An Urban Decision Room Based on Mathematical Optimisation

A pilot study supporting complex urban decision questions

P.P. van Loon and E. Wilms[1]

Faculty of Architecture, Delft University of Technology, The Netherlands

[1]Adecs BV, Delft, The Netherlands

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Abstract: In general the Urban Decision Room is an interactive computer system based around a digital model for the simulation of complex urban decision questions. Such questions involve various parties with often differing interests. The UDR can assist in finding collective solutions. The UDR is a useful instrument for making the great variety in interests and ideas of the participants manageable. Furthermore, insight is quickly and clearly provided into the results. This enhances the efficiency and effectiveness of processes of urban development. A pilot of the Urban Decision Room based on mathematical optimisation has been made for Schieoevers, an industrial area on the bank of the river Schie to the south of Delft. This pilot is based on a feasibility study for a new urban development in this area which has been carried out by a consultancy firm (Adecs BV) under commission from the municipality of Delft.

1. INTRODUCTION

In the Urban Decision Room Schieoevers, the various parties are each seated behind a computer. In a series of rounds, a collective solution is constructed on a central computer. Each party enters proposals in the search for a collective solution. The parties provide sub-solutions, based on their professional knowledge and their role in the development process, for the problems that arise. A group decision is reached in a repeating series of these interactive actions and decisions. During the process, the intermediate solutions, possibilities, and (then) unsolvable issues are presented to the participants (for instance on projection screens). This provides the parties

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with the information they need to collectively work towards a solution. Thus, the input from the various parties, each with differing disciplines and stakes, leads via an iterative process to feasible planning options.

The UDR is intended to be a methodological answer to one of the most radical changes which have taken place in the fields of urban development and urban decision making over the past few decades. Namely the replacement of hierarchic by decentralised urban planning and decision making. During this replacement four essential shifts took place:

1. The shift from superior-subordinate positions of authority to parallel positions of authority between equal partners, each with their own goals and means to achieve them (Figure 1.).
2. The shift from hierarchically ranked decision-making areas to individually positioned decision-making areas in which each stakeholder in the process is responsible for decision-making in his own particular area (Figure 2.).
3. The shift from decision making instructions to decision making negotation relationships between decision makers, which involve a special form of cooperation (Figure 3.).
4. The shift from a hierarchically structured to a participatory structured relationship, each stakeholder has his own relationships with the decision making environment and therefore his own conception of (a part of) the decision making problem and decision making solution (Figure 4.).

The OPM Research Group of Delft University of Technology has developed a new methodologically consistent framework for decentralised urban decision making in 'inter organisational' urban planning and decision making situations (Van Loon, Micheels, Wilms, 1987; Van Loon, 1998; Van Gunsteren, Van Loon, 2000). This framework is an operational extension of earlier frameworks in the field of 'urban and regional planning models' (Freind and Jessop, 1969; Catanese, 1972; Lee, 1973). In addition, the new framework has a systematic connection with a 'reflective group decision making environment' (Schön, 1983; Schön and Rein, 1994). Based on this framework ADECS, a consultancy firm for advanced urban planning and decision making, has made a pilot for an Urban Decision Room for Schieoevers, an industrial area on the river Schie to the South of Delft.

2. THE BASIC PREMISE OF THE URBAN DECISION ROOM

In the practice of decentralised, multi-actor and multi-stakeholder urban planning and decision making, the number of alternatives and related components might be so great that the issue of choice becomes too large and

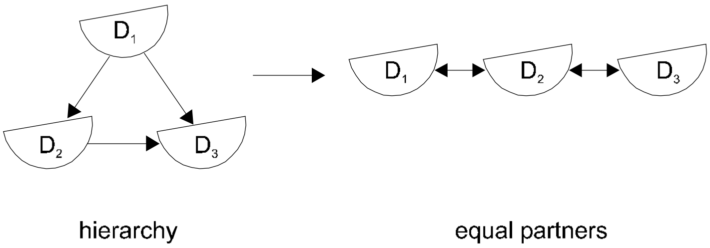

Figure 1. The shift to parallel positions of authority between decision makers (Dn).

