A practical experiment in representation and analysis of buildings

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ABSTRACT

The TYPOLOGY project was set up by the Dutch Government Building Agency (GBA) to explore computerised representations of buildings that allow analysis of various aspects of their performance. So far this project produced the RF-model, an abstract computerised representation. Physical elements of the building are not represented as such, only individual spaces and boundary segments along which they are adjacent are represented explicitly. Spaces can have any number of functional properties such as the general category of floor area they are included in, the activities they accommodate, or the particular safety compartment or circulation system they belong to. Similarly, boundary segments may, for example, provide access or view, may be included in a particular category, such as interior walls, or in a safety or security barrier.

The RF-model enabled the presentation and quantitative analysis of design proposals for large and complex buildings such as courts of justice and prison buildings. The model is also used in a multi-aspect analysis of a series of recently erected Dutch prison buildings. We expect that these first results will develop into a rich and professional precedent-based system, to be used in the early stages of design. The strategic goal of the project is to derive from the accumulated models and their analysis a more general understanding of the relations between a building’s actual characteristics and various aspects of its performance.

1 TYPOLOGY PROJECT

The primary task of the Dutch *Government Building Agency (GBA)* is to provide appropriate housing for government services. Since the housing needs of these services are continuously changing their housing facilities are subject to regular change as well. This may vary from choosing a fitting building from the large reservoir of government buildings that the agency manages, to the design and construction of new ones. To carry out this task properly the GBA needs to have up-to-date and detailed knowledge of its client’s needs and of the building characteristics relevant to those needs.

In the past such knowledge was largely *implicit*, that is, hidden in the personal expertise of those involved in the process. In recent years, however, architectural design has become a more complex process in which communication and joint decision-making between various parties (client, consultant, project manager, designer and many others) play an important role from the onset. For such a collective approach to be effective we need, among other things, design knowledge to be made *explicit*. To pursue this the GBA has a research program in which a wide range of design-related issues are listed (Pullen and Kouwenhoven 1997). This research is carried out jointly by the agency itself and by external partners.

The TYPOLOGY *project* was initiated by the GBA in 1994 -in co-operation with Advanced Architectural Research & Design (AAR&D). So far the project has had primarily an explorative character. Methods and techniques however are continuously being tested in the practical context of analysis and evaluation of both design proposals and existing buildings. This close connection between research and everyday practice is sometimes difficult, but it has proven to be challenging and fruitful at the same time.

In the most general terms the project aims at improving our understanding of the relations between a wide variety of building performances on the one hand and actual, objective characteristics of buildings on the other. Particularly where such characteristics are determinable at the early stage of the design process this could lead to more effective decision-making and, eventually, to buildings which are more likely to perform according to the desires and expectations of their users. Before we establish such relations serious empirical research is needed. Information must be gathered on large numbers of actual buildings and the actual activities they accommodate, performance aspects must be specified in more concrete terms, methods of representation and analysis must be developed and tested.

The focus of the project has been, and still is, on these last issues of representation and analysis. We hope that in the future a powerful database, containing a large number of building models together with detailed information about their actual use and performance will evolve from the present work. In the end a system of types should be developed and superimposed on this reservoir of precedents – a perspective which, in theoretical terms, has been discussed in previous publications (Leusen 1994, 1995, 1996). This will hopefully lead to more general knowledge about mutual relations between characteristics of buildings and, from there on, about mutual relations between aspects of their performance.

2 REPRESENTATION OF SPACE AND FUNCTION

Within the TYPOLOGY project we developed an experimental representation of space and function which was given the working title *RF-model* (a Dutch acronym for Spatial-Functional model). The basic idea of this representation and its definition both in terms of primitives and their allowed configurations and in terms of the interpretation of those primitives and configurations goes back to earlier work by British researchers (March and Steadman 1971, Steadman 1983). In that respect particularly the *plan graph* and the *rectangular arrangement* are relevant (Steadman 1983 pp6-19 and pp61-78).

