upper right:** a dimensionless description of this distribution. **Lower right:** interpretation of labels.

A particular distribution of spaces in a sector group is called a basic variation. Basic variations are visualized on basis of a 'simplified diagram of the sector group'. In this diagram margins are reduced to single lines and the particular dimensions of zones and sectors are ignored. The distribution of habitable spaces is indicated by placing the corresponding functional labels in the diagram. If a living space occupies more than one zone – commonly an $\alpha$-zone and the neighbouring $\beta$-zone, this is indicated by an arrow crossing the line that represents the $\alpha\beta$-margin.

**Computer aided exploration** • Even though the SAR method does not explicitly present it in such terms, this dimensionless version of the basic variation is a type in the sense
that it describes a class of space layouts in a particular configuration of sectors.

![Diagram showing variations in space layouts](image)

**Figure 2.10** A range of six basic variations (after Habraken et al 1976). The position of K1/E is constant while L, B3 and B1/B1 are distributed over the three remaining \( \alpha \)-sectors in all possible ways.

Given a dimensioned sector group and given a set of labelled spaces the minimal dimensions of which are constrained, all possible basic variations can be enumerated. A computer program called SAR70 has been developed which supports the evaluation of zone distributions, of individual sectors, and of complete sector groups by calculating possible ways in which they allow spaces to be positioned [SEW 1970; Bax et al 1973; Amkreutz and Dinjens 1976]. Where sector groups are concerned the program produces complete ranges of basic variations.

![Diagram showing basic and subvariations](image)

**Figure 2.11** Basic variation (left) and a subvariation (right) which demonstrates its feasibility (after Habraken et al 1976).

**Subvariations** • Whether or not a basic variation is feasible cannot be determined by the positioning rules alone. It might be
the case for example that an allowed layout of spaces does not leave sufficient room for additional non-habitable spaces, or leads to an inefficient routing. Therefore the basic variation must be developed into at least one subvariation in order to demonstrate its feasibility [Habraken et al 1976 p91]. The layout of spaces is transformed into one of rooms, much like a conventional architectural plan. The simple rectangular shape of spaces may be amended and non-habitable rooms may be inserted into the layout. The method provides an elaborate vocabulary of symbols representing separation walls, doors, various kinds of furniture, sanitary equipment, cupboards etc. [Habraken et al 1976 p116, p118]. These are to be positioned in compliance with a detailed system of coordinating zones, a practice which has become widely known as modular coordination.

2.2.4. Basic types for housing

The idea of a dimensionless representation of room layouts has been pursued in other Dutch research as well. The Studiegroep Efficiënte Woningbouw (Research group Efficient Housing) proposes a diagram which reduces a dwelling’s plan to a 2×2 matrix in which only the position of the living space (W) and that of the cooking space (K) is indicated. A vocabulary of primitive elements is offered from which WK patterns are to be composed [SEW 1967, 1969]. In addition to the WK pattern, which retains the rough geometry of the plan, a second representation is offered. The routing of plans is represented by an access graph with a high degree of abstraction. The vertices of this graph represent rooms or combinations of rooms, while an edge joining a pair of vertices represents the presence of direct access between two such (combinations of) rooms. Only four components of a dwelling are represented: the living room, the kitchen, the other habitable rooms and the entrance.

1 The SEW study does not speak of an access graph but of a relation pattern [SEW 1969 p1235]. However, this pattern seems to be defined as a graph whose edges represent access relations.
**Figure 2.12** Above: the WK pattern (after SEW 1969). Left: vocabulary of primitives and some indication of their interpretation. Right: a general pattern (A) indicating the position of living space and cooking space next to one another. In patterns (a), (b), (c) and (d) the position of those spaces is further specified.

Below: the access graph (after SEW 1969). Left: interpretation of vertex-labels and edges. Right: a general graph (1) for which only the access relations between W, T and K are relevant, and three more specific graphs (1.1), (1.2) and (1.3) in which the fourth component ‘other habitable spaces’ is represented as well.
Figure 2.13 Matrix overview for walk-up flats (source: SEW 1969). Only four basic types—to be understood as particular combinations of WK patterns and access graphs—are supported by the sample; the first number in the corresponding cell indicates the number of projects, the second one indicates the total number of instances in those projects. If a cell is crossed by a diagonal line the basic type is considered impossible for the category of walk-up flats.
The aim of the SEW project is not only to provide a means of classification of existing dwellings, but also to be able to trace down 'possibly valuable floor plans, not- or scarcely used up till now' [SEW 1969 p1234]. Additional aims were the support of communication among the parties involved in the design process a well as a more explicit formulation of the building programme.

A comprehensive system of WK patterns and access graphs has been developed. In the SEW report a matrix overview is presented, the columns in which correspond to the nine distinct access graphs and the rows in which correspond to the twelve distinct WK patterns. Distinct pairs of them are considered to describe basic types. In the overview a few combinations of WK patterns and graphs are marked as impossible 'on theoretical grounds' [SEW 1969 p1235]. A number of empirical explorations have been carried out on basis of the system of basic types [Priemus 1969; Priemus and Van Elk 1971 pp56-61]. For the general categories rowhouses-maisonettes, corridor flats and walk-up flats it is explored which of the basic types are supported and which are suggested to be popular by the numbers of instances found in the Dutch housing production of 1965, 1966 and 1967.

2.2.5. The programming method

Support of communication between the partners involved in the planning and design of housing and a more explicit formulation of the building programme were also the main goals of a more rigorous approach known as the programmeermethode (programming method). This method, the development of which has been sponsored by the Dutch Ministry of Housing, is presented as a means of communication between future inhabitants, the building industry, and the government [Bergman et al 1974 p6, transl. by the author]:

'As an attempt towards such a means of communication we are presenting a programming method: this method serves to cross the no man's land in between formulation of the programme and architectural design, where at present numerous fundamental decisions are made in an obscure manner.'

The programming method shares many characteristics with the SAR method. Representations at different levels of abstraction are defined. Again a central point of attention is the variety of room layouts allowed by a particular building structure or, more generally, by particular constraints upon the overall width and depth of a dwelling plan. There is a fundamental difference however between the respective methods of exploring this variety. In the SAR method a fully dimensioned support structure forms the point of departure. Basic variations allowed by this structure are then generated either by hand or with help of the computer. This amounts to a trial-and-error approach the success and efficiency of which depends a great deal on the user's a priori insights as to which support structures are more promising then others.

In the programming method a dimensionless description of a dwelling's room layout referred to as basic pattern forms the point of departure. Once constraints upon the depth and width of individual functional regions have been determined, a set of dimensioned plans referred to as basic layouts can be generated. Computer programs are offered which assist the user by producing ranges of basic patterns, as well as ranges of basic layouts consistent with particular basic patterns.

At higher levels of spatial organization a couple of rather sketchy systems of types are presented. Let us first have a quick look at two of them.

**Horizontal repetition types** • The horizontal repetition of dwellings is likely to constrain the number of its sides at which view and natural light is in principle available. The programming method offers an overview of diagrams in which, as we have seen in the SEW study, a dwelling is represented by a square with its open and closed sides distinguished, as well as its entrance side. If rotated or reflected versions are ignored there are twelve distinct types in all.
Figure 2.14 Above: horizontal repetition types (after Bergman et al 1974). Continuous and dashed lines represent closed and open sides respectively; the arrow indicates the entrance side.

Differentiated dwelling types • Seven differentiated dwelling types are described by schematized sections in which the individual dwelling is represented by a configuration of rectangles [Bergman et al 1974 pp16-17]. Those rectangles represent the single storey components of multi storey dwellings. Three basic situations are distinguished with respect to the relative position of two such components: the difference between their respective vertical positions may be (1) less than one storey height, (2) equal to one storey height, or (3) more than one storey height. A significant merit of these schematized sections lies in the fact that they make it clear which are the actual components of a dwelling, the internal organization of which is described by a basic pattern or a basic layout.

2.2.6. Basic pattern and basic layout

The basic layout is a fully dimensioned loose packing of functionally labelled regions in a bounding rectangle. It represents the internal organization of a single storey component of a dwelling. The basic pattern describes a class of basic layouts by ignoring their dimensions. The basic pattern is a matrix which enables the indication of fundamentally different positions of functional regions relative to one another, and relative to the open and closed sides. This matrix may have any number of rows and columns. The following discussion assumes a 3×3 matrix with two opposite open sides for the purpose of illustration.

A position in the matrix is occupied by at most one functional label. Such a label represents the activities accommodated by a particular functional region. The interpretation of the relative position of functional labels in the matrix is largely implicit in the method by which a basic pattern is refined into a basic layout. The following two rules seem to apply with respect to the position of functional labels and functional regions relative to each other:

• If in a basic pattern two functional labels are positioned in the same row, then in every corresponding basic layout there is
a longitudinal zone with which both corresponding regions intersect.

- If in a basic pattern two functional labels are positioned in the same column, then in every corresponding basic layout there is a transversal zone with which both corresponding regions intersect.

\[
\begin{array}{c|c}
Z &=& \text{living/dining} \\
S3 &=& \text{sleeping parents} \\
S &=& \text{sleeping children} \\
T &=& \text{entrance} \\
NC &=& \text{bathroom/WC} \\
BG &=& \text{storage} \\
K &=& \text{cooking} \\
\end{array}
\]

\[
\begin{array}{c|c}
Z & S3 \\
NC & BG \\
K & T & S \\
\end{array}
\]

\[
\begin{array}{c|c}
Z & S3 \\
NC & BG \\
K & T & S \\
\end{array}
\]

\[
\begin{array}{c|c}
NG & K \\
S & \\
\end{array}
\]

\[
\begin{array}{c|c}
longitudinal zone & transversal zone \\
\end{array}
\]

**Figure 2.15** Above: the basic pattern (after Bergman et al 1974). Left: interpretation of functional labels. Right: seven labels positioned in the matrix. Dashed lines indicate open sides, arrow indicates entrance side.

Below: interpretation of the relative position of functional labels in a basic pattern (after Bergman et al 1974). The regions labelled K and S intersect with the same longitudinal zone, those labelled K and NC intersect with the same transversal zone.

There is also an apparent rule with respect to the position of functional regions relative to the four sides of the plan:

- If in a basic pattern two functional labels are bordering on one and the same—open or closed—side, then in every corresponding basic layout the corresponding regions have a side collinear with the corresponding side of the bounding
Computer aided exploration • Exploration of the system of types which is implicit in these representations is supported by two computer programs. For a given a matrix and a given set of labels, the first program produces the complete range of basic patterns which satisfy certain user-specified constraints with respect to the positions that may be occupied by particular labels [Bergman et al 1974 pp29-30].

![Diagram of two layouts](image)

**Figure 2.16** Two basic layouts width minimal depth and width (after Bergman et al 1974). Both are consistent with the basic pattern shown in the previous figure. In both layouts functional regions have the same sizes. Left: regions labelled BG and Z intersect with a transversal zone. Right: regions labelled BG and Z intersect with a longitudinal zone. In both cases there is a minimal distance between them (double arrow) which is motivated by the wish to provide access to S3 without forcing other regions to be passed through.

Given certain minimal depths and widths of functional regions as well as certain minima to the distances between them, the second computer program produces a set of basic layouts which are consistent with a particular basic pattern [Bergman et al 1974 pp68-85]. The additional constraints upon the distances between regions are to make sure that sufficient space for circulation is left over in between them. If two functional labels are neither positioned in the same row nor in the same column, there are three possibilities with respect to the relative position of the corresponding functional regions: (1) the
regions intersect with one and the same transversal zone, (2) they intersect with one and the same longitudinal zone, or (3) neither of the two is the case. Thus in basic layouts consistent with a particular basic pattern there may be differences with respect to the occurrence of situation (1), (2) or (3) for certain pairs of regions. Every pair of basic layouts produced by the program are distinct in this sense. They are minimal in the sense that neither their overall width nor their overall depth can be reduced without forcing regions to overlap or violating the constraints upon their mutual distances.

By producing a complete set of minimal basic layouts, it can be determined which are the minimal distances between facades and between transversal structural walls if a certain basic pattern is to be allowed. This provides interesting information in relation to the formulation of building codes, or the choice in favour of particular kinds of building structures [Bergman et al 1974 p5]. The basic pattern as such is explicitly considered a means of communicating a design option. It is suggested that at the programmatic stage of the process the partners involved would communicate about the desirability or undesirability either of functional labels at particular positions in a pattern, or of entire patterns themselves [Bergman et al 1974 pp24-33].

**Differences with the SAR method** • When comparing the basic pattern with the basic variation proposed by the SAR, two differences are worth mentioning. First, the basic pattern is explicitly defined as a dimensionless representation, whereas the basic variation is only defined in relation to a specific dimensioned sector group. The user may generate basic patterns without having yet determined the overall sizes of corresponding layouts or sizes of functional regions. Second, it is recognized by the SAR that a distinction can be made between those spaces which, as a result of the kind of activities they accommodate, must be lined up close to the facades and those that may be positioned deeper inside the building. This distinction corresponds largely to the one between habitable and non-habitable spaces. The basic pattern only ignores circulation spaces.
2.3. A well-defined typology of dwelling plans

This section discusses a number of closely related studies which are produced mainly by English research from the 1970's on. Together these studies define and explore abstract representations of architectural plans which distinguish themselves from those discussed by the previous section, by the fact that both their syntax and their interpretation are explicitly and unambiguously defined. The representations are defined for architectural plans in general but the studies reviewed here consider only plans of a limited number of rooms. It is obvious that they concern first of all the domain of housing.

- The rectangular arrangement represents a floor plan as a close packing of rectangles, or rooms, within a bounding rectangle. If the sizes of those rooms are ignored this yields an abstract representation referred to as the dimensionless arrangement.

- In relation to the rectangular arrangement two graphs can be defined. Edges in the adjacency graph represent the presence of a wall segment shared between rooms, and edges in the access graph represent the fact of such a wall segment being permeable with respect to human circulation.

- The computer aided enumeration of dimensionless arrangements has lead to catalogues in which arrangements are listed up to a certain number of rooms. In Bloch's catalogue arrangements are ordered hierarchically according to several characteristics which are considered significant from a designer's point of view.

- Empirical explorations have been carried out based upon derivation of dimensionless arrangements and access graphs from samples of existing dwelling plans. Apparent constraints upon accidental characteristics of the plans are discovered in relation to particular graphs.
2.3.1. Rectangular arrangements

The idea of representing a floor plan as a ‘mosaic of rectangles’ is presented at least as early as 1971 in *The geometry of environment* [March and Steadman 1971 p269]. In later work a range of synonyms for this representation emerges such as dissection, rectangulation, close-packing of rectangles and rectangular arrangement. The present study adopts the latter term. The rectangular arrangement is defined as follows:

**Dimensioned rectangular arrangement** • A rectangular arrangement consists of one or more rectangles closely packed within a bounding rectangle. Close packing means that these component rectangles do not mutually overlap and no space is left over in between them.

![Figure 2.17 Extreme left: dimensioned rectangular arrangement (after Steadman 1983). Left: decomposition into rooms; right: decomposition into walls; extreme right: perpendicular walls meet at junctions (encircled), a wall segment is a stretch of wall from one junction to the next, rooms (b) and (c) are adjacent.](image)

The rectangular arrangement is a configuration not only of rooms but also of walls, wall segments and junctions. An important relation between rooms, to which we will return, is the fact of their adjacency: if two rooms coincide with one and the same wall segment they are said to be adjacent.

The rectangular arrangement ignores wall thicknesses, minor wall crankings, cupboards, doors and windows. The room, as a primitive of the representation, does not necessarily correspond to a room in the conventional sense of the word [Steadman 1983 p14]. In the example below it can be seen that
walls, as primitives of the rectangular arrangement, do not always represent actual physical separations. If a room in an actual plan has a shape more complex than a simple rectangle it is represented by two or more rooms in the arrangement.

![Figure 2.18](image)

**Figure 2.18** Interpretation of walls and rooms. Left: an actual floor plan. Right: rectangular arrangement superimposed upon the plan. Wall thickness, cupboards, doors and windows are ignored. Stair and hallway—though not spatially separated—are represented by two rooms. Because of its L-shape the living room can represented by two rooms in two alternative ways (dashed lines).

**Dimensionless arrangements** • The dimensioned rectangular arrangement preserves information about the size of rooms: it is a metric representation. Dimensions are preserved efficiently by means of a grating [March 1976; Mitchell et al 1976 pp38-40].

Given a rectangular arrangement, the corresponding *minimal rectangular grating* is formed by a combination of lines that are collinear with the walls of the arrangement. For every wall there is precisely one such grating line and for every grating line there is at least one wall. In order to preserve sizes it is sufficient to attach metric values to the grating's rows and columns. A *dimensionless* rectangular arrangement ignores metric information. This is commonly visualized by attaching an arbitrary unit size to the grating’s rows and columns. A dimensionless arrangement is in fact a class of rectangular
arrangements which are mutually different only with respect to their dimensions [Mitchell et al 1976 pp38-41; Steadman 1983 pp10-11, p20].

![Diagram of gratings superimposed on a rectangular plan](image)

**Figure 2.19** Gratings superimposed on a rectangular plan (after Mitchell et al 1976). Extreme left, left and right: gratings have the same number of rows and columns but are dimensioned in different ways. Extreme right: in the dimensionless arrangement sizes are irrelevant, which is shown by the attachment of arbitrary unit sizes.

2.3.2. Plan-related graphs

Graphs and their use in the representation of arrangements in the horizontal plane are the subject of a well-established body of mathematical theory known as graph theory. In relation to architectural plans two kinds of graphs are frequently used.

**Adjacency graph** • A higher degree of abstraction than that of the dimensionless arrangement is established by eliminating information on the orientation of wall segments. The information then retained is purely topological: only the fact of adjacency between rooms is represented. This information can be expressed elegantly by means of a graph. In the adjacency graph a vertex represents a room and an edge joining two vertices represents the occurrence of a wall segment shared between two rooms [Steadman 1973 p161, 1983 p61]. An adjacency graph represents a class of rectangular arrangements which are mutually different only with respect to their pattern of adjacencies. On basis of a more general interpretation of adjacency the definition of the adjacency graph
can be generalized for any arrangement of contiguous regions in the horizontal plane [Steadman 1983].

**Figure 2.20** Adjacency graph (after Steadman 1983). Left: arrangement with four rooms. Middle: adjacency graph superimposed upon the arrangement, additional vertices represents exterior regions (N, S, W and E) surrounding the arrangement. Right: if exterior regions are ignored only internal adjacencies are represented.

It is usual to depict a vertex as a point or small circle and an edge as a line connecting two such points. How an adjacency graph is depicted is not entirely trivial. Adjacency graphs must be planar which means that they have an embedding in the plane. A planar embedding is a way of drawing the graph so that no pair of its edges cross [Harary 1969 pp102-125; Steadman 1973 p161]. For a particular adjacency graph there may be several distinct embeddings. An embedded graph divides the plane into regions, or faces. These have a one-to-one correspondence to the junctions in a rectangular arrangement.

It can be tested not only whether a graph is planar [Harary 1969 pp109-113] but also wether an embedded graph does represent rectangular arrangements [Steadman 1983 pp100-104]. This means that there is a criterion for the well-formedness of adjacency graphs, not only with respect to plans or maps in general, but also in the narrower context of rectangular arrangements.

**Access graph** • In the access graph all rooms are represented by vertices. An edge represents the fact that the
wall segment shared between rooms is permeable with respect to human circulation: it contains one or more doors or similar openings [Steadman 1983 pp74-75; Hillier and Hanson 1984 pp147-148].

![Diagram of access graph]

**Figure 2.21** Access graph (after Steadman 1983). Left: plan in which doors are indicated. Middle: access graph superimposed upon the plan. Right: if exterior regions (N, S) are ignored only permeability of internal wall segments is represented.

In the rectangular arrangement rooms are closely packed, so that travelling from one room to another without visiting an intermediate one is only possible if those rooms are adjacent. Therefore, the access graph tells us which rooms have to be adjacent as a result of the presence of a direct access relation between them. Assuming that all the rooms in an arrangement indeed accommodate human activities the access graph must be connected, that is, it may not consist of two or more disconnected components [Harary 1969 p13; Steadman 1983 p75]. Since their vertices represent the same rooms the access graph is a spanning subgraph of the adjacency graph. Then, in the context of the rectangular arrangement, a criterion for syntactical correctness of access graphs is available as well. This is a fundamental difference with the access graph presented by the SEW (subsection 2.2.4).
2.3.3. Enumeration of arrangements

The fact of their syntactical well-definedness enables the controllable generation, or enumeration, of all dimensionless arrangements up to any maximum number of rooms. From the resulting complete range of arrangements a complete range of corresponding adjacency graphs can be derived.

![Diagram of arrangements](image)

**Figure 2.22** Beginning of Steadman's catalogue (source: Steadman 1973).

Arrangements are intended to be dimensionless. Ordering is first according to number of rooms and second according to number of internal adjacencies. For some of the graphs no corresponding arrangement exists.

**Steadman’s catalogue** • Steadman [1973 p164] suggests that such complete ranges of type descriptions could be presented in the form of a catalogue out of which the designer would select those fit to his particular intentions. In the same 1973 article a catalogue is presented in which all dimensionless
arrangements and all connected planar graphs are listed up to a maximum of six rooms. In this catalogue arrangements and graphs are ordered simultaneously according to two implicit characteristics. The primary ordering is according to number of rooms, the secondary ordering according to the number of internal adjacencies. This first enumeration already made it clear that the number of arrangements—even when mirrored and rotated versions or isomorphs are ignored— as well as the number of corresponding graphs grows rapidly with the number of rooms ($p$). Steadman [1973 p166] calculates a number of 117 arrangements for $p = 6$, isomorphs and aligned arrangements (in which grating lines occur with which two or more walls coincide) being ignored.

In view of such numbers it is understandable that algorithms have been developed which enable the computerized enumeration of dimensionless arrangements for larger numbers of rooms [Mitchell et al. 1976 pp42-46; Flemming 1978 pp218-223; Bloch 1978; Krishnamurti and Roe 1978]. The enumeration programs developed by Bloch and by Krishnamurti and Roe were tested up to $p \leq 9$ and $p \leq 10$ respectively [Bloch and Krishnamurti 1978]. The number of non-aligned arrangements for $p = 10$ was found to be close to half a million — 423,724 to be exact.

**Bloch's catalogue** • In a catalogue developed by Bloch arrangements are listed up to $p = 8$ [Bloch 1979]. Arrangements are ordered hierarchically according to a number of characteristics which are thought to be significant from a designer's point of view.

1. There is a division into large sets of arrangements having the same number of rooms ($p$). Those sets are listed according to increasing $p$.
2. Such a set is subdivided into grid sets containing arrangements with the same grating size ($l, m$), where $l$ is the number of columns and $m$ the number of rows. Grid sets are listed according to an increasing product $lm$.
3. A grid set is divided according to the number of fronts ($f$) of arrangements, a front being a room adjacent to an exterior region. The resulting subsets are listed according to an increasing value of $f$. 
Figure 2.23 Three arrangements and the ordering of the corresponding graph partitions.

(4) Those subsets are divided into smaller ones corresponding to particular graph partitions. An arrangement's graph partition ($\Pi$) is an ordered list of $p-1$ integer numbers $(q_1, q_2 \ldots q_{p-1})$, where $q_i$ is the number of rooms of degree $i$, that is, being adjacent to $i$ other rooms. An ordering relation ($\rightarrow$) is defined for graph partitions of the same length: given $\Pi = (q_1, q_2 \ldots q_{p-1})$ and $\Pi' = (q_1', q_2' \ldots q'_{p-1})$, $\Pi \rightarrow \Pi'$ if and only if $q_{p-1} \ldots q_2 q_1 < q'_{p-1} \ldots q'_2 q'_1$. The subsets are listed according to their ordering.

(5) Within every such graph partition set there is a subdivision according to a decrease in 'degree of symmetry'. A rectangular arrangement for which $l = m$ may possess reflected symmetry about both its orthogonal and its diagonal axes at the same time. If so, it also possesses rotational symmetry through $90^\circ$. The other extreme is an arrangement which possesses neither reflected nor rotational symmetry. In between there is a range of possibilities which will not be considered by the present review.

Bloch's catalogue is intended to be consulted by a designer dealing with a particular design problem 'to find an arrangement or some few arrangements corresponding to his requirements' [Steadman 1983 p132]. For this purpose it is important that the characteristics governing the catalogue's structure are meaningful in the sense that they have an understandable impact on aspects of a dwelling's performance. The maximum number of inhabitants for example is to a
certain degree dependent on the value of $p$, but it is perhaps more specifically dependent on the value of $f$ which can be understood as an upper limit on the number of habitable rooms. For the other characteristics mentioned above, the implication for performance are more difficult to pinpoint.

**Figure 2.24** Beginning of Bloch’s catalogue showing arrangements for $p \leq 5$ (source: Steadman 1983). The main subdivision — according to $p$ and $(l, m)$ — is indicated in italics. Numbers of fronts ($f$) and graph partitions ($\Pi$) are in smaller characters. Codes like $C_2$, $D_{1\nu}$ and $E$ refer to various symmetries.

If two arrangements have graph partitions $\Pi$ and $\Pi'$ respectively, then $\Pi \to \Pi'$ can be interpreted as an indication
that in the second arrangement rooms occur in more central positions than in the first. Such rooms would in principle be able to serve as hallways, providing independent access to other rooms which would therefore not be passed through. The relevance of symmetries in the context of housing design is doubtful. If a particular symmetry of a dimensionless arrangement is to be preserved at the metric level, this puts serious constraints upon the shape and size of rooms. These may easily conflict with a desired economy of floor area and with many other practical requirements with respect to room layout.

2.3.4. Empirical research

The distribution of characteristics over complete ranges of dimensionless arrangements and graphs does not provide an indication of the actual relevance of certain kinds of plans and of certain of their characteristics. Such knowledge must be discovered empirically, that is, by examination of existing plans. Graphs and rectangular arrangements have been employed at several occasions in the analysis of samples of existing buildings—sometimes in a specific historical and geographical context. One example is Hillier’s analysis of a sample of seventeen vernacular farmhouses in Normandy, where several characteristics of the corresponding access graphs are compared in order to determine which of those characteristics are essential for the Norman vernacular farmhouse [Hillier et al 1987]. Another example is an analysis of three samples of British houses—19th century terrace houses, working-class cottages built directly after World War I, and private semidetached houses from the interwar period—in relation to sets of constraints known or suspected to have influenced their design [Brown and Steadman 1987]. A computer program (DIS) developed by Flemming [1978] identifies arrangements which can be dimensioned in compliance with those constraints. These are then compared with the plans in the sample. It is argued that this kind of experiment ‘can help to clarify the historical and social influences that impinge on housing design’.
Empirical facts may be relevant to contemporary design. From a designer's point of view at least two kinds of knowledge about materially existing instances of a type are significant:

(1) The availability of even just one such instance demonstrates the type's feasibility, at least in the particular historical and geographical context in which it was realized. The occurrence of relatively large numbers of instances – the popularity of a type – provides further evidence of its feasibility.

(2) Accidental characteristics may be shown to be constrained among existing instances. This is something not to be ignored when choosing such a type, while at the same time wanting to violate such a constraint.

Of course the degree by which such information is relevant much depends on whether the instances are still relevant in the context of contemporary design.

Combes' diagram • An early and rather limited exploration of this kind is the one by Steadman on 'the typology of historical and contemporary house plans' on basis of a diagram developed earlier by Combes [Combes 1976; Steadman 1976]. Combes' diagram sets out two characteristics against one another: the number \((w)\) of an arrangement's external wall segments and the number \((p)\) of its internal wall segments \((w\) and \(p\) refer to \textit{walls} and \textit{partitions}, the terms used by Combes for external and internal wall segments respectively).

Combes shows that there are limits to the value of \(w\). For any \(p\) there is an upper limit to \(w\), given by \(w = 2p + 4\). For \(p \geq 5\) the lower limit is given by \(w = 8\). Positions in the graph which are close to the upper limit correspond to arrangements which tend to be more outward-looking, in the sense that relatively more of their rooms are adjacent to the exterior, than the ones close to the lower limit.