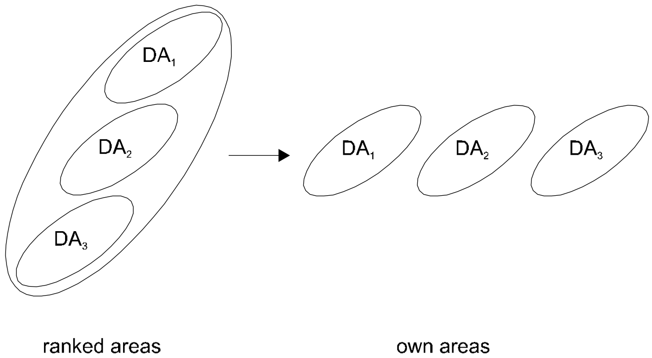

Figure 2. The shift to individually positioned decision-making areas (DAn).

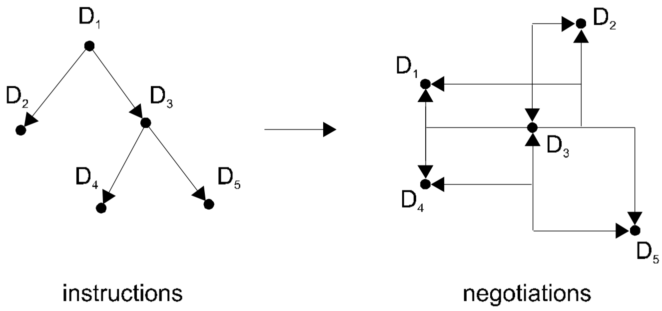

Figure 3. The shift to decision making negotiation relationships.

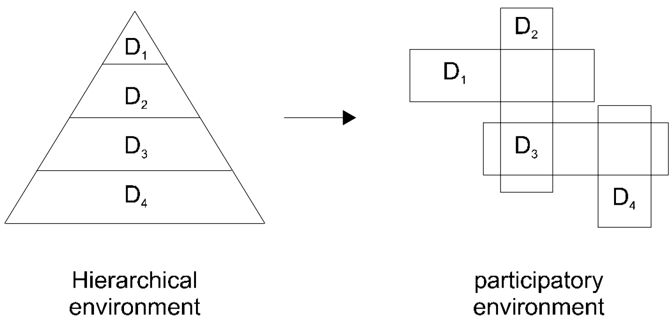

Figure 4. The shift to a participatory relationship.

complex. In the domain of decision making methodology Herbert Simon offers a concept to overcome this problem. Based on the postulate that it is nearly impossible to strive towards an overview of all alternatives and consequently it is impossible the find the best (optimal) solution, he has introduced the concept of the ‘satisficing’ principle (Simon, 1957, 1969). This holds that individuals strive only to achieve a limited, usually concrete level of aspiration because their image of a problem is limited by their incomplete knowledge and because solutions still have to be devised and the effects of the solutions are not entirely known. The criterion is not then ‘the house must be as big as possible’ but ‘the house must have at least 200 m2 of floor space’.

Describing decision criteria as specific levels of aspiration offers important practical and theoretical advantages, even if those involved have only a vague notion of how their situation could be improved. It is an unambiguous means of measuring whether the goal has been achieved. This divides the decision-making area into a ‘permitted’ (or realisation) area and a ‘forbidden’ area. Already by two decision criteria the ‘satisficing’ principle leads to a solution space. Figure 5 illustrates this.

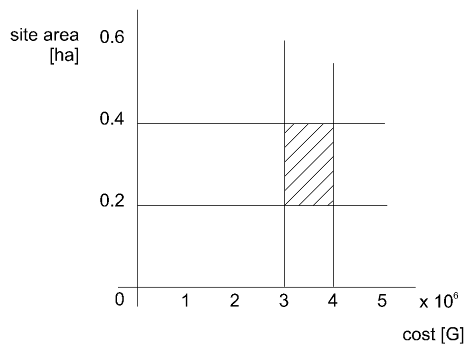

Figure 5. The realisation area (shaded) as the feasible solution space. In this example, the cost of the residential property must be between 3×10^6 and 4×10^6 euros, and the site area between 0.2 and 0.4 hectares.