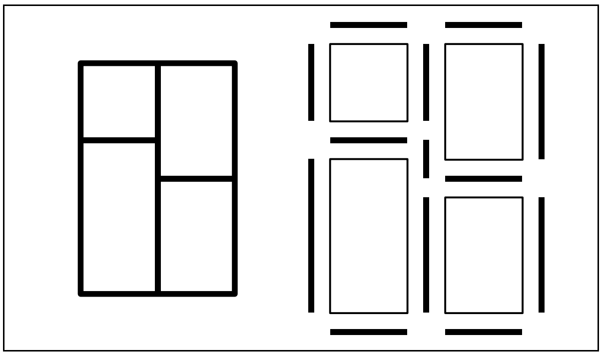
An individual space, determined by physical boundaries, is represented by a *polygon* in the horizontal plane. Where two spaces share a straight length of such a physical boundary, so that they are adjacent, a *line* represents this boundary segment. Polygons do not overlap; they are closely packed in the horizontal plane. Thus each line is coincident with two polygons. Lines do not cross or overlap. At both ends a line is coincident with one or more other lines. (See figure 1)

In principle the RF-model is an abstract spatial representation: physical elements of the building are not represented as such. Many details of shape, like wall thickness or minor protrusions and indentations in physical boundaries, are ignored. Thus the model contains imprecise geometrical information about spaces and boundaries. Although topological relations (adjacency of spaces and other coincidence of primitives) are not represented explicitly they can be easily detected.

Spaces can have any number of functional properties such as various categories of floor area they are included in, activities they accommodate, or a particular safety compartment or circulation system they belong to. Similarly, boundary segments may for example provide access or view (doors and windows not being represented as individual objects); or they may be part of a particular safety or security barrier.

Although the primitives are two-dimensional, the metric properties *elevation* and *thickness* provide information about their location and vertical size in three-dimensional space.

Figure 1: **A simple rectangular plan and its decomposition into four spaces and thirteen boundary segments.**



3 SOME ASPECTS OF COMPUTERISATION

In order to actually use the RF-model in an efficient and reliable way, particularly where large buildings are concerned, computerisation is inevitable.

The current implementation of the model is based on the CAD system *MiniCad*. We use the system’s 2D polygons and lines as primitives, and the built-in database to attach properties to them. It is also possible to describe, by means of 2D polygons, a few other entities such as the outline of building mass, the terrain, or functional areas independent from physical boundaries. From these primitives and their properties various additional objects can be generated, such as text objects or solids and 3D polygons for three-dimensional visualisation.

Layers serve to distinguish between floors. An individual building or a complex of buildings is modelled in a single CAD drawing. A wide range of added routines, written in MiniCad’s programming language MiniPascal, serve the editing, visualisation and quantitative analysis of the representation. A few general categories of them are the following:

- Routines which automatically or semi-automatically *generate* primitives or additional objects. Polygons for example can be produced directly from an imported list of required functions and floor areas. Given a set of polygons another routine automatically creates the coincident boundary segments (which of course are implicitly determined by the shape and adjacencies of the polygons).
- Routines which check the *syntactical correctness* of the model. Incorrect polygon overlaps or line crossings for example are retrieved and marked automatically. It is then left for the user to choose between alternative corrections.
- Various kinds of *selection* routines. These mostly produce selections of objects on basis of their type or attached properties. A few produce selections on basis of coincidence of objects: for example all lines which are coincident with a previously selected set of polygons or vice versa. In combination with visual inspection these routines have proven to be particularly useful to check the model's correctness.
- Routines which calculate *quantities*. Some of these calculate numbers, lengths or floor areas immediately 'on screen', some generate lists of objects together with their properties and sizes which are subsequently exported and processed in Excel.

Visualisation of polygons and lines that carry heterogeneous properties is not a trivial matter. We have used various two- and three-dimensional visualisations for different purposes. Most frequently we use a schematic floor plan in which the general category of a space (office space, circulation space, etc.) is shown as a background colour of the polygon, while more specific functions ('visiting area', 'restaurant', etc.) are shown by overlaying coloured patterns. More detailed information is added by means of text objects. Properties of boundary segments are indicated by variations in the width and colour of lines.

4 AD HOC DESIGN SUPPORT

During the past few years the RF-model enabled the presentation and evaluation of design proposals varying from simply rearranging employees in an existing office building to the design of entirely new, and sometimes highly complex buildings such as prisons, courts of justice, or laboratories.

We use the model in the early phase of design to support communication and decision-making among the partners involved, like the client, the project manager, the designer, consultants in various disciplines, and others. Discussion at this stage often concentrates on the way in which functions can be arranged in such a way that their required floor areas and mutual relations are realised to a sufficient degree. In this context both visualisation by means of 'functionally coloured' plans and calculation of numbers and floor areas of the corresponding spaces have proven to be effective. (see figure 2)

An important characteristic in relation to this kind of use is that the RF-model does neither impose a particular level of detail in the description of spaces and functions, nor does it require completeness. Functions can be described either in general terms like ‘financial department’ or ‘sporting facilities’ or in detailed ones like ‘director’s office’ or ‘toilet’. In terms of spaces the model does not have to be complete to allow functional colouring; we have often worked with incomplete models in which, within the boundaries of a building mass, only the more important spaces and their functions were determined.

