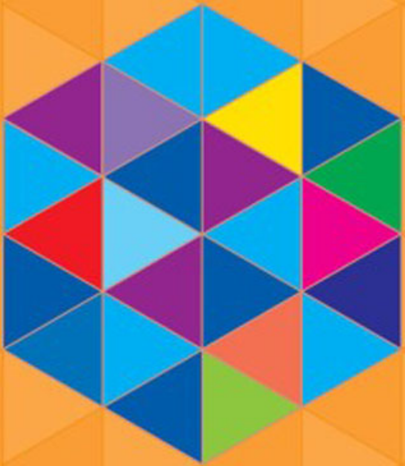
Research in Design Series, volume 1

Open Design,
a Stakeholder-oriented Approach in Architecture, Urban Planning, and Project Management



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Open Design,

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Open Design, a Collaborative Approach to Architecture, 2000

Open Design & Construct Management, Managing complex building projects through synthesis of stakeholders' interests, 2001

Open Design,

a Stakeholder-oriented Approach in Architecture, Urban Planning, and Project Management

collecting the following works:

Open Design, a Collaborative Approach to Architecture

Open Design and Construct Management

Open Design, Cases and Exercises

Ruud Binnekamp
Lex A. van Gunsteren
Peter-Paul van Loon

in collaboration with:

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Foreword

This book is the third in a series of publications on Open Design. The first, *Open Design: A Collaborative Approach to Architecture* by Lex van Gunsteren and Peter-Paul van Loon, opens with the question 'Why, so often, do we build what no one wants?' Considering that despite the accumulation of much knowledge and the identification of important basic principles there is no theory of design, it is perhaps not surprising that the outcome of design is not always satisfactory.

Design is a complex, multi-faceted process with many factors contributing to successes and failures. As in other fields, the Open Design group at Delft has identified the process of collaborative decision making in design as one of these key factors. A single designer contemplating a simple design problem usually faces the difficult task of reconciling multiple conflicting goals while large urban planning projects are not simple and usually involve multiple players with conflicting goals in addition to other challenges.

Until recently, the scientific discipline that deals with these issues – decision theory, which in turn is based on the theory of measurement – had little to offer. In the case of group decision making, i.e. the case of multiple stakeholders or players, based on misinterpretations of the meaning of 'Arrow's Impossibility Theorem,' this problem has been commonly viewed as unsolvable. In contrast, in the case of a single decision maker with conflicting multiple criteria, the literature offers a bewildering number of methodologies that produce contradictory results. Since their results are contradictory, at least some of these methodologies cannot be correct but the literature offers little guidance on how to evaluate such methodologies besides numerical comparisons from which nothing can be learned except that they are different. Even in the case of a single decision maker and a single measurement attribute (or a single evaluation criterion), none of the models of the classical theory of measurement produce scales that enable the operations of addition and multiplication and even elementary variables such as position of points on a straight line is not modelled correctly.

Rather than following the classical theory of decision making, Open Design utilizes a sophisticated linear programming model to capture the elements of group decision making. The limitations of this linear model seem more acceptable than those of the tools of classical decision theory in view of the fact that recent analysis reveals foundational problems with the application of mathematical operations to the social sciences and, in particular, with the theory of measurement, decision theory, utility theory, game theory, economics and other disciplines. A new theory that addresses these issues has been developed and the challenges of integrating its practical application into design are being studied by the Open Design group.

Open Design is a significant contribution to architectural design but its impact will be felt beyond its applications in this field. The challenge which this book addresses is the integration of existing and new methodologies and tools from diverse fields such as management, negotiation, decision theory and preference modelling, linear and non-linear programming, simulation, risk assessment, regression analysis, and geometric modelling into a single coherent design methodology that synthesizes technical and social aspects of group design and group decision making.

Naturally, the development of Open Design is an ongoing undertaking. Although much progress has been made and Open Design is already a methodology of great value, undoubtedly it will continue to evolve. This book provides a view of its current state and hints of its future direction.

Jonathan Barzilai
Dalhousie University

Preface to the collected edition

> There is no such thing as a frozen design

This volume collects three interrelated books on *Open Design*, the stakeholder-oriented approach in Architecture, Urban Planning, and Project Management as developed by the Chair of Computer Aided Design and Planning, Faculty of Architecture, Delft University of Technology:

1. *Open Design, a Collaborative Approach to Architecture*,

   by Lex A. van Gunsteren and Peter-Paul van Loon, second revised edition (first edition 2000).

2. *Open Design and Construct Management, Managing complex building projects through synthesis of stakeholders' interests*,

   by Lex A. van Gunsteren and Peter-Paul van Loon, second revised edition (first edition 2001).

3. *Open Design, Cases and Exercises*,

   by Ruud Binnekamp, Lex A. van Gunsteren, and Peter-Paul van Loon, first edition.

These books are interrelated by their stakeholder-oriented approach, but can be read independently. *Open Design, Cases and Exercises* enables the reader to become familiar with the decision-oriented design tools of Open Design, and their application in practice. It includes the latest developments in Open Design methodology.

Software

We assume that the following software is available to the user:

- Microsoft Excel
- Lindo Systems What's Best! add-on for Excel (demo version obtainable from www.lindo.com)
- Autodesk AutoCAD

The following software can be obtained via the authors' department:

- Monte Carlo Investment Simulation (MIS)
- Project Network Planning and Risk Assessment
- Preference Function Modelling

Example files

Many of the files used in the examples are available to the readers, indicated as follows: [○ example.xls]. These can be downloaded from the authors' website:

http://www.bk.tudelft.nl/users/binnekam/internet/od3/

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Open Design,
a Collaborative Approach
to Architecture

Lex A. van Gunsteren
Peter-Paul van Loon

Preface

This book is about the application of the *Poldermodel* in the realm of architecture and urban planning. The *Poldermodel* refers to the way major political issues tend to be resolved in the Netherlands through dialogue and exchange of views between parties having conflicting interests. Our new perspective is that *technical optimisation* and *social optimisation* should not be carried out separately, but be integrated into one design process. We have labelled this process *Open Design* because of its characteristic feature of *openness* in how decisions come about. As in a democracy, certain rules are agreed in advance on how decisions will be made. In traditional approaches, by contrast, the design process largely remains a black box, at least to interested outsiders.

In the concept of Open Design, any stakeholder having an interest in the outcome of the design process is allowed to influence the design. This means that we distance ourselves from the position adopted by many professional designers who believe that *professional (technical) group optimisation* must be regarded as distinct from, and a necessary prerequisite for, *social group optimisation*. In other words, we do not see the optimum social design as a derivation from the optimum professional design. In Open Design, experts and laymen (having an interest) are treated equally.

Professional designers often refer to the social optimum as a political compromise. Such a distinction cannot be drawn and the order in which the two optima come about cannot be dictated. A professional design also incorporates the social views of the professionals and therefore implicitly includes their social group optimum. And a social design incorporates the technical views of the non-professionals, thus implicitly including their technical group optimum. They are, therefore, two aspects of the same design.