Briefly, this involves interpreting the limits imposed on the values of the variables not only as a reduction in the number of possible alternatives, but also as ‘a representation of the restrictions imposed on the use of resources by the (decision) environment’. Restrictions on the usable resources occur in every decision making situation. They are usually referred to as ‘constraints’, and the solution has to remain ‘within’ them.

This makes it possible to evaluate outcomes of urban planning processes with the classical Pareto criterion (1906). This criterion provides a scale for measuring increase in the collective welfare of a group. Collective welfare is deemed to have increased if the welfare of one or more members of the group increases without diminishing the welfare (the constraints) of the other members. The criterion not only comprises a measure of the direction of change, but also its end point. According to this criterion, collective welfare is optimum as soon as it is no longer possible to increase the welfare of one or more individuals without decreasing (violating the constraints) that of one or more of the others.

3. CONSTRAINTS AS THE BASIS OF THE URBAN DECISION ROOM

For using constraints in a decentralised multi-actor urban decision making process, a distinction between the quantitative and qualitative aspects of a constraint occurred to be very important.

The quantitative aspect can be expressed as a maximum (maximum resources to be used), a minimum (minimum resources to be used), or a fixed amount (resources available). For example, municipality M has made available a maximum of 14 hectares of land for the construction of a number of dwellings in area A. It might argue that the site may not cover more than 14 hectares, or area A will become too full and the natural environment in the area will suffer. An example of a minimum is a local park that must cover at least 2 hectares. This is the minimum amount of space required at the site to ensure that there are enough green areas distributed throughout the urban zone of which area A is a part. An example of a fixed amount is 700 dwellings that have to be built in area A.

The qualitative aspect ties in with this, and can be expressed in the qualities of the object being designed. These qualities must be reflected in the final solution. For example, the 2 hectare local park is to be a botanical garden, and the 14 hectare residential area is to be environmentally friendly.

In general, constraints can be seen as expressions of (sub)solutions. For instance, the constraint 'no more than 14 hectares in area, to be developed in an environmentally friendly way' is obviously a good solution for the municipality, and an important part of its plan in and around area A. As soon as the constraints are open to discussion (14.5 hectares might be acceptable, and a 1-hectare park might also suit the plan for the green areas) their representations in a decision making model become part of the process. This allows the underlying (quantitative and qualitative) considerations to be brought into the open.

This approach to maximum and minimum values – which can easily be expressed as constraints in a mathematical decision model in the form of upper and lower limits – and this treatment of their qualities – which can be expressed mathematically as types of variables as shown below – provide the extra instruments for the mathematical structuring of an urban planning problem which brings together devising (designing) possibilities, indicating limits, etc., and choosing from possibilities. This is represented in Figure 6.

limits	residential area ≤ 14 [ha] park ≥ 2 [ha]
variables	ESRA ≤ 14 (ESRA: Environmentally Sound Residential Area) BG ≥ 2 (BG: Botanical Garden)

Using this approach of constraints, two dimensions recognisable in a constraint are very relevant for the practical use in the Urban Decision Room: the goal-oriented dimension and the resource dimension. These will be explained next.

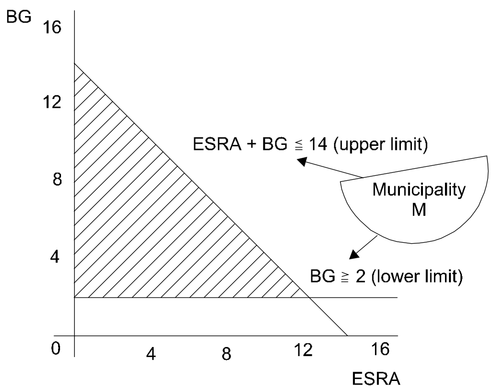

Figure 6. The upper and lower limits of municipality M.