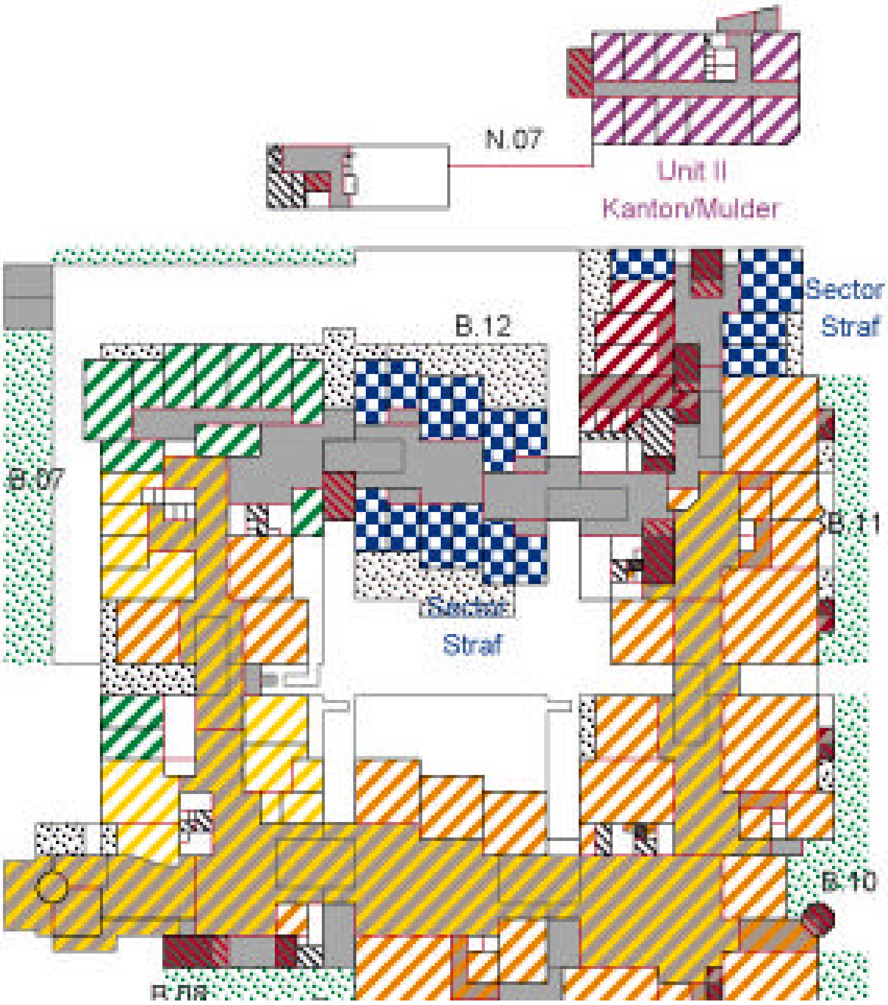


Figure 2: **Plan visualisation of a court of justice in Breda (The Netherlands) generated from the RF-model; patterns, colours and annotations indicate functional information.**

The model also supports the assessment, previous to any actual design proposal, of existing buildings as to their potential use. The Dutch building code for example refers to various general categories of floor area, like *usable* area, *lettable* area, *sanitary*, or *circulation* area (NNI 1997). Such and other quantities can be derived from the model in order to help assess whether a particular building might accommodate a particular client organisation.

5 COMPARATIVE ANALYSIS

From 1996 on we have started using the RF-model in the comparative analysis of existing prison buildings and their actual or potential use. In view of the growing crime-rate and the increasing diversity in offenders and corresponding regimes, the Dutch Prison Service feels the need to critically evaluate its present building stock in preparation for a next serious addition of cell capacity. Obviously in this context a uniform approach, both towards the representation of these buildings and towards the methods of analysis, is of great importance. The prison evaluation is an ongoing project in which so far only a limited number of buildings and building complexes have been modelled and analysed. At this stage our main concern is to determine which actual, in particular quantitative, characteristics of prison buildings are relevant to the aspects of performance considered important by the prison service. Therefore the present models and analyses should be seen primarily as a first examination of the possibilities. Nonetheless a few preliminary results are worth mentioning as an example. (See figure 3)

We calculated floor areas of a range of functional components for a number of prisons, for example the cell area, the labour department, the reception area, or the visiting area. Particularly the *relative* (that is: divided by the total number of cells) numbers and floor areas of such components are an indication of the frequency and the amount of time inmates can take part in activities like labour or sport. In figure 4 a considerable difference can be observed for example between five prisons for adults and two for underage offenders.

