ABOUT THE MATHEMATICS OF KNOWLEDGE-BASED DESIGN

T. Oksala
Helsinki University of Technology
Otakaari 1, 02150 Espoo, Finland

Abstract: The aim of this paper is to enlighten the role of mathematics in architectural planning with the view of CAD-teaching. First attention is focused on the general development in planning methodology and technology. Planning mathematics provides for the basic tools to support mastering this development. Finally the common possibilities of exact methods and CAD-technology are characterized.

The breakthrough of methodology in planning

Planning theory

Active interest in exact methods in planning started first of all due to the discussion concerning post-war OR techniques inspired especially by the system theoretic and cybernetic movements. Afterwards one can say that until those days there existed surprisingly little research of planning or at least normally one did not know about such enterprises before the rise of cross-scientific enthusiasm. However, modern action-theory offers an excellent and ageold frame for planning theories together with decision theory [5,7]. In fact many branches of science have today connections with environmental culture, planning and design, e.g. geography, psychology, sociology, economics, aesthetics etc.

Methods and CAD-technology

A special scientific tool, which has created facilities to modern planning theories, is statistics together with probability calculus and information theory [5]. These old scientific techniques are only so-to speak turned to be used backwards with respect to their role to aid empirical investigations. The total view schetched is, however, quite rough if we do not pay attention to the development of technology and engineering and to architectural research as well. Those before mentioned statistical methods and OR techniques got a great importance in the sixties due to the influence of data processing. Central event from the point of view of design was the effect of graphic data processing, which made it possible further to develop the CAD-CAM technology. Finally, it is worthwhile to notice that planning theories have especially deep roots in architectural-profession, which has as a know-how area adapted to the before mentioned change [3].

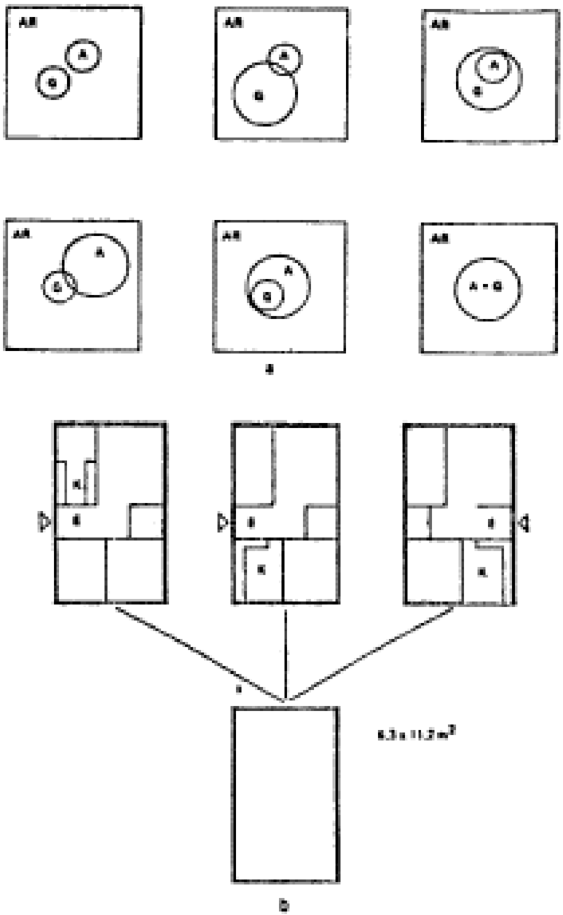


Figure 1

Figure la illustrates the tendency towards balance between generation and acceptance in an architectural solution space. In figure lb variations between intermediate solutions are exemplified as well as their relation to a more general architectural expression.

Knowledge-based technologies

Today it is possible to perform the basic manipulations needed in environmental design with the help of quite a sophisticated CAD-technology. The growth in plan production capacity, however, presupposes a corresponding sharpening in critique. Under the surface we need quite a deep knowledge about the know-how structures in planning and design expertises. Somebody might seek them basing his enterprise to tools offered by technology, cognitive psychology or by investigating planning scientifically. Thus besides of productivity we should rise questions concerning principles of evaluation and quality control [1]. Responsible research is the only possible ground, if one tries to develop AI and knowledge-based systems to reconstruct human expertise in planning automation. To this end economically reasonable facilities are becoming available along with micro computer based CAD and AI work stations.

Planning and design mathematics

Selection and construction of solutions

In modern mathematical planning theory we consider sets of realizations consisting of e.g. buildings, their groups or parts thereof. Some such set forms the basic solution set for a planning problem. The subsets of the basic set correspond to the hopes, principles, requirements, norms, sketches etc. entities it is linguistic or graphical representations about the target hoped for. In the planning or design process we try by gathering knowledge to reach Information about a fictive target in an abstract solution space. Then we eliminate our uncertainty about it and try to form a partial but sufficiently complete description of the target [4]. The finding of the solution should not, however, be characterized merely as mathematical filtering, but rather when needed by means of action-theory. Thus, in planning action we should separate the definition of goal, the formation of performance structure and the testing of the product and this all with appropriate semantic deepness so that compromises avoiding contradictions are taken into account as well. Well known descriptions of performance structures include projection graph lattices e.g. PERT-networks. In order to describe the products lattice-theoretical parsing [7], graph theoretical analyses [2,6] or group theoretic transformation techniques [2] are applicable [4].