4. CONSTRAINTS IN THE URBAN DECISION ROOM AS A REFLECTION OF GOALS

A constraint is literally a restriction, determined in advance, which the solution must in any event observe. But in an urban planning process, not all constraints are seen in such fixed terms. In fact, a distinction is drawn between ‘hard’ and ‘soft’ constraints. Only the hard ones are fixed in advance. The soft constraints are flexible and negotiable, and are determined more fully during the urban planning process. The planners can experiment with these flexible constraints, in the search for the best ‘form’ and ‘position’ for those constraints in the solution space or, in other words, the best form and position for the final outcome.

In a multi-party urban planning process, these experiments can soon become complicated. Each party has its own ‘flexible’ constraints, which they fix only after they have conducted experiments. At that moment, these constraints also become fixed for the other parties. However, if they pose insurmountable obstacles to the other parties' experiments, they will try to render them free again, to allow them to experiment more freely, and set their constraints at a point more convenient for them. This is brought before all the parties, who will respond, and the process may start all over again.

The motives underlying the constraints are very important when it comes to the structuring of the multi-party urban planning brief. In urban planning methodology, these motives are said to belong to the field of goals. After all, a constraint is an expression of a goal, as we have seen in the example of the municipality wanting to create a local park: to ensure a good spread of green areas, a local park of at least 2 hectares must be created in area A.

4.1 Definitions of Goals

The urban planning methodology literature is unanimous about two points when it comes to the function of goals in the urban planning process: they must be set at the beginning of the process, and at the end of the process the outcome must conform to them as far as possible. Incidentally, planning goals are largely referred to as the 'bill of requirements' when it comes to concrete objects such as buildings etc. The term 'project goals' is often used for complex projects, such as neighbourhoods and infrastructure.

However, these two agreed principles are put into practice in wide-ranging, and often confusing, ways. At the beginning of a process goals are seen as a formulation of the brief: 'plan a building B that conforms to requirements 1 to 100'; 'draw up a plan for a neighbourhood N which indicates how project goals 1 to 10 can be achieved'. At the end of the process, goals are used as evaluation criteria: to what extent does the plan fulfil the goals, and where can improvements be made? Between these two meanings lies a vast area in which goals are also used to derive sub-solutions, select from alternatives, guide negotiations in a certain direction, and support particular choices. In urban planning situations where there are several specialists, goals are also seen as a basis for the allocation of tasks: each specialist is responsible for the goals connected with his own speciality. Goals are also seen as an instrument the project manager can use to steer and regulate the process. If someone comes up with a sub-solution that deviates too widely from the goals, the work must be corrected.

This confusing multiplicity of uses and definitions makes it all the more difficult to represent goals in urban decision models in a way that is understandable to all. The term 'goal' is first systematically analysed below, and a description of a goal that can be used in urban decision models is then distilled (Berkhout, Van Loon, Micheels, 1982; Van Loon 1998).

A goal is a primary mental fact. The goal of a particular act is what a person hopes to achieve by his action, or non-action. It is thus a conceived state of affairs, not a description of a state of affairs. The term ‘goal’ refers to things one is seeking to achieve. Goals can be regarded as more or less standardised conceptions of what is desirable. The goal (of an actor) is a future situation, which may or may not involve the actor, that he aims at in a given starting situation, or at least accepts as desirable, and whose advent he believes he can promote or bring about.

A number of examples: ‘efforts should be made to ensure that the land-use planning brings about a regional hierarchy of urban shopping centres, which are situated as favourably as possible with respect to the existing transport system’; ‘efforts must be made to attract a mixed residential population to the inner city’; ‘specific parts of the organisation must be recognisable in the building’; ‘the construction costs must be financially sound and may not exceed a given budget’; ‘the architecture of the building must blend in with its surroundings’.

It is possible to distinguish between a ‘goal’, an ‘end’, and an ‘objective’. The first refers to something specific the individual in question has in mind, whereas an end is often further away, and is only vague in outline. The term objective is used for a formally described and established aim or end: “an objective is a formulation pertaining to a goal; it is a sentence that constitutes a statement about a goal”. The term ‘goal’ will be used below only to refer to the general concept of a ‘goal’.