We also measured and compared the size of terrain in relation with the ‘amount’ of building on it. Calculations of proportions such as floor-space index (floor area divided by terrain area) or stacking factor (floor area divided by built area) offered a better insight in why some solutions are more ‘terrain-consuming’ then others. In view of the difficulty of finding available sites both large enough and appropriately located to accommodate a prison building with a particular cell capacity, these are valuable statistics. (See figure 5)

Figure 3: **Overview of eight prisons; building mass and outermost security barrier are indicated.**

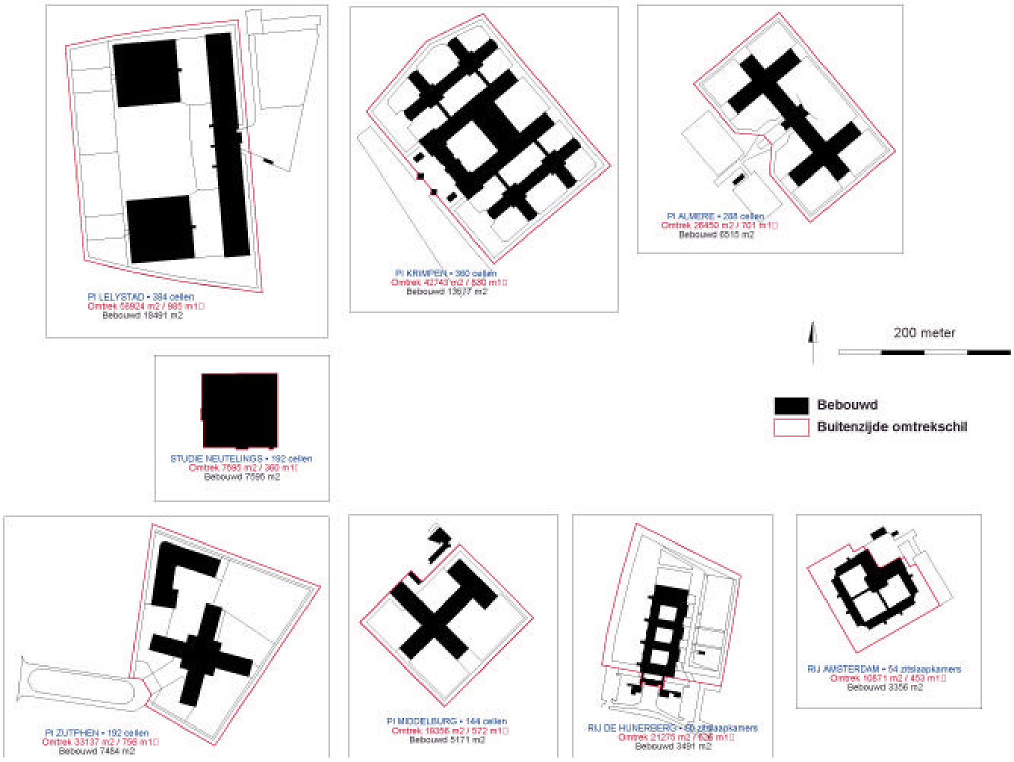


Figure 4: **Absolute (left) and relative (right) floor areas decomposed into functional categories; to the left are five prisons for adults, to the right are two prisons for underage offenders.**