We do not follow the classic theory on decision-making since this theory takes little account of the processing of differences of opinion and conflicting goals, of power imbalances and lack of information and rationality. These issues certainly come into play in design processes involving several designers from several organisations. We use, therefore, decision-making models which do incorporate differences of opinion and power imbalances, and which can cope with incomplete information.

The methodology of Open Design integrates relevant findings from various fields, in particular operations research, management and political sciences. This integration has become possible by the dramatic improvement in computer capabilities (speed, storage, user friendliness) over the past decades.

Acknowledgements

The basis of this book originates from the eighties, when the OPM-Group (Ontwerp en Planning Methodologie) of the Faculty of Architecture of the Technical University Delft developed a new methodology which was focused on quantification of design decisions in urban planning. The method was tested in numerous urban planning and housing projects and formed the basis for the subsequent establishment of the ADECS (Advanced Decision Systems) consultancy firm. Its founder, Erik Berkhout, is to be regarded as the pioneer who conceived the methodology of the OPM-Group. The experiences of the OPM-Group and ADECS provide an empirical validation for the theoretical urban planning concepts described in this book.

Application to complex construction projects has been proven to be of great value in numerous graduation studies at our faculty. These studies led us to extend the original concept with new elements related to construction projects rather than urban planning, in particular our concept for uncertainty reduction and risk assessment (Chapter 4) and our views on the role of the bill of requirements and legislation (Chapter 6).

We are grateful for all these practical experiences, which show that what we advocate is not merely theory but actually works in practice.

Ir. Casper Krebbers made us aware of the continuously increasing relevance of the Open Design approach in the practice of urban planning in The Netherlands. He wrote the computer program for Monte Carlo simulation and provided valuable help in the preparation of the figures. The assistance of ir. Peter Barendse related to geometric modelling is gratefully acknowledged. We thank Jeroen Burger for his efforts in polishing the English of our manuscript. We express our gratitude to Marja Landzaad, who has worked as management assistant in the OPM-Group since 1978, for her encouragement at the stage of writing and her help in editing the book. Finally, we thank our colleagues, in particular ir. Rein de Graaf – who also reviewed Chapter 7 – and dr.ir. Alexander Koutamanis, for taking over our obligations towards students at times when we were too engrossed in our writing.

Contents

Introduction

Why, so often, do we build what no one wants? Whenever a new residential area is completed, the happiness of the people involved about the creation of something new is tempered by feelings of dissatisfaction, because the end result of the building process was not what they had hoped for.

In a multidisciplinary study (Rijksplanologische Dienst, 1983) on the development of the Randstad, i.e. the area of Amsterdam, Utrecht, Rotterdam, and The Hague, some typical Dutch values related to urban planning surfaced: tolerance, diversity, variety, freedom, autonomy, individual touch, etc.

These characteristics are well represented in Amsterdam, a city that has developed over several centuries towards its present status. New urban areas, by contrast, which were built in only a few years, do not reflect these characteristics. They look as if they all originate from the same drawing board. Actually, they do! Urban planners, project developers, architects, construction firms, etc., all tend to stick to proven concepts and methods. As a result, new residential areas look alike, quite contrary to what their new inhabitants would have preferred. Their preferences, however, were not taken into account at a stage when options were still open. They can only 'take it or leave it', not influence it. Hence their feelings of dissatisfaction.

We will show in this book that this disappointing state of affairs is not at all an unavoidable reality of life. Nowadays it is possible to incorporate the preferences of a multitude of players into the design of large and complex building projects or residential areas. Computer models and computer graphics have become so powerful and user friendly that the effect of an individual preference on the total design can be calculated and communicated numerically as well as graphically. The computer model we use for analysing the effect of constraints on desirable outcomes is the algorithm to solve a number of linear inequalities known as Linear Programming (LP). Basically the LP model is extremely simple, but to apply it meaningfully to real life situations requires specific skills.

Outcomes from the design process have to be communicated. The very nature of architectural design requires that communication is done to a large extent through images, two or three dimensional. The classical vehicle for this, the paper drawing, lacks the flexibility of the computer drawing, which can be altered almost instantly. Communicating outcomes per computer screen is basically simple, but requires specific skills to be effective in practice.

Computer modelling and computer graphics are important tools for the modern architect, but are not sufficient on their own to accomplish the incorporation of all the relevant preferences of stakeholders into the design. The most essential condition is that the architect must feel a genuine desire to do so. He or she must respect and value these preferences and leave the design process really open-ended, as opposed to using that process as a means to achieve what he or she had in mind all along. Such open-minded, non-manipulative behaviour, called Model II by Argyris and Schön (1996), as opposed to Model I which is focused on achieving one's own objectives, does not come about by itself. For most people, it has to be learned and pursued in practice with a lot determination and perseverance.

To summarise, the success of the modern architect depends increasingly on his ability to use the contributions of others. To this end he needs skills in computer modelling – both numerical and geometrical – , computer graphics and communication. His behaviour should encourage possible contributors to provide their input to him.

This book is intended to assist in developing the three essential skills required of urban planners and architects of large, complex construction projects:

- Skills in numerical computer modelling;
- Skills in geometrical modelling;
- Skills in managing open-ended processes.

We feel that a wider proliferation of these skills is essential to close the gap between the wishes and preferences of stakeholders and what is ultimately built.

We use the word *stakeholder* here, where in the literature we often see the word *actor*. A stakeholder is an actor who has a right to act because he has a stake in the issue. In our concept, an actor who does not have a stake cannot directly exercise power. He can only influence the design indirectly via a stakeholder who does have an interest in the outcome of the design process.

The meaning of the word *architect* has evolved over time. At first, the architect was the designer of the whole building, its shape as well as its technical details. When these technical details became too complex to be dealt with by a single individual, the architect's role was gradually reduced to designing the shape of the building – the use of space and light – leaving the details to specialists. Esthetical aspects are still very important, but not more than many other aspects like functionality and cost. The architect can only regain his central position in the design process, if he attaches the same weight to all relevant aspects. His function becomes similar to the role of the conductor of an orchestra, whose responsibility it is to ensure that the musicians of the orchestra produce a coherent piece of music collectively. An architect, in our view, is someone who creates a design that constitutes the best synthesis, as perceived by the stakeholders involved, of all possible design solutions. According to this definition there is no difference between an architect and a manager of the design process that results in a set of specifications of what has to be made. The architect *is* the manager of that process.