‘Goal’ is a collective term for a number of specific, closely inter-connected concepts such as value judgments, value goals, object goals, tasks, etc. The whole can be referred to as a ‘goal complex’ whose elements – the actual goals – are linked in various ways. Below I shall summarise the categories that can be distinguished within such a goal complex, in ascending order of ‘concreteness’.

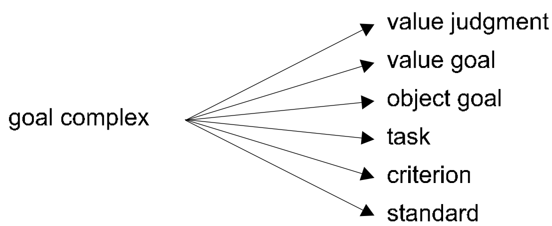

Figure 7. Categories within a goal complex.

– A value judgment is a statement involving a value, such as ‘enhance individual freedom’, or ‘guarantee individual safety’, whereby individual freedom and safety are values.

– A value goal is a statement in which the goal is expressed in terms of more general and often more abstract values, such as ‘strive for optimum self-development’, or ‘improve freedom of movement’.
– An object goal refers to more specific and concrete variables of the object under consideration, such as ‘create a safe living environment’ or ‘improve access to public transport’. Whereas value goals can be seen as general statements about the direction which the solution of problems should take, object goals set the requirements for the solutions themselves. The goal ‘improve access to public transport’ is thus a more concrete expression of ‘improve freedom of movement’.
– A task is a fully measurable goal, such as ‘there must be at least a 5% increase in the number of dwellings in area A’.
– A criterion indicates that something should be achieved as well – or as much or as little – as possible. For example, ‘the maximum possible number of dwellings must be built in area A’ or ‘the number of dwellings to be built should meet demand as far as possible’.
– A standard indicates that something should be bigger or smaller, or must lie between two values. For example, ‘there must be more than 1000 dwellings in area A’ or ‘there must be between 300 and 500 parking spaces in area A’.

4.2 Mathematical Analysis of Goals

In mathematically linear terms there are five types of goal:

A = B	(something must equal something else)
A ≥ B	(something must be greater than something else)
A ≤ B	(something must be smaller than something else)
A max!	(something must be as big as possible)
A min!	(something must be as small as possible)

These five types are subject to one definition, composed of three elements. A goal is an imperative, normative, relational statement:
– imperative because the described goal must be achieved as fully as possible, or to a certain level;
– normative because the desired situation specified in the goal functions as a desired ‘norm’;
– relational because it describes a relationship between two (or more) variables.

This last characteristic deserves further explanation. It appears that many goals are statements about one variable, such as ‘improve the living environment’ (which can be classified as a value goal). But what is in fact being said is that the future new living environment (first variable) must be better (relationship) than the current living environment (second variable). A statement such as 'there should be enough dwellings' (an object goal) also actually concerns two variables (available dwellings and demand for dwellings) that have to be attuned to each other. A statement such as 'the dwelling density must be 40 dwellings per hectare' (a task) is also relational. It states that the ratio between the number of dwellings and the total site area must (imperative) be such that there are an average of 40 dwellings per hectare (norm).

A goal statement can thus be divided into two (or more) variables and the relationships between them. For example:

'the living environment in area A must be (equal to) a varied living environment'

variables	Living Environment in area A (LE_a) Varied living environment (Vle)
relationship	LE_a = Vle

Another example:

'the percentage of subsidised dwellings in area A must be at least 40% of the total number of dwellings in area A'

variables	number of Subsidised Dwellings (SD) Total number of Dwellings (TD)
relationship	SD $\geq$ 0.4 × TD

Finally, an example with more than two variables:

'the housing supply, by building type, size and cost category must match housing demand as well as possible'

(two groups of) variables	Housing Supply ($HS_{b,s,c}$) (by building type, size and cost category) Housing Demand ($HD_{b,s,c}$)
relationship	$HS_{b,s,c}$ $\geq\leq$ $HD_{b,s,c}$ (match as well as possible)

In this way, entire collections of goals can be analysed and represented clearly and consistently.