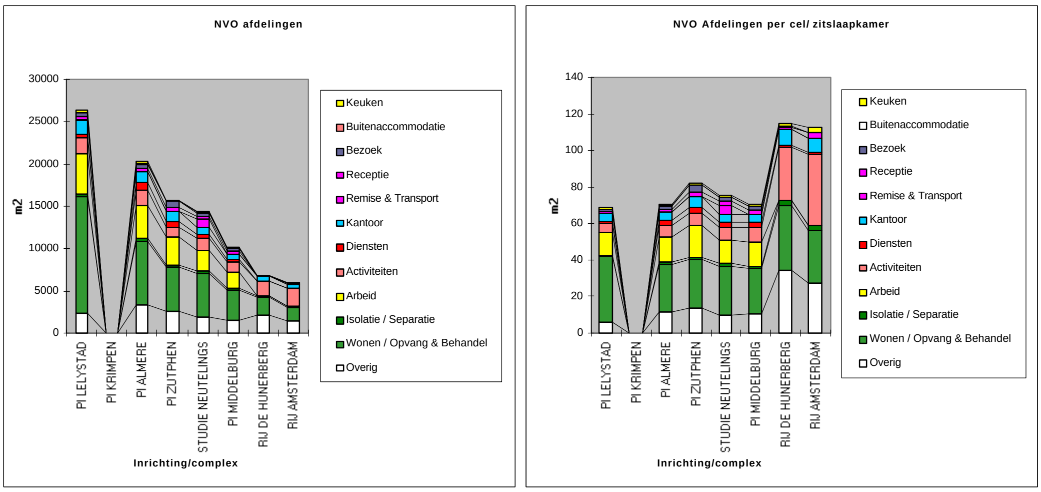
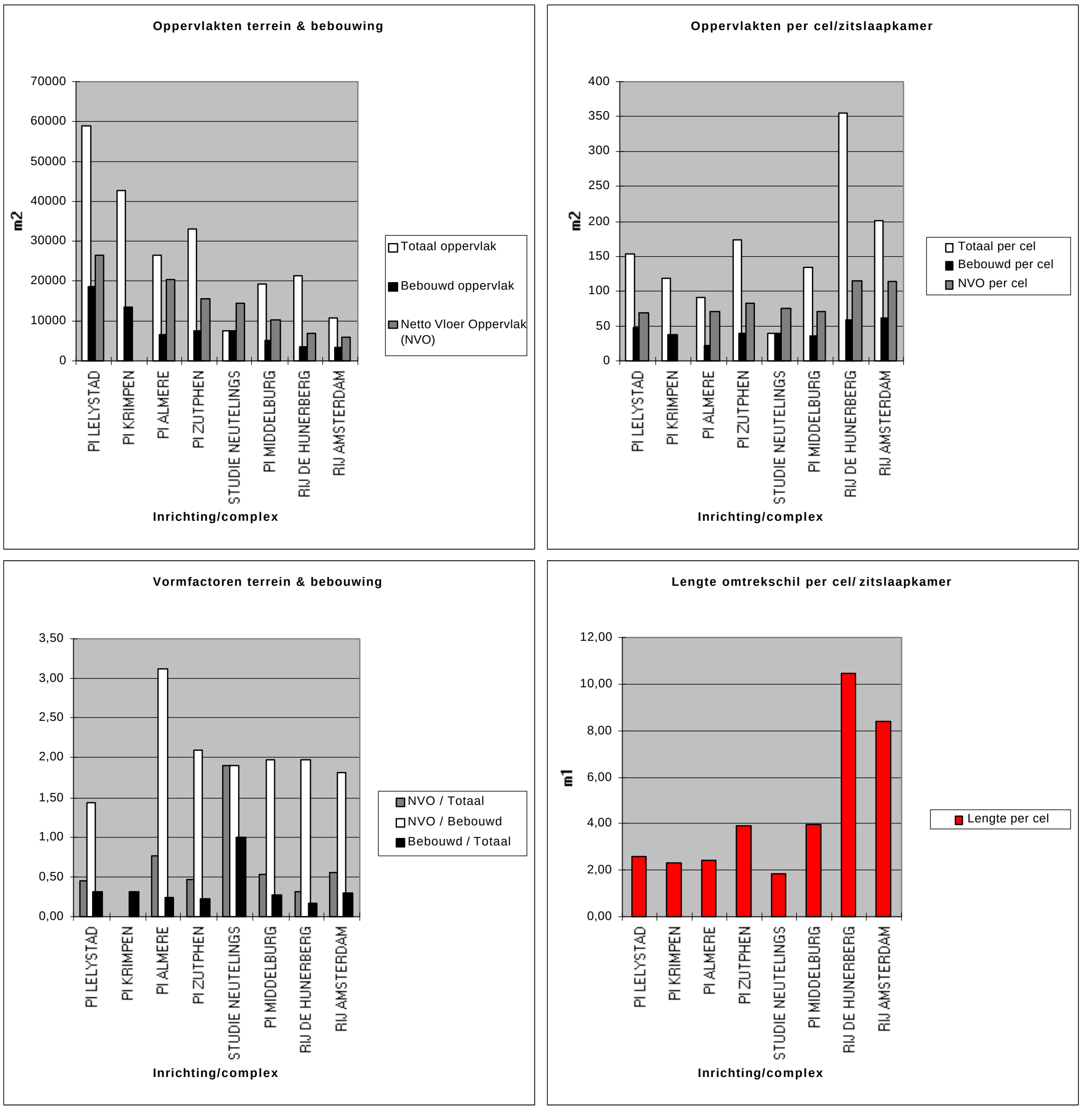


Figure 5: **Above: absolute (left) and relative (right) terrain area (white), built area (black) and total floor area (grey). Below left: size of terrain in relation with the amount of building on it; proportion of total floor area to terrain area (grey), proportion of total floor area to built area (white); proportion of built area to terrain area (black). Below right: relative perimeter length of terrain.**



By attaching specific properties to spaces and boundary segments we explicitly indicated in the models the location of *security barriers*, of specific *circulation systems*, and of spaces to be *visually controlled* from static positions. Such issues are obviously of great importance to security performance. At the same time, however, there are implications for other aspects of performance, such as efficiency of circulation, number of security personnel needed, or building cost.