Rectangular arrangements interpreted from a sample of contemporary 'Generic Plans' for two and three storey houses composed by the National Building Agency where plotted on Combes' diagram. A concentration of arrangements is found along the diagonal \(2w = 11 + p\): 117 out of a total of 164 lie on this particular line. It is then demonstrated that the packing of rectangles of equal size and proportion, if one wishes to arrive at
a maximum even spread of adjacencies between them, leads to this particular relation between \( w \) and \( p \). Such an even spread might be considered desirable because in principle it provides great flexibility and a variety of possibilities for the assignment of interconnected room functions to various spaces.

\[ w = 2p + 4 \]

\[ 2w = 11 + p \]

\[ w = 8 \]

\[ p \]

**Figure 2.25** Combes’ diagram (after Steadman 1976). For every pair \((p, w)\) the number of ground-floor plans (bold) and first-floor plans (italic) found in the NBA sample are indicated. A concentration can be observed along the diagonal \( 2w = 11 + p \).

**The morphology of British housing** • A much broader analysis of British dwelling plans has been published recently under the title *The morphology of British housing* [Brown and Steadman 1991a, 1991b]. A sample of over three hundred contemporary plans is considered representative for the housing stock in the country as a whole. A distinction is made between three general categories: the terrace house, the semidetached house and the flat.

Dwellings are represented at three distinct degrees of abstraction:

(1) Pattern of room use, which is an unstructured set of rooms which are labelled according to their approximate
functions.

(2) Access graph, the vertices of which are labelled to indicate the functions of the represented rooms.

(3) Detailed floor plan, not to be mistaken for the dimensioned rectangular arrangement discussed earlier.

Figure 2.26 Number and function of living spaces per dwelling (after Brown and Steadman 1991a). Functions are indicated by d (dining room), k (kitchen), l (living room), p (parlour) and s (scullery). Where functions are combined in one and the same room they are separated by /.

Individual characteristics • The distribution of numerous characteristics is explored. Let us have a look at a few examples.

The number of living spaces and their distribution over different storeys in terraces and semidetached houses are examined. Living spaces are defined as spaces that accommodate ‘daytime activities and activities that form part of ordinary domestic life’. This includes living rooms, kitchens and sculleries, as well as more specialized areas such as studies and music rooms. Perhaps not too surprisingly, it turns out that that the majority of living spaces are located on the ground floor.
Only when many living spaces are present in a dwelling, do they tend to be located on other storeys more often.

It is also examined at what frequency certain simplified access graphs occur in the sample. These access graphs are *rooted trees*, one vertex is distinguished from the others [Harary 1969 p187]. The root vertex represents the street or other external space to the front of the house, the other vertices are labelled only so as to distinguish whether they represent a room or a transitional space. Furthermore cycles have been removed from these graphs in a consistent way. In case of terraces and semidetached houses it is observed that on the ground floor of both two room and three room plans two graphs are dominant. Various characteristics of the fully labelled graphs—in which all rooms are distinguished by means of individual labels and the back(garden) of terraces and semidetached houses is represented by an additional vertex— are examined separately. These are for example the depths and valencies of particular rooms.

*Depth* is understood as the graph distance of the corresponding vertex from the vertex representing the front or from the one representing the back. The *valency* of a vertex, sometimes called its *degree*, is the number of edges incident with that vertex [Harary 1969 p14]. Several relations between depth or valency and the function of rooms are revealed. The living room for example is found much more likely to be univalent, having only an access relation with one other room, than the dining room. It is also found to be consistently deeper from the back than the dining room. In semidetached houses the dining room is found to be deeper from the front than the living room. Partially on basis of such characteristics it is concluded that ‘the living room is a relatively private room, normally at the front of the house and typically with access directly from the hallway, whereas the dining room is more commonly at the back and linked with the kitchen, the living room, or both’ [Brown and Steadman 1991b p394].

Various metric characteristics are examined as well. Among these are the dwelling’s total floor area, the floor area of living rooms, dining rooms and kitchens, its overall width or *frontage width* and its overall depth.
Figure 2.27 Above: access graphs found on the ground floor of terraced and semidetached houses (after Brown and Steadman 1991b). Above: graphs for two room plans; below: graphs for three room plans. Black vertices represent rooms, the white vertex represents a hallway, the grey vertex represents the street or a similar exterior region. The frequency of occurrence of the four most dominant graphs is indicated as a percentage.

Below: Characteristics of principal ground-floor rooms in terraces which are implicit in the access graph (after Brown and Steadman 1991b). Depth from front (left), depth from back (middle) and valency (right). On the vertical axes are the numbers of cases in which a particular depth or valency is found.
Mutual dependency of characteristics • For many of the above characteristics it is specified how they are distributed over the three general categories, often in relation to the period of realization. Particularly interesting though is the relation between characteristics at different degrees of abstraction. Let us have a look at one example.

![Figure 2.28 Distribution of frontage widths in terrace houses for the access graphs 2A, 2C and 2D (after Brown and Steadman 1991b). Frontage width (in intervals of 0.5m) is set out on the horizontal axis, number of plans on the vertical axis. From 2A via 2C to 2D there is a considerable increase in mean frontage width.](image)

The frequency of those simplified graphs which were found to be relatively popular is examined in relation to frontage width. The following general features are noticed:

(1) Graphs 2A and 3A, the linear sequences, are restricted solely to dwellings of narrow frontage (5m or less). Frontages of less than 4m are associated entirely with these two graphs.

(2) The branching trees are found predominantly in wider frontages. 3E does not occur at all in frontages of less than 4.5m and 2D and 3C are uncommon below 5m and 4.5m respectively.

(3) The linear sequences incorporating an entrance hall, 2C and 3B, span between the two, peaking in each case somewhere between 4.5m and 6.5m, but they do not appear in frontages narrower than 4m or wider than 7m.

Brown and Steadman conclude that in general ‘the types 2A and 3A arose by virtue of necessity rather than choice: they were imposed by a frontage dimension which was inadequate to
Figure 2.29 Hierarchical classification of terraced and semidetached houses for ground-floor plans of two habitable rooms (source: Brown and Steadman 1991b). At the top are the most common combinations of room functions. These are followed in downward order by the observed access graphs, rectangular arrangements, and a selection of actual plans.
allow a hall and living room (or parlour) to be placed side by side. To judge by their frequency, the shallow trees 2D, 3C and 3E are the preferred option, and these come into their own once frontages are wide enough to accommodate them.

In a concluding section they argue that, more than the individual characteristics themselves, such interdependences are significant. Two overviews are presented, for two room and three room ground-floor plans respectively, in which relations between characteristics at different degrees of abstraction are visualized. At top level patterns of room use with their relative popularity are listed. At a second level the simplified access graphs are shown, again with their relative popularity. At a third level the corresponding original access graphs are shown on all the found rectangular arrangements. At base level for each of the access graphs a limited selection of actual plans is presented which is split up into terraces and semidetached houses. The plans are coded to indicate age and ownership (private or public). Frontage width and total ground-floor area are given as well.

2.4. A comparative evaluation

This section evaluates the six studies discussed by the three previous sections by mutually comparing them in view of different aspects of their performance. From this comparative evaluation a general problem in the state of the art of housing typology emerges.

• One aspect of a type representation’s well-definedness is the complete and unambiguous specification of its syntax. Precedent-based typologies do not explicitly define a representation. Most of the syntactical specifications offered by representation-based typologies are incomplete and ambiguous. The syntax of rectangular arrangements and plan-related graphs is thoroughly specified.

• Another aspect of a representation’s well-definedness is the complete and unambiguous specification of its interpretation. A
sufficient specification is only found where rectangular arrangements and plan-related graphs are concerned. As a result these are the only representations for which a justification of syntactical rules can be offered.

- All four representation-based typologies are limited to the level of the single storey component or that of the individual dwelling. In all cases the representation's degree of abstraction seems insufficient which does harm to the system's overvviewability. The two precedent-based typologies apply at higher levels of spatial organization and they show the intention that types are highly abstract.
- The challenge emerging from the evaluation is to develop well-defined type representations which are at the same time sufficiently abstract and which apply at higher levels of spatial organization.

2.4.1. Syntax of type descriptions

A first aspect of well-definedness is that the syntax of type descriptions is specified completely and unambiguously. It must be clear which are the primitives of the type representation and which configurations of them are allowed. On this specification depends the reliability of the following two statements about types $T$, $T_1$ and $T_2$:

'T is well-formed'
'T$_1$ and T$_2$ are distinct'

Only if such statements can be tested a controllable enumeration of complete ranges of types becomes possible.

The precedent-based typologies discussed by section 2.1 do not provide such a specification of syntax: graphic type descriptions are the product of intuitive schematization of plans and sections of existing buildings. These typologies can only consider types for which existing instances are available. This brings the risk that relevant types are missing, as may be suspected for example when comparing Sherwood's split level sections with Sting's: both writers present sections which are not presented by
the other.

![Diagram](image)

**Figure 2.30** Split level sections (after Sting 1975 and Sherwood 1978). Left: section presented only by Sting; Right: section presented only by Sherwood.

Where the representation-based typologies discussed by section 2.2 are concerned the specification of syntax can be qualified as more or less naive. Particularly the definitions by the SAR and the SEW leave serious doubts as to how primitives may be arranged in order to form a type description. In the presentation of the SAR method for example it is stated that 'a zone does not necessarily have to be of uniform depth' [Habranen et al 1976 p55]. This raises many questions which are left unanswerend in the text and untouched by the examples given. May a zone's depth change in the middle of a sector, or in the middle of a space? May a zone's depth and position change in such a way that it becomes divided into two entirely disconnected parts? Another example are the access graphs which are presented by the SEW without being explicitly defined as graphs. Must all four vertices be present in a graph? May there be an edge joining any pair of vertices? Could multiple edges occur?

The syntax of rectangular arrangements and plan-related graphs is specified completely and unambiguously. As we have seen (subsection 2.3.3) this allows the production of complete and non-redundant ranges of them.

### 2.4.2. Interpretation of primitives and their configuration

A second aspect of well-definedness is the complete and unambiguous specification of the *interpretation* of primitives.
and their possible configurations. This comes down to the specification of the actual spatial or physical components and relations between them that are represented by those primitives, and of the actual arrangements of components represented by configurations of primitives. On this specification depends the reliability of the following statements about a type $T$, an object $i$ and a characteristic $c$:

'instances of $T$ necessarily possess $c$'
'i is an instance of $T$'
'instances of $T$ are likely to possess $c$'

If $c$ is relevant to the evaluation of $T$ in the context of design the reliability of such general knowledge is significant.

Figure 2.31 Split level sections presented in Bauentwurfslehre (source: Neufert 1992). In both cases storeys are at unequal distances. In the left section different storey heights occur.

Where the precedent-based typologies reviewed by section 2.1 are concerned, essential characteristics of a type as well as other general characteristics of its instances are largely to be interpreted by the user from the paradigmatic precedents. The kind of uncertainties to which this may lead are perhaps best demonstrated by an example. The schematic split level sections in Grundriss Wohnungsbau suggest that storeys are positioned at equal vertical distances (sometimes called 50% split level). That this characteristic is essential seems to be confirmed by the supporting precedents. The question arises: what about split-level sections in which storeys have varying vertical distances? Such cases are by no means hypothetical, as can be seen in
[Neufert 1984 p251, examples 8 and 12]. Either Sting ignores their existence entirely or he considers them instances of the presented split level types as well – the mentioned equal distances between storeys being a characteristic accidentally shared by the paradigmatic precedents.

In every one of the representation-based typologies discussed by section 2.2 specification of interpretation is incomplete and ambiguous. Interpretation of primitives and configurations is largely to be understood from examples. Where the SAR and SEW studies are concerned, it is actually hidden in methods of refinement. The interpretation for example of the position of functional labels in the basic pattern is largely implicit in the method by which a basic pattern is transformed into a basic layout.

Interpretation of primitives and configurations is sufficiently specified where rectangular arrangements and plan-related graphs are concerned. These representations are defined by explaining how a configuration of primitives can be derived from a detailed floor plan, instead of how it can be refined into one. This enables a controllable derivation of arrangements and graphs from actual plans, as opposed for example to the intuitive derivation of basic types by the SEW.

These matters are relevant with respect to the reliability of a system of types as a design supporting tool. Where there are differences between the user’s interpretation of a type and its intended interpretation, there is the danger that for example the user associates a certain performance with wrongly interpreted essential characteristics.

**Justification of syntactical rules** • A specification of interpretation is a prerequisite for judging whether a syntactical rule is justified or not.

As far as in the studies discussed by section 2.2 rules of well-formedness are given, or can be guessed, these are not being justified on basis of the interpretation of primitives and their configuration. In order to illustrate this, let us return to a previous example. The overview of basic types presented by the SEW suggests certain rules of well-formedness for access graphs: there is never an edge joining the non-labelled vertex and the K-labelled vertex, and the W- and T-labelled vertices
are always joined by an edge. Justification of these apparent rules is not entirely obvious. Situations in which habitable rooms other than the main living room have a door to the kitchen, or situations which allow travelling from the entrance hall to the living room only via the kitchen, may not occur frequently but they cannot be qualified as irrelevant.

The complete and unambiguous specification of the interpretation of rooms and walls, and of vertices and edges prevents similar problems where rectangular arrangements and plan-related graphs are concerned. This enables for example the justification of planarity and connectivity of plan-related graphs.

2.4.3. Level of spatial organization and degree of abstraction

In architectural design choices between types present themselves at different levels of spatial organization. The previous sections have reviewed systems of types at the level of the building as a whole, the access unit, the individual dwelling, and the single storey component.

Figure 2.32 Upper and lower storey of a dwelling in the Unité d’Habitation (source: Boesiger 1953). The two plans could be schematized individually as shown in the upper right corner.
The conventional typologies discussed by section 2.1 are not always very clear about those levels. Where Sherwood speaks of unit types for example, it is unclear whether the term unit refers to the dwelling as a whole, or to its single storey components. The schematized plans by means of which the three general unit types and particularly their subtypes are given clearly describe situations at one particular storey. However, in multi-storey dwellings it may well occur that at one storey only a single orientation is available while at the other two opposite orientations are available. Such difficulties, which are also found in the interpretation of schematized sections, are largely due to the fact that these type descriptions are basically two dimensional. At least where multi-storey access units and dwellings are concerned this is a serious shortcoming.

\[ \text{Figure 2.33 A modest single storey dwelling (Van den Broek 1934; source: Stroink 1981). Left: detailed plan; right: the rectangular arrangement contains ten rooms one of which is a so-called dummy (grey).} \]

**Overviewability and degree of abstraction** • As the number of distinct primitives, the number of their occurrences in a type description, or the number of their possible relations become too large, the number of distinct configurations of those primitives tends to grow out of hand. This reduces a typology’s usefulness as a design supporting tool, which depends a great deal on the total number of types being limited and their mutual differences being significant and easily observed. Hereafter a system of types which possesses these qualities will be qualified as offering good overviewability. In order to render an overviewable system of types a representation must be
sufficiently abstract.

The catalogues by Steadman and by Bloch (subsection 2.3.3) show that particularly the dimensionless arrangement becomes insufficiently abstract for larger numbers of rooms. The catalogues lose their overviewability approximately at \( p = 6 \) or \( p = 7 \). Particularly where single storey dwellings are concerned the total number of rooms in an arrangement may be much larger. In Bloch's 1979 catalogue an attempt is made to improve overviewability by imposing a hierarchical ordering upon the set of arrangements according to certain of their characteristics. For certain kinds of statistical analyses of large samples of existing cases – as carried out for example on basis of Combes' diagram – such a well-structured catalogue would be helpful. It does however not sufficiently improve the catalogue's overviewability to a design oriented user.

![Diagram](image)

**Figure 2.34** Magnifying effect of dimensionless arrangements and access graphs. Above: three simplified floor plans which are highly similar (hallways indicated in grey, doors indicated by narrow lines). Below: the corresponding dimensionless arrangements with access graphs superimposed (grey vertex represents the exterior region). Arrangements as well as graphs are mutually distinct.

There are two main reasons for this problem to emerge. First, all rooms are represented individually irrespective of their size or function. Second, while their dimensions are ignored, the shape of rooms and the presence of shared wall segments are represented in detail. As a result the differences between
dimensionless arrangements are often minor ones such as the presence or absence of a single adjacency. A similar argument holds for plan-related graphs. The three simplified floor plans shown above are very similar: four major rooms occupy the corners of the plan and all can be reached from the exterior via one or two minor hallways at similar positions. The corresponding dimensionless arrangements show the effect of blowing up certain details in the local geometry around the circulation spaces. A similar magnifying effect accounts for the differences between the corresponding access graphs.

General characteristics of different natures such as geometry, function of rooms and access between rooms are simultaneous ingredients of the similarity of the three plans. The dimensionless arrangement ignores characteristics of one nature entirely, such as room sizes, while retaining detailed characteristics of another nature, such as the sharing of wall segments. Similar arguments hold for the access graph.

To some degree the representations discussed by section 2.2 seem to recognize these difficulties. The basic pattern for example ignores interior circulation spaces and it represents the relative position of functional regions in more general terms than the rectangular arrangement. Still, the number of different functional labels and the number of their possible positions in the matrix renders large numbers of basic patterns. The computer program which produces ranges of basic patterns does not solve this problem. These ranges become overviewable only if serious constraints have been determined in advance. The SEW study for example presents a range of 84 basic patterns in which eight functional labels are positioned in a 3×3 matrix in compliance with several constraints as to their allowed position [Bergman et al 1974 pp29-30]. Similar arguments hold for the basic variation and the SAR70 program.

The advantages of not representing all rooms individually and of representing their arrangement in more abstract terms become visible in the SEW study. In the SEW graphs for example, only the W- and K-labelled vertices represent individual spaces while the other two vertices represent combinations of spaces. The edges do not necessarily represent direct access between (combinations of) spaces, but access possibly via intermediate circulation spaces. This results in a
simple and highly abstract representation: only nine distinct access graphs are considered. Similarly, in the WK pattern only the living space and the cooking space are represented individually and only a few possible positions are distinguished. There are twelve such patterns in total. As a result the basic types form an overiewable system which can even be shown on a single page.

It is remarkable that the representations discussed by sections 2.2 and 2.3 are all confined to the single storey component or in some cases to the individual dwelling.

Where the precedent-based typologies of Sting and Sherwood are concerned no representations are explicitly defined. As a result it is difficult to judge the degree of abstraction of the various schematized plans and sections presented. Just as the verbal type descriptions, certain of these graphic type descriptions at least express the intention of a high degree of abstraction. Sherwood's general unit types ignore a dwelling's room layout entirely. Some of Sting's types of horizontal access units are described by schematized plans in which individual dwellings cannot be recognized. The systems of types and subtypes implicit in the ordering of precedents certainly provide good overiewability.

2.4.4. Summary of evaluation and preliminary problem formulation

The comparative evaluation presented in the previous subsections is summarized in the matrix shown below. Four aspects of performance of the six typological studies are distinguished:

(1) Specification of syntax of type representations.
(2) Specification of interpretation of type representations.
(3) Level of spatial organization at which systems of types (apparently) apply.
(4) (Apparent) degree of abstraction in view of this level.
**Figure 2.35** Summarized evaluation of all six typological studies. Rows correspond to four general aspects of performance, where performance is considered sufficient comments are on white background, where it is considered insufficient they are in grey background.
None of the six studies have a sufficient performance on all four aspects. The following general problem emerges from this analysis of the state of the art in housing typology.

On the one hand, where systems of types are based upon sufficiently or insufficiently defined representations they are all confined to the lowest level of spatial organization: that of the single storey component. Of those four systems only the SEW's basic types have a sufficient degree of abstraction. At the same time however the specification of syntax and interpretation of basic types is radically incomplete. On the other hand, where systems of types apply at a higher level of spatial organization (that of the access unit for example) and their degree of abstraction seems appropriate to this level, no serious attempt is made to explicitly define type representations.

**General problem** • The difficulty of developing sufficiently abstract, but nonetheless well-defined representations of spatial organization can be illustrated by comparing the dimensionless arrangement and the access graph with the SEW basic types. Especially in small dwellings rooms, walls and doors are easily recognizable. The primitives of the rectangular arrangement and the access graph are defined straightforwardly in such terms. The apparent interpretation of the primitives in the WK pattern and the SEW graph is much more general. Their definition in terms of recognizable spatial and physical components seems not at all straightforward. How for example would the ‘separation zone’ be defined in terms of walls or in terms of the shape of rooms? And how would the component ‘one or more other habitable rooms’ be defined in terms of rooms, their functions and their access relations?

This study intends to demonstrate that it is possible to develop (1) well-defined type representations (2) at higher levels of spatial organization, which (3) are sufficiently abstract.

A typology's reliability depends a great deal on (1). A truly well-defined system of types is developed only by the studies discussed by section 2.3. The described empirical research (subsection 2.3.4) produces reliable results precisely because types are based upon a well-defined representation. A typology's overlookability is largely dependent on (3). In view of the
dilemma formulated by subsection 1.2.3 it is important that
typology supports decision making as early as possible in the
design process. The stage at which a system of types becomes
useful is dependent on the level of spatial organization which it
addresses. Since in the complex residential building there are
several levels of spatial organization above that of the individual
dwelling condition (2) forms a significant challenge.
3. Spatial organization of residential buildings

The previous chapter concluded with formulating a general problem related to the development of systems of types in the domain of housing. The present study wants to demonstrate a possible way of solving this problem. The present chapter forms a preparation for that demonstration. First, it develops a vocabulary of terms which allow accurate discussion of the spatial organization of complex residential buildings. Second, it reduces the problem to a size which is manageable in view of practical limitations of this work.

- A three dimensional metric representation is defined in which spatial components bounded by fixed circulation barriers, or rooms, as well as openings in those barriers are represented individually. Stairs and elevators are represented by considering pairs of openings to be related.

- Rooms may be considered, in general, as forming room systems. Both dwellings and communal circulation system can be understood as room systems defined by territorial boundaries. Both can be decomposed into systems which are formed by rooms occupying one and the same storey. Where the circulation system is concerned these are referred to as corridors.

- A slab is an arrangement of dwellings which are packed closely on top of one another and side by side, so that in principle a dwelling may have at most two opposite orientations. In some cases slabs are associated with corridors of considerable length, in other cases they are associated with vertical sequences of short and mutually connected corridors, or vertical circulation axes.
• While a residential building may consist of a number of slabs, those slabs are themselves largely the product of the repetition of smaller arrangements of dwellings. Those basic arrangements are most commonly found to be repeated either along a vertical circulation axis, or along an elongated corridor.

• The tasks set for chapters four and five respectively are the definition of an abstract representation of basic arrangements, and the exploration of the system of types implicit in this representation.

3.1. A metric representation

This section proposes a metric representation of the spatial organization of residential buildings – meaning that information, not only about the shape, but also about the size of components is retained. This representation forms a basis for the definition of various concepts in following sections. It is fundamental to the definition of a type representation in chapter four.

• The room is defined as a three dimensional primitive. A room may be any spatial component which accommodates human activities and it may be delineated by various kinds of circulation barriers.

• Any length of circulation barrier which is permeable is represented as an opening located on a room’s perimeter. While stairs and elevators are not explicitly represented, their presence as such is retained by considering one or more pairs of such openings to be related.

3.1.1. Rooms as three dimensional primitives

Sections 2.2 and 2.3 have reviewed several metric representations in which rectangles, referred to as rooms, regions or spaces, act as primitives. Though at the time little
attention was paid to the issue, the reader may have observed certain difficulties in the interpretation of those terms. In the following discussion two of those difficulties need to be avoided in particular:

(1) Components which accommodate human activity are often defined by closed surfaces at all sides (walls, floors and ceilings) but this is not always the case. Examples are landings, corridors, balconies, or rooms which open onto a void.

(2) Since they are spatial components they should be represented by truly three dimensional primitives, that is, primitives with three dimensional shape and dimensions and with a relative position in three dimensional space.

**Rooms** • The present study considers the basic spatial components of a building to be defined by fixed activity barriers. Those components are represented by primitives which will be called rooms. More precisely, a room represents the free space directly above a continuous horizontal surface on or above which no fixed physical parts are present which obstruct the activities which the room accommodates. This free space is delineated in plan view by fixed activity barriers, such as walls, parapets, railings or simply the edge of the horizontal surface itself – an exceptional case is the obstruction of an activity by a reduction of the available height above the surface.

Geometrically speaking, a room results from the vertical extrusion of a continuous region in the horizontal plane over a certain distance. This region is bounded by one or more closed sequences of straight or curved lines. The extruded sequences are referred to as the room’s perimeter. The distance of extrusion is the room’s height. A room’s height and vertical position can be given simultaneously by an interval on the vertical axis \((v_1, v_2)\). The vertical distance between two rooms with corresponding intervals \((v_1, v_2)\) and \((v_3, v_4)\), \(v_1 < v_3\), is \(v_3 - v_1\). Perimeters represent activity barriers and the height is appropriate to the accommodated activities.
Figure 3.1 Examples of rooms. Left: room with curved and straight sides. Middle: orthogonal room with a perimeter which consists of two separate parts. Right: two adjacent rooms with different heights and vertical positions.

Two rooms at intervals \((v_1, v_2)\) and \((v_3, v_4)\) respectively are said to be *vertically overlapping* if neither \(v_1 < v_2 \leq v_3 < v_4\) nor \(v_3 < v_4 \leq v_1 < v_2\). Rooms do not intersect with one another, which means that only if they are not vertically overlapping may the corresponding regions in the horizontal plane overlap. Perimeters of different rooms may coincide for some length. If vertically overlapping rooms have coincident perimeters they are said to be *adjacent*.

To say that a metric description is *orthogonal* means that every length of perimeter is straight and oriented parallel to one of two perpendicular axes in the horizontal plane. Under the same conditions we may speak of an individual room as being orthogonal.

In order to describe a building in terms of rooms one must be able to decide whether physical bounds indeed act as activity barriers – a decision which is principally dependant on the sort of activities one assumes to be accommodated. Of course there are buildings in which activities are 'carried' by non-horizontal surfaces: one may think of theatres, cinemas, or sporting arenas. Where the residential building is concerned such non-
horizontal surfaces do not occur, with the single exception of stairs and ramps. The representation of stairs is a matter to which we will return.

**Height required for circulation** • When limiting the discussion to residential buildings, the notion of the activity barrier can be specified into that of the *circulation barrier*. It seems reasonable to assume that the human activities commonly accommodated by a dwelling or a circulation system, are truly bounded only at the point where human circulation is obstructed.

![Figure 3.2 Residential building in Amsterdam (Zanstra, Giesen and Sijmons 1934; source: Fanelli 1978). Studios are located to the left.](image)

There are cases where exceptional activities are accommodated, like the painters and sculptors studios in the Zomerdijkstraat building in Amsterdam by Zanstra, Giesen and Sijmons [Fanelli 1978 pp169-170]. These should be represented as rooms with a height appropriate to the type of activity – one and a half times the height of ordinary rooms seems to be considered appropriate by the designers. A more general exception should be made with respect to the representation of
gardens, streets, and courtyards. The free height needed for vegetation to survive or for motorized traffic to be possible is beyond the height required for human circulation. However, the discussion in this and following chapters does not ask for a specification of such heights.

The question remains: which height should be considered appropriate to circulation within residential buildings? It seems dangerous to choose some fixed size. Minimal storey heights as laid down in building codes may vary historically as well as geographically and designers may have some freedom in choosing a storey height in the context of every new design. This study takes the point of view that the height apparently considered appropriate to circulation can be found in a particular case as the actual minimal vertical distance between rooms overlapping in the horizontal plane. This height will be referred to as the Minimal Storey Height (MSH).

Figure 3.3 Rowhouses at the Vienna Werkbund Siedlung (Rietveld 1932; source: Krischanitz 1985). Left: Minimal Storey Height (MSH) is found to be 2.7m. Right: schematized section in which rooms have a height of 1 MSH.
3.1.2. Representation of doors, stairs and elevators

Where a spatial component accommodates human activities, it is obvious that at some point the circulation barriers by which it is determined must be permeable, so that one may pass from this component to another or vice versa.