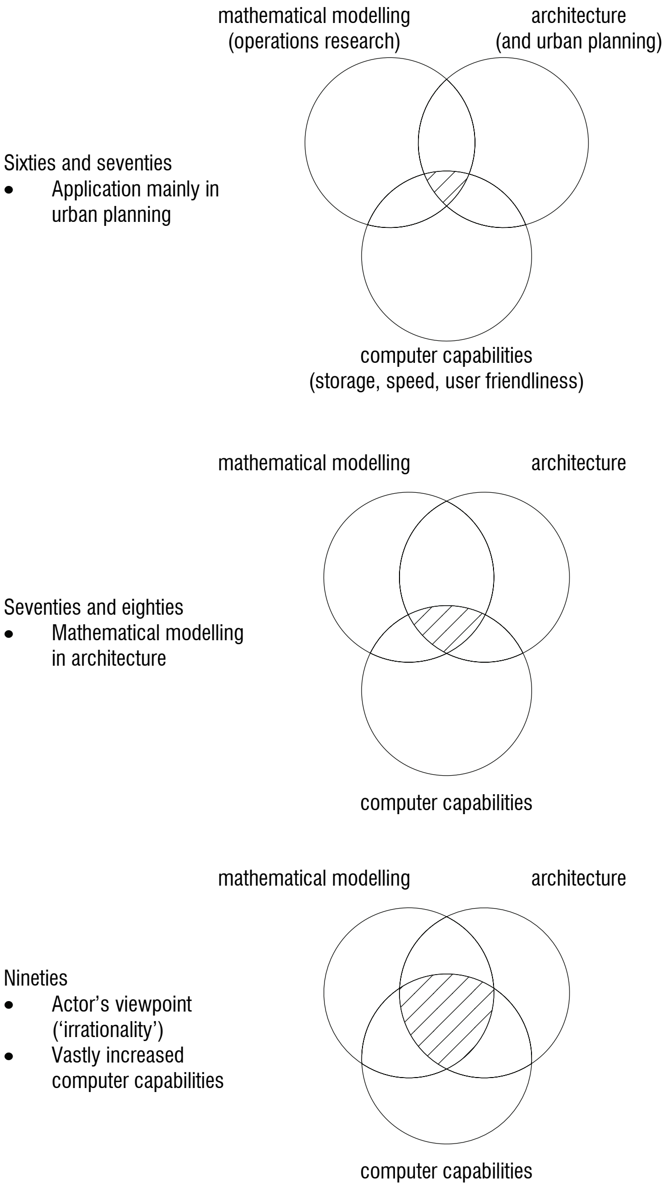
The application of mathematical modelling to urban planning and architecture has been pursued in the past by many scientists and practitioners (see for instance Ackoff and Sasieni (1968), Radford and Gero (1988)) but has never really taken off. We feel that a breakthrough in this respect has become possible due to two important developments in the nineties (Fig. 1):

1. The incorporation of the actor's viewpoint – actor's 'irrationality' – in the mathematical modelling (Van Loon, 1998);
2. The vastly increased capabilities and user friendliness of computers.

The latter constitutes a decisive change compared to the preceding decades.

This book is intended primarily for our students in architecture. Actually, we feel that every graduate in architecture ought to have knowledge and skills in the three areas mentioned before: computer modelling – both numerical and geometrical – , computer graphics and managing open-ended processes. Secondly, we address ourselves to architects who wish to update their knowledge in these areas. Finally, we hope that the book will be useful to other parties involved in the realisation of large construction projects: urban planners, contractors, suppliers, and so forth.

The concepts we present may appear rather straightforward and simple. The essence, however, is not only to obtain *knowledge* about them, but also to acquire the *skills* needed to apply them in practice. Like when learning to play a musical instrument, lots of practice is far more important than knowing how to play. But, like reading about music can contribute to becoming a good musician, we hope this book will help our readers to become good architects in the sense that their creations are perceived as being the best synthesis of all possible solutions to the issue concerned.



Sixties and seventies

- Application mainly in urban planning

Seventies and eighties

- Mathematical modelling in architecture

Nineties

- Actor's viewpoint ('irrationality')
- Vastly increased computer capabilities

Figure 1 The potential of mathematical modelling for architecture and urban planning has increased dramatically in the nineties

1 The Purpose of Open Design

What is the purpose of Open Design? Is it not just a way to make already complicated matters even more complicated? Is it not just another attempt to structure and formalise the work of the architect or the urban planner? In this chapter, where we outline the framework of Open Design as a new methodological approach to architectural design, we argue that the Open Design approach achieves exactly the opposite:

1. Basically, it makes the architect's task simpler, not more complicated.
2. It enriches his work in the sense that it enables him to exploit to the full any available room for creative and innovative solutions.

The Open Design concept acknowledges and leaves intact the very nature of architect's work as observed by Schön (1982, 1985, 1987), who describes the work of the architect as *reflection in action*, as an art of experimenting in a complex manner, with various ways of evaluation, using words, numbers and drawings. As a result, Open Design methodology is complementary to and does not limit architectural work.

1.1 Expert design versus Open Design

The classical approach to the problem of designing a new building or new residential area is to consult an expert or a limited group of experts. In the case of a new building, architects and structural engineers are consulted. In the case of a new residential area, additional advice is sought from urban planners and traffic engineers.

These experts provide a solution to the design problem which has to be 'sold' to the users of the building and project developers, or the future inhabitants of the residential area, representatives of pressure groups and local politicians. These interested groups are not at all happy with the design. The expert design, i.e. the design produced by a limited group of experts, does not reflect the wishes of all stakeholders. In particular the influence of the end users – seen by the experts as ignorant laymen – on the design is piecemeal, at least in their own perception.

To prevent these feelings of dissatisfaction, the aid of process experts is called in. They are asked to devise a decision-making process for the project which sets out what has to be produced when, and who should decide what. This, supposedly, enables the designers to work towards a result that, with some degree of certainty, incorporates more wishes into the final design. A consequence of this approach is a series of sub-optimum design decisions

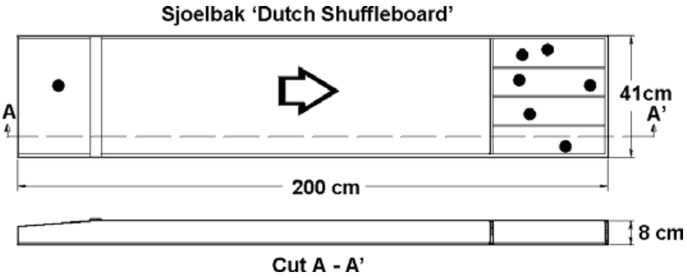


Figure 1.1 Sjoelbak (Dutch shuffleboard)

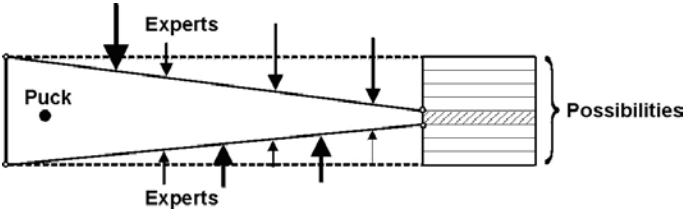


Figure 1.2 Expert design sjoelbak

leading to a total sub-optimum design in which, again, a lot of wishes are left unfulfilled.