We used various 2D and 3D visualisation methods to show the key differences between prisons where security barriers, circulation systems, and visual control are concerned. Figures 6 and 7, for example, show the location of the outermost security barrier (consisting at maximum of a wall, a clearzone and a fence). In one case this barrier is nowhere adjacent to either prison buildings or outdoor facilities for inmates; in another case it fully coincides with the buildings façade. In between various hybrid solutions can be observed.

Figure 6: **Location of clearzone, transport area and outdoor sporting facilities.**

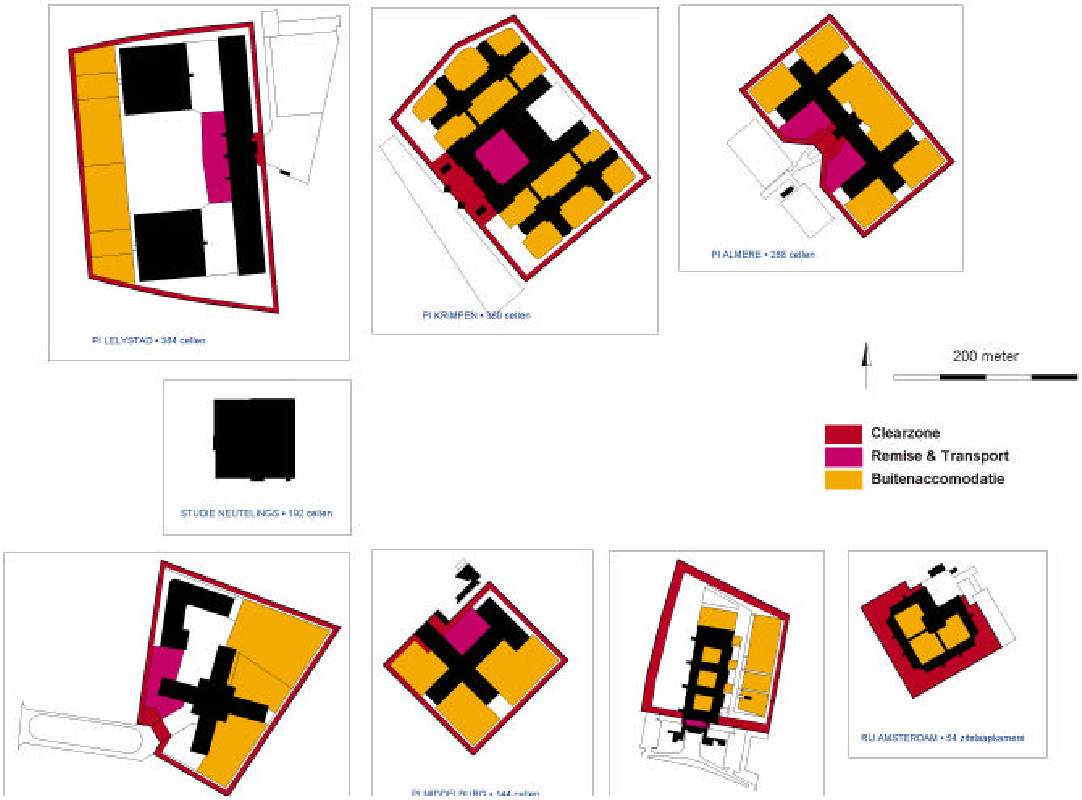
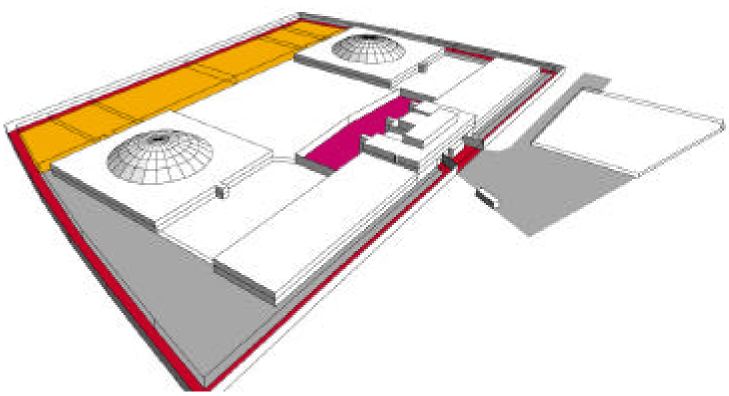