**Openings** • Any permeable length of circulation barrier is represented as an *opening*. Most commonly an opening is shared between two rooms. If the vertical distance between those rooms is zero then, where perimeters are coincident for some length, an opening may be located within this length. Several openings may be located on a room’s perimeter. If an opening is shared by two rooms it most commonly represents a door of some kind. The opening has a certain length corresponding to the width of such a door.

However, in the context of multi-storey buildings we must also consider the possibility of travelling between rooms, between which there is a vertical distance. Such travels are enabled by ramps, stairs or combinations of stairs and halflandings, and elevators. In chapter four their significance as spatial components will be discussed in more detail. In the present chapter it is sufficient to be aware that stairs (which are understood in a wider sense as ramps, stairs, or combinations of stairs and halflandings) and elevators all have one thing in common: they provide the possibility of travelling directly, without passing any intermediate circulation barrier that is, from one opening to another. Such a fact is retained by indicating that a pair of openings are related. Related openings are located on perimeters of rooms between which there is a vertical distance and obviously they are not shared between rooms. The presence of a stair is usually represented by a single pair of related openings. Elevators are often represented by several such pairs: one for each pair of elevator stops.

**Visualization** • Besides a few transversal sections and frontal views, throughout this study two visualizations of the
metric representation will be used constantly. These are axonometric projections, and often they are 'vertically exploded' which means that the vertical distances between rooms are exaggerated for reasons of clarity. There is (1) a detailed visualization in which all individual rooms and openings are shown, and there is (2) a rough visualization in which only storey systems are shown – a term which will be explained in the following section.

![Diagram](image)

**Figure 3.4** Dwelling in the Narkomfin building (Ginzburg and Milinis 1928). Left: schematic indication of walls and parapets, doors and windows are indicated in light grey. Middle: a description in terms of rooms, the 'gaps' result from void, staircase and corridor. Right: a pair of related openings (connected by double arrow) and an opening shared between adjacent rooms (circle).

In visualization (1) rooms are shown as grey solids, which may have various 'top colours' in order to indicate, for example, whether they accommodate certain activities or whether they are included in the circulation system or not. The default colour is white. Perimeters can be read from the black borderlines of a coloured top, and openings are shown as narrower line segments in that borderline. The fact of openings being related is indicated by an arrowed polyline connecting them. In principle, metric characteristics may be represented at any resolution. The size and relative position of rooms and openings are normalized on a three dimensional 0.30m grid, wall and floor thicknesses are ignored together with minor wall crankings, cupboards and shafts.
While the detailed visualization fully shows this resolution, visualization (2), which is at a larger scale, occasionally ignores represented details. Storey systems are visualized as rooms, openings are not shown, and relations between opening are indicated by polylines.

3.2. Dwellings, corridors and storey systems

The metric representation enables the redefinition of a few general concepts which are usual in the discussion of residential buildings. It is fundamental to those definitions that rooms are considered to form systems on basis of their mutual access relations.

- A *room system* is any arrangement of rooms which corresponds to a connected subgraph of the access graph. A room system may include several smaller disjunct room systems.

- A *dwelling* is a room system which is defined by territorial boundaries. A residential building may include other territories as well. Dwellings and other included territories, if any, are all connected to a complementary room system: the *communal circulation system*.

- Both the individual dwelling and the circulation system can be decomposed into *storey systems*: these are formed by rooms which occupy one and the same storey. Where the circulation system is concerned this provides a more general definition of the term *corridor*.

3.2.1. Access graph and room system

In sections 2.2 and 2.3 we have met with the mathematical concept of the graph, and with its use as a representation of
access relations in architectural plans. The interpretation of edges in access graphs can be defined in different ways. In the work of Steadman for example, the edge represents the fact of permeability of a shared wall segment, whereas Hillier and Hanson [1984 p147] understand the edges in their 'permeability maps' as representing individual openings in walls.

**Access graph** • In relation to the metric representation, the present study defines an access graph in which vertices represent rooms and edges represent an access relation between a pair of rooms. An access relation exists if rooms share any number of openings, or share any number of related pairs of openings. This definition implies certain general characteristics of the access graph:

1. It is inconceivable that for a pair of rooms no sequence of rooms would exist via which one may travel from the one to the other (it is assumed that the terrains immediately surrounding a building are also represented by one or more rooms). As a result the access graph is connected. This means that every pair of its vertices are joined by a path. A *path* is defined as an alternating sequence of distinct vertices and edges, whereby every edge in the sequence joins the vertices immediately preceding and following it. A path is said to join the vertices with which it begins and ends [Harary 1969 p13].

2. It is assumed that a room does not share an opening with itself. It will be assumed that it is equally impossible for a room to share a pair of related openings with itself. Therefore no *loops* occur in the access graph. A loop is an edge which joins a vertex to itself [Harary 1969 p10].

3. Openings or related pairs of them are not represented individually. Therefore no *multiple edges* occur in the access graph. One speaks of multiple edges when a pair of vertices are joined by more than one edge [Harary 1969 p10].

**Included, disjunct and connected room systems** • An arrangement of rooms the corresponding maximal subgraph of which is connected forms a *room system* or, in short, a *system*. A *subgraph* of a graph $G$ is a graph having all its vertices and edges in $G$. A subgraph is *maximal* under the condition that any two of its vertices are joined by an edge if they are joined by an
edge in $G$ [Harary 1969 p11].

A room system $S_1$ is said to be included in a second system $S_2$ if and only if the maximal graph corresponding to $S_1$ is a subgraph of the maximal graph corresponding to $S_2$. Two room systems $S_1$ and $S_2$ are said to be disjunct if and only if the graphs corresponding to $S_1$ and $S_2$ have no vertex, and thus no edge, in common. Two disjunct room systems $S_1$ and $S_2$, both included in a system $S_3$, are said to be connected if and only if in the $S_3$ graph there is an edge joining a vertex in the $S_1$ graph to a vertex in the $S_2$ graph.

\[\text{Figure 3.5 Access graph representing a hypothetical and highly simplified residential building. Vertices in the exterior system are indicated in black. Subgraphs corresponding to two major disjunct subsystems connected to this exterior system are indicated in grey.}\]

With respect to the residential building it will be assumed that the immediately surrounding terrains from which the building is entered are represented by one or more exterior rooms. For reasons of simplicity those are all assumed to have a height of 1 MSH. It is furthermore assumed that those exterior rooms always form a system referred to as the exterior system. \(^\text{1}\)

\(^\text{1}\) The exterior system as defined here is largely similar to the carrier defined by Hillier and Hanson [1984 pp66-67] as the space containing or surrounding an object.
A residential building as a whole is not necessarily a single room system: it may well consist of several mutually disconnected systems which are connected to the exterior system.

3.2.2. Dwellings and circulation system

Habraken [1985 pp128-133] proposes the understanding of spatial environments in terms of territories which are defined by spatial control:

'We can say that we are in control of a space when we can determine what can go into it. The control of a space is the control of its boundaries. There are 'gates' that can only be entered by consent of the power inside. Such units of spatial control I will call territories.'

He furthermore suggests that territories are typically included in one another: they form so-called territorial hierarchies. It is significant that territories are not merely aggregations of included territories. According to Habraken [1985 p131] 'the division of the larger territory in two kinds of space, the private space occupied by the included territories and the public space that is shared by all, is common to all territories on all scales'.

In the present context the territory can be understood as a room system, so that Habraken's 'inclusion' fits the definition given earlier.

Dwellings as included territories • It can be argued that in the complex residential building there may be several levels at which territories are included in larger ones. Certain rooms, particularly bedrooms, may be considered as individual territories included in the dwelling. Sting [1979 pp20-25] presents a range of diagrams, certain of which suggest that in large residential buildings dwellings are grouped around communal facilities, thus forming higher level territories. However, it is the separation between the private character of the individual dwelling and the public character of the world outside of it which is typical for housing. This cannot be said of territorial boundaries at other levels.
A *dwelling* is a room system which is controlled by a relatively small group of inhabitants – possibly even a single person – and which is self supporting in the sense that it accommodates certain essential domestic activities such as sleeping, cooking and receiving guests. Every pair of dwellings are disjunct and non-connected. All dwellings are disjunct from and connected to the *communal circulation system*, which is a room system the primary function of which is to enable inhabitants and visitors to travel from and to dwellings. The communal circulation system is assumed to include the exterior system.

![Access graph representing a hypothetical and highly simplified residential building. Subgraphs corresponding to individual dwellings are indicated in grey; one corresponding to an additional included territory is encircled. These systems are all mutually disconnected and all are connected to the communal circulation system.](image)

One of the typical characteristics of the complex residential building – distinguishing it from various other kinds of housing – is the fact that the exterior system and the communal circulation system are not the same. Certain rooms from the circulation system are not exterior: they represent spatial components *within the building*.

It may well occur that additional territories are included in a building – one may think of the shopping centre included in the Unité d’Habitation or the garages and storage facilities at ground level in many high-rise buildings. This study considers
such additional included territories, like dwellings, as disjunct from and connected to the circulation system. Circulation system, dwellings and additional territories are assumed to be complementary: every room is included in precisely one of them. In actual buildings the territorial boundaries by which dwellings are determined are usually easily recognized, but difficulties may occasionally arise. An individual inhabitant may for example have only one or two rooms at his disposal, where it is doubtful whether these add up to a self-supporting dwelling. Several activities (cooking, bathing, or receiving guests) might be accommodated by communal rooms controlled by larger groups of inhabitants. This situation is found for example in student housing, old people's homes, and hotels. In such cases the present definition of the dwelling are perhaps not always appropriate.

3.2.3. Storeys and storey systems

Complex residential buildings are multi-storey buildings. In order to understand what this means, let us first define the concept storey in relation to the metric description.

**Storeys •** A storey is any interval \((v_1, v_2)\) on the vertical axis which corresponds to a room. A room is said to *occupy* one particular storey. Thus the height of a storey \(v_2 - v_1\) is equal to the height of any room occupying it. The distance between two stories is the vertical distance between any room occupying the one and any room occupying the other. In one and the same building storeys may occur at varying mutual distances.

A multi-storey building is a building in which there are two or more storeys. In multi-storey buildings a large number of rooms are usually organized in a limited number of storeys. This may be explained by at least three considerations:

1. The wish to arrive at a relatively simple and economical building structure leads to a preference for floor slabs to be uninterrupted over large distances.
2. The cost of stairs and staircases as well as their
obstructive effect on human circulation cause a preference for access related rooms to occupy the same storey.

(3) Usually the majority of a building's rooms need to have a uniform height, while a certain variety is required in their sizes in the horizontal plane. Organizing rooms in storeys reduces the task of finding a three dimensional packing to the task of finding a packing in the horizontal plane.

![Image of a diagram showing the spatial organization of residential buildings.](image)

**Figure 3.7 Rowhouses at the Vienna Werkbund Siedlung** (Rietveld 1932; source: Krischanitz 1985). Right: schematized section in which all rooms, and thus all storeys, have a height of 2.7m. Two storeys are indicated which have a relative distance of 0.9m.

Most commonly in residential buildings the majority of storeys have a height of 1 MSH and their relative distances are multiples of this height. The most frequent exception is formed by so-called split-level buildings, such as for example the rowhouse by Rietveld shown earlier (figures 3.3 and 3.7). Further on this chapter describes two other examples in detail: the Hansaviertel tower and the Narkomfin building.

**Storey systems** • A *storey system* is a room system with all rooms occupying one and the same storey. Any room system can be decomposed in a unique way into a minimal number of included storey systems. Since every room occupies only a single storey every pair of those constituent storey systems are disjunct.
Figure 3.8 Storey systems in a dwelling from the Narkomfin building. Left: visualization at the level of rooms. Right: two storey systems included in the dwelling share one pair of related openings, while the third opening represents the dwelling’s front door.

While the metric representation is defined in terms of rooms it can be discussed in terms of storey systems as well. The storey system has the same geometric characteristics as the room itself. Similarly we may speak of its height, its vertical position and its perimeter. We may also speak of storey systems sharing an opening or a related pair of openings. When speaking of it in such ways, the storey system’s internal organization is implicitly ignored. In this and following chapters this will often be the case, and therefore the rough visualization, showing storey systems as if they were rooms, is frequently used. Where the drawing scale is very large, for practical reasons the openings are not shown at all; their approximate location is indicated by a short line segment crossing the perimeter or, in case of related openings, by a polyline connecting one perimeter to another.

In an individual dwelling we find mostly one or two storey systems – in split-level cases sometimes three or four. Usually a storey system is only connected to the storey systems directly above or below it. We return to this issue in chapter four.
Figure 3.9 Examples of circulation systems (illustration covers two pages). Exterior corridors are shown only for as far as including non-exterior rooms. This page: Narkomfin building. Next page: Immeuble Clarté.
Corridors • The storey systems into which the circulation system is decomposed are referred to as *corridors*. In common use the term corridor has of course a richer meaning: it indicates a more or less elongated spatial component with a considerable length, and in contrast with balcony access it is often understood as being fully absorbed in the building [Neufert 1980 p90]. The storey system does not have such connotations: it may have any shape and size and it may be positioned anywhere in the building. Thus a single corridor may well serve dwellings in different building masses. This can be observed, for example, in the Spangen block in Rotterdam where a complexly shaped corridor lingers along a number of separate building masses.

The circulation system may include any number of corridors, depending to some extent on the size of the building, and these may share several pairs of related openings. It always includes at least one corridor including an exterior room. This one is referred to as *exterior corridor*.

3.3. Close packing of dwellings

The previous section has defined certain arrangements of rooms in terms of access systems, most notably the dwelling and the corridor. This section discusses an arrangement which is defined not in terms of systems, but as a close packing of dwellings which has certain distinctive characteristics typical for the complex residential building.

• Within a *slab* dwellings are packed closely on top of one another and side by side, so that in principle a dwelling may have at most two opposite orientations. In a complex residential building dwellings do not necessarily form a single slab: the building may be a composition of any number of slabs.

• The basic appearance of a slab is that of a simple box which, in comparison with its limited depth, has a considerable height and length. This appearance may be affected in several ways: its height or length may be reduced to the extreme, or stacks or
rows of storey systems may be 'slided' relative to one another.

- Among the six exemplary buildings introduced by section 1.5 we find slabs of widely different sizes and proportions. In some cases slabs are associated with corridors of considerable length – some writers speak of horizontal access or corridor buildings. In other cases individual slabs are associated with vertical sequences of extremely short and mutually connected corridors – some writers speak of vertical circulation axes.

### 3.3.1. Decomposition into slabs

Commonly, the larger rooms in a dwelling accommodate activities which require daylight, natural ventilation and a more or less unobstructed view. These habitable rooms are usually living rooms and bedrooms. When large numbers of dwellings are packed closely together the overall shape and size of this packing must allow habitable rooms to be 'on the outside'. Discussing rectangular arrangements with large numbers of rooms, Steadman [1983 p173] argues:

'Such dissections consist, certainly, of rectangular components corresponding to rooms, packed together in different configurations. But these configurations are not at all probable architecturally, in ways which are hard to pinpoint precisely, but are no less real for that. It is something to do with such facts as that real buildings tend to have a limited depth, because of the needs of daylighting and natural ventilation, so that when large they become organized into regular patterns of wings and courts. Or that rooms are set along relatively simple and coherent circulation systems consisting of a few branching corridors which extend along the building's whole length.'

In principle Steadman's argument supersedes the presence or absence of a designer's explicit intention to arrive at such a form. The overall plan shape of a building or a complex of buildings may, for example, result initially from the shaping and positioning of public spaces such as streets and squares rather than from the shaping and positioning of the building masses themselves.

Even in such cases (1) the need for most of the building's floor area to be within a limited distance from its external skin
and (2) the wish to avoid the relative quantity of this external skin from being excessive lead to a composition of wings. Considerations (1) and (2) are usually taken seriously where multi-storey packings of dwellings are concerned.

Figure 3.10 Design drawings for housing and offices on the 'Lauv-site' in the The Hague, The Netherlands (Krier and others 1990-1992; source: VROM 1991, 1992). Left: an early sketch which shows a preoccupation with the composition of public space. Right: a detailed overall plan in which the limited depth of most building masses, certainly those which are formed largely of dwellings, can be observed.

Slabs and orientations • This study refers to an arrangement of dwellings packed on top of one another and side by side as a slab. Thereby the terms 'on top of' and 'side by side' should be understood loosely: further on in this chapter it will become clear that dwellings may have overall shapes which are rather more complex than the one assumed by certain theoretical examples for reasons of simplicity.

Dwellings, or rather: rooms, are not closely packed in the absolute sense of the term, such as rectangles in a rectangular arrangement or boxes in a box packing. However, the distances between rooms are close to the effect that in general habitable rooms may only have two opposite directions of orientation, or orientations [Sherwood 1978 p10]. At room level orientations are defined as follows. If, in a habitable room, activities which require daylight and view are located at the 'front' side of the slab the room is said to have a front orientation. If they are located at the 'back' side of the slab the room is said to have a back orientation. If they are located at both sides we speak of a double oriented room. Commonly habitable rooms only have a
single, back or front, orientation.

The concept of orientation can be generalized for higher levels of spatial organization. A storey system, a dwelling or an entire slab are said to be front oriented if they include a front oriented room. They are said to be back oriented if they include a back oriented room. Storey systems, dwellings and slabs may be single or double oriented. While dwellings and thus also slabs necessarily include habitable rooms, this is not the case for every storey system included in a dwelling. We may therefore distinguish a dwelling’s oriented storey systems from those, if any, which do not have an orientation.

![Diagram of buildings](image)

**Figure 3.11 Decomposition into slabs. Slabs indicated in black, orientations by triangles.**

**Combinations of slabs** • In its present definition the term slab does not refer to a type of building. In much writing on residential buildings terms like ‘slab’, the german ‘Scheibe’, or the french ‘barre’ are used to indicate solitary high-rise buildings with the appearance, roughly, of a tall rectangular box [Sherwood 1978 p113; Neufert 1992 p242; Castex et al 1977]. Castex et al describe an evolutionary process taking place
from approximately 1850 to 1950, in which the traditional 19th
century city block is transformed via various intermediate
stages into the solitary building of which the Unité d'Habitation
is considered the prototype.

A complex residential building may be decomposed into a
number of slabs. The Narkomfin building, Immeuble Clarté,
and Hansaviertel tower are solitary double oriented slabs. The
Unité d'Habitation however, is a combination of an elongated
double oriented slab with a shorter single oriented one. Larger
numbers of double oriented slabs are combined in the
Vroeselaan and Spangen Blocks.

![Map of the third district in Vienna, Austria](image)

**Figure 3.12** Map of the third district in Vienna,
Austria (source: Tafuri 1981). Lower left: Rabenhof (Schmid
and Aichinger 1925-1927) in which a slab curves with a street
passing through the complex; right: Hanuschof (Oerley 1923-
1925) in which slabs meet under angles of 90°, 60° and 30°.

**Orthogonality** • These examples, though widely different in
many respects, have two characteristics in common: slabs are
arranged parallel and perpendicular to one another and, as we
will see in a following section, the internal organization of slabs
is predominantly orthogonal.

Slabs may well be positioned in other ways relative to one
another. Various examples can be found in Vienna, where during the 1920's many large city blocks were designed in a fight against serious housing shortage among the working class [Tafuri 1981]. The combination of high density housing with building sites that were often irregularly shaped and of limited size—together no doubt with certain architectural preferences—led to complex arrangements of slabs. Frequently one observes slabs which are curved in plan view and slabs which meet under angles other than 90°.

There is a difference between orthogonality understood in a strict sense (subsection 3.1.1) and in a looser sense. A room, a dwelling, a slab or even an entire building is said to be predominantly orthogonal if it is exceptional that room sides are not parallel to axes of the orthogonal axial system: there are only minor disturbances of orthogonality.

![Diagram of residential building 'Julia' in Stuttgart, Germany](image)

**Figure 3.13** Residential building ‘Julia’ in Stuttgart, Germany (Scharoun 1959). Left: curved slab interrupted by stair and elevator core. Right: dwelling with three habitable rooms; (a) and (b) are single oriented and (c) is double oriented.

The concepts of slab and orientation are not limited to predominantly orthogonal cases, as can be illustrated with the residential building ‘Julia’ in Stuttgart, Germany (1959) by Hans Scharoun [Jones 1979 pp48-50]. It consists largely of a
high-rise slab which is curved in plan view, almost to the point of forming a closed circle, and which has a wildly shaped facade on the outside. In spite of all this, habitable rooms can be seen to have front as well as back orientations and dwellings are closely packed side by side and on top of one another.

3.3.2. Appearances of orthogonal slabs

The majority of the slabs shown in figure 3.11 have the approximate shape of a rectangular box with a limited depth and a length and height which may be much greater. This shape may be viewed as the basic appearance of the orthogonal slab. There is a variety of ways in which this box shape may be affected without loosing orthogonality. Let us have a closer look at a few basic principles.

In order to avoid misunderstandings it will be useful to assume that every individual slab is aligned with a system of three orthogonal axes: a transversal (T) axis, a longitudinal (L) axis, and a vertical (V) axis. The T-axis corresponds to the slab's direction(s) of orientation, its positive direction being from front to back. The L-axis' positive direction is from left to right and the V-axis' positive direction is from below to above. One may speak respectively of a slab's depth, its length and its height. Since often, particularly in axonometric projections, the direction of the V-axis is obvious it will usually not be shown.

**Extreme proportions** • Many of the slabs discussed in the previous subsection are relatively long and tall (heights vary between 4 and 18 MSH). For a dwelling which is located to the extreme left or right of the slab or which occupies the lower or higher storey(s) there are certain exceptional opportunities:

1. If a dwelling occupies the lower storey(s) it is usually close to ground level and thus it may have private access, which means that it is connected to an exterior corridor. This is the case in the Spangen Block.
2. At the highest storey daylight is not obstructed by higher positioned dwellings, so that light may enter at any depth and
constraints upon the position of habitable rooms are relaxed. This is the case with the uppermost dwellings in the Immeuble Clarté.

(3) If a dwelling is located to the extreme left or right, habitable rooms may have a left or right orientation, besides the front and back orientations commonly available. This occurs in all three slabs of the Vroeselaan Block.

![Diagram showing slabs with extreme proportions]

*Figure 3.14 Slabs with extreme proportions. Dwellings at lowest storey(s) may have private access (dark grey), at upper storeys constraints upon position of habitable rooms are relaxed (dark grey) and dwellings at extreme left or right may have additional orientations (triangles). A limited length (b) is found in towers, a limited height (c) is typical for rowhousing, and a combination of both (d) characterizes detached and semidetached housing.*

If a slab's length is limited and opportunity (3) is used it may be difficult to distinguish the transversal direction from the longitudinal one. Ultimately it may even be the case that no
dwellings are packed side by side at all. Such extremely short slabs are found in buildings referred to as towers. A good example is the Hoogbouw (Highrise) design (1929) by Duiker and Wiebenga [Molema 1989 pp138-141]. Sting [1975 pp29-35] presents several appropriate examples. If a slab’s height is limited and opportunity (1) is used it may be the case that all dwellings have private access or even that no dwellings are packed on top of one another at all. Such extremely low slabs are often found in row housing. Theoretically, one could even argue that a combination of limited length and height ultimately leads towards a slab that includes only one or two dwellings. These are the components of detached and semidetached housing, or of the higher density complexes of single family houses that Sting [1975 p61] refers to as integrated dwelling complexes.

In any of the above situations the term slab, as presently defined, tends to lose its appropriateness. If however a slab is relatively long and tall, then to the majority of its dwellings the opportunities (1), (2) and (3) are not available.

**Sliding transformations** – Of course orthogonal slabs do not always appear as simple boxes. There are a variety of ways in which the box-shape, depending on its proportions, may be affected without losing the slab’s orthogonality. Perhaps the most common way is where the box is not completely ‘filled’ with dwellings, such as when a slab’s height increases from one end to the other. There are also ways of ‘sliding’ rows or stacks of storey systems relative to one another: ¹

(1) Transversal sliding of rows of storey systems leads in general to a terraced or stepped section in which dwellings may be provided with large terraces on top of lower dwellings. A relatively uncomplicated example is the Durand project for Algiers (1933-1934) by Le Corbusier [Boesiger 1935 pp160-169]. As indicated by Deilmann et al [1973 p46], slabs which are

¹ The term ‘sliding’ is taken from Macsai et al [1982 p223]. Macsai et al show some theoretical examples of the transversal sliding of stacks of storey systems.
transformed in this way may also be combined into ‘hills’ or ‘pyramids’. Several examples are offered by Sting [1975 pp90-100] and Neufert [1992 p245].

(2) Transversal sliding of stacks of storey systems may be motivated by the wish to ‘break up the building’s volume’ or result from ‘adaptation to diagonal property lines’ [Macsai et al 1982 p223 and 261]. Sting [1975 p23] even defines a subtype especially for access units in which this kind of displacement occurs.

**Figure 3.15** Principles of sliding stacks or rows of storey systems. Above, left: transversal sliding of rows, right: transversal sliding of stacks. Below, left: longitudinal sliding of rows, right: vertical sliding of stacks.

(3) Longitudinal sliding of rows of storey systems is highly exceptional in comparison with the other three combinatorial possibilities – none of the general handbooks on housing pays any attention to it. One may think of several reasons, the main one being that the transversal walls between dwellings must be
continuous through the entire height of the slab. However, the transformation may be advantageous with respect to the spatial organization within multi storey dwellings. Dutch examples are three double storey rows in Klein Driene (1958) by Van den Brock and Bakema [Joedicke 1963 p141] and a four storey slab in Amsterdam (1988) by Koolhaas [Leupen 1989].

(4) Vertical sliding of stacks of storey systems is rather common in low-rise housing. An example is the row of single family houses designed by Oud for the 1927 Weissenhof Siedlung [Kirsch 1987 pp90-99]. It does occur in higher slabs as well. Several examples are found among Vienna city blocks such as Blathof (1924) by Holzmeister and Lindenhof (1924) by Ehn [Tafuri 1981 p168, pp173-174]. This transformation seems to be caused invariably by a longitudinal slope of the site.

More complex appearances may result from the combination of two of the above transformations. An example is a project by Ebert in Munich, Germany (1968), where transformations (1) and (2) are combined [Deilmann et al 1973 pp136-137]. Particularly these two transformations may easily result in situations where it is doubtful whether we may still speak of a close packing. Transformation (1) provides the possibility of daylight penetrating dwellings much deeper than in a non-transformed slab. Transformation (2) provides dwellings with the opportunity of an additional left or right orientation.

3.3.3. Slabs and the circulation system

The slab has been defined as an arrangement of dwellings: a corridor is no part of that arrangement. A corridor and a slab may however be associated by the fact that the first is connected to certain of the dwellings in the second. In the Narkomfin building, the Immeuble Clarté and the Hansaviertel tower, corridors are obviously associated with at most a single slab. In the Unité d’Habitation we find six elongated corridors associated with both of its two slabs. The Spangen block may be described as a multitude of shorter and longer slabs associated with two corridors, one of which is an exterior corridor. Where there is a
Narkomfin building

Immeuble Clarté

Hansaviertel tower
Figure 3.16 Schematized frontal view of slabs in relation to circulation system (vertical sizes exaggerated for reasons of clarity; illustration covers three pages). Slabs are indicated by dashed frames, parts 'filled' with dwellings are white. The lower bound of storeys is indicated by a line in background grey (these lines are only shown where the occupying storey systems are front oriented). A corridor is indicated by a wide line which is arrowed in case of an exterior corridor; staircases and elevators by which corridors are connected are shown as a narrow vertical line.
combination of slabs there need not be a corridor associated with all of them. This can be seen in the Vroeselaan block where none of the two exterior corridors—representing the block’s courtyard and the pavements surrounding it, which have a relative distance of 0.5 MSH—are associated with any of the three slabs.