The Open Design approach avoids these conditions of sub-optimality by giving equal weight to experts and laymen having an interest in the outcome of the design process. This will be explained below using a metaphor: the 'Sjoelbak' (Dutch shuffleboard, Figure 1.1).

A 'Sjoelbak' (pronounce as Shool-buck) is an originally Friesian family game. The disks, which are similar to ice hockey pucks, have to be pushed into four openings at the end of the shuffleboard. The expert design process can be visualised by the 'Sjoelbak' in Figure 1.2. This board has been made in such a way that the puck always ends up in the opening representing the design option of the experts. The choice of this option is determined by a struggle between the experts to direct the sides of the shuffleboard. The arrows in Figure 1.2 indicate this tug-of-war process.

This design process – typical of large, complex construction projects – has two fundamental shortcomings:

1. The possible contributions of layman-users and other excluded stakeholding parties are ignored;

2. Even if these contributions would be irrelevant – quod non – the perception of their being excluded significantly reduces the acceptance of the

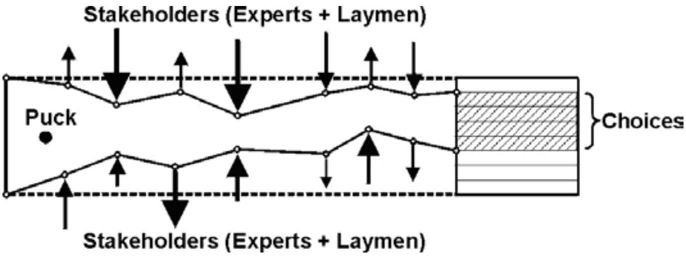


Figure 1.3 Multi-stakeholder sjoelbak design

expert design.

To overcome these shortcomings a design process is needed which allows the taking into account of the wishes and preferences of a multitude of stakeholding parties. Such a design process can be visualised by the shuffleboard of Figure 1.3*.

The arrows represent the influence stakeholders can exercise on the position of the sides of the Dutch Shuffleboard. The ultimate position of the sides does not lead to one design outcome, but to several options. The decision as to which of these options should be implemented, can be dealt with by a democratic process, for instance by means of voting among the future users.

1.2 Multi-stakeholder design problem

In Open Design philosophy, all stakeholders having an interest can influence the design. As such they become *decision makers*, i.e. parties who collectively decide on how the design will ultimately look. Decision makers are, therefore, stakeholders who have a real influence on the design, as opposed to parties who only have a right to express their views but do not have any formal or sanction power.

In the fields of architecture and urban planning, a continuous transition from hierarchic to decentralised design has taken place over the past few decades.

In the seventies, the design process in construction and urban planning projects was almost always headed by one, or perhaps several, professional designers. While these were usually architects, they were sometimes construction engineers or, in the case of large-scale projects, urban and landscape designers. Today, however, a comprehensive design team consisting of all the parties involved in the preparatory work is responsible for the design process

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*We have adapted a real sjoelbak in this way, and have observed that if one of the 'players' wishes to frustrate the process by manipulating his hinge-point, he succeeds – just as in practice!

and, as a consequence, designers other than architects nowadays also have a direct and strong influence on the design.

In the course of time the new participants acquired their own responsibility for a particular aspect of the design: the structural engineer for stability, the services engineer for the installation systems, the materials supplier for the materials used, the cost expert for the pricing, the traffic engineer for the infrastructure, the urban planner for the allocation of land, the contractor for the realisation of the construction work, the investor for funding, official institutes for standards and technical specifications and the user for the functional requirements. It is clear that professional designers have less influence than was formerly the case.

These developments have meant that most design work is currently done on a cooperative basis within a design team. During a collaborative work process, all designers (architectural and specialist designers) put forward their ideas and alternatives, discuss and evaluate combinations of solutions and select the best possible design. Team design in architecture and urban planning has become what is known in political science as a 'multi-actor' or 'multi-party' negotiation and decision-making process.

Over the past decades, we can notice a steady increase in the size of the design team and the number of specialists involved. Additionally, more time is now spent on specialist design than on architectural design. These developments have continuously increased the relevance of the multi-stakeholder design problem: how to cope with such a multitude of stakeholders in an effective and efficient design process? In dealing with this issue, the Open Design concept makes use of the following four paradigms:

1. The actor's viewpoint;
2. Pareto's criterion;
3. Methodological individualism;
4. Collective action.

The actor's viewpoint

The actor's viewpoint has been developed in the rational choice theory which describes decision-making models related to the progress of individual choice processes (Pellikaan, 1994). Initially, these models were based on the image of the individual as *homo economicus* who ranks his preferences rationally in an economic order as the basis for his decision. Later, they came to be based on the image of the individual as *homo sociologicus* who has different types of considerations for his preferences and decisions: not only individual (economic) interests but also altruism, solidarity, social norms and so on. The actor's viewpoint is based on the latter image.

Moreover, according to this perspective each individual shapes his order of preferences at the moment when he has to decide, i.e. while acting. This implies that where individuals have to take a decision together, something which on paper could be considered a dilemma between them will not necessarily turn out to be so. Conversely, what appears to be a problem-free issue may well prove to be a dilemma in practice .

The actor's viewpoint is significant in team design because preferences are formed mainly during the design process. As a result, new solutions can be devised and combined in new ways. This means that designers and users can voice their preferences for such solutions only during the design process. The actor's viewpoint implies that, even without enforced social norms and commitment to constituencies, actors *can* adopt a co-operative attitude.

People are not selfish by definition. Individuals have their own subjective preferences, their own view of the best outcome and in a group there will always be several preference orderings for one and the same group dilemma. Only in practice will it become clear whether a specific collective issue that is a dilemma on paper will actually be so in reality. And, conversely, an issue that seems uncontroversial on paper might turn out to be a dilemma in practice.

In short, one cannot say in advance how preferences and goals will be weighted. This can only be established on the basis of concrete actions. We shall look at the optimum Open Design from the actor's viewpoint. This viewpoint means that actors (designers) must above all have the opportunity, as they work together, to weigh their preferences and goals during the design process. The design method they use must cater for this.

Pareto's criterion

Pareto's criterion (Pareto, 1971) 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 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 at optimum as soon as it is no longer possible to increase the welfare of one or more individuals without decreasing that of one or more of the others.

Pareto's criterion does not imply a value judgment. It does not dictate that collective welfare must increase, but merely offers a means of measuring any increase. It must be known which groups are enjoying the increase. If, for instance, it is only individuals with a relatively high income who profit from an increase in welfare, the change merely accentuates the unequal distribution of wealth and can be rejected on these grounds, despite the fact that Pareto's criterion has been met (Van den Doel, 1993).

If a design is regarded as a plan for the distribution of costs and benefits among the parties involved, Pareto's criterion can be applied. The design is then at optimum when it can no longer be improved to the benefit of one or more of those involved without diminishing the benefits enjoyed by one or more of the others, benefits which they would enjoy if one of the earlier versions of the plan were implemented.