Figure 7: **Prison complex in Lelystad (The Netherlands); clearzone, transport area and outdoor sporting facilities are indicated by colouring.**



In addition we compared a few quantitative characteristics of security barriers, circulation systems, and visual control. A good example is the analysis of the different circulation systems along which inmates regularly travel from their cells towards other areas of the prison, such as labour or sporting facilities, and back. (See figure 8) We measured length and complexity of several routes within those systems. As to complexity, this meant counting the number of separate indoor spaces visited, the number of separate staircases entered and the number of times outdoor space is visited. (See figure 9) In some cases we have found significant differences, both in length and in complexity of inmate routing.

Presently we are preparing a more detailed exploration of a range of characteristics related to staffing – the costs of running a prison are largely due to the number of personnel being hired. In order to analyse this performance aspect the prison's use must not only be considered in greater detail but also as a *dynamic* process rather than in terms of a static functional colouring of spaces and boundaries. For example we take into account the daily routine of individual inmates or groups travelling to various destinations, staying there for a certain period of time and returning, all at particular times of day, in a particular sequence and without unwanted encounters between them.

Figure 8: **Ground floor of the Lelystad complex; inmate circulation system as well as routes and destinations are indicated.**

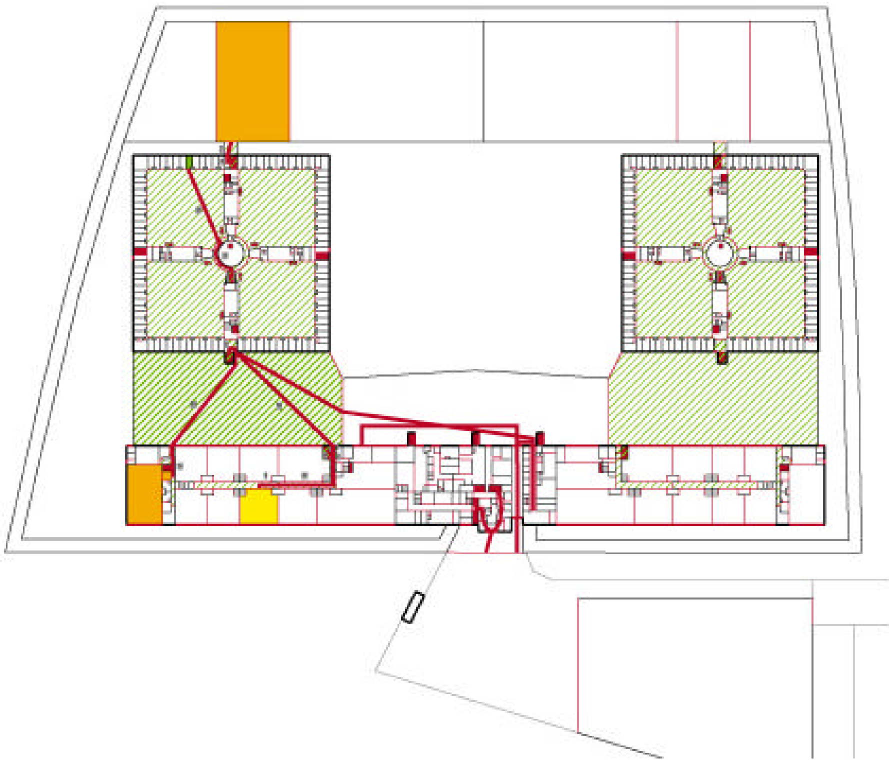
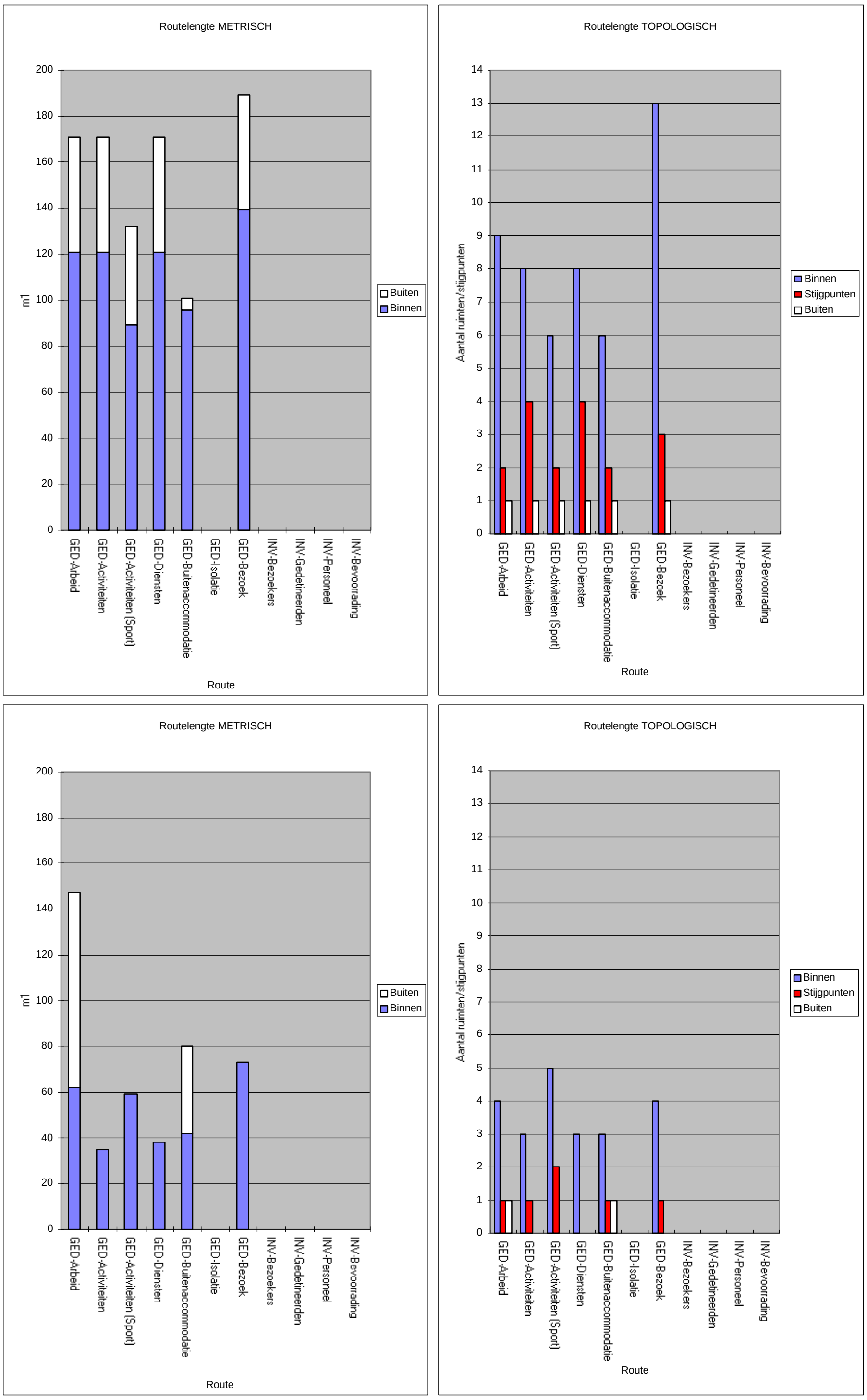