Logical generation

In general level we might speak about realizations to be planned or designed in the sense of logic, when one defines the basic set of individuals in the target and relat-

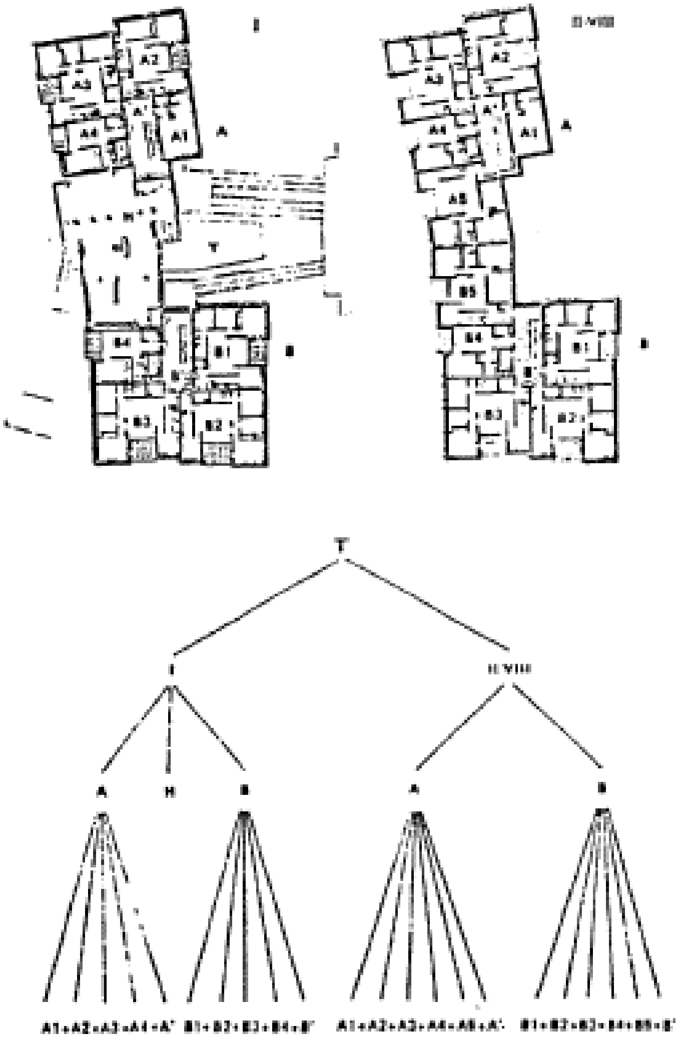


Figure 2

A constituent analysis of Interbau apartments by Alvar Aalto.

ions between as have been considered essential in the situation. Thus it is possible to analyze the goals by means of predicate logic. Especially in trivial planning such as geometric modelling one Is satisfied with individual calculus. On the other hand in carefully investigated and repetitive situations it is possible to use sentential calculus. In various situations it Is possible to produce in principle all possible realizations, which include e.g. in the case of sentential calculus 2^k items, where k is the amount of independent requirements.

Optimization

In planning and design one should master on the one hand the field of realizations and on the other the goals associated. Their hierarchy might be clarified by means of methodologies like value-analysis [1], when the selection situations of planning might be reconstructed by means of decision theory based on the maximization of utility. As a special case we have the principle known as cost-benefit analysis. In planning, however, methods of multidimensional optimization [5] are central. Ready designs satisfy then the so-called Pareto principle: it is that the improvement of one factor makes at least one other less satisfiable.

Programming

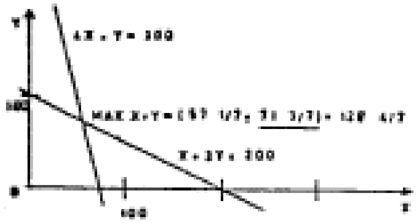
The logical analysis of planning goals and the possibility to represent the results as realizations in the sense of logical model theory brings in discussion important consequences today. It is worthwhile to notice that any programming language might be seen as a special case of logical calculi e.g. PROLOG is an excellent example of this fact. Similarly LISP is associated to the very roots of our mathematical thinking and it is not any accident that 'fifth generation computers' and other advanced machines are based on these languages. Thus design fields analyzed by logical methods and planning knowledge are easily manipulated with this advanced machinery in the near future. Besides of this development we might see the realization of the original CAD-ideology: to master the simulation - of real planning in relevant ways and using a reasonable amount of work.