Practical objections to Pareto's criterion arise from the fact that changes in welfare seldom meet the criterion, since almost every gain for some entails some form of loss for others. The *compensation principle* has been formulated to overcome these objections. This principle involves assessing whether the 'winners' are able to compensate the loss suffered by the 'losers'. If the winners enjoy such a large profit that, after the losers have been compensated for their loss, a net profit still remains, it may be said that the change in welfare is potentially an improvement in terms of Pareto's criterion.

Methodological individualism

Methodological individualism was developed in economics and, more specifically, in the economic theory of political decision-making (Van den Doel, 1993). The simple view that a group of people working together form one independent entity is replaced by the view of the group as a collection of individuals (or sub-groups) producing something for another collection of individuals (or sub-groups), who may or may not be working together.

The idea that the group, which produces something together, has its own responsibility for taking (paternalistic) decisions for others is incompatible with methodological individualism. Individuals and sub-groups of individuals working together have special authority that enables them to take decisions for others and renders them accountable .

Methodological individualism is becoming increasingly relevant to team design. The growing complexity of design commissions has made it impossible for professional designers to decide alone what is relevant to achieving the (individual) goals of all the parties involved.

Collective action

Collective action involves actors working together voluntarily to achieve a collective interest, a collective good, such as defence, justice, health care, price agreements, nature conservation or environmental protection. Collective action produces both a collective to coordinate the actions of the members and a collective good from which all can benefit. Such a cooperation process is also referred to as a collectivisation process (De Swaan, 1989, p. 14).

Welfare theorists have developed many models to describe the features of decision-making and the logical dilemmas that can occur in the collectivisation process. The two-person decision-making game known as the Prisoner's

Dilemma is the most important principle here (Van den Doel, 1993; De Swaan, 1989; Pellikaan, 1994). It has been shown many times using this game that, in the course of collective action, such dilemmas that make cooperation impossible might arise for the participants.

However, in practice, cooperation does prove possible, despite the problems on paper. De Swaan (1989) has shown that if knowledge from historical sociology is added to the models from welfare theory it is possible to explain why these logical dilemmas do not always occur in practice. This historical view allows processes of change that occur during cooperation to be described, thus indicating how the logical dilemmas are solved. More dynamic models of decision-making in collective action have now been produced using this knowledge (Pellikaan, 1994).

1.3 Necessity of tailor-made models

The decision-making models relevant to Open Design are 'glass box' models. In these models the control unit, in which the decision variables are represented, is open and transparent. An open control unit enables the decision maker to work out what the best solution is. The goals and criteria on the basis of which he decides are known.

In current practice, decision making models for design problems are more of a 'black box' type: the control unit is closed and often fixed. Model specialists consider design problems to be too complicated to be incorporated into the model in an open and transparent form. In order to simplify matters, they first devise a standard behaviour for the decision maker, which they then incorporate into the model.

The usefulness of black box models can only be tested by evaluating the outcomes of the model, not the behaviour of the model itself. The best known black box models are the System Dynamics model (Forrester, 1969), and the Gravity model (Lee, 1973).

In Open Design, it is necessary for stakeholders to be able to change their decisions during the decision making process. It has been shown (Van Loon, 1998, p. 239) that the 'glass box' models facilitate this very well, and that they can be constructed during the process itself.

If a model of a system with an open control unit is required, the goals and criteria of the decision-makers have to be incorporated. This must take place in such a way that the decision-makers can reach agreement. This lays the foundation for a departure from the fixed solution space. In goal-oriented models this space is in fact 'free' since it can be discussed, negotiated and changed during use. Moreover, the modelling process for the 'free' solution space progresses quite differently from what is set out in operations research modelling. The modelling itself becomes part of the design process, because

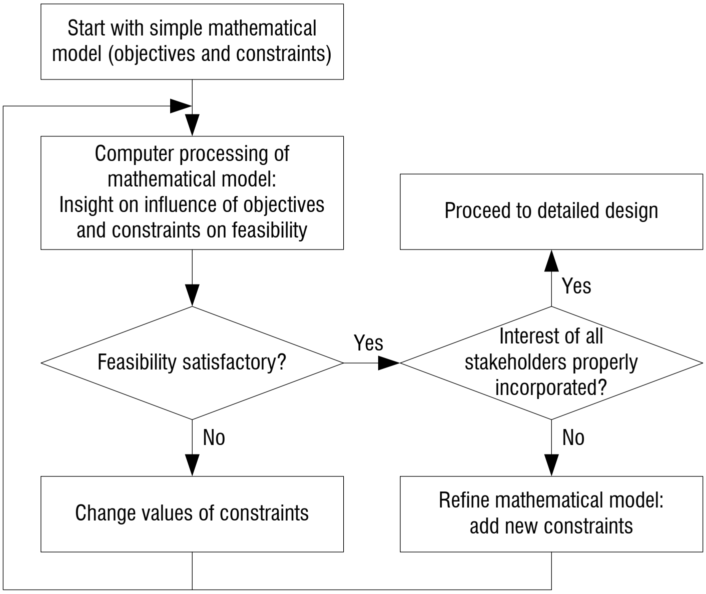


Figure 1.4 Mathematical modelling in Open Design

the modelling runs parallel to the designing.

At the outset of the design process, the solution space will be an unstructured collection of possibilities, such as a stock of materials, a plot of land, an assortment of building elements (doors, windows, etc.), prototypes, etc. The goals are vague to begin with: a good living environment, an attractive building, enough space, efficient use of energy and so on. As the process progresses, the collection of elements will become structured. During this process, the vague initial goals are gradually expanded, allowing for explicit requirements and limitations on the use of the available resources.

In Open Design, this whole process is based on mathematical modelling and computer processing of the mathematical model (Fig. 1.4). As becomes apparent from the figure, modelling and model application are interwoven, which produces many advantages in a multi-party design situation. The members of the team can see from the various sub-solutions whether the related parts of the model are acceptable to them. Usually, they will not all agree. Each person will judge the situation from the point of view of his own interests and will try to influence the model accordingly. The modelling thereby also becomes a multi-party process. It is, therefore, necessary to combine modelling and the use of the model in one integrated process.

The nature of this intertwined process of mathematical modelling and (computer) processing the results, brings along the necessity to build a tailor-made model for each individual case. Attempts to build models with a wide validity, for instance certain categories of office buildings, are bound to fail. The architect must be able to 'play' with his model. When new stakeholders are identified, their preferences must be incorporated by adding new constraints. Creating such tailor-made models can only be learned by doing so. We have seen students at first wrestling for weeks with a fairly simple model, yet later being able to set up a completely new model in just a few hours.

1.4 Conclusions

1. The preceding introductory considerations enable us to formulate the purpose of Open Design: the purpose of Open Design is to generate a *design* in which the interests of *all* stakeholders are reflected *in an optimal way*.

2. The architect in the classical sense – the artist who plays with light and space – is a stakeholder as much as the user who is after a favourable price-performance ratio or the urban planner who wishes to achieve the objectives set by the politicians. In this concept, no distinction is made between experts and laymen. Every stakeholder is supposed to be knowledgeable.