Figure 9: **Routing analysis for Lelystad (above) and for Zutphen (below). Left: metric length of inmate routes decomposed into indoor and outdoor length. Right: complexity of inmate routes where a distinction is made between the number of indoor spaces visited (first column), the number of staircases entered (second column) and number of times outdoor space is visited (third column).**



6 CONCLUSIONS AND PERSPECTIVES

Looking back at our work of the past few years it is fair to say that so far both computerisation of the RF-model and the ways in which the model has been used in actual design and analysis are experimental. The representation and the kinds of visualisation and quantitative analysis presented in this article are perhaps not innovative as such, but the primary achievement is the very fact that *a well-defined and relatively abstract representation of space and function has begun to earn a place in the GBA's daily practice*.

Among the parties involved in design we have often found two extreme attitudes beforehand towards this kind of innovation. Some consider it a complicating and unnecessary disturbance of the conventional process, while others have exaggerated expectations about automatic evaluation or even generation of design proposals. Threatened by these, respectively, conservative and naïve extremes intelligent computerised representations and methods of analysis will only become accepted by proving themselves in a process of step-by-step evolution.

We expect, as mentioned in the introduction, that in the long term this evolutionary process will lead to a large reservoir of information about buildings and their actual use and performance. For 1998 the TYPOLOGY project concentrates on a first experimental multimedia database that contains models of approximately a hundred buildings, both prisons and office buildings. It also contains information about workplace capacity, building cost and energy use. It will be possible to retrieve relevant precedents and to better understand their performances by means of a variety of visualisations and quantitative analyses. The RF-model will play a central role in this system, which we have given the working title *RF-database*.

7 REFERENCES

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