There is furthermore a wide variety to be observed among the examples with respect to the length and relative distance of corridors. In the Immeuble Clarté and the Vroeselaan Block there are vertical sequences of mutually connected corridors which are extremely short and which occur at regular distances of 1 MSH. Such a sequence is often referred to as a vertical circulation axis [Sting 1975 p11] or a walk-up [Sherwood 1978 p18] and entire buildings are characterized correspondingly as being of the ‘multiple vertical access’ or ‘walk-up’ type. However, vertical sequences of connected corridors with similar length and positioned at regular distances are also found in buildings which are usually distinguished as being of the ‘corridor type’. In the Unité d’Habitation the main corridors are commonly positioned at a relative distance of 3 MSH, and in the Hansaviertel Tower we find a sequence of relatively short corridors at regular distances of 2.5 MSH. It is unclear at what point such a sequence stops being a vertical circulation axis.

3.4. Decomposition of the slab into smaller arrangements

While a residential building may be formed of several slabs those slabs themselves are largely the product of the repetition, possibly in large numbers, of smaller arrangements of dwellings. This phenomenon is noted by several writers and it is discussed in detail by Sting. This section defines some of the concepts introduced by him in more general terms.

• Sting distinguishes buildings with ‘vertical access’ and
buildings with 'horizontal access'. The first are characterized by the repetition of small groups of dwellings along vertical circulation axes, the second by repetition of such groups along elongated corridors.

- Slabs can be decomposed into corridor arrangements: these are arrangements of dwellings connected to one and the same corridor. Often such corridor arrangements, or combinations of them, are vertically repeated. Sometimes they are small and repeated along vertical circulation axes.

- Where corridor arrangements have a considerable length, they tend to be formed of smaller arrangements of dwellings which are repeated along the corridor. These smaller arrangements, as well as the corridor arrangements which are repeated along vertical circulation axes are referred to as basic arrangements.

3.4.1. Repetition of arrangements of dwellings

As we have seen in chapter two (subsection 2.1.1) Sting tries to define spatial components at a level of organization between that of the individual dwelling and that of the slab as a whole. He speaks of vertical or horizontal access units which are characterized respectively by the 'stacking and concatenation of similar groups of dwellings' [Sting 1975 p11].

Concepts proposed by Sting • Those concepts are worked out in more detail in his later book Wohnbau, Perspektiven der Planung (Housing, prospects of planning) [Sting 1979]. In this book two clarifying illustrations are presented which refer to buildings with vertical access and buildings with horizontal access. Both show an arrangement of three dwellings referred to as a 'group of dwellings'. The arrangement is repeated along a 'vertical circulation core' in case of buildings with vertical access, and along an internal or external corridor -in the conventional meaning of the term- in case of buildings with horizontal access. This repetition produces stacks or rows of arrangements which are referred to as a vertical or horizontal access unit respectively. In turn, the building is a row or stack of such vertical or horizontal access units.
Figure 3.17 Vertical access and horizontal access (source: Sting 1979). A group of three dwellings (1, 2 and 3) is repeated in an access unit (4), access units are repeated in the building (5).

In addition to these two rather uncomplicated examples Sting presents a third one which is referred to as 'combination of vertical and horizontal access'. This third type is not visualized in a similar way as the other two and it remains unclear at what point one should stop considering a building as a case of, say, horizontal access and start considering it a case of combined access. However, two underlying ideas are fruitful:

(1) Within a slab arrangements of dwellings can be distinguished at different levels of organization in correspondence with the circulation system.

(2) At a certain level those are arrangements of one or just a few dwellings, the longitudinal or vertical repetition of which produces stacks and rows.

One may think of various reasons why it is so common for larger slabs to be formed of instances of one or just a few standard arrangements of dwellings. Here are some of them:

(1) The building programme usually demands large numbers of dwellings which are diversified in just one or a few categories. Both economy of designing effort and limitations to building cost tend to result in standard solutions for each of those categories.

(2) The wish to arrive at a building which technically
speaking is not too complicated, is more easily satisfied if standard arrangements are repeated. One may think of the wish that structural walls are straight and positioned at regular distances, or the wish that vertical ducts penetrate the building structure at regular points and without crankings.

(3) Repetition of standard arrangements complies with the wish to organize a circulation system in a comprehensible way. In larger buildings this leads to the linear character of elongated corridors and vertical circulation axes.

(4) Repetition is a device used to organize the appearance of a building by forming groups and patterns. The facades of the Unité d'Habitation for example are the expression of a complex game of repeating arrangements of dwellings and disturbing those repetitions at the right moment.

![Diagram](image)

**Figure 3.18 Distinct embeddings of an arrangement of two dwellings.** Given (a) the three additional embeddings (b, c and d) result from reflection in a TV-plane, reflection in an LV-plane, and a combination of both (reflection planes are shown as dashed frames, corresponding corners of the arrangements are marked by a dot).

**Distinct embeddings** • Given the LTV axial system related to a orthogonal slabs, there are in principle four distinct handed or rotated versions of an arrangement. An arrangement’s additional embeddings can be produced by reflecting it (1) in an LV-plane, (2) in a TV-plane, or (3) in both – which is the same as rotating it through 180° about a vertical axis. Transformations (1) and (2) are referred to as LV- and TV-reflection respectively. These embeddings are similar to the eight isomorphs discussed by Steadman [1983 pp24] in the
context of the rectangular arrangement. \(^1\)

Correspondingly we may distinguish three relevant types of symmetry for an arrangement of dwellings: (1) it may possess reflected symmetry in an LV-plane, (2) it may possess reflected symmetry in a TV-plane, and (3) it may possess rotational symmetry through 180°. The number of distinct embeddings is dependent on the number of symmetries. If the arrangement possesses just one of those symmetries, there are only two distinct embeddings. If it possesses two symmetries, there is only one embedding.

In principle, when it is said that two arrangements of dwellings are related by any of the above geometrical transformations, this is meant to apply not only to their external shape but to their entire internal organization as well, that is, down to shape and size of rooms and the location of openings. However, in actual buildings instances of a typical arrangement are often subjected to minor individual adaptations: an opening's location may be different, a room may be added, or its shape or dimensions may be slightly changed. At what point an adaptation stops being a minor one is dependent on the level of spatial organization. Certain arrangements of large numbers of dwellings in the Unité d'Habitation for example may be considered similar in spite of the fact that a number of dwellings in the one are entirely absent in the other.

3.4.2. Decomposition of the slab into corridor arrangements

The two examples presented by Sting as illustration of the vertical access type and the horizontal access type show us a relatively uncomplicated situation. An important question is how to deal with more complicated cases.

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\(^1\) Those isomorphs result from rotations through 0°, 90°, 180° or 270° which may or may not be combined with reflection in an orthogonal mirror line. In the present context, because left and right orientations are in general not available, the 90° and 270° rotations can be ignored.
Corridor arrangements • Dwellings which are connected to one and the same corridor are said to form a corridor arrangement. Every slab can be decomposed into corridor arrangements. Together with the corridor a corridor arrangement forms a system. In theory it is possible that a dwelling is connected to more than one corridor. This a highly exceptional situation though, and if it occurs the matter could be resolved by considering one of the dwelling’s connections as the primary one.

Vertical circulation axes occur frequently. Usually one, or sometimes two, corridor arrangements is vertically repeated along such an axis. In the Vroeselaan block we find in every one of the three slabs vertical repetitions of one and the same, occasionally adapted, corridor arrangement (a). In the Immeuble Clarté along each of the two vertical circulation axes a combination of a double storey (a) and a single storey corridor arrangement (b) is repeated three times. In the larger slab of the Unité d’Habitation a huge three storey corridor arrangement (a) is repeated five times, this repetition being interrupted by two storeys with smaller corridor arrangements and a shopping centre.

These examples have in common that corridor arrangements are vertically repeated without a change of embedding. That this is not always the case can be seen in the smaller slab of the Unité where instances of a single corridor arrangement (b) are repeated in two alternating embeddings, which are related by TV-reflection. In the Hansaviertel Tower a single corridor arrangement is also repeated in two alternating embeddings related by LV-reflection.

A characteristic shared by all repeated corridor arrangements found in the above examples is the fact that their overall shape approximates a simple rectangular box. In the case of the Immeuble Clarté the same holds, not for (a) or (b) individually, but for the combination of them. In the Narkomfin building no vertical repetition occurs, but its two main corridor arrangements are elongated boxes nonetheless, if certain minor complications at their extreme left and right side are ignored.
Figure 3.19 Schematized frontal view of slabs decomposed into corridor arrangements (vertical sizes exaggerated for reasons of clarity; illustration covers three pages). Circulation system is shown in dark grey, approximate contours of corridor arrangements are shown in black (where contours at back side are different they are dashed). Where similar corridor arrangements occur these are labelled a, b etc. Distinct embeddings of those instances are indicated by dot markers: where a corridor arrangement possesses reflected symmetry in a TV-plane the marker is positioned in the middle, otherwise it is positioned to the left or right (other symmetries do not occur). Changing the marker's position from left to right indicates that embeddings are related by TV-reflection, changing its colour from black to white indicates that embeddings are related by LV-reflection.
Height of corridor arrangements • It can be observed furthermore that where corridors have a limited overall length the vertically repeated corridor arrangements corresponding to them commonly have a height of 1 MSH, corridor arrangement (a) from the Immeuble Clarté being an exception. Where corridors are longer we find repeated corridor arrangements with heights up to 3 MSH. Among the precedents presented by Sting under ‘vertical access units’ corridor arrangements with a height of more than 1 MSH are highly exceptional. As we have seen (subsection 2.1.1) under ‘horizontal access units’ individual subtypes are introduced for corridor arrangements with a height of 2 and of 3 MSH. The following two considerations play a role:

(1) Elongated corridors are often distinguished into the internal kind and the external kind. For a dwelling which only occupies the same storey as the corridor there is in general the following problem. If the corridor is internal the dwelling can only be single oriented, a characteristic which is often considered not desirable. If on the other hand the corridor is external, giving this dwelling a second orientation may cause a serious conflict between the privacy of the dwelling and the public character of the corridor. Such difficulties can, in principle, be evaded by deciding in favour of multi storey dwellings [Sting 1975 p12; Macsai et al 1982 pp231-233; Gieselmann 1979 pp94-95]. These difficulties are less relevant if the corridor is short and, particularly, if it does not pass any dwellings.

(2) Economical considerations often lead to the wish to minimize costs spent on the circulation system as a whole [Macsai et al 1982 p197, p229]. If an elongated corridor provides access to multi storey instead of single storey dwellings, which have smaller widths, the corridor’s length is smaller in proportion to the number of dwellings connected to it. In case of a vertical circulation axis the same reasoning has the opposite effect: choosing for single storey dwellings minimizes, in principle, the length of vertical circulation axis in proportion to the number of dwellings connected to it.

In general the height of corridor arrangements is constrained by the desirability of limiting the vertical distance
between oriented storey systems and the corridor from which they are reached.

3.4.3. Basic arrangements of dwellings

Where corridor arrangements are elongated, they tend to be segmented: certain dwellings or arrangements of dwellings are repeated longitudinally. In fact most of the drawings offered in Sting's 1975 book under 'horizontal access units' refer to such repeated arrangements. Like in the case of repeated (combinations of) corridor arrangements, the overall shape of those arrangements commonly approximates a rectangular box.

**Repetition within corridor arrangements** • In both of the main corridor arrangements in the Narkomfin Building such repetitions occur. Along the lower corridor a single dwelling (b) is repeated nine times, mostly in alternating embeddings which are related by TV-reflection. This dwelling includes a back oriented storey system in the lower storey and a front oriented storey system in the upper storey. Along the upper corridor an arrangement (a) of two dwellings is repeated sixteen times in a single embedding. It is an arrangement of two dwellings. The upper dwelling includes a back oriented storey system positioned at 0,5 MSH from the corridor and a front oriented storey system at 1 MSH. The lower dwelling includes one double oriented storey system positioned at 0,5 MSH from the corridor. The width of (b) is twice the width of (a), so that two instances of (a) fit nicely on top of one instance of (b).

In the main corridor arrangements of the Unité d'Habitation, with exception of the uppermost one which is seriously adapted, we find a repetition of a single arrangement (a) in alternating embeddings related by TV-reflection. The repetition is occasionally interrupted by the more exceptional arrangements (b) and (c).

Repetitions of varying length, exceptionally short as well as long, are found in the Spangen block. Almost without exception the lower corridor arrangements result from the repetition, in alternating embeddings related by TV-reflection, of an
Figure 3.20 Longitudinal repetition of basic arrangements (illustration covers four pages). Corridor arrangements are shown transparently, repeated arrangements are labelled, and embeddings are indicated by dot markers. The internal organization of basic arrangements is shown at the level of storey systems, of which orientations are indicated.
Unité d'Habitation
arrangement (a) of two similar single storey double oriented dwellings on top of one another. In the upper corridor arrangements only a single dwelling (b) is repeated, mostly in alternating embeddings related by TV-reflection. It includes a front oriented storey system at level with the corridor and an upper double oriented storey system at a distance of 1 MSH. Like in the Narkomfin building the width of (b) is twice that of (a).

The one repeated corridor arrangement in the Hansaviertel tower is itself a repetition, four times, of a single arrangement (a) in alternating embeddings related by TV-reflection. The arrangement is formed by three dwellings. The lowest and uppermost of these dwellings each include two single oriented storey systems: one which is front oriented and positioned at 0,5 MSH from the corridor, and one which is back oriented and positioned at 1 MSH from the corridor. In between those last two storey systems a small back oriented dwelling is positioned which occupies the corridor storey.

**Basic arrangements of dwellings** • It can be argued that in small corridor arrangements, formed of only a few dwellings, longitudinal repetition may occur just as well. The corridor arrangement in the Vroeselaan for example is formed of two similar dwellings – it could be described as a two-times repetition of a dwelling in alternating embeddings. The main difference however with the longitudinal repetitions described earlier is, that the corridor does not pass by oriented storey systems in order to connect to additional dwellings. In the Immeuble Clarté such bypassing does occur in corridor arrangement (a) but one cannot really speak of a longitudinal repetition of storey systems.

It is perhaps not always easy to decide whether a repeated (combination of) corridor arrangements should be viewed, in its entirety, as a basic arrangement of dwellings or as the result of longitudinal repetition of smaller basic arrangements. Certainly there are cases in which both views are justified. The following chapters deal exclusively with basic arrangements of dwellings. Arrangements which are part of a vertical repetition, as described earlier, are referred to as Vertical Access (VA) arrangements. Arrangements repeated along a corridor are referred to as Horizontal Access (HA) arrangements.
3.5. Scaling down the problem

The task for the following two chapters is to demonstrate that it is possible to develop a type representation which applies at a high level of spatial organization. The present section scales down this task to a manageable size.

Definition of a type representation • The previous section has defined a level of spatial organization in the complex residential building, which is above that of the individual dwelling: the level of the basic arrangement of dwellings. The following two chapters define a highly abstract representation of such basic arrangements and explore the system of types which is implicit in that representation. There are two considerations which motivate the choice for this particular level of organization. First, the relevance of the basic arrangement is
acknowledged by several writers on the subject of residential buildings, such as Sting, Sherwood and Neufert. It will be interesting to see to what degree this study is actually able to improve on the achievements of those writers. Second, there is the practical advantage that those writers, together with several others, have described a large number of precedents precisely at this level of organization. Those descriptions are in general fairly detailed and sufficiently complete. They are indispensable for some of the tentative explorations carried out by chapter five.

When defining the representation two main subtasks are to be carried out:

(1) The specification of a criterion of syntactical well-formedness for type descriptions.

(2) The specification of the interpretation of those primitives and their possible configurations in terms of primitives and configurations of the earlier defined metric representation.

The criterion specified under (1) is to be motivated on basis of the interpretation specified under (2). The fact that a certain configuration of primitives qualifies as a type should be justified by the acceptability of every corresponding metric description. On the one hand the representation should be sufficiently restrictive: every well-formed type description should refer to arrangements which are on certain reasonable grounds possible. On the other hand it should not be too restrictive: for every reasonably possible arrangement there should be a well-formed type description.

Exploration of the system of types mainly serves the purpose of demonstrating the advantages of the combination of well-definedness and high degree of abstraction. This involves the following:

(1) The enumeration, within well-chosen limits, of complete ranges of type descriptions.

(2) The derivation of type descriptions from a variety of precedents offered by other writers.

(3) Analysis of the distribution over those ranges of characteristics which are meaningful in relation to design.
The demonstrations (1), (2) and (3) will be only of a tentative nature. It is not the intention of this study to actually produce anything like a typological handbook in the style of Hellmuth Sting, or a catalogue in the style of Steadman and Bloch. The idea of a reservoir of precedents is challenging nonetheless and the final chapter will discuss it in more detail, in the context of Computer Aided Architectural Design (CAAD).

**Nature of the representation** • Representations of architectural form can take two points of view which are, in a sense, complementary: (1) the view of architectural form as an organization of *spatial* components, and (2) the view of architectural form as an organization of *physical* components. Spatial components such as rooms can be thought of as bounded by physical components such as walls, and vice versa. Some of the studies discussed in chapter two, most notably the SAR method, try to combine the representation of spatial and physical components. Whenever this occurs representations address a low level of organization: they are in fact limited to the internal organization of the single storey component of dwellings. Writers who apparently try to describe types of basic arrangements of dwellings, such as Sting and Sherwood, discuss these types exclusively in terms of spatial components.

It is difficult to fully explain this preoccupation with spatial components. One reason seems to be that spatial components can be understood straightforwardly as accommodating particular human activities. One of the major challenges at the early stages of the process of designing a residential building is to organize those components so that proper accommodation is provided for the anticipated activities of the building's inhabitants. Often, explicit representations of the building as an organization of physical parts begin to play a more important role at later stages of the process. This is confirmed by the refining procedures proposed by the SAR and by Bergman et al. Section 2.2 discussed those procedures only briefly, but it will be remembered that in both cases the introduction of physical components in a floor plan starts after a layout of spaces or regions has been completed.

In view of the level of organization it addresses, it seems appropriate that the type representation concerns only spatial
components.

**Scope of the representation** • At higher levels of spatial organization the task of combining well-definedness with a sufficient degree of abstraction is not an easy one. It might be too ambitious to attempt the definition of a representation which applies to any basic arrangement of dwellings. In order that the task of defining such a representation be of a manageable size, its scope is reduced by several additional restrictions:

(1) All rooms in the arrangement have a height of 1 MSH. This excludes those arrangements in which exceptional activities are accommodated, such as those in the Zomerdijkstraat building mentioned earlier (subsection 3.1.1).

(2) Arrangements are strictly orthogonal: all rooms are aligned with one and the same LTV axial system. This excludes arrangements like those in the Julia building (subsection 3.1.1).

(3) Arrangements are not affected by any of the four sliding transformations discussed earlier (subsection3.3.2). If such a transformation occurs in the slab it may not affect the relative position of storey systems within the arrangement.

(4) Left and right orientations may occur in the slab but within the arrangement habitable rooms may only have front and back orientations. Of course, this does not mean that the arrangement could not be positioned at the extreme left or right of the slab.
4. A type representation of basic arrangements

This chapter defines an abstract representation of basic arrangements of dwellings. As stated at the end of the previous chapter (section 3.5) this requires a specification of primitives and possibilities of their configuration, as well as a specification of the interpretation of those primitives and configurations. Because there are several points where the second of these specifications provides a motivated of the first, they are presented simultaneously and in a stepwise manner.

Throughout the chapter nine basic arrangements, found in the buildings described by the previous chapter, are used for the purpose of illustration. Simplified hypothetical arrangements are presented frequently for the explanation of various basic concepts.

- In relation to the metric representation three concepts which have been introduced before are revisited: that of the habitable room, of the minimal parallel grating and of the α-zone.
- Graphs provide a convenient way of representing spatial components and relations between them. Three graphs are defined. The first represents the pattern of access relations among oriented storey systems and corridors. The second represents the vertical order of storeys. The third represents the orientations of storey systems and their longitudinal order.
- A complete and coherent type description also includes two functions which map the vertices of one graph onto those of another. Type descriptions may or may not imply efficient routing and they may or may not imply the external passing of oriented storey systems.
• Well-definedness of the type representation enables a well-defined visualization of type descriptions. The box-visualization shows oriented storey systems as individual boxes packed in a bounding box.

4.1. Habitable rooms, gratings and α-zones

The earlier discussion (subsections 2.2.1 to 2.2.3) of the design method proposed by the SAR introduced the concept of the habitable space and that of the α-zone coordinating the position of habitable spaces. This section redefines both concepts within the limitation of orthogonality.

Habitable rooms • In the previous chapter the habitable room has already been loosely defined as accommodating activities which need daylight, natural ventilation and view (subsection 3.3.1). It is not always easy to decide whether or not a room should be considered habitable. The activities actually accommodated are often, for practical reasons, unknown. We will consider only the activities which the room is apparently intended to accommodate. If in the available drawings a room is labelled or furnished as bedroom or living room, it certainly qualifies as a habitable room. Rooms labelled or furnished for example as kitchen, bathroom, or toilet are understood as non-habitable. Sometimes we find exceptional characterizations, such as certain rooms in the Immeuble Clarté which are labelled as bibliothèque or salon-studio [Boesiger 1935 p68]. In such cases, as in cases where no specific labelling is found, the decision is a speculative one based upon the room’s furnishing if indicated, the size of its windows if visible, and its depth from the facade.

In the metric representation habitable rooms are distinguished from non-habitable ones by labelling them $f$, $b$ or both. The labels $f$ and $b$ indicate a front and a back orientation respectively. In visualizations of the metric representation the
Figure 4.1 Basic arrangements found in the buildings discussed by the previous chapter (illustration covers five pages). Habitable rooms are coloured white and their orientations are indicated by black triangles. Perimeters of corridors and other storey systems are in greater line width. Minimal parallel gratings are associated with the arrangements, α-zones are coloured grey.
orientations are indicated by black triangles pointing in the
front or back direction.

**Minimum parallel grating** • In relation to an orthogonal
basic arrangement, a two dimensional grating can be defined
which is similar to the minimum rectangular grating discussed
earlier in the context of Steadman's work (subsection 2.3.2). A
*minimum parallel grating* is a set of lines parallel to the L-
and T-axes, so that in plan view every straight length of perimeter
coincides with precisely one such a line. A minimum parallel
grating may thus correspond to more than one basic
arrangement, for every particular arrangement however there
is a unique minimum parallel grating.

Every pair of parallel grating lines bound a *zone*. A particular
L-line is given by a single value $t$ on the T-axis; a T-line is given
by a single value $l$ on the L-axis. A particular L-zone is given by
an interval $(t_1, t_2)$ on the T-axis; a T-zone is given by an interval
$(l_1, l_2)$ on the T-axis. The size (depth or width) of a zone $(x, y)$ is
$y - x$.

**$\alpha$-zones** • As we have seen (subsections 2.2.2 and 2.2.3) an
essential ingredient of the SAR design method is a distribution of
L-zones, often related to a packings of dwellings which much
resemble the slab as defined by this study. In this 'zone
distribution' there are commonly two deeper zones positioned at
opposite sides of the packing. These $\alpha$-zones, indicated hereafter
as $\alpha^f$ at the front and $\alpha^b$ at the back, coordinate the positioning
of habitable rooms.

In the present context the $\alpha$-zone is understood as
constraining the position of those habitable rooms in a basic
arrangement which share a particular orientation. Since we do
not consider non-orthogonal or slided arrangements, it is
reasonable to assume that all habitable rooms with a similar
orientation intersect with one and the same L-zone. The main
reasons are (1) that one habitable room may not obstruct view
and daylight of another, and (2) that a habitable room cannot be
positioned too deep inside a slab. We should be aware however
that commonly in relation to a particular arrangement several
different $\alpha$-zones could be defined at the front as well as the
back side. In correspondence with the more subtle and largely
implicit intentions that underlie the examples offered in SAR publications, the following definition seems appropriate.

In relation to a particular arrangement, and for \( a \in \{f, b\} \), \( \alpha^a \) is an L-zone \((t_1, t_2)\) for which the following holds:

1. For every \( a \)-labelled room there are two T-lines \( l_1 \) and \( l_2 \), \( l_1 \neq l_2 \), with which its perimeter fully coincides in between \( t_1 \) and \( t_2 \), while it does not coincide with any L-line \( t_3, t_1 < t_3 < t_2 \) (the room is said to occupy the interval \((l_1, l_2)\) in \( \alpha^a \)).

2. There is no L-zone \((t_3, t_4)\), \( t_3 \neq t_1 \) or \( t_4 \neq t_2 \), which satisfies condition (1) while \( t_2 - t_1 < t_4 - t_3 \).

3. For every L-zone \((t_3, t_4)\), \( t_3 \neq t_1 \) or \( t_4 \neq t_2 \), which satisfies condition (1) while \( t_2 - t_1 = t_4 - t_3 \): \( t_1 < t_3 \) in case \( a = f \) and \( t_4 < t_2 \) in case \( a = b \).

This definition implies that an \( \alpha \)-zone is (one of) the deepest L-zone(s) in which all rooms with a similar orientation have a constant width. It implies furthermore, that for each of the two orientations there is at most one \( \alpha \)-zone. In general the size of the interval which an \( a \)-labelled room occupies in \( \alpha^a \) is a significant constraint upon the kind of activities accommodated by this room at this particular side of the slab, and upon the number of people that may be involved in them at the same time.

One could be struck by the fact that in the 'Corbusian' arrangements the \( \alpha \)-zones are exceptionally shallow. In case of the Unité it could certainly be argued that for certain habitable rooms the characteristic width is not found in one of these zones but somewhere to the front or to the back of them. This can be explained by the presence of large voids which seriously relax constraints with respect to a habitable room's limited depth from the facade.
4.2. Primitives of the type representation

This section defines the primitives of the type representation in relation to the metric representation. Various concepts borrowed from graph theory are used in the specification and motivation of conditions of well-formedness for three different graphs. Every one of these graphs retains a specific kind of information.

- The pattern of access relations between oriented storey systems and corridor(s) is represented in a connection graph. The access relation is understood more abstractly than in the previous chapter: systems may be connected via intermediate rooms and stairs.
- The vertical order of storeys is represented in a storey graph. This graph retains whether or not storeys are mutually overlapping.
- The longitudinal order and the orientations of storey systems are represented in a longitudinal graph. The order of oriented storey systems is retained only if the facts that they share an orientation and that they vertically overlap imply such ordering.

4.2.1. Intermediate systems

It has been mentioned earlier (subsection 3.1.2) that the occurrence of a pair of related openings indicates the presence of a spatial component other than a room. For simplicity such components will be referred to as stair-components. In the context of the following discussion the access graph (subsection 3.2.1) is redefined so that its vertices correspond to individual rooms as well as individual stair-components. As a result, an
edge in this redefined graph represents the presence of one or more openings shared between rooms or between a room and a stair-component. The system, previously defined exclusively in terms of rooms, is from here on understood as an arrangement of rooms and stair-components.

Several of the studies discussed in chapter two have shown the possibility to represent dwellings more abstractly as arrangements of single-storey components. Where Sting and Sherwood are concerned, this idea seems implicit in various schematized sections (section 2.1). It is more explicit in the 'differentiated dwelling types' proposed by Bergman et al (subsection 2.2.5). The transversal sections by which those types are described also show the distinction between single-storey components with one orientation and those with two opposite orientations. These are valuable ideas.

**Intermediate systems** • At type level oriented storey systems and corridors are represented as the individual systems among which a pattern of access relations is present. The possibility of travelling directly from one such system to another does not imply the presence of a shared opening. In multi-storey arrangements such travels are often enabled by stair-components, possibly combined with non-oriented storey systems. In such cases we speak of *intermediate systems*:

1. An intermediate system is connected to two or more corridors or oriented storey systems.
2. An intermediate system is disjunct from any corridor, oriented storey system or other intermediate system.
3. No pair of intermediate systems are connected.

Together with the earlier definitions of corridor and oriented storey system (subsections 3.2.3 and 3.3.1) this definition implies that an intermediate system always includes a stair-component. Among the nine arrangements we find many intermediate systems which simply are stair-components. There are some examples of intermediate systems including a non-oriented storey system as well. These are the Hansaviertel arrangement, arrangement (a) in the Narkomfin Building, and arrangement (a) in the Spangen Block.