3. The work of the architect as the central figure in the whole design process – the manager of that process – is facilitated and enriched by the Open Design approach.

2 Managing the Open Design Process

As mentioned before, the collaboration between various stakeholders often gets stuck. Solutions to get the ball rolling tend to be characterised by compromise rather than synthesis, as a result of the autocratic way of decision-making by a limited number of experts.

Some causes of this rather disappointing state of affairs are the following:

- Combinatory explosion: there are more possibilities, opinions, alternatives than any one player can handle.
- Power games: players try to dominate.
- Unilaterally sticking to certain concepts: architects tend to nourish solutions originating from themselves rather than from others.
- Conflicts of interest: parties try to defend their own interests so vigorously that a solution for the project as a whole becomes impossible.
- Stubbornness: sticking to conventional and familiar concepts.

These issues have to be dealt with when managing the Open Design process. The open designer will be tempted to react in the same way as different players confront him, but in the long run that is counterproductive, as we will explain in this chapter.

2.1 The essence: acceptance of an open-ended outcome

The process leading to an Open Design, i.e. a design in which the interests of all stakeholders are reflected in an optimal manner, is complex. The building of an appropriate mathematical model is only one of its complexities. To communicate outcomes, to gain acceptance for these outcomes, to avoid stalemate situations, to maintain momentum, etc. – i.e. the management of the entire Open Design process – is in practice even more crucial to success than the mathematical methods and computer tools involved.

When the interests of all stakeholders have to be incorporated in the design, no one can predict beforehand how the design will ultimately look. Since the end product is unpredictable, the management of Open Design has to focus on process rather than content. The outcome of that process remains open-ended.

In the usual notion of management the end result aimed at is known in advance. Managers are used, therefore, to direct their attention towards achieving preconceived objectives, hence the evolution of widely accepted terms like 'managing by objectives', 'managing for results', and 'management is getting things done through people'. These statements presume that the results and things to be done are known from the outset, which is per definition never true in Open Design. Managers do not feel at ease when the outcome of what they manage remains open-ended. They like to be 'in control' and have 'their feet firmly on the ground'.

Most of the management literature is about being in control and achieving your own objectives. As a result, the concepts involved are actually recipes for manipulation.

In Open Design, manipulation in whatever form is counter-productive. The essence of Open Design is the genuine acceptance of an open-ended outcome. If the manager tries to manipulate outcomes towards his own preferences or those of his constituencies, he or she will lose respect from other players involved and the whole process may come to a halt.

What we need in Open Design, therefore, is a management concept that rejects any form of manipulation. Such a concept is offered by the behavioural theory of Argyris and Schön (1974, 1978, 1996). Non-manipulative behaviour from the part of the open designer is of such paramount importance, that we feel that we have at least to summarise the main features of the theory, which has been done in Appendix A. The reader who wishes to become really familiar with this concept, is advised not only to read the original publications, but also to experiment with it in practice.

Another reason to reject manipulation in whatever form in the Open Design process is that it is a prerequisite to bring about collective action, as we will explain in the next section.

2.2 Prerequisite for collective action: genuine treatment of constraints

A new complex building or a new residential area can be seen as *collective goods* for which a *collective optimum* must be found. For a summary of economic theory regarding the individual versus the collective optimum and its consequences for Open Design methodology, we refer to Appendix B.

Let us consider the example used there regarding how many bridges can be built from the money that people, collectively, wish to spend on bridges. What would happen if part of that money was secretly spent on other issues than bridges? Undoubtedly, when such manipulation surfaced, people would feel betrayed and refuse to cooperate any more, so *collective action* would become impossible.

A prerequisite for collective action is, therefore, that someone – in our case the open designer – *genuinely* adds up all the individual contributions the people involved are prepared to make to the common cause. This implies that the open designer should *never change a constraint without the consent of* *the associated stakeholder*. The open designer may only do so in a trial run to find out which stakeholder to address and ask for possible alleviation of the constraint concerned.

2.3 Collective action and the risk of too much uniformity

Collective action also brings along a risk: the risk of generating too much uniformity. Based on the principle of justice and equity and on the need to let everyone contribute to the whole, collective action can give rise to a collective good that provides the same benefit for all. As a result, the collective good is a standardised average of potentially different possibilities. For example: social provision that is the same for everyone, a uniform syllabus for all students, a residential area where every home has the same yard and garden. Apart from the fact that such uniformity can be boring, it also fails to do justice to individual differences in need. For example: people's differing needs for social assistance, children with different interests and residents' differing desires regarding their surroundings.

To express these individual differences in collective goods, and prevent them from becoming monotonous, welfare theorists came up with the idea that in the process of collective action a distinction must be drawn between the part that divides up the contributions necessary to achieve the good and the part that determines individual use of the goods. The first part is controlled centrally and uniformly by the group leaders (the state) on the basis of the agreed power relations. The second part is controlled decentrally by self-managed sub-groups (corporations), on the basis of voluntary membership (De Swaan, 1989). This approach makes for fair distribution, while at the same time allowing for variation and personal preferences.

However, this approach is only possible in a dynamic process, because only then do the participants have the opportunity to address dilemmas. A dilemma such as 'what concessions should I make regarding my personal preferences in order to remain individual and unique, while still honestly and openly contributing to the whole?' is caused by ignorance of the choices others are about to make. To obtain information on this matter participants must first study the effects of several people's choices at the same time and derive from them reasons for weighting their own preferences.

The conclusion is that a design team operating as a collective is likely to produce uniform design results if the team works very statically, failing to distinguish between central decision making and individual choice. This can easily be avoided using the Open Design method, which is highly dynamic, focusing on the weighting of preferences and distinguishing sharply between central decision making and individual choice.

2.4 Open designer as product champion

Innovations, no matter how attractive they may appear to be, do not sell themselves. They need a 'product champion', someone who is prepared to fight for the acceptance of the innovation and overcome the resistance to change that prevails in every organisation. This is not a new phenomenon. Machiavelli already observed the 15th century (*The Prince*):

> There is nothing more difficult to take in hand, nor more perilous to conduct, or more uncertain in its success, than to take the lead in the introduction of a new order of things because the innovator has for enemies all those who have done well under the old conditions, and only lukewarm defenders in those who may do well under the new.

The Open Design approach constitutes an innovation, a first application of something new, that fundamentally changes the power structure in the design process. As in technological innovation, those losing power (experts in the old technology) to new players (experts in the new technology) do not give up without a fight. The parties losing power by adoption of the Open Design approach will try to defend their 'territory' by all means.

For instance, in the example of the urban planning project described in Section 3.3 the urban planning experts of the municipality lost quite some power to the future inhabitants as a result of the adoption of the Open Design approach. The inhabitants of the residential area were extremely content with the outcome, but the experts of the municipality realised that their influence had been reduced and showed feelings of discontent. As a result, they never adopted the Open Design methodology again.