About architecture and CAD

Conceptual plans and typologies

The development in planning research and CAD has been quite rapid and practical applications might explode in the near future. For example in planning of physical environment separate problems are solved in computer assisted manner as exercise work, that two decades earlier

Land use	building area	green area
small houses = x	400	200
row-house apartments = y	200	400
supply	60000	40000



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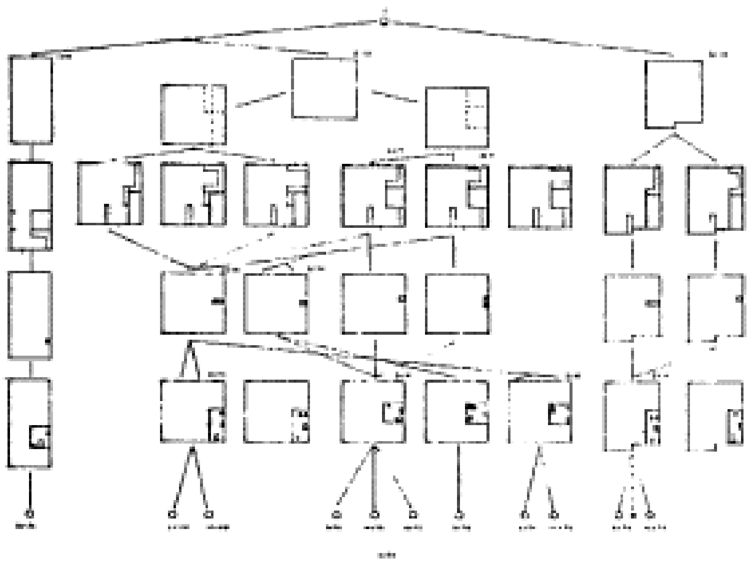

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Figure 3

Figure 3a gives a graphical solution to a typical planning problem, where multidimensional version is easily handled with linear optimization program packages. Figure 3b maps a partial field of typological solution space containing single room apartments in Helsinki town production.

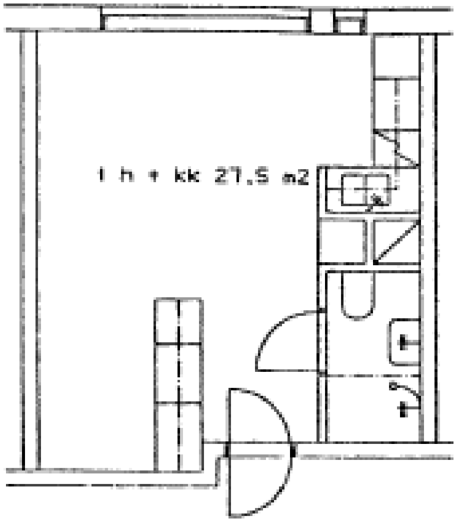
were mastered by only a specialist. I mean dimension, location, traffic and routing problems associated with urban structure and solved with standard program packages. Also analogous with methods familiar in pattern recognition quite sophisticated generative systems are developed In order to help design in typological level. In such systems one might seek relevant solutions in some planning or design situation and test them further with respect to engineering expertise.

Drafting

Concrete physical planning and design presupposes large notational systems. Their use might be simulated with standard drafting procedure and program packages. These are now familiar and under use in most universities and consulting firms. With the help of exactly defined design languages one might produce real drawings developed from schemes and accepted by different controlling units. One of the great advantages is then without doubt the easiness of making small changes as well as the possibility of integration of data-bases.

Illustration of future quality

Finally we might combine to the levels of planning and design work discussed earlier modern illustration techniques such as the use of CAD-assisted video and stereo montages or holography. This makes it possible to pre-evaluate the impression of plans and designs, which, however, is not a new neither a grand achievement, if we do not learn to understand the basic principles in artistico-technical expression. To this end, however, mathematical planning theory offers information theoretical tools. Without thinking such problems there exists a danger, that technology assist degeneration in art, although it should help the progress in environmental culture. Such a degeneration due to technological 'progress' was quite clear in the beginning of industrialized building production based on prefabricated elements in the sixties. The danger is, however, more fatal with its potential consequences when the new planning and design technologies are marching in. We should hope that not only our technical tools but our new environment itself express and confirm in the deepest sense our future optimism.



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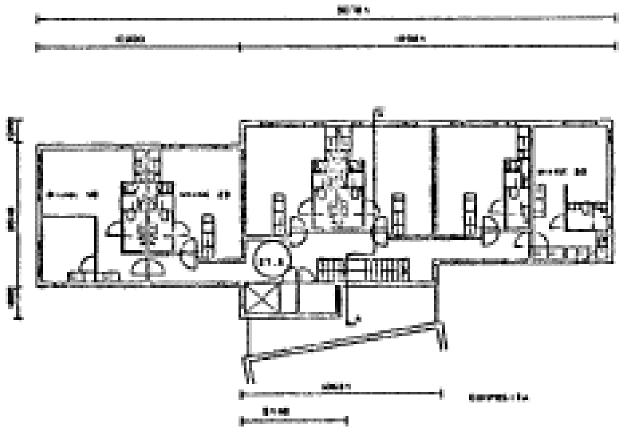

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Figure 4

Figure 4a depicts a design language output. The language is a PASCAL-based version of COMPOSITA languages (Computerized programming, optimization and simulation techniques In architecture) developed in Helsinki University of Technology. Figure 3b is an apartment house for retired. It is composed from type apartments and might be analyzed anew is the apartment in figure 2.

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