In the context of the type representation, a pair of oriented
storey systems or corridors, \(x\) and \(y\), are said to be access related if either there are one or more intermediate systems to which both \(x\) and \(y\) are connected, or \(x\) and \(y\) share one or more openings. The access relation is denoted \(x \sim y\).

**Connection graph** • Oriented storey systems, corridors and the pattern of access relations between them are conveniently represented by means of a vertex-labelled graph. ¹ In this connection graph \(G^c\) every oriented storey system and every corridor is represented by a unique vertex. An access relation between two such systems is represented by an edge joining the two corresponding vertices. A vertex is either \(c\)-labelled to indicate that it represents a corridor, or \(o\)-labelled to indicate that it represents an oriented storey system. There are the following conditions of well-formedness:

• \(G^c\) is a connected graph.

![Connection graphs](image)

**Figure 4.2** Connection graphs (vertices are coloured white if \(o\)-labelled, grey if \(c\)-labelled).

Every maximal connected subgraph of \(G^c\) with only \(o\)-labelled vertices represents an individual dwelling. And since every dwelling is connected only to a single corridor:

• Precisely one \(c\)-labelled vertex is joined to one or more of the vertices in such an \(o\)-labelled subgraph.

¹ According to Harary's definitions a graph has no loops or multiple edges [Harary 1969 p10].
And assumed that every represented corridor is connected to a dwelling:

- Every \( c \)-labelled vertex in \( G^c \) is joined to at least one \( o \)-labelled vertex.

As a result of these two conditions, where two or more dwellings are involved every \( c \)-labelled vertex is a cut vertex: its removal, together with its edges, would make \( G^c \) disconnected [Harary 1969 p26]. Where VA-arrangements associated with more than one corridor are concerned, such as the Clarté arrangement:

- There is precisely one maximal connected subgraph of \( G^c \) with only \( c \)-labelled vertices.

4.2.2. The vertical order of storeys

Perhaps with the exception of the work of Bergman et al, none of the studies discussed in chapter two succeeds in representing the heights and relative distances of storeys at a sufficient degree of abstraction. At type level, only those storeys are of interest which are occupied by oriented storey systems or corridors. The type representation retains two kinds of information about the position of those storeys relative to one another:

1. The vertical order of storeys.
2. The fact that storeys overlap one another.

The vertical order of storeys is total: for every pair of storeys \( F_1 = (v_1, v_2) \) and \( F_2 = (v_3, v_4) \), \( F_1 \neq F_2 \): either \( v_1 < v_3 \) or \( v_3 < v_1 \). In the first case \( F_2 \) is said to be above \( F_1 \), denoted \( F_1 \uparrow F_2 \). In the second case \( F_1 \) is said to be above \( F_2 \), denoted \( F_2 \uparrow F_1 \). If \( F_1 \uparrow F_2 \) and there is no third storey \( F_3 \), so that \( F_1 \uparrow F_3 \uparrow F_2 \), this is denoted \( F_1 \uparrow F_2 \).

A pair of storeys \( F_1 = (v_1, v_2) \) and \( F_2 = (v_3, v_4) \) for which \( F_1 \uparrow
\( F_2 \), are said to overlap, if and only if \( v_3 < v_2 \). It will be assumed that such an overlap may only occur in case \( F_1 \uparrow F_2 \) and if it does, this is denoted \( F_1 \uparrow F_2 \). The situation where there are three storeys \( F_1, F_2 \), and \( F_3 \) so that \( F_1 \uparrow F_2 \uparrow F_3 \) while \( F_1 \) and \( F_3 \) overlap is perhaps theoretically possible but it is highly unlikely.

The importance of retaining the overlaps of storeys lies in the fact that corridors, oriented storey systems and intermediate systems only constrain each other's position in the horizontal plane if they are vertically overlapping, meaning that they occupy the same storey or overlapping storeys. An intermediate system is said to occupy those storeys that are occupied by the corridors and oriented storey systems to which it is connected.

**Storey graph** • The vertical order of storeys and the occurrence of overlaps between them are conveniently represented by a storey graph \((G^v)\) which is a directed and edge-labelled graph. In a directed graph, or digraph, the edges have a direction: we say that there is an edge from a start vertex to an end vertex. When visualizing a digraph, it is usual to show an edge as an arrow pointing towards the end vertex. In \(G^v\) every storey is represented by a unique vertex. For a pair of storeys \( F_1 \) and \( F_2 \) the fact that \( F_1 \uparrow F_2 \) is represented by an edge from the vertex representing \( F_1 \) to the vertex representing \( F_2 \). If \( F_1 \uparrow F_2 \) this edge is \( i \)-labelled, otherwise it is \( n \)-labelled. In visualizations of \( G^v \) the \( i \)-label is indicated by the arrow being a continuous line, in case of an \( n \)-label the arrow is dashed.

A (directed) walk from vertex \( x \) to vertex \( y \) in a digraph \( G \) is an alternating sequence of vertices and edges of \( G \), which begins with \( x \) and ends with \( y \), and in which every edge is preceded by its start vertex and followed by its end vertex. The length of a walk is the number of edges in it. A path is a walk in which all vertices, and thus all edges, are distinct [Harary 1969 p198].

The earlier definition of the \( \uparrow \) relation has one simple but serious implication for the well-formedness of \( G^v \):

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1 According to Harary's more formal definitions the edge is a pair of vertices \( \{x, y\} \). In the context of the directed graph it is an ordered pair \( (x, y) \) [Harary 1969 p9, p198].
• There is a path which includes all the vertices and all the edges in \( G_v \).

Said in a more popular way: \( G_v \) is an alternating string of vertices and edges, these edges being ordered head to tail.

\[ \text{Hansaviertel tower} \quad \text{Unité d'Habitation} \quad \text{Narkomfin building, arrangement (a)} \]

**Figure 4.3** Storey graphs in combination with schematic transversal sections (\( i \)-labelled edges are continuous, \( n \)-labelled edges are dashed). Left: Hansaviertel arrangement. Middle: Unité d'Habitation, arrangement (a). Right: Narkomfin Building, arrangement (a).

### 4.2.3. Longitudinal order and orientation of storey systems

In several of the schematized plans and sections discussed in chapter two directions of orientation seem to be retained as a characteristic of single storey components of dwellings. Examples are Sherwood’s orientation types (subsection 2.1.2) and the differentiated dwelling types proposed by Bergman et al (subsection 2.2.5). Since at type level oriented storey systems are represented individually it is logical to retain direction of orientation at this level as well. An issue closely related to the orientations of storey systems is that of their longitudinal order.

Some writers present schematized plans of single storey VA-arrangements in which orientations are explicitly indicated. The most recent edition of *Bauentwurfslehre* provides a good example [Neufert 1992 p243]. Neufert's walk-up types show the intention that shape, size and internal organization of storey
systems be ignored. However, like the schematized sections presented by Sting and Sherwood, they fail to express beyond reasonable doubt what information about the relative position of storey systems is essential.

\[\text{Figure 4.4 Walk-up types presented in Bauentwurfslehre (after Neufert 1992). Orientations are indicated by the larger arrows.}\]

**Longitudinal order** • Let us distinguish, for a pair of storey systems $S_1$ and $S_2$, and for $a \in \{f, b\}$, the following two cases:

1. For every pair of $a$-labelled rooms $R_1$ and $R_2$, included in $S_1$ and $S_2$ respectively and occupying intervals $(l_1, l_2)$ and $(l_3, l_4)$ in $\alpha$ respectively, $l_2 \leq l_3$, or
2. For every such pair $l_4 \leq l_1$.

In both cases all pairs of rooms have the same longitudinal order. If indeed there are one or more such pairs the pair of storey systems themselves is said to be longitudinally ordered. It may occur that storey systems $S_1$ and $S_2$ are vertically overlapping while case (1) holds for some $a \in \{f, b\}$. This is denoted $S_1$ left of $S_2$ ($S_2$ left of $S_1$ if case (2) holds). If for storey systems $S_1$ and $S_2$: $S_1$ left of $S_2$ and there is no storey system $S_3$ so that $S_1$ left of $S_3$ left of $S_2$, this is denoted $S_1 \rightarrow S_2$.

If there is a sequence of oriented storey systems $(S_1, S_2 \ldots S_{n-1}, S_n)$ whereby for every $1 \leq i < n$: $S_i \rightarrow S_{i+1}$, this is denoted $S_1$
Thus $S_1 \Rightarrow S_2$ implies $S_1 \Rightarrow S_2$, but $S_1 \Rightarrow S_2$ does not imply $S_1 \Rightarrow S_2$.

![Diagram](image)

**Figure 4.5 Arrangement in Immeuble Clarté. The intervals occupied in $\alpha$-zones by habitable rooms are indicated by double arrows.**

From here on the following is assumed with respect to the $\Rightarrow$ relation:

1. For every pair of vertically overlapping storey systems $S_1$ and $S_2$ that share an orientation: either $S_1 \Rightarrow S_2$ or $S_2 \Rightarrow S_1$.
2. The relation is antisymmetrical: $S_1 \Rightarrow S_2$ implies that not $S_2 \Rightarrow S_1$. 
These assumptions exclude certain packings of oriented storey systems which are highly unlikely. The reasons for this unlikelihood are mainly to do with the extreme sizes or complicated shapes of storey systems, as implied by such packings.

Figure 4.6 Unlikely packings of oriented storey systems. Left: $S_2$ has front oriented rooms to the left as well as to the right of those in $S_1$, so that the left of relation and thus the $\Rightarrow$ relation are not defined. This is excluded by assumption (1). Right: $S_1 \Rightarrow S_2$ as well as $S_2 \Rightarrow S_1$. This is excluded by assumption (2).

As to the relative position of oriented storey systems in plan view, the type representation only retains their $\rightarrow$ relations and their orientations. What this means is that the longitudinal order of storey systems is retained only for as far as the fact of systems being ordered is implied by their vertical position and their orientations.

The number of systems $\rightarrow$ related to any one system is limited. Where $a \in \{f, b\}$: for every system $S_1$ including an $a$-labelled room there are at most two distinct systems $S_2$ and $S_3$, which both include an $a$-labelled room, so that $S_1 \rightarrow S_2$ and $S_1 \rightarrow S_3$ and there are at most two distinct systems $S_4$ and $S_5$, which both include an $a$-labelled room, so that $S_4 \rightarrow S_1$ and $S_5$
→ $S_1$. What is more: $S_2$ and $S_3$ as well as $S_4$ and $S_5$ cannot be vertically overlapping, since this would cause them to be related, and this would violate the definition of the relation.

**Figure 4.7** Longitudinal order of oriented storey systems. Left: $S_1$ and $S_3$ are not vertically overlapping, but still $S_1 \Rightarrow S_3$. Middle: $S_1$ and $S_2$ are both front oriented and $S_3 \rightarrow S_1$ as well as $S_3 \rightarrow S_2$, by consequence $S_1, S_2$ and $S_3$ occupy three different storeys. Right: $S_1, S_2$ and $S_3$ are mutually overlapping (they occupy the same storey) and all three are front oriented. Since $S_3 \rightarrow S_1$ and $S_1 \rightarrow S_2$, not $S_3 \rightarrow S_2$.

A corridor may pass oriented storey systems to the front as well as to the back without obstructing view or daylight, and it does not contain any habitable rooms itself. For those reasons its position relative to oriented storey systems cannot be described in terms of the relations defined above. As shown in the following subsection, for a corridor the type representation only retains which storey it occupies. However, it will be shown later on that more specific information about the position of a corridor relative to oriented storey systems may be implicit in a type description.

**Longitudinal graph** The ordering of storey systems by the relation and their orientations are conveniently represented by a *longitudinal graph* ($G^h$), which is a vertex-labelled digraph. Every oriented storey system is represented by a vertex in $G^h$. A vertex is labelled $f$ if the system includes an $f$-labelled room, it is labelled $b$ if the system includes an $b$-labelled
room. If for a pair of systems \( S_1 \) and \( S_2: S_1 \rightarrow S_2 \), this is represented by an edge in \( G^h \). The start vertex of this edge represents \( S_1 \) while the end vertex represents \( S_2 \). By consequence, if for a pair of systems \( S_1 \) and \( S_2: S_1 \Rightarrow S_2 \), then in \( G^h \) there is a path from the one corresponding vertex to the other.

![Diagram](image)

**Figure 4.8 Longitudinal graphs.**
Both graphs are non-connected, the one to the right is formed of two isolated vertices.

Since it is not necessarily the case that every pair of systems are \( \Rightarrow \) related, \( G^h \) may be a disconnected graph. Several conditions of well-formedness can be formulated.

![Diagram](image)

**Figure 4.9 Cycles and bypasses.** Left: cycle including three edges. Right: edge bypassing one vertex.

The antisymmetry of \( \Rightarrow \) implies:

- In \( G^h \) there are no cycles.

A *cycle* is defined like a path, with the only difference that its first and last vertices are one and the same [Harary 1969 p198].
The definition of the $\rightarrow$ relation implies:

- In $G^h$ there are no bypasses.

If, for two distinct vertices $x$ and $y$, there is path of length $\geq 2$ from $x$ to $y$ then any edge from $x$ to $y$ is a bypass.

The definition of the $\rightarrow$ relation implies furthermore:

- Vertices which are joined by an edge in $G^h$, have at least one label in common.
- Where $a \in \{f, b\}$, for every vertex in $G^h$ there are no more than two edges from $a$-labelled vertices, and no more than two edges to $a$-labelled vertices.

The second of these conditions limits the indegree as well as the outdegree of vertices in $G^h$ to four. The indegree of a vertex is the number of edges to it, the outdegree of a vertex is the number of edges from it [Harary 1969 p198].

4.3. Complete type descriptions

The previous section has defined three different graphs, every one of which retains a specific kind of information at a high degree of abstraction. It has also discussed conditions of well-formedness which relate to those graphs individually. This section deals with the complete and coherent representation of types of basic arrangements.

- The three graphs are related by functions, which map the vertices of one graph onto the vertices of another. The combination of related graphs is visualized in a way which explicitly shows the mapping of their vertices.
- There are several additional conditions of well-formedness to be satisfied by a complete type description. These are to do with the possible ways in which oriented storey systems can be connected and packed in three dimensional space.
• A path in the connection graph represents a particular way of travelling via oriented storey systems and corridors. Two types of paths are defined, travelling by which should require only a minimal vertical distance to be covered if the type is to imply efficient routing.

• Situations are possible in which travellers via a corridor are forced to pass in front of a front oriented storey system, or to the back of a back oriented one. At type level such external passing is or is not implied.

4.3.1. Relations between graphs

A complete type description is a 5-tuple:

\[(G^h, G^c, G^v, f^h\cdot c, f^c\cdot v)\]

Where in general \(V(G)\) denotes the set of all vertices in \(G\), \(f^h\cdot c\) is a function from \(V(G^h)\) to \(V(G^c)\) and \(f^c\cdot v\) is a function from \(V(G^c)\) to \(V(G^v)\). Thereby a third function \(f^h\cdot v\) from \(V(G^h)\) to \(V(G^v)\) is implicitly defined: for every vertex \(x\) in \(G^h\), \(f^h\cdot v(x) = (f^c\cdot v(f^h\cdot c(x)))\).

The interpretation of \(f^h\cdot c(x) = y\) is that \(x\) and \(y\) represent one and the same oriented storey system. This has the following implications:

• Every vertex in \(G^h\) has an \(f^h\cdot c\) image.

• There is no vertex in \(G^h\) for which the \(f^h\cdot c\) image is \(c\)-labelled.

• Every \(o\)-labelled vertex in \(G^c\) is the \(f^h\cdot c\) image of precisely one vertex in \(G^h\).

The interpretation of \(f^c\cdot v(x) = y\) is that the oriented storey system or corridor represented by \(x\) occupies the storey represented by \(y\). This has the following implications:

• Every vertex in \(G^c\) has an \(f^c\cdot v\) image.

• Every vertex in \(G^v\) is the \(f^c\cdot v\) image of at least one vertex in \(G^h\).
Figure 4.10 Complete type descriptions. Above: types corresponding to HA-arrangements. Below: types corresponding to VA-arrangements.
For the discussion in following sections it is convenient to visualize type descriptions in a way which explicitly shows the graphs and the functions relating them to one another. If \( f^{h-c}(x) = y \), then \( x \) and \( y \) are depicted simultaneously as a small circle. If \( f^{h-v}(x) = y \), then \( y \) is depicted as a larger ellipse including the circle depicting \( x \). This visualization has advantages as well as disadvantages. These are discussed in the final section (4.4) of this chapter, which presents an alternative way of visualizing the type representation.

4.3.2. The packing of oriented storey systems and intermediate systems

The packing in three dimensional space of oriented storey systems and intermediate systems implied by a type description must of course be physically possible.

\[ \includegraphics[width=0.8\textwidth]{figure4.11.png} \]

**Figure 4.11** Well-formedness of \((G^h, G^v, f^{h-v})\).
Left: path between two vertices in \( G^h \), the \( f^{h-v} \) images of which are not joined by an \( i \)-labelled edge. Middle: in \( G^h \) there are edges from one vertex to two vertices with a shared label \((f)\); as a result all three must have a different \( f^{h-v} \) image. Right: three vertices in \( G^h \) have the same \( f^{h-v} \) image; as a result at most two pairs of them can be joined by an edge.

The definition of the \( \to \) relation has the following implications for \((G^h, G^v, f^{h-v})\):

- If vertices \( x \) and \( y \) in \( G^h \) are joined by an edge, then either \( f^{h-v}(x) = f^{h-v}(y) \) or \( f^{h-v}(x) \) and \( f^{h-v}(y) \) are joined by an \( i \)-labelled
edge.

- If, for $a \in \{f, b\}$ and for vertices $x, y$ and $z$ in $G^h$: $x$ and $y$ are both labelled $a$ and there are edges either from $x$ and $y$ to $z$, or to $x$ and $y$ from $z$, then no pair of vertices out of $f^n(x), f^n(y)$ and $f^n(z)$ are identical.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{figure4.12}
\caption{Travelling via intermediate systems (intermediate system indicated by double arrow, height of 1 MSH suggested by bottom line). An intermediate system connecting $S_1$ and $S_2$ inevitably contradicts at least one of the assumptions with respect to travelling via intermediate systems. Left: intermediate system implies the external passing of $S_3$ at the front side. Right: intermediate system forces a traveller between $S_1$ and $S_2$ to climb as well as descend.}
\end{figure}

**Travelling via intermediate systems** • With respect to intermediate systems, the following will be assumed:

1. An intermediate system which connects two other systems enables a travel from the one to the other, or vice versa, without forcing the traveller to climb as well as descend.

2. The unobstructed height needed for such a travel is 1 MSH.
(3) An intermediate system which connects two oriented storey systems does not force a traveller between those systems to pass a third storey system at a side towards which it is oriented.

Assumption (3) has to do with the fact that an intermediate system enabling a travel within one and the same dwelling is not transparent in the sense in which a corridor may be transparent. The external passing of an oriented storey system ruled out by (3) would result in an unacceptable obstruction of view and natural light. External passing is considered possible only if a person travels via a corridor – an issue which will be discussed in a following subsection.

Assumption (1) has the following implication for \((G^c, G^v, f^{c-v})\):

- For every pair of vertices \(x\) and \(y\) in \(G^h\): if \(f^{h-c}(x)\) and \(f^{h-c}(y)\) are joined by an edge, then \(f^{h-v}(x) \neq f^{h-v}(y)\).

**Separation**

- In general terms, two oriented storey systems may be separated by a sequence of systems. If this sequence includes just one element the two systems are said to be separated by this one system. Two oriented storey systems are separated by an individual system, if and only if they can be denoted \(S_1\) and \(S_2\) in such a way that one of the three following situations is found.

(1) There is a double oriented storey system \(S_3\), so that \(S_1\) and \(S_2\) both vertically overlap \(S_3\) and \(S_1 \Rightarrow S_3 \Rightarrow S_2\).

The separating system may also be formed of two oriented storey systems, both vertically overlapping \(S_1\) as well as \(S_2\) and an intermediate system connecting them. This complex system separates \(S_1\) and \(S_2\), if the oriented storey systems included in it can be denoted \(S_3\) and \(S_4\) in such a way that one of the following conditions holds:

(2) \(S_3\) and \(S_4\) have opposite orientations, whereby neither \(S_3 \Rightarrow S_1\) nor \(S_4 \Rightarrow S_1\), and whereby neither \(S_2 \Rightarrow S_3\) nor \(S_2 \Rightarrow S_4\).

(3) \(S_3\) and \(S_4\) have a shared orientation, whereby \(S_3 \Rightarrow S_1 \Rightarrow\)
$S_4$ and not $S_3 \Rightarrow S_2 \Rightarrow S_4$.

**Figure 4.13** Basic situations in which separation occurs. (double arrows indicate intermediate systems). Left: oriented storey systems $S_1$ and $S_2$ are separated by a double oriented storey system $S_3$. Middle: oriented storey systems $S_1$ and $S_2$ are separated by a system including storey systems $S_3$ and $S_4$ which have opposite orientations. Right: oriented storey systems $S_1$ and $S_2$ are separated by a system including storey systems $S_3$ and $S_4$ which have a shared orientation.

In the context of $(G^h, G^c, G^v, f^h-v, f^c-v)$ these three basic situations can be described as follows:

(1) There are three distinct vertices in $G^h$ which can be denoted $x_1$, $x_2$ and $x_3$ in such a way that first: the pair $f^h-v(x_1)$ and $f^h-v(x_2)$, as well as the pair $f^h-v(x_2)$ and $f^h-v(x_3)$ are identical or joined by an $i$-labelled edge, and second: $x_2$ is labelled $f$ and $b$ and in $G^h$ there is a path of the form $(x_1 \ldots x_2 \ldots x_3)$.

There are four distinct vertices in $G^h$ which can be denoted $x_1$, $x_2$, $x_3$ and $x_4$ in such a way that first: every one of the pairs $f^h-v(x_1)$ and $f^h-v(x_3)$, $f^h-v(x_1)$ and $f^h-v(x_4)$, $f^h-v(x_2)$ and $f^h-v(x_3)$, and $f^h-v(x_2)$ and $f^h-v(x_4)$ are identical or joined by an $i$-labelled
edge, that second: \( f^{h-c}(x_3) \) and \( f^{h-c}(x_4) \) are joined by an edge, and that third: one of the following two holds:

(2) In \( G^h \) there are no paths of the form \((x_3 \ldots x_1)\), \((x_4 \ldots x_1)\), \((x_2 \ldots x_3)\), or \((x_2 \ldots x_4)\).

(3) In \( G^h \) there is a path of the form \((x_3 \ldots x_1 \ldots x_4)\), but there is no path of the form \((x_3 \ldots x_2 \ldots x_4)\).

\(\text{Figure 4.14 Partial type descriptions implying basic situations of separation. Left: separation by a double oriented storey system. Middle: separation by a combination of story systems with opposite orientations. Right: separation by a combination of story systems with a shared orientation.}\)

In situations (1), (2) and (3) separations between individual oriented storey systems are described. Two systems \( S_1 \) and \( S_2 \), each being either an individual oriented storey system, or a system formed of two connected oriented storeys systems, are said to be separated by a system \( S_3 \), if and only if every oriented storey system included in \( S_1 \) is separated by \( S_3 \) from every oriented storey system included in \( S_2 \).

Now we have defined separation between systems which themselves can act as a separator, the following definition can be given:

If and only if there is a sequence of at least three systems \((S_1, S_2 \ldots S_{n-1}, S_n)\), whereby for every \( i, 1 < i < n: S_{i-1} \) and \( S_{i+1} \) are separated by \( S_i \), \( S_1 \) and \( S_n \) are said to be separated by the sequence \((S_2, S_3 \ldots S_{n-2}, S_{n-1})\).
Figure 4.15 Separation.
Oriented storey systems $S_1$ and $S_4$ are not separated by $S_2$ or $S_3$ individually, but by the sequence $(S_2, S_3)$.

In the context of $(G^h, G^c, G^v, f^{h-c}, f^{c-v})$ this corresponds to the occurrence of a sequence of at least three subgraphs in $G^h (G_1, G_2 \ldots G_{n-1}, G_n)$, whereby for every $i$, $1 < i < n$: in combination with every pair of vertices, the one in $G_{i-1}$ and the other in $G_{i+1}$, the vertices in $G_i$ satisfy at least one of the basic situations (1), (2) and (3).

Under the earlier assumptions with respect to travelling via intermediate systems, oriented storey systems can be connected only if they are not separated. This has the following implication for $(G^h, G^c, G^v, f^{h-c}, f^{c-v})$:

- For every pair of vertices $x$ and $y$ in $G^h$: if $f^{h-c}(x)$ and $f^{h-c}(y)$ are joined by an edge, there is no sequence of subgraphs in $G^h (G_1, G_2 \ldots G_{n-1}, G_n)$ as described above, so that $G_1$ includes $x$ and $G_n$ includes $y$. 
4.3.3. Efficient routing

In the context of a non-directed graph a path is an alternating sequence of distinct vertices and edges, in which every edge joins the vertices preceding and following it [Harary 1969 p13].

Every path in $G^c$ represents the possibility of travelling via a particular sequence of distinct oriented storey systems and corridors. Since $G^c$ does not have parallel edges a sequence of distinct vertices $(x_1, x_2 \ldots x_{n-1}, x_n)$ is sufficient to indicate a path $P$ from $x_1$ to $x_n$ [Harary 1969 p13]. If for some pair of vertices, $x_i$ and $x_{i+1}$, there is a directed path in $G^v$ from $f^c-v(x_i)$ to $f^c-v(x_{i+1})$, then $P$ implies climbing. If for some pair of vertices, $x_i$ and $x_{i+1}$, there is a directed path in $G^v$ from $f^c-v(x_{i+1})$ to $f^c-v(x_i)$, then $P$ implies descending. A path in $G^c$ is said to be efficient if it does not imply both climbing and descending.

**Vertical travelling distances** • A person travelling via an inefficient path is forced to cover a vertical distance larger than that between the storeys in which this travel begins and ends. Where the path is efficient the distance covered is equal to that between the storeys.

For every pair of distinct storeys $F_1$ and $F_2$, $G^v$ implies a minimum to their relative distance $d^v(F_1, F_2)$. Any path $(x_1, x_2 \ldots x_{m-1}, x_m)$ in $G^v$, where $x_j$ represents storey $F_j$ for every $1 \leq j \leq m$, can be decomposed into paths of maximal length all edges in which have the same label. For every such component path $(x_k, x_{k+1} \ldots x_{l-1}, x_l)$, $1 < k \leq l < m$, one of the following cases holds:

1. The edges are $n$-labelled, in which case $l-k$ MSH $\leq d^v(F_k, F_l)$.

2. The edges are $i$-labelled, in which case $0.5 \ (l-k)$ MSH $\leq d^v(F_k, F_l)$ if $l-k$ is even, and $0.5 \ ((l-k)-1)$ MSH $< d^v(F_k, F_l)$ if $l-k$ is odd.
The minimal distance $d_\nu(F_1, F_m)$ is the sum total of the minimal distances found for the component paths.

![Hansaviertel tower](image)

**Figure 4.16** Minimal distance between storeys. Left: schematized transversal section through the Hansaviertel arrangement. Middle and right: two hypothetical variations on basis of the same storey graph. The distance between the lowest and uppermost storeys cannot be less than 2 MSH.

**Efficient routing** • It will be useful to distinguish two types of paths in $G^c$:

1. Paths in which only the first, or only the last vertex is $c$-labelled.
2. Paths in which all vertices are $o$-labelled.

A type description is said to imply efficient routing if it satisfies the following conditions:

1. Towards every $o$-labelled vertex in $G^c$ there is precisely one efficient path of type (1).
2. For every pair of $o$-labelled vertices in $G^c$ there is at most one path of type (2) from the one to the other, and if so this path is efficient.