The importance of a 'product champion' or 'organisational guerrilla' for the acceptance of technological innovations is well known, but how he operates or should operate to be successful is still rather unclear.

In this Section we describe two important features of the successful 'product champion' (Fig. 2.1):

1. The product champion always needs the blessing of a benefactor high up in the organisation (Van Gunsteren, 2003). In Open Design, he may even need several benefactors belonging to relevant stakeholder organisations.

2. The code of conduct for the product champion is Model II behaviour: his attitude and work style should be open and non-manipulative.

A product champion wishing to introduce something new is often felt to be a nuisance by others involved. The introduction of the new invariably brings along changes in the power held by individuals involved. Those having the

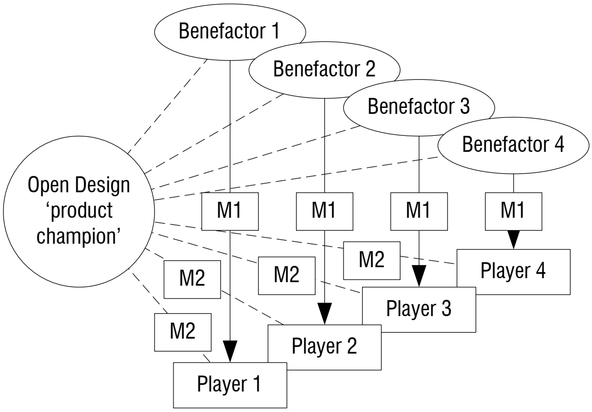


Figure 2.1 In Open Design, the product champion needs several benefactors

perception that they will lose power will counteract the product champion wherever they can. The product champion cannot convince them with so-called rational arguments. They do actually lose influence and are indeed not better off with the introduction of the new. They have to give in for the sake of the whole organisation. It is up to their boss to tell them that, not the product champion. If necessary, the boss, acting as a benefactor of the product champion, can pass the message in an autocratic way (Model I behaviour).

The product champion, by contrast, should always try to display Model II behaviour towards relevant players. If he cannot resist the temptation to achieve short-term victories by manipulative (Model I) behaviour, he will lose credibility and become ineffective in the longer term. If too many relevant players are putting banana peals in his path, he should address his benefactor high up in the organisation. The benefactor can then take appropriate action, which will generally be done in an autocratic (Model I) way.

If such a benefactor cannot be found, the product champion is stuck. That means the Open Design approach will not be adopted. He should then focus on finding benefactors high up in the relevant stakeholders organisations. Efforts to convince people at lower levels without the backing of a high-up benefactor are bound to fail and are a waste of time.

The product champion's influence is mainly based on knowledge power – due to his in-depth knowledge of the subject – and on reference power – due to his individual prominence. His reference power is reinforced by his open, non-manipulative Model II behaviour. The product champion usually has little formal power or sanction power. Whenever these are needed, he has to rely on his benefactors.

2.5 Persuasion by numerical and geometrical modelling

If the code of conduct for the open designer is non-manipulative Model II behaviour, he should convince relevant players through facts and figures, and present them in such a way that they are understood and accepted. In this respect, computer calculations showing the consequences of options can help a lot to persuade opponents.

Example: Selling an invention

> An inventor of a new ship propulsion device wanted his invention to be applied on the world's most powerful tug at the time (20 000 Horse Power). He knew that only his invention could make it possible to meet the owner's requirements of 180 tons bollard pull and a free running speed of 20 knots. Conventional solutions could only satisfy one of these requirements.
>
> A propulsion consultant was involved who understandably was very reluctant to give his blessing, since the invention had so far only been applied on a small river tugboat. He desperately asked again and again for analyses of new combinations of the relevant design parameters (related to the conventional solutions).
>
> After several of such requests for more homework, the inventor decided to make computer calculations in which the design parameters were systematically varied in small steps.
>
> In the next meeting when the consultant asked for the effect of a certain combination of the design parameters, a five inch thick pile of computer output was put on the table by the inventor. By turning some pages, the combination asked for was found in a few seconds and the answer given to the consultant. This was repeated a few times. It then became clear to all present in the meeting, that conventional solutions could never meet both requirements, whereupon the invention was accepted by the consultant.

Numerical calculations are often not convincing enough. architects are generally not impressed by numbers, they want to see what outcomes look like. To convince, therefore, outcomes of numerical calculations need to be visualised. Any numerical outcome should be visualised by associated geometrical modelling. For instance, if an alternative for the number of 2-person and 1-person rooms of an office building is proposed, a drawing of the floor plan should immediately appear on the display to visualise the features of the proposed distribution of 2 and 1 person rooms.

Geometrical computer modelling, therefore, should be integrated with numerical modelling.

2.6 Conclusions

1. The essence of the Open Design process is the acceptance of an open-ended outcome by all players involved. In practice, this feature constitutes both a strength and a weakness of the Open Design approach.
2. The prerequisite for collective action – genuine treatment of constraints – implies that the open designer should never change a constraint without the consent of the associated stakeholders.
3. The risk of collective action generating too much uniformity is avoided in Open Design by distinguishing sharply between central decision making and individual choice.
4. Application of the Open Design approach requires a product champion, someone who fights for its adoption with all available means.
5. The product champion's code of conduct is open, non-manipulative behaviour. If necessary, his benefactors high up in the stakeholder organisations can address opponents in an autocratic way.
6. For genuinely convincing opponents, the product champion can benefit significantly from numerical and geometrical modelling.

3 Modelling in Open Design

Open design is about optimisation. It is a new methodology to achieve *group optimisation*, i.e. to achieve an optimal result as perceived by a group of people having diverging views and interests.

Optimisation through mathematical modelling – both linear and non-linear – has been extensively treated in the Operations Research textbooks. In this chapter we explain linear optimisation as applied in Open Design.

3.1 Principles of linear optimisation

Let us consider the following problem.

> A professor wishes to work for his university an average of no more than 40 hours per week in view of his family commitment. His contract specifies that on average he must devote at least 10 hours per week to teaching and at least 15 to research. How should he allocate his time?

This can be translated into mathematical formulae as follows:

At least 10 hours per week teaching (x_1):

$$x_1 \geq 10 \tag{3.1}$$

at least 15 hours per week research (x_2):

$$x_2 \geq 15 \tag{3.2}$$

no more than 40 hours per week in view of family commitment:

$$x_1 + x_2 \leq 40 \tag{3.3}$$

These inequalities can be represented graphically as shown in Figure 3.1. The shaded area is called the *solution space* or *feasible region*, because any combination of the *decision variables* x_1 and x_2 in this area satisfies inequalities (3.1), (3.2), (3.3), i.e., the contract requirements and the professor's own wish to work no more than 40 hours/week. The right-hand sides in the three inequalities (3.1), (3.2), (3.3) are called *constraints*, i.e. boundary conditions limiting the solution space.