5. CONSTRAINTS IN THE URBAN DECISION ROOM AS A STATEMENT ABOUT RESOURCES

The other dimension (other than the imperative, goal-oriented dimension discussed in the previous section) of constraints is the resource dimension. After all, a constraint indicates what resource(s) may be employed to achieve the goal. For instance, the constraint:

'the park in area A must be at least 2 hectares'	
	$PA \geq 2$ (meaning: a park of at least 2 hectares would provide sufficient greenery for this residential area)

implies that the resource 'park' must be used to ensure there is sufficient greenery. This might also be achieved using 'smaller green areas' or on the basis of 'existing landscape elements'. In the constraints: 'the living environment in area A must be (equal to) a varied living environment', and 'the percentage of subsidised dwellings in area A must be at least 40% of the total number of dwellings in area A', the resources 'living environment' and 'dwelling' are the resources for the realisation of the goals.

In the discussion of the origin of constraints in the previous section it was stated that each constraint is linked to its own unique (individually-based) conception of how it is to be realised. Since each constraint also involves a resource, an individual conception of this resource is linked to every constraint.

5.1 Definitions of Resources

Generally speaking, a resource is that which one employs to achieve a goal. Resources might be available in different forms: as a quantity of something (ordered or otherwise), such as an area of land to build on, a sum of money to invest, a stock of building materials for a new building, or a certain space for an activity; a ready-made solution, such as a dwelling in which to live, a park for recreation, a room to work in; a combination of these two, i.e. a certain number of solutions, such as a stock of dwellings, a green area for parks and playgrounds, a building with rooms for offices.

These examples are often referred to collectively as primary resources, to distinguish them from secondary resources. These are resources found more in the 'background', such as specialist knowledge, experience, aids (instruments, machines, energy, etc.). Continuing along the same lines, we may regard procedures, planning, working arrangements and organisational forms as tertiary resources, while management science, methodology and political science would be our quaternary resources. These resources feature in every planning process. This does not, however, mean that each resource has to be identified, considered and weighed up every time. Many resources will be 'fixed', and given.

These classes of resource can be described more fully by relating them to the design-decision process. In this case, I shall take the architectural design-decision process as an example (Berkhout, Van Loon, Micheels, 1982).

In the architectural process, primary resources are used by do-it-yourself enthusiasts and small contractors. In such situations, the solution to an architectural problem depends heavily on the amount, quality, and characteristics of the building materials, and on the number of working hours and the properties of the tools used. The problem-formulating actor both commissions and performs the work. In both capacities he exercises a direct influence on the choice and use of these primary resources.

The use of primary resources in this pure form is rare these days, because do-it-yourself enthusiasts and small contractors have to take into account statutory regulations laid down in building ordinances and land development plans, and by the building inspectorate. They are forced to put their ideas into effect via a more circuitous route, using secondary and tertiary resources – plans and applications for building permits.

Secondary resources come into play in the architectural process whenever the solution to a problem is sought first on the basis of experience with similar problems. The next shed, home, or interior layout will be based on a past design. This serves not only constructive and functional goals and interests but also social and cultural interests. Consider, for example, the many increasingly popular traditional structural solutions and architectural forms. Our appreciation of things built in the past is well known.

Secondary resources appear to make it easier to assimilate the effect of standardised solution models, where the influence of one solution on another is regulated in advance. This is particularly so if these resources are clearly based on previous experience, on what is generally accepted. There will also be less resistance to rules and regulations.

Tertiary resources begin to play a role in the architectural process from the moment professional designers, administrators, and community organisations begin to direct and regulate the problem-solving process. In general, they will set up a number of standard problem-solving routines based on a number of standard problems. If the problem in question can be fitted to one of the standard problems, then the solution will flow more or less automatically from the relevant standard problem-solving routine. Tertiary resources are used mainly to comply with legal and administrative rules. Sometimes the problems do not fit, but have to be forced into the standard, in which case the solution will not be appropriate to the original problem.