At this point is understandable that every one of the storey graphs referring to the nine cases presented earlier is a tree. A graph $G$ is a tree if there is, for every pair of vertices in $G$, precisely one path from the one to the other [Harary 1969 p32]. Condition (2) forces all subgraphs corresponding to individual dwellings to be non-branching trees. Condition (1) is likely to force those subgraphs to have only one vertex joined to a $c$-
labelled vertex.

\[\text{Figure 4.17 Inefficient paths. Left: path of type (1). Right: path of type (2).}\]

It is difficult to pinpoint why the occurrence of inefficient routings is unlikely. The following two closely related reasons seem to play an important role however:

(1) In view of the comparatively insecure and strenuous character of travelling by stair there must be exceptional reasons for accepting a situation where in order to reach some oriented storey system, either from the corridor or from another oriented storey system in the same dwelling, a vertical distance must be covered which is larger than the one between the corresponding storeys.

(2) Stairs are space-consuming and expensive building parts. There must be exceptional reasons to accept a 'quantity of stairs' larger than minimally needed to prevent the situation described under (1).

Furthermore there are certain apparent limits to the vertical distances that are to be covered when travelling via paths of type (1) and type (2). In the nine arrangements for example, we find 1 MSH to be the maximum for both types of paths. Sting [1975 p51 and p55] presents an arrangement (II 2.2.7) in which 2 MSH occurs for a type (2) path, and another one (II 3.2.7) in which 1.5 MSH is the distance for a type (1) path. Perhaps with the exception of arrangements related to an exterior corridor, the dwellings having private access, these values seem to indicate what is maximally possible.
4.3.4. External and internal corridors

The type representation does not retain explicit information about a corridor’s shape and position in plan view. It only retains which storey is occupied by a corridor. Several writers who discuss the the spatial organization of residential buildings in more general terms distinguish between internal and external corridors and some of them point at the implications for certain aspects of a building’s performance. It is never entirely clear though, on which criteria this distinction is based. Several considerations such as the entrance of natural light into the corridor, the corridor not being closed against exterior climate, and the occurrence of habitable rooms with an orientation across the corridor seem to be ingredients of its externality.

The confrontation between the public character of the corridor and the private character of one or more habitable rooms is often mentioned as a disadvantage of the external corridor [Neufert 1980 p90, 1984 p250; Macsai 1982 p261]. On the other hand this confrontation has the advantage of natural surveillance of the corridor. ¹ It is often pointed out that in corridor buildings double oriented dwellings can be realized without the mentioned privacy conflict being inevitable [Gieselmann 1979 pp94-95; Neufert 1992 p244]. Gieselmann mentions that ‘a solution is offered by dwellings that occupy more than one storey – maisonettes or split-level dwellings’. The advantages of the double oriented dwelling in comparison with the single oriented one are obvious: if a dwelling contains habitable rooms at two opposite sides there is the opportunity of enjoying direct sunlight more often, and of having a view at both sides of the slab. Smaller dwellings however, particularly those that contain only a single habitable room, tend to be

¹ Studies on crime and vandalism in the built environment pay much attention to the aspect of natural surveillance of the circulation system [Newman 1972; Van der Voordt and Van Wegen 1991; Elsinga and Wassenberg 1991].
considerably more economical if single oriented and positioned at both sides of an internal corridor [Deilmann 1973 p44; Gieselmann 1979 p97].

The internal corridor is often pictured as deprived of view and daylight, which is generally considered undesirable. Macsai [1982 p229] disqualifies especially the longer internal corridor 'unless broken up or daylighted' as barren and inhuman. Gieselmann [1979 p97] comments:

'Efficient use [of the internal corridor] requires dwellings at both of its sides. This means that the corridor is not daylighted or at most that it receives daylight via windows at its ends. Difficulties in orienting oneself and identifying a particular dwelling are the result of this situation. The continuously needed artificial light causes an increase of energy costs and it degrades the corridor to a mechanistic, monofunctional axis.'

There are also advantages to the internal corridor such as the economy of floor area used for public circulation [Macsai 1982 pp228-229] and the natural provision of shelter against wind, rain and low temperatures.

**External and internal passing** • In view of the above, it seems reasonable to consider the occurrence of habitable rooms oriented across the corridor as the most significant characteristic distinguishing the external corridor from the internal corridor. As mentioned in subsection 4.3.2 a traveller may only pass an oriented storey system externally when travelling via a corridor. A type description may or may not imply such external passing:

If there are a corridor C and two oriented storey systems S₁ and S₂ so that S₁ ~ C ~ S₂, then for every system S₃ which is (in a sequence) separating S₁ and S₂, the following holds: if every oriented storey system included in S₃ vertically overlaps C, external passing of at least one of those oriented storey systems is inevitable. Of course, travels from S₁ via C to S₂ or vice versa are not likely to happen frequently. But if for some S₃ the above

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1 In German literature such dwellings are sometimes indicated as 'Einraumwohnungen' (single-room dwellings) [Oesterle-Schwerin 1973].
situation exists, then irrespective of where travellers enter C, they must externally pass S₃ either in order to reach S₁ or in order to reach S₂.

Whether the position of a corridor causes *internal passing*, understood as the passing of a traveller in between single oriented storey systems, cannot be decided straightforwardly on basis of the type representation. However, it may be the case that no external passing occurs in an arrangement but the hypothetical presence of an intermediate system connecting single oriented storey systems S₁ and S₂, or their merging into a single storey system, would make external passing inevitable. If so, internal passing between S₁ and S₂ is inevitable if none of them is to be passed externally. Thus a type description can be said to imply internal passing provided that external passing does not occur.

![Diagram of external passing](image)

*Figure 4.18 External passing. Left: S₂ does not separate S₁ and S₃ and thus external passing of S₂ could have been avoided by positioning the corridor in such a way that S₂ is passed at its back side. Right: S₂ does separate S₁ and S₃ and thus external passing, to the front or to the back, of S₂ is inevitable.*

A type concerns an individual basic arrangement. Since an HA-arrangement is repeated along the corridor other arrangements can be expected to its left and right. Therefore it is assumed from here on that every double oriented storey system, or pair of storey systems with opposite orientations connected to the same intermediate system, separates
imaginary systems connected to the corridor. Type descriptions are labelled VA or HA to indicate whether they represent VA- or HA-arrangements.

4.4. Visualization of type descriptions

The techniques used throughout this chapter to visualize type descriptions have the advantage that a configuration of primitives is shown without suggesting any information not retained by the type representation. Those techniques are common practice in studies in which graph theory is involved – such as the work of Steadman and of Harary frequently referred to by the present study. However, compared to the plans and sections discussed in chapter two these techniques have the disadvantage that even when only a few oriented storey systems are involved the interpretation of their relative position in three dimensional space requires considerable effort. Type descriptions should not require too much interpretation: they should be easily understood and mutual differences should be quickly observed. In this subsection a more accessible visualization of the type representation is presented. Like the type representation itself such a visualization can be well-defined. Since this visualization shows oriented storey systems as orthogonal boxes, packed within a bounding box, it will be referred to as box visualization.

Throughout the following explanation a single rather extravagant type description is used for the purpose of explanation. It should not be expected that arrangements of such complexity are of any practical relevance. The description is very useful though to demonstrate the principles on which the box visualization is based.
**Figure 4.19** A highly complex type description. Altogether 10 oriented storey systems occupy four different storeys and are grouped into 6 dwellings. Two dwellings are connected to a lower corridor, the others to an upper corridor.

**Box visualization** • A box packing is aligned with an LTV orthogonal axial system. It is always shown in axonometric projection, whereby it is seen from above, from the front and from the right. Every oriented storey system is represented by a single box and these boxes are shown transparently.

If back as well as front oriented storey systems are present, the bounding box is divided into imaginary front and back halves, each with a depth of 1 \( u_2 \), \( u_4 \) being an arbitrary but fixed size. Otherwise, one of these halves is ignored. A box representing a double oriented storey system occupies both halves. If a storey system is only front or only back oriented, the representing box occupies only the front or back half,
respectively.

\[ \text{Figure 4.20 Boxes within a bounding box. Left: three oriented storey systems which occupy two overlapping storeys. Right: two single oriented storey systems with opposite orientations.} \]

For every storey there is an imaginary slice \((v_1, v_2)\) in the bounding box whereby \(v_2 - v_1 = 1 \, u_v\), \(u_v\) being an arbitrary but fixed size. If a storey system occupies a storey, the box representing it occupies the corresponding slice. Thus, all boxes have a height of \(1 \, u_v\). If for storeys \(F_1\) and \(F_2\), corresponding to slices \((v_1, v_2)\) and \((v_3, v_4)\) respectively, \(F_1 \uparrow F_2\), then \(v_3 - v_1 = 0,5\) \(u_v\). If \(F_1 \uparrow F_2\), then \(v_3 - v_1 = 1 \, u_v\). As a result, the height of the bounding box depends on the number of \(\uparrow\) related pairs of storeys, for the moment denoted \(i\), and the number of \(\uparrow\) related pairs, denoted \(n\). The height of the bounding box is equal to \((0,5 \, i + n + 1) \, u_v\).

Boxes which represent \(\rightarrow\) related systems are adjacent. The width of boxes however depends on the overall pattern of \(\rightarrow\) relations. For the purpose of explanation it is useful to introduce the following adaptations to \(G^h\):

(1) All \(f\)- and \(b\)-labels are removed.
(2) Two vertices are added to \(G^h\). Edges are introduced from the one to every vertex in \(G^h\) the indegree of which is 0, and edges are introduced to the other from every vertex in \(G^h\) the outdegree of which is 0.

The added vertices are called the source and the sink of the
adapted $G^h$. In the context of the directed graph a *source* is a vertex from which there is a path to all other vertices. Reversely, a *sink* is a vertex to which there is a path from all other vertices [Harary 1969 p201].

![Figure 4.21 Adapted longitudinal graph. Edges which necessarily correspond to the same plane of adjacency are crossed by a line (where the bounding box's left and right sides are concerned these lines are black). Of the planes (a) and (b) it is as yet unknown whether or not they are the same: this depends eventually on the length of individual boxes.](image)

For every pair of vertices $x_1$ and $x_2$ in the adapted $G^h$: an edge from $x_1$ to $x_2$ corresponds to a vertical plane perpendicular to the L-axis, so that the right side of the box corresponding to $x_1$ and the left side of the box corresponding to $x_2$ coincide with this plane. The first box is said to end in this plane of adjacency, the second is said to start in it (no actual boxes correspond to the sink and source). If for three vertices $x_1$, $x_2$ and $x_3$, there are edges from $x_1$ both to $x_2$ and $x_3$, or there are edges to $x_1$ both from $x_2$ and $x_3$, those edges necessarily correspond to one and the same plane of adjacency. In other cases edges do not necessarily correspond to one and the same plane of adjacency.

In relation to the box packing a second graph can be defined, denoted $G^b$, in which every such possibly distinct plane of adjacency is represented by a unique vertex. If there are one or more boxes starting in one particular plane and ending in another, then in $G^b$ there is an edge from the one vertex to the other. Thus the number of edges in $G^b$ is at most equal to the number of oriented storey systems.
The length of the individual boxes can be determined by attaching values, or weights, to the edges of $G^b$. Such a weighted digraph is called a network [Harary 1969 p52].

![Diagram of a network with weighted edges](image)

**Figure 4.22** Network $G^b$ derived from the adapted $G^h$. Every vertex represents a possibly distinct plane of adjacency. The weight attached to an edge expresses the length of the boxes corresponding to this edge. In this particular example there is just one path of maximal length from source to sink.

The weight attached to an edge expresses the length of the corresponding box(es). Since boxes representing → related systems are adjacent all paths in $G^b$ between two particular vertices have the same total weight, total weight being the sum of weights attached to the edges in the path. The following conditions are satisfied by $G^b$:

1. Given any particular pair of distinct vertices, the edges in a path of maximal length from the one to the other have equal weights.
2. All edges in a path of maximal length from source to sink have a weight equal to 1 $u_l$, $u_l$ being an arbitrary but fixed longitudinal size. Thus, the length of the bounding box is determined by the length of such a path.

As a representation of the spatial organization of buildings box packings, or three dimensional rectangular dissections as they are sometimes called, have received some attention [Earl 1978; Krishnamurti 1979]. The present study considers them only as a means of visualization. The fact that oriented storey systems are shown as rectangular boxes does not imply that at the metric level they actually should have such uncomplicated
shapes. Neither does an adjacency among boxes imply an adjacency between the represented oriented storey systems.

![Diagram](image)

**Figure 4.23** Box packing. Left: the complete packing in which boxes occur of length \(1 \omega, 1.5 \omega \) and \(2 \omega\). Right: five boxes corresponding to the longest path in \(G^b\), relevant planes of adjacency are indicated as dashed frames.

If it is known which of the \(i\)-labelled vertices in \(G^c\) correspond to one and the same dwelling and for every dwelling it is known which \(c\)-labelled vertex represents the corridor connected to it, then under the assumption of efficient routing \(G^c\) and \(f^h-c\) are implicit in the triple \((G^h, G^v, f^h-v)\). The grouping of oriented storey systems into dwellings is indicated by giving all boxes corresponding to a dwelling the same arbitrary number. Thus every box carries precisely one number which is positioned on its top side at the front left corner. Since the following chapter deals exclusively with arrangements and types in which only a single corridor is present, it is sufficient to indicate the storey which this corridor occupies. This indication is provided by an arrow at the left-front corner of the bounding box.
Figure 4.24 Types visualized as box packings. Above, left: instance; right: corresponding type description (dwellings 'coloured' by numbers, corridor storeys indicated by dashed frames and arrows). Below: type descriptions corresponding to basic arrangements from earlier examples.
5. Enumeration and exploration of types

The conditions formulated and motivated by the previous chapter define a system of well-formed type descriptions or, in short, a system of types. The present chapter explores certain ranges of type descriptions included in this system with the intention to demonstrate its potential in comparison with the systems discussed by chapter two.

- This chapter considers ranges of types which are consistent with particular selected triples of the form \((G^c, G^v, f^c-v)\). Types which are each other’s mirror or rotational image are not distinguished.
- Sting’s *Grundriss Wohnungsbau* offers a large number of single storey VA-arrangements and double storey HA-arrangements. From these arrangements a limited number of triples of the form \((G^c, G^v, f^c-v)\) can be derived. Against the background of the enumerated types for six of those triples a comparison with other samples shows the incompleteness of Sting’s typology.
- The distribution of three performance-related characteristics over the ranges of VA- and HA-types provides some explanation of the patterns of types found to be supported by those samples. Those patterns also suggest a general preference for types which possess one or more symmetries and which are of limited complexity.
5.1. Isomorphism and incompleteness of type descriptions

When discussing complete ranges of types we must have a way to define the limits within which a range is considered complete, as well as a criterion on basis of which types are distinguished from one another.

- If complete type descriptions are not strictly distinct, but each others mirror or rotational image, they are said to be isomorphs. The following sections do not distinguish between isomorphs: in complete ranges a single type description represents all its isomorphs as well, if any.

- Three degrees of completeness of type descriptions can be distinguished: the storey graph $G_v$, the triple $(G_c, G_v, f_{c-v})$, and the complete description $(G^h, G_c, G_v, f_{h-c}, f_{c-v})$. This chapter presents and investigates ranges of types consistent with particular selected triples.

5.1.1. Identical, mirrored and rotated type descriptions

Since the information retained by complete type descriptions is of a highly general nature differences between them are significant by definition. In relation to the type representation the concepts of identity and isomorphism can be defined as follows.

**Identity** • Type descriptions $T_1 = (G^h_1, G_c^1, G_v^1, f_{h-c_1}, f_{c-v_1})$ and $T_2 = (G^h_2, G_c^2, G_v^2, f_{h-c_2}, f_{c-v_2})$ are identical if and only if there is a bijective function $i$ from $V(G_c^1)$ to $V(G_c^2)$, so that for every $x \in V(G_c^1)$ the following holds:
1. $x$ is $p$-labelled if and only if $t(x)$ is $p$-labelled, where $p \in \{c, o\}$.

2. $f^{c \cdot h_1}(x)$ is $a$-labelled if and only if $f^{c \cdot h_2}(t(x))$ is $a$-labelled, where $a \in \{f, b\}$.

And so that for every $x, y \in V(G^{c_1})$, $x \neq y$, the following holds:

3. $x$ and $y$ are joined by an edge if and only if $t(x)$ and $t(y)$ are joined by an edge.

4. There is an edge from $f^{c \cdot h_1}(x)$ to $f^{c \cdot h_1}(y)$ if and only if there is an edge from $f^{c \cdot h_2}(t(x))$ to $f^{c \cdot h_2}(t(y))$, where $f^{c \cdot h}$ denotes the inverse of $f^{h \cdot c}$.

5. There is a $q$-labelled edge from $f^{c \cdot v_1}(x)$ to $f^{c \cdot v_1}(y)$ if and only if there is a $q$-labelled edge from $f^{c \cdot v_2}(t(x))$ to $f^{c \cdot v_2}(t(y))$, where $q \in \{i, n\}$.

Two basic arrangements are said to be identical at type level if the corresponding type descriptions are identical. If two arrangements are, in the strict sense of the word, identical at the metric level they are also identical at type level. The reverse is not true: two arrangements may be identical at type level, while the shape and size of storey systems and characteristics of their internal organization are widely different.

Mirror- and rotational images • Let us again consider type descriptions $T_1 = (G^{h_1}, G^{c_1}, G^{v_1}, f^{h \cdot c_1}, f^{c \cdot v_1})$ and $T_2 = (G^{h_2}, G^{c_2}, G^{v_2}, f^{h \cdot c_2}, f^{c \cdot v_2})$.

$T_2$ is said to be the transversal mirror image of $T_1$ if and only if there is a bijection $\tau^t$ from $V(G^{c_1})$ to $V(G^{c_2})$ which is defined as $t$ with exception of one condition:

(2) $f^{c \cdot h_1}(x)$ is $f$-labelled if and only if $f^{c \cdot h_2}(\tau t(x))$ is $b$-labelled, and $f^{c \cdot h_1}(x)$ is $b$-labelled if and only if $f^{c \cdot h_2}(\tau t(x))$ is $f$-labelled.

$T_2$ is said to be the longitudinal mirror image of $T_1$ if and only if there is a bijection $\tau^l$ from $V(G^{c_1})$ to $V(G^{c_2})$ which is defined as $t$ with exception of one condition:
(4) There is an edge from $\text{fc-}h_1(x)$ to $\text{fc-}h_1(y)$ if and only if there is an edge from $\text{fc-}h_2(\tau_l(y))$ to $\text{fc-}h_2(\tau_l(x))$.

$T_2$ is said to be the rotational image of $T_1$ if and only if there is a bijection $\tau_r$ from $V(Gc_1)$ to $V(Gc_2)$ which is defined as with exception of two conditions:

(2) $\text{fc-}h_1(x)$ is $f$-labelled if and only if $\text{fc-}h_2(\tau_r(x))$ is $b$-labelled, and $\text{fc-}h_1(x)$ is $b$-labelled if and only if $\text{fc-}h_2(\tau_r(x))$ is $f$-labelled.

(4) There is an edge from $\text{fc-}h_1(x)$ to $\text{fc-}h_1(y)$ if and only if there is an edge from $\text{fc-}h_2(\tau_r(y))$ to $\text{fc-}h_2(\tau_r(x))$.

\begin{figure}[h]
\centering
\includegraphics[width=0.8\textwidth]{symmetry_isomorphism}
\caption{Symmetry and isomorphism. Above: four isomorphs; these do not possess any of the symmetries. Below, left: two isomorphs possessing longitudinal symmetry. Below, right: type description for which there are no isomorphs; it possesses all symmetries.}
\end{figure}

**Symmetries and isomorphs** • The above definitions enable the definition of three kinds of symmetry at type level:

(1) A type description $T_1$ is said to possess *transversal symmetry* if and only if there is a function $\tau_t$ from $V(Gc_1)$ to $V(Gc_1)$ as defined above.
(2) A type description $T_1$ is said to possess longitudinal symmetry if and only if there is a function $\tau^l$ from $V(G^c_1)$ to $V(G^c_1)$ as defined above.

(3) A type description $T_1$ is said to possess rotational symmetry if and only if there is a function $\tau$ from $V(G^c_1)$ to $V(G^c_1)$ as defined above.

If a type description possesses two of these symmetries it also possesses the third one.

If a description $T_1$ is related to a description $T_2$ by any of the functions $t$, $\sigma$, $\tau$, or $\tau$ then $T_1$ and $T_2$ are said to be isomorphic. If $T_1$ and $T_2$ are isomorphic but not identical they are said to be distinct isomorphs or simply isomorphs. If a type description possesses none of the above symmetries it is one out of a total of four isomorphs. If it possesses just one symmetry it is one out of a total of two isomorphs. If it possesses all symmetries there are no distinct isomorphs.

5.1.2. Degrees of incompleteness of type descriptions

So far we have only discussed complete type descriptions. The following sections frequently discuss incomplete descriptions. An incomplete type description is said to be contained in a complete one if it can be completed in such a way that it is identical to this complete description. In the following discussion three distinct degrees of incompleteness are considered:

(1) The storey graph $G^v$.
(2) The triple $(G^c, G^v, f^{c-v})$.
(3) The complete description $(G^h, G^c, G^v, f^{h-c}, f^{c-v})$.

A triple $(G^c_1, G^v_1, f^{c-v}_1)$ is contained in a 5-tuple $(G^h_2, G^c_2, G^v_2, f^{h-c}_2, f^{c-v}_2)$ for example, if there are a $G^h_1$ and a $f^{h-c}_1$ so that $(G^h_1, G^c_1, G^v_1, f^{h-c}_1, f^{c-v}_1)$ and $(G^h_2, G^c_2, G^v_2, f^{h-c}_2, f^{c-v}_2)$ are identical. If a storey graph or a triple is contained in a
particular complete description it is also contained in its isomorphs if any. Identity, previously defined only at level (3), can be generalized for all three levels. Two storey graphs, two triples, and two complete descriptions are identical if and only if there is a complete description in which they are both contained.

**A complete range of storey graphs** • Where \( s \) represents the number of vertices in \( G^v \), for a particular value of \( s \) the number of distinct storey graphs is equal to the number of distinct ways in which the \( s-1 \) edges can be labelled either \( i \) or \( n \), which is \( 2^{(s-1)} \).

\[ \begin{align*}
    s = 1 & \quad \circ \\
    s = 2 & \quad \circ \circ \\
    s = 3 & \quad \circ \circ \circ \\
    s = 4 & \quad \circ \circ \circ \circ \\
    s = 5 & \quad \circ \circ \circ \circ \circ
\end{align*} \]

**Figure 5.2** Storey graphs for \( s \leq 5 \). The graphs on grey background satisfy the condition that there must be at least one storey for which the minimal distance to every other story is less than 2 MSH.

For higher values of \( s \) an increasing portion of the storey graphs can be qualified as unrealistic because, under the assumption that only one corridor is present, any complete description containing those graphs implies type (1) paths of
unacceptable length. If the distance covered via paths of type (1) should be less than 2 MSH (see also subsection 4.3.3) then for $s = 6$ only 5 out of the 32 graphs are acceptable. For $s = 7$ there is just one and for higher values of $s$ no storey graph satisfies this criterion at all.

**Complete ranges of triples** • Let $p$ represent the number of vertices in $G_c$. The number of well-formed triples $(G_c, G_v, f^{-v})$, containing a particular storey graph $G_v$ and for a particular $p \geq s$, is finite:

1. The number of graphs with $p$ vertices is finite.
2. The number of surjective functions from a set with $p$ originals to a set with $s$ elements is finite.

![Diagram of enumeration of triples](image)

**Figure 5.3** Enumeration of triples. Above: a storey graph and all three distinct connection graphs with two o-labelled vertices and one c-labelled vertex. Below: the ten well-formed triples into which these graphs can be combined. Six of these imply efficient routing (grey background).

It can be expected that for larger $p$ an increasingly large portion of the well-formed triples containing a particular $G_v$ implies inefficient routing.
Figure 5.4 Enumeration of non-isomorphic types. Above: ordering in rows corresponds to number of fb-labelled vertices (all 5-tuples contain the same triple; Gv and f-v as indicated in the upper left corner). Below: the same range of types visualized as box packings; the ordering is identical.
Complete ranges of 5-tuples • Where $o$ denotes the number of vertices in $G^h$, and thus the number of $o$-labelled vertices in $G^c$, the number of 5-tuples $(G^h, G^c, G_v, f^h-c, f^c-v)$ containing a particular triple $(G^c, G_v, f^c-v)$ is finite:

1. The number of directed graphs with $o$ vertices is finite.
2. The number of ways in which $o$ vertices can be labelled $f$, $b$ or $fb$ is finite.
3. The number of bijective functions from one set with $o$ elements to another is finite.

It can be expected that the larger the value of $o$, the more the average number of isomorphs among the 5-tuples approaches four: the more oriented storey systems are involved, the smaller is the relative number of symmetric arrangements of them. In following sections the distinction between isomorphs is ignored: when ranges of type descriptions are presented, only one out of two or four isomorphs is taken as a representative. Assuming that routing is efficient and only one corridor is present, ranges of complete types can be presented by means of the box-visualization without loss of information. In following sections such overviews of box packings are shown frequently. Overviews will be organized in rows. The downward order of these rows corresponds to an increase in the number of double oriented storey systems. The left to right order within rows is trivial.

5.2. Complete ranges of types

This section demonstrates the type representation’s potential to anticipate basic arrangements: two ranges of type descriptions are enumerated and a body of precedents are compared with those ranges. This comparison is a test as to whether the interpretation of primitives and configurations of the type representation has been unambiguously specified.

• Sting’s Grundriss Wohnungsbau offers a large number of
single storey VA-arrangements and double storey HA-arrangements. Both categories receive much attention in other housing literature as well.

- From the arrangements in Sting's sample only a limited number of triples of the form \((G^c, G^v, f^{c\cdot v})\) can be derived. For most of these triples only one or two types are supported by the sample.
- Against the background of the complete sets of types for six of those triples, a comparison of Sting's sample with arrangements found in other books on housing design shows its incompleteness for some of these triples.

5.2.1. A sample of basic arrangements

It would be unrealistic to criticise Sting's handbook simply on basis of the fact that it contains so few of the huge number of actually existing basic arrangements. Housing typologies in the form of books may contain only a limited number of drawings and a modest amount of descriptive text. Understandably, these books concentrate on precedents which are paradigmatic for those types considered more generally relevant than others. So the question is rather more interesting, as to what degree such generally relevant types are missing in a handbook like Grundriss Wohnungsbau. Something of an answer may be found by comparing Sting's sample with precedents presented in other handbooks.

We have seen (subsection 2.1.1) that the type descriptions offered by Sting are ill-defined: they are largely to be interpreted from the paradigmatic precedents themselves. However, the type representation defined by the present study retains more or less the sort of distinctions between arrangements that we have observed in several available studies, most notably those by Sting, by Sherwood, and by Bergman et al. This provides a justification for considering the completeness of Sting's sample in relation to the system of types implicit in that representation.

The comparison is carried out only for the following categories of arrangements:
(1) Single storey VA-arrangements.
(2) Double storey HA-arrangements (where storeys are non-overlapping).

This choice is motivated by the comparative richness of Sting’s sample in these categories: typological distinctions are detailed and types are often illustrated with more than one precedent. Categories (1) and (2) receive much attention in other housing literature as well. The following section tries to offer something of an explanation for the fact that so many existing basic arrangements fall into these categories.

Sting’s sample • Single storey arrangements occur as VA- as well as HA-arrangements. Probably the main reason for their popularity lies in the circumstance that neither entering a dwelling from the corridor, nor travelling within a dwelling involves climbing or descending stairs. Sometimes multi storey arrangements occur as VA-arrangements as we have seen in case of the Immeuble Clarté, but they are far more common as HA-arrangements, as reflected in the large number of arrangements presented by Sting under II-2.

From here on, when speaking of Sting’s sample a specific portion of the entire set of presented arrangements is referred to. These are the single storey arrangements under I-1.1 and I-1.2, and the double storey arrangements under II-2. The majority of them are orthogonal and non-slided. Below an overview is shown of metric descriptions derived from the uniform plans and sections presented by Sting. Occasionally these descriptions ignore a minor disturbance of orthogonality or vertical sliding. Habitable rooms are identified mainly on basis of furnishing which is shown in most of the plans. Arrangement I-1.2.2.5 is ignored because of a serious vertical sliding and arrangements I-1.2.2.6, I-1.2.4.3 and I-1.2.4.4 are ignored because of their lack of orthogonality. The result is a total of thirty single storey VA-arrangements and fourteen double storey HA-arrangements.
Figure 5.5 Selection of basic arrangements from Grundriss Wohnungsbau (illustration covers three pages). Habitable rooms are indicated in white. Previous pages: thirty single storey VA-arrangements. This page: fourteen double storey HA-arrangements.
5.2.2. A preliminary exploration of incomplete type descriptions

Let us first consider the ranges of triples \((G_c, G_v, f^c-v)\) allowed in categories (1) and (2). This will enable us to find out which of them are supported by arrangements in Sting's sample, so that the discussion in following (sub)sections can be limited to type descriptions containing those triples. From here on a particular triple will be indicated by a code of the form VA-\(m\) or HA-\(m\), where \(m\) is an arbitrary but unique number and VA and HA indicate the categories (1) and (2) respectively.

**Single storey VA-arrangements** • For single storey types \(G_v\) consists of a solitary vertex. If only a single corridor is present and no inefficient routing is implied, \(G^c\) is a star with the \(c\)-labelled vertex at its centre. A graph qualifies as a *star* if one central vertex is joined to all others and no other pair of vertices are joined by an edge [Harary 1969 pp.17-18]. Then obviously for every particular \(G^c\) there is only one \(f^c-v\). For any reasonable maximum of \(p\), for example: \(p \leq 6\), the set of triples containing \(G^v\) is extremely limited:

![Figure 5.6 All five triples for single storey arrangements in which only a single corridor is present and for which routing is efficient (p ≤ 6).](image)

The larger the value of \(p\), the more appropriate it is to view the represented VA-arrangements as repetitions of less complex single storey HA-arrangements. The single storey VA-arrangements presented by Sting under I-1.1 and I-1.2 do not include more than five dwellings (precedent I-1.1.5.1). There is a considerable imbalance between the large number of arrangements, twenty-one to be precise, that fit the triple VA-2 and the very few that fit the others: VA-1, VA-3, VA-4 and VA-5.
represent one, four, three and one of the arrangements respectively. This reflects the popularity of the ‘Zweispänner’ type in comparison with the other ‘Spänner’ types, as VA-1 to 5 are usually referred to in German literature.

Figure 5.7 Types supported by one or more VA-arrangements in Sting’s sample (numbers indicated in bold). For every triple there are just one or two types; the number of arrangements supporting types under VA-2 is comparatively large.

It is furthermore remarkable that for every one of these five triples just one or two complete type descriptions are derived from Sting’s arrangements.

Double storey HA-arrangements • Since the two storeys are not overlapping there is only one possible $G^v$: two vertices joined by an $n$-labelled edge. The maximal value of $o$ found among Sting’s arrangements under II-2 is four (arrangement II-2.1). If it is assumed that only a single corridor is present and that no inefficient routing is implied, then in $G^c$ the distance between any $o$-labelled vertex and the $c$-labelled vertex is at most 2. In a graph the distance between two vertices is defined as the length of any shortest path between them [Harary 1969 p14].

For $o \leq 4$ there are thirty-two distinct triples, the number of dwellings varying between one and four. Among those thirty-two triples there are four for which arrangements can be found under II-2: for triples HA-5, HA-7 and HA-17 there is one arrangement, for HA-3 there are eleven. The relative popularity of arrangements represented by HA-3 is to some
Figure 5.8 Enumeration of HA-triples (storey graph shown in upper left corner, only one c-labelled vertex occurs, no inefficient routing is implied). For the first pair of rows o = 1, for the second pair o = 2 and so on.

Two criteria are visualized: the number of dwellings being at most two (dashed frame) and every dwelling having an oriented storey system at corridor level (continuous frame). The four triples (HA-3, HA-5, HA-7 and HA-17) which are supported by Sting's sample (grey background) satisfy both criteria.
degree understandable. The single dwelling in HA-3 is usually referred to as a duplex or maisonette: it includes one oriented storey system occupying the lower (corridor) storey and another occupying the upper storey. This has certain advantages. First, the dwelling may be comparatively narrow so that the corridor serving a number of longitudinally repeated dwellings may be relatively short. Second, it is commonly considered convenient that at least some rooms, particularly the kitchen and the main living room, are at corridor level while others are more remote from the dwelling’s entrance. Third, for inhabitants who already have to climb a number of stairs to arrive at this corridor it may be a frustrating experience that in order to reach some part of their dwelling they are forced to descend again. If this situation occurs nonetheless it is usually in buildings were the corridor can be reached by elevator.

Considering the criteria that (1) the number of dwellings is at most two and (2) in an arrangement every dwelling includes an oriented storey system at level with the corridor, it can be seen that HA-3, HA-5, HA-7 and HA-17 satisfy both criteria. Like in case of the VA-triples, it is remarkable that for these four HA-triples Sting’s II-2 arrangements support only seven complete type descriptions. Three of these contain HA-3 and one is clearly popular: it fits 9 of the 14 II-2 arrangements.

**Figure 5.9** Types supported by one or more HA-arrangements in Sting’s sample (numbers indicated in bold). Only one type is supported by more than one arrangement.
5.2.3. Ranges of VA- and HA-types

This subsection presents complete overviews of type descriptions containing some of the triples that have been found to be supported by Sting's arrangements. These are VA-2, VA-3 and VA-4, and HA-3, HA-7 and HA-17. The triples VA-1 and VA-5 are ignored because their number of dwellings makes them rather exceptional, and HA-5 is ignored because it is simply the upside-down version of HA-3. As can be expected the number of complete non-isomorphic descriptions containing these triples grows with their complexity: for VA-2 there are four complete descriptions, for VA-3 and VA-4 the numbers are nine and nineteen respectively. For HA-3, HA-7 and HA-17 these numbers are five, fourteen and thirty-eight respectively. From here on a particular type will be indicated by a code of the form VA-\(m.n\) or HA-\(m.n\), where HA-\(m\) indicates the triple and \(n\) is an arbitrary but unique number.

It is obvious that very few of the type descriptions are supported by Sting's sample. Altogether the twenty-eight appropriate I-1 arrangements support four type descriptions out of a total of thirty-two. The thirteen appropriate II-2 arrangements support only five out of a total of fifty-seven type descriptions. Some indication of whether this means that generally relevant types are indeed missing in Grundriss Wohnungsbau has been found by a comparison with other samples. The following books have been consulted:

- *Multi-Storey Housing* [Schmitt 1964].
- *The dwelling* [Deilmann et al 1973].
- *A decade of british housing* [Crawford 1975] containing many double storey HA-arrangements which were popular in England and Scotland after World War II.
- *Modern housing prototypes* [Sherwood 1978].
- *Housing* [Macsai et al 1982] containing a sample of projects realized in the USA.
- *Bauentwurfslehre* [Neufert 1984] containing many single storey VA-arrangements which were popular in the continent of Europe before and shortly after World War II.
Figure 5.10 Enumeration of VA- and HA-types (illustration covers three pages). Types supported by any of the samples are in continuous frames, those supported by Sting's sample are on grey background.
Every one of these books contains a sample of exemplary precedents, sometimes organized according to typological distinctions.

The overwhelming popularity of VA-2.4 and HA-3.3 is confirmed: large numbers of arrangements are found which support these types. Furthermore the relevance of types as suggested by Sting's sample is confirmed. Most of the types supported by Sting's sample are also supported by one or more of the other samples. For larger values of $\alpha$ however, several types ignored by Sting are supported by one or more of the other samples. These are:

- VA-4.5 [Schmitt 1964 p12].
- VA-4.11 [Neufert 1984 p248 fig.16].
- VA-4.19 [Neufert 1984 p249 fig.4, p250 fig.8].
- HA-17.4 [Crawford 1975 p93, p242].
- HA-17.6 [Sherwood 1978 p3 fig.5].

It is inevitable that every one of the samples has its particular geographical, historical and other preoccupations. Nonetheless the conclusion seems justified that where the VA-4 and HA-17 types are concerned, Sting's sample does not sufficiently represent the variety of apparently relevant types.

### 5.3. Distribution of characteristics

This section explores how a limited number of characteristics are distributed over the ranges of types presented by the previous section. It intends to demonstrate that in relation to the type representation characteristics can be defined which are meaningful in the sense that they have an impact upon certain aspects of the performance.

- The relation between formal characteristics retained by the type representation on the one hand and aspects of performance on the other hand is not always straightforward. Often this is
due to the fact that performance is dependent on accidental characteristics which are not strictly constrained at type level.

- The distribution of three performance-related characteristics over VA- and HA-types is investigated. The patterns of supported types found by the previous section seem to confirm the desirability of double orientation of dwellings and the absence of external passing.
- The patterns of supported types also suggest a general preference for types which possess one or more symmetries and which are of limited complexity. Practical considerations seem to underlie this preference.

5.3.1. Performance in relation to types

Writers on housing design pay attention to various implications of form for performance. Of the writers that have been referred to previously, Macsai is clearly the most explicit in this respect. In Deilmann’s *The dwelling* an attempt is made to describe, for a variety of dwelling types and building types, the implied performance with respect to various aspects of living-value and building costs [Deilmann et al 1973 pp44-48]. In *The dwelling*, and this holds for many studies addressing higher levels of spatial organization, good or bad performance is simply mentioned with the type. None of these books describe types other than by means of verbal statements or schematic plans and sections similar to the ones used by Sting and Sherwood. Often it remains unclear to what degree a mentioned performance is actually implied by a type’s essential characteristics, rather than being the result of certain characteristics accidentally shared by paradigmatic precedents.

**Dependency on accidental characteristics** • The main difficulty is of course the fact that many aspects of performance are not exclusively dependent on the general characteristics of spatial organization which are essential for a type, but on certain accidental characteristics as well. Deilmann et al for example mention that the single oriented flat does not allow cross-ventilation – an undesirable characteristic. If being single
oriented means to have habitable rooms at only one of two opposite sides, then in certain cases cross-ventilation can be achieved by placing a small window, insufficient to provide serious view or daylight, somewhere in the opposite side of the dwelling. Similar arguments hold for other aspects of performance mentioned by Deilmann et al in relation to the single oriented flat, such as ‘extravagance of pure access-space inside the dwelling in larger housing units’ and ‘disturbance likelihood for open sitting space’ [Deilmann et al p44].

**Figure 5.11** Three single storey dwellings occupying two storeys. Left: type description. Right: metric description. Oriented storey systems and corridor are more or less closely packed within an imaginary bounding box (light grey) so that the total floor area of the upper dwelling approximates the sum of floor areas of the lower dwellings.

Many aspects of performance are to a large degree dependent on the shape, size and internal organization of oriented storey systems. The number of inhabitants accommodated by a dwelling which is largely dependent on the number of habitable rooms and their floor areas, provides a good example. Let us consider for example a double storey arrangement containing three double oriented storey systems, two of which occupy the lower storey while the third occupies
the upper storey. Every system is an individual dwelling. If those systems are closely packed within an imaginary bounding box the floor area of the upper dwelling will be more or less equal to the sum of floor areas of the lower dwellings. Thus it is likely that (one of) the lower dwellings accommodates only a small number of inhabitants or that the upper dwelling accommodates a large number of inhabitants. However, since floor area and number of habitable rooms are characteristics which are not strictly constrained by a type description such performance is not implied in the strict sense of the word.

**Performance related characteristics** • Reliable knowledge about the relation between types and performance should be acquired through empirical research. However, some characteristics implicitly retained by the type representation have an obvious and significant effect upon performance. Let us explore how three of these, which have all been introduced in previous chapters, are distributed over the two ranges of VA- and HA-types:

- The characteristic of an individual dwelling –not just a storey system– being double oriented.
- The implication of external passing.
- The implication of internal passing.

As we have seen earlier (subsection 4.3.4) these are issues to which many writers pay attention in the context of HA-types. It will become clear that in the context of VA-types they are just as relevant.

The three characteristics are significant first, because their presence or absence is often a matter of choice: there are advantages as well as disadvantages to be considered by the designer. This is not the case for example with the implication of efficient routing, since inefficient routing is likely to be an option only in highly exceptional situations. External as well as internal passing occur in many existing arrangements and single oriented dwellings do occur in large numbers. The following subsections explore the degree by which certain conditions, formulated in terms of those characteristics, are restrictive in the sense that they are only satisfied by a certain portion of the types.
Second, the three characteristics are not entirely independent. It is interesting to know in which types these characteristics exclude each other, and in which they are combined.

Third, there might be a correlation between the distribution of characteristics and the patterns of apparently relevant types found by the previous section. Of course, in view of the limited number of arrangements found for many of the types and in view of possible preoccupations underlying the samples, these patterns should not be given too much significance. Rather than offering reliable explanations for empirical facts, the following explorations are an indication that the type representation may help to find such explanations.

5.3.2. Distribution of performance-related characteristics

**VA-types** • In a single storey VA-arrangement every dwelling consists of only one oriented storey system. Thus the fact that a dwelling is double oriented means that this system is double oriented. Let us consider the following condition:

(1) All dwellings are double oriented.

It is obvious that for every one of the triples VA-2, 3 and 4, there is precisely one complete type description that satisfies condition (1). These are VA-2.4, VA-3.9 and VA-4.19 respectively. As we have seen in the previous section, VA-2.4 and VA-4.19 are both supported by the samples and Sting’s sample suggests a high popularity of VA-2.4. However, particularly where VA-4 is concerned, several other types are supported by the samples as well and among those VA-3.8 may even be considered popular: it is supported by four of Sting’s arrangements.

What the supported types with the single exception of VA-4.19 have in common is that they satisfy the following condition:
(2) No external passing is implied.

To some degree the popularity of VA-2.4 can be explained by the fact that it is the only type under VA-2, 3 and 4 which satisfies conditions (1) and (2) at the same time. It is remarkable that of those descriptions under VA-3 and 4 for which neither (1) nor (2) holds, not a single one is supported by the samples. Let us consider the idea that condition (1) is desirable, but not beyond the point where it rules out the satisfaction of (2). This leads to their combination in the following condition:

(2a) No external passing is implied and the maximal number of dwellings is double oriented.

For the VA-types studied at present, there is a maximum of two double oriented dwellings if external passing is to be avoided: one to the extreme left and one to the extreme right. As a result condition (2a) holds for very few of the types: besides VA-2.4, those are VA-3.8, VA-4.11 and VA-4.12. All of these are supported by the samples, particularly those of Sting and Neufert.

The overwhelming popularity of VA-2.4 is perhaps not only due to its simultaneous satisfaction of conditions (1) and (2). It distinguishes itself from VA-3.9 and VA-4.19, as well as from VA-3.8, VA-4.11 and VA-4.12 by the fact that it does not imply the passing of any oriented storey system whatsoever. As soon as in a single storey VA-arrangement there are three oriented storey systems $S_1$, $S_2$ and $S_3$ so that $S_1 \Rightarrow S_2 \Rightarrow S_3$, $S_2$ is passed either at its front or at its back side. At the metric level the length of the corridor depends on the width of the passed storey system(s). The effect of the corridor becoming elongated can only be diminished—if passing is internal—by complications in the shape of the extreme left and the extreme right storey system, as can be observed clearly in the arrangements supporting VA-3.8 and VA-4.11. Economy of floor area spent on public circulation provides a second explanation for the popularity of VA-2.4.

A maximal economy of floor area used for public circulation, can be achieved in arrangements of type VA-4.3 where the
**Figure 5.12** Enumeration of VA- and HA-types (illustration covers three pages). Types in which all dwellings are double oriented are in continuous frames (wide lines). Types which do not imply external passing are in dashed frames, those with a maximal number of double oriented dwellings are on grey background. Types which imply internal passing are in continuous frames (narrow lines; only relevant under VA-4, HA-7 and HA-17).
maximal number of four single oriented dwellings are arranged so that no passing needs to occur. The apparent relevance of VA-4.3 can be explained, at least partially, by a combination of the mentioned economy and a particular fitness in the context of small dwellings.

In the context of VA-types internal passing can only be implied if at least four oriented storey systems are present. Only VA-4.2, VA-4.5 and VA-4.12 satisfy the following condition:

(3) Internal passing is implied if external passing does not occur.

Many of the disadvantages (see subsection 4.3.4) of the internal corridor are less relevant in the context of VA-arrangements because of its limited length, and thus internality of the corridor may well be considered desirable. In a considerable number of the VA-arrangements offered by Sting, including those that fit VA-2 and VA-3, the corridor is entirely encapsulated by oriented storey systems. An interesting case in this context is provided by the Immeuble Clarté: Le Corbusier reacted upon his client’s criticism against the originally proposed elongated internal corridors—much in the style of his earlier design for the Immeuble Villas—by introducing a walk-up system with shorter corridors. These remained what they were though: internal corridors [Sumi 1989].

Where VA-4.12 is concerned the acceptance of internal passing has the advantage that in comparison with VA-4.11 the above mentioned difficulties caused by the implied passing of the two single oriented dwellings are reduced. On the other hand, in situations where there is a preferred orientation it might be considered a disadvantage that these dwellings have opposite orientations.

HA-types • A double storey dwelling may be double oriented, without any of its component storey systems being double oriented. One result is that many of the HA types satisfy condition (1). Since those dwellings may well have a single oriented storey system at the corridor storey, several of the types satisfying (1) at the same time satisfy condition (2). Under HA-3 and HA-17 there are two and seven types respectively,
which satisfy both (1) and (2). Under HA-7 there is not one such type, since HA-7 implies a single storey dwelling at the corridor storey. So if condition (2) is to be satisfied this dwelling cannot be double oriented. Four types under HA-7 satisfy condition \((2^a)\). The pattern of relevant types found in the previous section weakly suggests the desirability of \((2^a)\). There are only two of the eight types supported by the samples, which do not satisfy condition \((2^a)\): these are HA-3.1 and HA-17.4.

Since in HA-3 there is only one oriented storey system present at the corridor storey, the implication of internal passing is relevant only under HA-7 and HA-17. Three of the types under HA-7 and six of the types under HA-17 satisfy condition (3). Again, the pattern of relevant types found in the previous section weakly suggests the desirability of (3): only one of the five supported types under HA-7 and HA-17 (HA-17.19) does not satisfy this condition.

In architectural design considerations with respect to the number of a dwelling’s orientations and the occurrence of external or internal passing are likely to play some role in the evaluation of HA-types. But in view of the very few types under HA-7 and HA-17 that are supported by the samples and the fact that for each of those only a single arrangement was found, an attempt to explain the pattern of apparently relevant types in terms of conditions \((2^a)\) and (3) would be too much of a speculation.

5.3.3. Complexity and symmetry

The desirability of a condition like \((2^a)\) can be motivated by aspects of performance in a rather straightforward way. Let us consider two characteristics for which such a motivation is less obvious but which may help nonetheless to explain why so few of the types, especially those under HA-7 and HA-17, appear to be generally relevant.

**Limited complexity** • What the exploration carried out by the previous section has perhaps shown more than anything else, is a preference for types with a limited number of oriented
Figure 5.13 Enumeration of VA- and HA-types (illustration covers three pages). Longitudinal, transversal and rotational symmetry are indicated by labels L, T and R respectively. Types which posses one or more of these symmetries are in continuous frames.
storey systems. In subsection 5.2.3 we have seen that HA-3.3 is supported by nine out of a total of fourteen HA-arrangements in Sting's sample. We have also seen that VA-2.4 is supported by twenty out of a total of thirty VA-arrangements. It could be argued that the apparent popularity of VA-2.4 and HA-3.3 is due to the desirability of (2a). However, the limited complexity of these types (o = 2) seems to play a role as well.

HA-3.3 consists of a single dwelling. It is quite usual that residential buildings are based upon building programmes which require large numbers of dwellings of a more or less equal size and type (maisonette, flat). In this respect buildings like the Immeuble Clarté, the Narkomfin building, and the Unité d'Habitation are exceptional. A similar argument holds with respect to the popularity of VA-2.4: the two dwellings in VA-2.4 may easily be the left and right handed versions, perhaps somewhat adapted, of the same dwelling. This can be observed in many of Sting's arrangements supporting VA-2.4.

Symmetry • When glancing over the overviews of VA- and HA-types one can be struck by the fact that, only with exception of VA-2.3 and VA-4.5, the supported ones possess one or more of the symmetries defined in subsection 5.1.1. For smaller values of o this is not necessarily significant because many of the types are symmetrical, but for larger values of o the portions of symmetrical types become smaller. Under VA-4 nine out of a total of nineteen types are symmetrical (47%) and four of them are supported by the samples. Under HA-7 only three out of a total of fourteen are symmetrical (21%). One of these has been shown relevant while none of the asymmetrical types are supported. Under HA-17 we find the strongest correspondence between apparent relevance and symmetry: eight of the thirty-eight types possess a symmetry (21%) and all four supported types are among them.

To some degree this apparent preference for symmetry at type level may be explained by the fact that symmetry at the metric level has a certain elegance which is appealing to the architectural designer. However, there seem to be more practical reasons as well. Where the VA-4 types are concerned symmetry is the inevitable result of the satisfaction of condition (1) or of condition (2a). Where the HA-7 and HA-17 types are concerned this is not the case but it can be seen that many of the
asymmetrical types have characteristics which are somewhat improbable. The following considerations might play a role:

(1) Many of the asymmetrical types under HA-7 are likely to result, at the metric level, in a situation where the one dwelling is considerably larger than the other – this holds particularly for HA-7.3, HA-5 and HA-6. Such a situation is not usually allowed by building programmes.

(2) Where HA-arrangements are usually repeated along an elongated corridor, a designer’s decision about the number of orientations of storey systems is likely to be a strategic one. It is decided for example that all storey systems at the corridor storey are single oriented, while all those at other storeys are double oriented. In view of this, many of the asymmetrical types under HA-7 and HA-17 have the unlikely characteristic that storey systems at the same storey have a different number of orientations.

(3) Many of the asymmetrical types under HA-17 possess the characteristic, that at one storey the longitudinal order of the storey systems included respectively in dwelling 1 and dwelling 2 is the reverse of the order at the other storey: in frontal view the two dwellings form a ‘scissored’ pattern. At the metric level this is likely to lead to a situation where storey systems contained in different dwellings are positioned more or less directly above each other, which brings about the problem of sound transmission via the separating floor. This disadvantage is not balanced by any obvious advantages.

This study has only considered symmetries which are, at the metric level, analogous to reflective symmetry in a vertical plane and rotational symmetry about a vertical axis (subsection 5.1.2). Where types with a larger number of storeys are concerned it may be interesting to introduce symmetries analogous to reflective symmetry in a horizontal plane or rotational symmetry about a horizontal axis. The type of arrangement (c) in the Unité d’Habitation for example, does not possess any of the three defined symmetries. It can be argued however to possess a symmetry analogous to rotational symmetry through $180^\circ$ about a transversal axis.
6. Conclusions and extensions

A general intention of this study has been to demonstrate the possibility of making explicit architectural knowledge which is useful to architectural design. In this light, a discussion of the value of its results before actually having implemented them in architectural design or in related environments is highly speculative. It seems important though at least to indicate a possible direction for future research, which may eventually lead to implementations which allow a reliable evaluation of the approach demonstrated by this study.

- Chapter four and five have presented a type representation of basic arrangements of dwellings and have demonstrated its well-definedness and its high degree of abstraction.
- In order to test the generalizability of the approach, similar representations should be defined, not only for other levels of spatial organization, but also for entirely different architectural domains. Office buildings and hospitals seem good candidates.
- Precedent-based design offers a challenging model for the implementation of type representations like the one developed by this study. Both retrieval and adaptation of architectural precedents in a precedent-based design system can be supported by a system of types.
- There is a role for precedent-based design systems in architectural education, in architectural practice and in empirical research. Of these environments, architectural practice is undoubtedly the most demanding one.
6.1. Summary of results

The intention of chapter four was to define a representation of basic arrangements of dwellings which combines well-definedness with an appropriate degree of abstraction. Looking back, the question may be asked as to what degree it actually achieved this goal.

First, the primitives of the representation and the conditions to be satisfied by their configuration—the criterion of well-formedness—have been specified in terms of graphs and functions, which are themselves well-defined mathematical concepts. Second, the interpretation of those primitives and configurations has been specified in terms of the metric representation defined in chapter three. This second specification has enabled a detailed motivation of the criterion of well-formedness at all points that seemed beyond triviality.

The explorations in chapter five indicate a decreasing relevance of types in relation to increasing complexity. It seems that the complexity of existing arrangements is limited in various ways. Rarely is there more than one storey in a VA-arrangement, or is it formed of more than four dwellings. Seldom does an HA-arrangement have a width larger than one, or is it formed of more than three dwellings. Precise numbers cannot be given, but the few enumerated ranges presented in chapter five show for VA-types, and suggest for HA-types, that within such limitations no serious combinatorial explosion occurs. It can be argued furthermore that many of the enumerated types have certain characteristics, such as the occurrence of scissored dwellings (subsection 5.3.3), which are highly exceptional.

From large numbers of precedents relatively few type descriptions are derived: the representation actually reduces a multitude of existing design objects to an overviewable range of types. It seems reasonable to conclude that the representation's degree of abstraction is appropriate where arrangements of realistic complexity are concerned. Type descriptions can be
visualized concisely and ranges of visualized descriptions can be observed at a glance, whereby their mutual differences are significant and easily observed.

The explorations carried out by chapter five demonstrate several advantages of the representation’s well-definedness:

(1) The criterion of well-formedness forms the basis of complete enumeration of types. Rather than the availability of complete ranges of type descriptions, the fundamental point is that in principle any well-formed type description can be produced in a finite number of steps.

(2) The derivation of types from a large number of precedents was a reliable and controllable one because interpretation of primitives and their configurations had been accurately specified in terms of the metric representation by which those precedents were given.

(3) Some formal characteristics have been defined, whose impact on performance is considered by several writers to be of importance for the evaluation of types. One may think for example of the implication of external passing, or of the number of a dwelling’s orientations. The definitions were exclusively in terms of the primitives and configurations of the type representation. Those characteristics seemed to offer something of an explanation for the apparent relevance, or even popularity, of certain types rather than others.

6.2. Generalization of the approach

The representation defined by this study has shown that the combination of well-definedness with a high degree of abstraction and a high level of spatial organization is in principle possible. A challenging question is whether such representations can be defined for larger or even entirely different architectural domains, and for higher levels of spatial organization. A reliable answer should be provided by future research – we can only speculate about the possibilities of
extending the approach beyond its present limitations.

**Extensions within the domain** • A modest but nonetheless significant extension would be that of the scope of the representation beyond the restrictions to orthogonal and non-slided arrangements (subsection 3.5.2). It would mean in particular that the interpretation of the edges and labels of $G^h$ would have to be specified in more general terms. This seems possible: we have already seen that the concept of the slab and its opposite orientations is not limited to orthogonality. Looking back to the Julia building (figure 3.13) it can be observed that basically the same holds for the longitudinal order of habitable rooms. The concept of longitudinal neighbourship could also be redefined for arrangements in which modest transversal sliding occurs (subsection 3.3.2).

Within the domain of the complex residential building the approach should be extended towards other levels of spatial organization. One may think for example of the entire building as a composition of slabs.

**Other architectural domains** • The availability, where housing is concerned, of a multitude of handbooks with an implicit or explicit typological character seems to confirm Sherwood’s opinion that in contrast with other design areas ‘housing lends itself readily to systematic typological study’ [Sherwood 1978 p2]. However, the present study considers architectural typology to be relevant beyond housing. This belief could be supported by a successful extension of the approach demonstrated in chapters four and five to architectural domains other than housing.

If we want to find out to what degree those other domains lend themselves to this approach it is important first to review the attempts, if any, that have been made to develop systems of types in other domains. This would show the problems emerging in those attempts and it would perhaps clarify at which points those domains are less fit for ‘systematic, typological study’. The main challenge though is the definition of type representations which are as much as possible based upon general concepts of spatial organization. That is to say that such concepts are not just meaningful in one specific domain – such as the concept ‘dwelling’ which is meaningless outside the
domain of housing.