Quaternary resources are important in the architectural process at the point where one reflects on actions and processes. This leads to alternative problem-solving routines, the creation of theories about problems and methodologies for routines. This process involves exchange between general reflections on human existence, philosophy and epistemology.

Using these definitions and schematic representations, one can consider resources separately but still in relation to the goals. This is very important when it comes to multi-party design and decision making.

6. A PILOT FOR AN URBAN DECISION ROOM BASED ON A MULTI-ACTOR PROBLEM STRUCTURE

The new method of structuring the multi-actor and multi-stakeholder planning and decision making problem is illustrated in brief by the following pilot study.

Schieoevers, an industrial area on the banks of the river Schie to the South of Delft, covers 130 ha. In the area more then 100 companies, big and small, are located. Parts of the area are deteriorating. The Delft municipality started an urban master plan study three years ago to develop alternatives for improving the area. From the start it was clear that the actual redevelopment of the area would take 10 to 15 years. So a final master plan (blue print plan) would not be appropriate. A flexible planning structure was needed to adapt new insights and an actual solution during the development process. Therefore the study should also result in a decision-making structure which enabled the stakeholders to take actual decisions during the whole development period.

The following stakeholders took part in the planning and decision-making process:

– Delft Municipality (departments of Transport, Environment, and others)
– Delft Town Councillors (Urban Development and Economic Affairs)
– Province of South Holland (Housing Planning Department)
– Regional Government Haaglanden
– Chamber of Commerce
– Business Association Schieoevers

Each stakeholder defined his own objectives and criteria and put forwards his possibilities in the availability of land, types of buildings (houses, offices, factories, etc), and investments. All this information is represented in one mathematical optimisation model (Linear Programming) which gives one common solution space for the planners and decision makers involved. This model as the core of an Urban Decision Room has been used to find out, by means of simulation, what urban redevelopments for the area are feasible.

This example illustrates the two main features of the new structuring of an urban decision making problem.

The first feature concerns the relationship between goals and resources. In the new structure, these are seen as being inextricably linked. In technical terms resources are variables in stated goals: building land is a resource with which to realise a new residential area; dwellings are a resource with which to fulfil a need for housing. Thus stated goals directly determine the plan in the sense of being a proposal for the use of available resources.

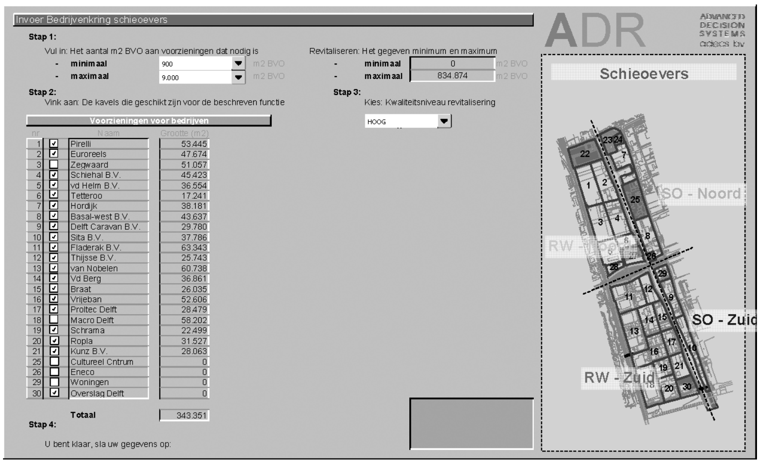

Figure 8. Input sheet Business Association Schieoevers.