Some of the concepts defined by chapter three such as room, room system and territorial boundary are meaningful in almost every architectural domain that comes to mind. Others such as slab could perhaps be defined in more general terms.

**Hospitals and office buildings** • It would be wise to direct a first attempt towards domains which have at least some characteristics in common with the present one – one may think for example of multi-storey office buildings and hospitals:

1. Like in the residential building, a large portion of the floor area in those buildings needs to be provided with view and daylight. The same considerations that lead to dwellings being packed into slabs, lead to hospitals and office buildings being compositions of individual building masses with a limited depth. The diagrams presented in *Planning office space* are significant in this respect (figure 1.8).

2. Like in the residential building, a circulation system is present which primarily serves the purpose of providing access to rooms which accommodate various combinations of activities. Like in residential buildings, one may distinguish internal and external corridors.

However, the territorial boundaries in hospitals and office buildings seem more complicated and it is doubtful whether those boundaries are always as well-defined as the one between dwellings and circulation system in the residential building. In the office building they may even undergo frequent changes. Another difference is in the fact that, in office buildings in particular, the rooms mentioned under (2) may have widely different and possibly very large sizes, whereas even the larger rooms in a dwelling are modest in size.

A quick look into the available literature shows a situation which is largely similar to the one found with housing. On the one hand there are books on the design of hospitals or office buildings which are in fact mere presentations of ranges of actual buildings. For each building the user is provided with some of the original drawings, some photographs, and one or two pages of descriptive text. Examples are *Office building design* (Schmertz 1975), *Bürogebäude* (Office buildings)
[Bédarida and Milatovic 1991], or the ‘Illustrations’ part of *Hospital architecture and beyond* [Rosenfield 1969]. Those examples are sometimes ordered according to rather crude distinctions. One finds for example low- and medium-rise office buildings distinguished from high-rise office buildings, or small hospitals and health centres from medical centres.

<table>
<thead>
<tr>
<th>Type</th>
<th>Simple forms</th>
<th>Complex forms</th>
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<tbody>
<tr>
<td>Chronic Nongrampate</td>
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<td>Gastrointestinal</td>
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<td>Thoracic or Neurological</td>
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<tr>
<td>Medical or surgical patients</td>
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<td>Dental</td>
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<td>Endocrinol</td>
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<td>Endocrine patients in cinema</td>
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<td>Nephrology</td>
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*Figure 6.1 An overview of types of ward layouts in hospitals. Presented in Hospitals, design and development (source: James and Tatton-Brown 1986).*

On the other hand there are comprehensive and in-depth handbooks on the design of office buildings and hospitals – comparable with Macsai’s comprehensive book on housing design. Those books also present existing buildings but in addition, and more importantly, they explicitly present and discuss ranges of design options at various levels of the building’s organization. *Planning office space* [Duffy et al 1976] has already been mentioned. Where hospitals are concerned,
Krankenhausbau (Hospital design) [Dirichlet et al 1980] and Hospitals, design and development [James and Tatton-Brown 1986] are good examples. It is particularly interesting that, as in the housing literature, modest systems of types are presented in those books by means of schematic drawings. Some of those systems relate to lower and some to higher levels of spatial organization.

6.3. Types in the framework of precedent-based design

This section discusses a potential implementation of type representations in the context of an architectural precedent-based design system. The discussion concentrates on anticipated user aspects of such an implementation, leaving computational aspects aside.

- In correspondence with the different levels of organization addressed during the design process a precedent base should include separate files, every one of which contains records which describe a particular general category of buildings, lower level components or building parts. A precedent is not necessarily described at every one of those levels.
- Upon such a file a system of types can be superimposed. Then, besides retrieval of precedents on basis of individual characteristics, it is possible to retrieve them by type. Types can be picked directly from a visual overview or they can be selected by means of a type editor in which the user can define a type description.
- During the process of adaptation of a selected precedent the user can be informed about the effects of adaptation upon various individual characteristics. This is particularly important if apparent constraints upon a type's accidental characteristics are violated, or essential characteristics are affected so that the type itself is changed.
6.3.1. Global organization of a precedent-base

In the context of architectural design precedents are relevant at particular levels of spatial organization. When involved in the design of a sliding door a designer may feel the need to be informed about existing sliding doors irrespective of the overall composition of the precedent's building masses. Reversely, when being in the stage of determining the overall composition of building masses a designer would probably not select precedents on basis of particular characteristics of its doors or other matters of details. Which levels of spatial organization are appropriate depends on the kind of building. The building as a whole and the individual building parts are two levels which are appropriate in almost any case. In larger buildings there is often at least one intermediate level – we will speak of a building component. Where the residential building is concerned the basic arrangement of dwellings is such a component.

General categories • From the user's point of view a precedent base should include a separate file of records for every general category of buildings (hospitals, schools, kiosks), lower level components (hospital wards, classrooms) and building parts (stairs, windows, doors). Every record contains information on one particular building, component or part. Information about the example is contained in a number of fields, some of which are defined exclusively in relation to the general category. Besides certain identifying characteristics such as 'architect's name(s)' and 'year of realization' a record presents formal characteristics which are significant for a comparative evaluation of examples. In other words, they support the designer's search for an appropriate example. Records in the 'windows' file for example have a field 'frame-material'. Such a characteristic is not defined for a 'school' record, which for example has a field 'number of classrooms'.

General categories at one level of spatial organization may relate to general categories at other levels in various ways. Included in hospitals one finds hospital wards and possibly also
classrooms (for instruction), so that classrooms are relevant in the context of both hospitals and schools. Windows and doors occur in almost every building. Stairs occur in both hospitals and schools, but they are not likely to be found in a hospital ward or a classroom. Kiosks exist as independent buildings, but they are also components included in hospitals.

Figure 6.2 General categories at different levels of spatial organization. An arrow indicates that instances of the one category may include instances of the other.

An architectural precedent may be interesting, and thus be described in the precedent base, at only one or at several levels of spatial organization. It is quite conceivable that for example an office building has windows which show an exemplary solution to the problem of combining natural ventilation and excellent sound insulation. If the building does not provide particularly interesting examples in other general categories there is no need to spend records on it in other files than the ‘windows’ files. In the context of a precedent-based design system it is of great importance that for every general category the set of examples is rich; it must show as much as possible the degree of variation found for example among existing residential buildings, basic arrangements and doors.

Let us assume that for the Unité there are records in the files ‘residential buildings’, ‘basic arrangements’ and ‘doors’. A record in the ‘basic arrangements’ file has fields, among others, for the total number of habitable rooms per dwelling and for the overall depth and width of the arrangement. In addition there is a field which contains a reference to a metric description defined in a specialized metric editor.
Figure 6.3 Three levels of spatial organization in the Unité d’Habitation. The composition of slabs, the circulation system and the repetitions of basic arrangements are described by a ‘residential building’ record. An individual basic arrangement, as a composition of rooms and of parts, is described by a ‘basic arrangement’ record. An individual door is described by a record in the ‘doors’ file.

When a user is presented with the record, he is allowed to have a look at this description and switch between several different visualizations such as plan view vs. axonometric projection, or rooms and their functions vs. building parts and materials. The latter visualization may inform the user about building parts, if any, which are described separately at part level. The content of the identification fields such as year of
realization must be interpreted by human indexers from available documentation. Others such as overall depth and width are derived automatically from the metric description.

Records at the building and part levels have similar characteristics.

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NAME: architect's names
LOCATION: country, place
YEAR: year of realization
DW: number of dwellings
ST: number of storeys
OW: overall width (m)
OD: overall depth (m)
HR: number of habitable rooms per dwelling
FA: total floor area per dwelling (m²)
ME: metric description

![Figure 6.4 Record from the 'basic arrangements' file. Left: interpretation of field names; the fields HR and FA contain information on the two dwellings individually. Right: metric description visualized by axonometric projection.](image)

6.3.2. Retrieval by type

The number of examples needed to show the actual variety among components of a general category is usually quite large. The explorations in chapter five (subsection 5.2.3) have produced a total of sixteen apparently relevant types. What this number would be if other triples and other categories than single storey VA and double storey HA arrangements were taken into account can only be guessed. Several split-level, double storey and three storey types could be found for example. Let us assume that a more thorough investigation of existing handbooks and other housing literature would produce a total between fifty and a hundred types. If for every one of these
there would be, say, five instances in the precedent base, then retrieving the most appropriate one(s) through a one by one inspection is not a realistic option.

Available systems for the retrieval of architectural information, such as the Architectural Periodicals Index (API) [BAL 1992] and the Avery Index to Architectural Periodicals [Getty Trust 1992] show that this is not at all a trivial problem. In many cases the controlled vocabulary of keywords by means of which records can be retrieved in those systems will fail to convey those formal characteristics of a precedent which may be relevant in view of a particular design problem. His prior knowledge of a particular design problem is likely to cause the user to have certain preconceived ideas about form. Commonly however keywords do not allow such ideas to be expressed in sufficient detail. This also holds for more specialized reference works than those mentioned above, such as Sozialer Wohnungsbau in Holland (Social housing in the Netherlands) [Brunnert-Bestian 1985] or Arbeiterwohnungen (Working-class dwellings) [Blum 1985].

Using the argument that ‘verbal expressions fail short of the specificity, abstraction and comprehensiveness of drawings’ Koutamanis and Mitossi [1992 p84] suggest the alternative of using abstract graphical descriptions instead of keywords. It is worth mentioning in this respect that in organic chemistry a more or less comparable problem is solved by allowing the user of a database to retrieve records on chemical compounds by entering a possibly incomplete description of a molecular structure which is then matched against descriptions available in the database [CAS 1985; Domokos 1993].

An overview of types • In our precedent-based design system one may define a selection of records by specifying constraints upon the contents of particular fields. If, rather than having in mind certain preconceived ideas about form, the user seeks to be inspired with such ideas this may be a sensible approach. He could for example specify that no dwellings occur which have less than three or more than four habitable rooms, since these constraints are stated in the building programme. Adding some further constraints may lead to a limited selection which can be subjected to a one by one inspection. Often preconceived ideas are present however and selection by
constraining individual characteristics does not allow the user to express them. Providing access to a large set of examples via a well-defined representation-based system of types has several advantages.

First, the user may ask to be presented with an overview of those types of which instances are available. The well-definedness of the type representation allows the automatic derivation of type descriptions from the stored metric descriptions. For this purpose rooms and openings should be explicitly defined in the metric representation. Yessios [1987] and Lawson and Roberts [1991] describe metric editors based upon such a representation. Isomorphic descriptions can be automatically recognized and removed. Browsing the complete overview of types, contrary to browsing the entire file, may be an efficient and effective search strategy. Furthermore it is possible to display on this overview which types have instances in a previously defined selection. The simultaneous presentation of a range of types invites the user to evaluate any one of them in direct comparison with the others, so that differences and similarities are easily observed.

If the user wants to be informed about a particular type in more detail, he can select it from the overview and be presented with its stored instances. Since these are limited in number their metric descriptions can be shown simultaneously which, again, allows a direct mutual comparison. The instances also suggest a type's apparent variation in size and internal organization at room level, as well as in shape, size and position of the corridor. By looking at its concrete implementations the user is informed about possible or likely consequences of choosing a type, which would have been difficult to anticipate. A designer may have in mind for example a split-level combination of dwellings of the Hansaviertel type, without being aware of the considerable difference to be expected between the size of the double oriented and the single oriented dwellings. Being confronted with a metric description of the actual Hansaviertel arrangement (figure 4.1) may stimulate such awareness.

A type editor • The user's role in the inspection and mutual comparison of types becomes a more active one, if he is allowed to define selections of types by expressing his preconceived ideas
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### Figure 6.5
Selection directly from the type overview. Above: one of the types is selected. Below: from the nine shown records in the 'basic arrangements' file those two are selected which describe instances of this type. The records as well as the metric descriptions of these instances are displayed simultaneously, which facilitates their mutual comparison.
about form in a specialized type editor. In this type editor the user manipulates a box visualization in order to define the relative position of oriented storey systems, to indicate their orientations and their combination into dwellings, and to specify the corridor-storey and the access-type. The user-defined description can be interpreted as a complete one, in which case its well-formedness is checked and the user is either presented with the available instances or he is informed that the type does not occur in the precedent base. In the latter case he can be informed about several characteristics which are implicit in the type description such as constraints upon vertical travelling distances or the implication of external or internal passing (subsections 4.3.3 and 4.3.4).

![Diagram](image)

**Figure 6.6** Three user-defined descriptions contained in the Hansaviertel type (right) or its one isomorph.

The user-defined description can also be interpreted as an incomplete one, in which case the user is presented with a selection of those type descriptions which contain this incomplete description or have an isomorph containing it (see also subsection 5.1.2). The box visualization allows various kinds of incompleteness: access-type and corridor storey may be unspecified, whether or not two oriented storey systems are included in one and the same dwelling may not be indicated, storeys may be occupied neither by a corridor nor by an oriented storey system, and so on.

A selection of types which are consistent with the user-

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1 An editor which allows the manipulation of a highly abstract representation is also described by a CAAD approach named *designing with diagrams* [Gross et al 1988; Ervin 1990].
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**Figure 6.7** Selection by means of the type editor. Above: two types are selected from the type overview through a user-defined description of an individual dwelling which is contained in both of them. The selection is displayed in the type overview. Below: from the nine shown records in the 'basic arrangements' file four are selected which describe instances of these types.
defined description can be displayed on the type overview. If the user finds the selection too large he can re-edit the description to make it more complete. If he finds the selection too small or if it is empty he can re-edit the description to make it less complete. Once a small selection has been defined to his satisfaction he can be presented with the available instances. A significant advantage of this strategy is that it supports retrieval of one or more appropriate examples, even when these do not entirely fit the user's initial ideas. The user is given the opportunity to modestly change these ideas if retrieval is not immediately successful.

6.3.3. Adaptation of precedents

A more controversial aspect of precedent-based design is the transformation and incorporation of descriptions of existing buildings and their components in the description of a new building. Schmitt [1993 pp12-14] claims that precedent-based design does not necessarily obstruct the designer's creativity, but whether this is true can only be tested when non-trivial design systems are actually implemented in architectural practice or education. There are also legal issues involved, since the designer would explicitly make use of products of another designer. At what point 'seeking inspiration' stops and plagiarism begins is unclear.

However, in view of the primitive stage of development of the precedent-based approach an elaborate discussion of such issues seems premature. Let us confine ourselves to a few possible merits of a well-defined type representation for designing in a precedent-based design system.

Editing a description • The user should first of all be offered a metric editor which incorporates the specialized editors for the general categories of buildings, components and parts. Where the residential building is concerned for example, the editor should allow the definition of an entire building in terms of slabs and repetitions of basic arrangements, the definition of a basic arrangement in terms of rooms and
building parts, and the definition of building parts in terms of smaller parts.

The user could begin by importing the metric description of a residential building which he considers appropriate as a composition of slabs. He may change the sizes of the slabs to fit a particular site. He might be dissatisfied with the circulation system and choose to adapt it, for example by changing a walk-up system into a system with elongated corridors. Similarly, the user may retrieve descriptions of appropriate basic arrangements, doors or windows from the precedent base, adapt them and incorporate them in the newly manufactured description. Thus components from many different precedents may be used.

**Display of individual characteristics** • A fundamental idea behind precedent-based designing is that a building or a component is selected for adaptation, because it has characteristics which are appropriate to certain of the desires and requirements forming the new design problem. When adapting a building or one of its components so that it satisfies other desires and requirements as well, the user may easily fail to preserve those characteristics. The system should not simply disallow such adaptations, since ‘objectives and priorities are quite likely to change during the design process as the solution implications begin to emerge’ [Lawson 1990 p88]. What the system should do is to allow the user at any time to be informed about the effect of his actions upon those characteristics.

One way of informing is by simply showing how an adaptation at a particular level of spatial organization affects individual characteristics at different levels of organization. Enlarging the width of a longitudinally repeated basic arrangement for example, enlarges the length of the slab in which it is included as well as the shape and size of certain rooms and building parts. Changing the number of habitable rooms in one of this arrangement’s dwellings may have a serious effect upon the total numbers of dwellings with particular numbers of habitable rooms and thus, ultimately, upon the number of inhabitants accommodated by the building. Sizes of slabs or of building parts, numbers of dwellings of a particular kind, and many similar individual characteristics can be displayed constantly or at the user’s request.
Constraints upon accidental characteristics • An adaptation of a building or a component may have two implications with respect to its type. First, an adaptation may violate certain apparent constraints upon accidental characteristics as these are suggested by the set of instances in the precedent base. It is important that the user is informed about such a violation: if it is assumed that the set sufficiently represents the actual variation of those characteristics he should be aware that he may well be stretching the type beyond the limits within which it is a realistic design option. For this purpose it may be useful to incorporate results of empirical research in the precedent base. If it is found for example that in a large and varied range of arrangements of a particular type one particular dwelling has without exception no more than two habitable rooms, this fact should not be taken lightly if one is designing on basis of a building programme which does require small dwellings.

In the end, of course, it is the user’s decision whether or not such apparent constraints are to be respected.

Essential characteristics • Second, adapting a building or a component may affect its essential characteristics or, in other words, change its type. Again it is important that the user is informed about such a change. At this point there are two possibilities: either instances of the new type are available in the precedent base or they are not. In the latter case it may be useful to inform the user about those type-implicit characteristics which are affected by the change, such as vertical travelling distances, the implication of internal or external passing, or the number of orientations of individual dwellings.

Even a modest change of type may seriously relax or tighten the constraints upon accidental characteristics mentioned above. If instances of the new type are available in the precedent base the user should be informed about their presence and about constraints suggested by them. It may well be that his objectives and priorities have changed to such a degree that one of those instances seems better suited than the one initially imported and adapted. It may occur for example that the user initially imports the Unité arrangement (a) and, in the process
of adaptation, becomes dissatisfied with the internality of the corridor. He might then decide to give the two single oriented storey systems in the arrangement the same orientation instead of opposite orientations.

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![Diagram](image)

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**Figure 6.8** Adaptation of essential characteristics. *Left: the Unité type may be changed by giving the two single oriented storey systems the same instead of opposite orientations. Below: an instance of the new type which shows how the overall depth and the position of the largest habitable rooms may be affected by the change of type.*

At this point the user may be presented with the available instances of the new type. He may of course select one of them and restart the process of adaptation. If he does not, he may nonetheless want to respect certain constraints upon accidental characteristics as they are apparent among the instances. If the largest overall depth found among these instances is 13.2m, the depth of 19.5m of the Unité arrangement might be unrealistic for the new type. If in none of the instances a dwelling has its largest habitable room occupying the corridor storey it may be wise to respect this constraint, or at least to be aware of it during the process of further adaptation.
6.4. Environments for implementation

There is a potential role for a precedent-based design system in the three environments of implementation distinguished by chapter one (subsection 1.3.4).

**Architectural education** • The acquisition of a broad awareness and understanding of types is an essential ingredients of an architectural education. It is common practice in schools of architecture to stimulate the acquisition of this kind of knowledge in two ways. On the one hand students are constantly fed with examples, which they are expected to be familiar with from then on. This is often done in the traditional form of lectures supported by books or other texts. The examples are well-known precedents, or at least precedents to which there are certain architecturally interesting aspects. On the other hand students take part in design studios. Most commonly a design studio is set up around a specified design problem which is analyzed by the students and for which they develop a solution individually or in teams. During their work students are guided intensively and, in the end, a solution must be described in certain detail (depending, of course, on the scale of the design problem) by means of drawings or models. Students involved in a design studio are often inclined to simply copy the precedents they have got to know. First, there is insufficient understanding of the precedent as representing a type and many of the precedent's accidental characteristics are copied without giving them serious thought. Second, there is insufficient understanding of the type's appropriateness, or its lack of appropriateness, in view of many possible desires and requirements.

A precedent-based system allows a marriage of the two approaches. The precedent base should contain a varied body of architecturally interesting precedents. Using the type editor to
define selections of types, being informed about their implicit characteristics and about existing instances, and adapting certain of those instances in relation to a specific design problem support familiarity with a large number of precedents as well as consciousness about their appropriateness to particular kinds of design problems.

Architectural practice • Undoubtedly the most demanding environment for implementation of a precedent-based design system is the architectural office. This holds in particular for the adaptation of precedents. The metric editor should allow a great deal of freedom in the order in which levels of organization are addressed and the order in which components at different levels are defined. Another problem to be resolved is the intellectual burden of having to structure input and perform operations on it more or less impeccably, as mentioned by Koutamanis (subsection 1.4.1).

Rather than being rich and varied in a general sense, the precedent base would be limited to the kind of buildings, components and parts a particular office is preoccupied with. This limitation enables an increase in the number of stored instances per type. Since it is usual that offices adapt their own successful solutions it is likely that an office would want to incorporate many of its previously designed buildings in the precedent base. At the level of building parts computerized descriptions are already offered by the building industry.

Empirical research • Empirical research investigates the distribution of characteristics over a given a body of precedents. Through the inspection of large ranges of instances of a type, apparent constraints upon accidental characteristics may be discovered – as we have seen in the work of Brown and Steadman (subsection 2.3.4). As mentioned in the previous section, such constraints may provide valuable information for the selection and adaptation of a precedent. Where architectural education and practice are concerned, it would be a good idea to store such information in the precedent base and to present it if needed. A more challenging intention of empirical research is to find explanations for apparent constraints. If such an explanation is found, this adds a great deal to the significance and reliability of the constraint, which is
shown to be more than a coincidence and which should therefore be taken even more serious.

Not only could a precedent-based system profit from the results of empirical research but, reversely, empirical research itself could profit from such a system by storing the descriptions of buildings, components or parts to be investigated in the precedent base. The uniformity of these descriptions is secured by the metric editor. The editor should allow user-defined labels to be attached to individual components of the description, so as to represent specific information in which the research is interested. Rooms in a basic arrangement might for example be labelled to indicate whether they have interior or exterior climate. The system should be able to derive various accidental characteristics from the metric descriptions, such as a dwelling’s ‘proportion of floor area in habitable rooms to floor area in interior-climate rooms’ or ‘number of habitable rooms, access-related to a room with exterior climate’. Thus the system would take over much tedious work and allow the researcher to quickly find interesting constraints upon such accidental characteristics.

As mentioned in chapter one (subsection 1.4.2) a significant advantage of the precedent-based approach to architectural design is that it does not require the simultaneous and explicit incorporation of all the knowledge relevant to an architectural domain. If however a precedent-based design system is to become more than just a database of indexed drawings combined with an editor in which these drawings can be adapted, it is essential that sufficiently abstract and well-defined representations of architectural form are developed for a variety of general categories of buildings, components and parts. Such representations facilitate effective and reliable support of the retrieval, selection and adaptation of precedents.

It is vital that future development of CAAD systems goes hand in hand with more fundamental research into the form and performance of actual buildings, and in particular with conscientious work in architectural typology.
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Samenvatting

Een probleem in het architectonisch ontwerpen — In de vroege stadia van het architectonisch ontwerpproces worden algemene beslissingen genomen met betrekking tot de ruimtelijke organisatie van een gebouw. Daarbij gaat het zowel om de globale vorm en afmeting van bouwmassa's als om hun inwendige organisatie. De ruimtelijke organisatie van een gebouw —tijdens deze vroege stadia slechts vaag en onvolledig beschreven— bepaalt in belangrijke mate hoe het gebouw zal presteren.

Consequenties voor de prestatie kunnen pas op betrouwbare wijze worden vastgesteld aan de hand van een gedetailleerde beschrijving, of zelfs pas na ingebruikname van het gebouw. De capaciteit van de ontwerper om zulke consequenties in een vroeg stadium te voorzien is grotendeels afhankelijk van zijn kennis van bestaande gebouwen, of precedents. In het bijzonder gaat het hier om kennis en begrip van typen en hun prestaties.

Architectonische typologieën — De betrouwbaarheid van beslissingen tijdens de vroege stadia van het ontwerpproces kan verbeterd worden door ondersteuning van genoemde kennis en begrip met behulp van architectonische typologieën. Een evaluatie van bestaand typologisch werk op het gebied van de woningbouw leidt tot de volgende algemene conclusie.

De meeste woningbouw typologieën mankeert het aan een een goed gedefinieerde representatie van typen. Dit brengt onzekerheid met zich mee met betrekking tot de volledigheid van een typologie, alsmede met betrekking tot de prestaties die met typen geassocieerd worden. Sommige typologieën besteden meer aandacht aan de volledige en ondubbelzinnige definitie van een type-representatie. Zulke representaties zijn echter gewoonlijk te weinig abstract en ze zijn onveranderlijk van toepassing op relatief lage niveau's van ruimtelijke organisatie.
Onderzoeksresultaten — Dit onderzoek tracht de mogelijkheid aan te tonen van type-representaties die niet alleen welgedefinieerd zijn, maar tegelijkertijd voldoende abstract en van toepassing op hogere nivo’s van ruimtelijke organisatie. Het onderzoek is beperkt tot het gebied van complexe woongebouwen.

Het proefschrift beschrijft de volgende twee resultaten:

(1) Definitie van een abstracte representatie van woningarrangementen. Gewoonlijk worden in complexe woongebouwen karakteristieke arrangementen van hooguit enkele woningen meerdere malen herhaald langs corridors of trappehuizen.

(2) Een demonstratie van enkele mogelijkheden zoals die worden geboden door deze representatie: enumeratie van complete verzamelingen van typen en enkele analyses van de verdeling van prestatie-gerelateerde eigenschappen over die verzamelingen.

Hoewel het onderzoek precomputationeel is, speelt computerisatie in het kader van precedent-based design op de achtergrond een belangrijke rol. Uitdagingen in dit verband zijn de automatische herkenning van typen uit opgeslagen precedenten en het opsporen van precedenten op basis van de (onvolledige) beschrijving van een type door de gebruiker.
Summary

A problem in architectural design — At the early stages of the architectural design process general decisions are made with respect to a building's spatial organization. These concern its overall shape and size as well as its internal organization. A building's spatial organization, however vaguely and incompletely described at those stages, has serious consequences for various aspects of its performance.

A reliable test of those consequences becomes possible only after time-consuming elaboration of the design or even not before the actual building is in operation. A designer's ability of foreseeing them is much dependent on his knowledge of existing buildings, or precedents. More particularly, it depends on his understanding of the performances of types.

Architectural typology — Decisions at the early stages of the process can be improved by supporting the designer's awareness and understanding of types. A review of existing work in the area of housing typology leads to the following conclusion.

Most housing typologies suffer from a serious lack of well-definedness in the graphical representation of types. This leads to uncertainty both about the typology's completeness and about the performances associated with types. Some typologies pay more attention to the complete and unambiguous definition of a type representation. Such representations however usually fail to be sufficiently abstract and they address only lower levels of spatial organization.

Results of the study — This study wants to demonstrate the possibility of combining well-definedness with sufficient abstraction at higher levels of spatial organization. This demonstration is limited to the domain of the complex residential building.

The thesis presents the following two results:
(1) Definition of a highly abstract representation of basic dwelling arrangements. In residential buildings such arrangements are commonly repeated along corridors or vertical circulation axes.

(2) A demonstration of the potential of this representation. This involves the enumeration of ranges of types and some analyses of the distribution over those ranges of certain performance-related characteristics.

While the study itself is precomputational the idea of implementing the system in the framework of precedent-based design is a constant preoccupation. Challenging issues are the automatic derivation of types from stored precedents, and precedent retrieval on basis of (incomplete) description of a type by the user.
Curriculum Vitae

1961 (10 July)  Born in Utrecht, The Netherlands

1972-1979  Attending high school at Stedelijk Gymnasium in Arnhem.
            Gymnasium-B diploma.

1979-1988  Studying architectural design at Delft University of Technology. Assistant designer with Campman Tennekes Architecten in Gouda during 1985. Master’s project awarded cum laude and selected for the Archiprix competition of young designers. Project published in De Architect (April ’90) and in Architektur + Wettbewerbe (June ’90).
            Bouwkundig ingenieur.

1988-1993  Research assistant with prof. Rijnboutt and prof. Tzonis at Delft University of Technology, Faculty of Architecture. From 1990 on member of the Design Knowledge Systems (DKS) group, investigating architectural typology in the domain of housing with the aim of computerization.