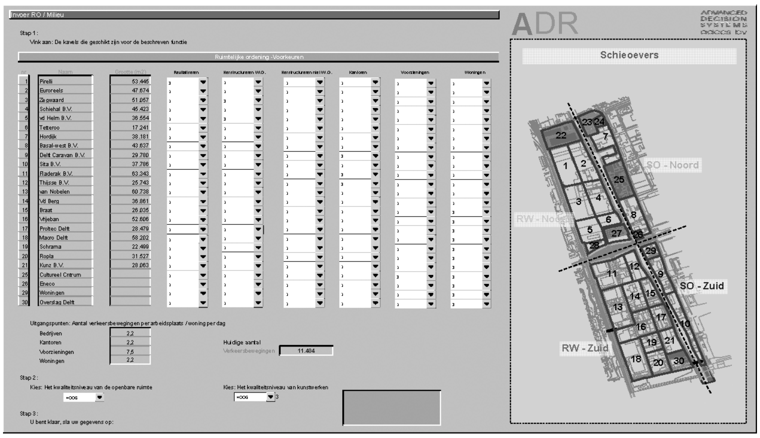

Figure 9. Input sheet Delft Municipality.

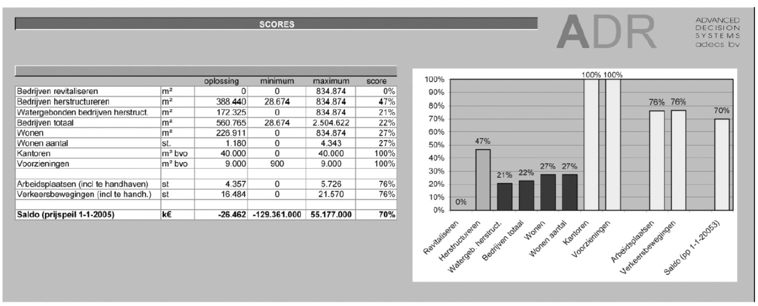

Figure 10. Output of a group decision.

The second feature concerns the concept of goal realisation. The new structure is geared to a plan at the level of the normal situation. For this purpose the goals are formulated in such a way that they relate to the current situation, to what is customary in practice: in a residential area it is customary to have a neighbourhood park; a family home with garden normally requires an area of 120 m2. This enables the process to be geared to the allocation of the resources available and accepted at that particular moment.

7. CONCLUSIONS

This structuring of a multi-actor design decision making problem can be used under the following conditions:

First, everyone involved must accept the goals of each party as the point of departure. While this appears logical enough in a multi-party process, it is frequently not the case. In such a situation the parties adopt diametrically opposed positions and tend to withhold their resources. The result of this is that the process grinds to a halt.

Second, each party must have their own decision-making area, as this enables them to seek upper and lower limits for the realisation of their goals both together and from an individual, autonomous negotiating standpoint. This too would appear to be logical in a multi-party process, but what in fact usually happens is that parties tend to avoid setting limits, because in practice they will either be set too rigidly, too high, which is often unrealistic, or too conservatively, which blocks innovation.

Third, it must be acknowledged that every quantitative statement has a qualitative implication. In practice this often proves a stumbling block, as all too often the assumption is that quantitative and qualitative aspects are separate and, more especially, opposite poles. The parties who present only quantitative goals and constraints are accused of not being concerned about the quality of the plan and qualitative goals are often labelled as being too idealistic and impractical.

The new structuring of the design decision making problem allows the gap between the decision-making model and the decision-making environment to be solved in the first place by the direct linking of the unpredictable decision-making area to all the components of the design commission. This removes the distinction often made in design and planning methodology (Van Loon, 1998) and also in Operations Research between: the ‘goal design’, a conceptual model of the desired new situation, and the ‘resources design’, a concrete proposal for a situation which can be achieved in reality. This provides the opportunity during the process of working both with various images of the goal realisation and with a wide variety of proposals for the deployment of resources. This forms the methodological basis of the multi-party process.

In the second place, the problem of the gap is solved as all ideas, wishes, requirements, constraints, etc. are 'translated' into goal statements which cover the specific elements of the situation. This creates a neutral benchmark for all parties: the existing reality in which elements can be identified and named and to which all ideas, no matter how abstract, vague, or idealistic, can be linked. This enables direct communication between the parties.

The authors have recently started as series of real-life experiments with their UDR approach. Urban planners and other professionals in the field of urban decision making are participating. These experiments should provide insight into how the UDR can and will be used in practice.

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