Within these constraints an *optimum* can be established depending on what the professor sees as most desirable (Fig. 3.2):

a. If he wishes to spend as much time as possible on research, he will choose the combination: $x_1 = 10$, $x_2 = 30$;

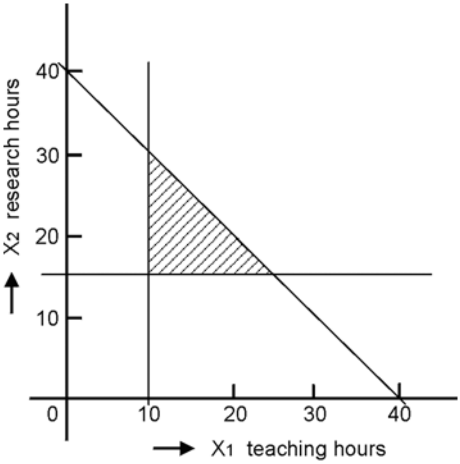


Figure 3.1 Graphical representation of professor's time allocation problem

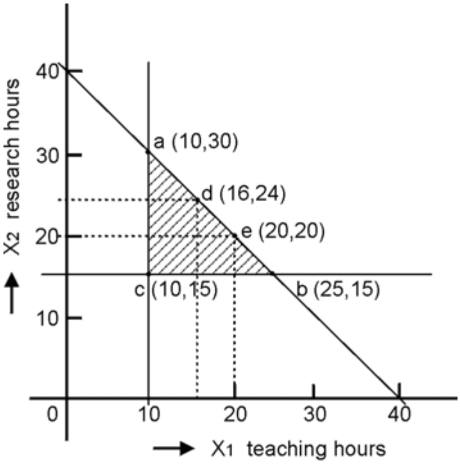


Figure 3.2 Professor's time allocation problem

b. Conversely, if he likes teaching most, he will choose the combination: $x_1 = 25$, $x_2 = 15$;

c. If he wishes to work as little as possible: $x_1 = 10$, $x_2 = 15$;

d. If he wishes to work as much as possible, dividing his time according to the ratio of his contract: $x_1 = 16$, $x_2 = 24$;

e. If he wishes to work as much as possible, dividing his time equally between teaching and research: $x_1 = 20$, $x_2 = 20$.

The method of establishing an optimum for given constraints is called linear programming, because the constraints are given by linear equations. As we have seen, exactly what is to be optimised depends on personal preference. Only one aspect can be optimised, but the constraints can be many.

Of course, it is quite possible that constraints are defined in such a way that no solution is possible. For instance, if the professor does not wish to work for more than 20 hours – i.e. $x_1 + x_2 < 20$ – no solution is possible which satisfies the conditions of his contract. In Open Design, we have to deal with much more than two decision variables and three constraints, in complex cases even several hundreds! The processing of so many variables in an LP model can nowadays be carried out easily by any personal computer.

Efficient, standard software packages are available for this purpose. These packages have been designed for a wide variety of LP problems. As a result, certain features of these software packages are not useful in the specific application of Open Design and can be ignored by the open designer. Conversely, the nature of Open Design problems requires some special 'tricks' when using standard software packages.

To use the LP software package effectively, the open designer has to be familiar with the mathematical model for the general problem of allocating resources to activities. He or she then can 'play' with the program without violating its underlying logic. It is not necessary to have detailed knowledge about how the program finds the optimum using algorithms such as the Simplex Method. It is sufficient to be aware of its essence, namely that it moves in an iterative process, systematically, from one corner-point feasible solution to a better one, until no better corner-point feasible solution can be found. That last corner-point solution is the optimum solution.

For the description of the mathematical model for the general problem of allocating resources to activities, we will use the nomenclature and the standard form adopted in the textbook on Operations Research of Hillier and Lieberman (2005).

This model is to select the values for the decision variables $x_1, x_2, \ldots, x_n$ so as to:

$$\text{Maximise} \quad Z = c_1x_1 + c_2x_2 + \cdots + c_nx_n \tag{3.4}$$

subject to the restrictions:

$$\begin{array}{rcl} a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n & \leq & b_1 \\ a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n & \leq & b_2 \\ & \vdots & \\ a_{m1}x_1 + a_{m2}x_2 + \cdots + a_{mn}x_n & \leq & b_m \end{array}$$

and

$$x_1 \geq 0, x_2 \geq 0, \ldots, x_n \geq 0$$

For the sake of brevity, we use $\sum$ notation and write:

$$\text{Maximise} \quad Z = \sum_{j=1}^{n} c_j x_j \tag{3.5}$$

subject to:

$$\sum_{j=1}^{n} a_{ij}x_j \leq b_i \qquad \text{for } i = 1, 2, \ldots, m$$

and

$$x_j \geq 0 \qquad \text{for } j = 1, 2, \ldots, n$$

This is adopted as the *standard form* for the linear programming problem. Any situation whose mathematical formulation fits this model is a linear programming model.

The function Z being maximised, $c_1x_1 + c_2x_2 + \cdots + c_nx_n$, is called the *objective function*. The *decision variables* – the x_j – are sometimes referred to as the *uncontrolled* or *endogenous* variables. The input variables – the a_{ij}, b_i, and c_j (a-matrix, b-vector and c-vector) – may be referred to as *parameters* of the model or as the *controlled* or *exogenous* variables. The restrictions are referred to as *constraints*. The first m constraints, $b_1, b_2, \ldots, b_m$ (those with a function $a_{i1}x_1 + a_{i2}x_2 + \cdots + a_{in}x_n$ representing the total usage of resource i, on the left) are called *functional constraints*. The $x_j \geq 0$ restrictions are called *non-negativity constraints*.

The above model describes the typical manufacturing allocation problem of several products competing for limited production facilities.

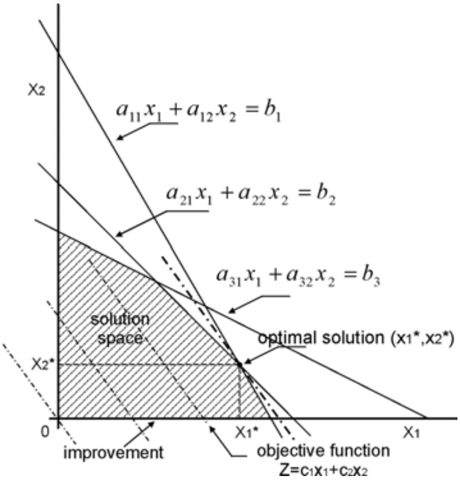


Figure 3.3 Manufacturing allocation problem

Example

Find the optimum allocation (giving the highest profit Z) to production facilities of two products x_1 and x_2 which:

contribute to profit:

per unit of x_1: c_1

per unit of x_2: c_2

consume from three production facilities, which are limited by capacities b_1, b_2, b_3:

$$\begin{aligned} a_{11}x_1 + a_{12}x_2 &\leq b_1 \\ a_{21}x_1 + a_{22}x_2 &\leq b_2 \\ a_{31}x_1 + a_{32}x_2 &\leq b_3 \end{aligned}$$

See Figure 3.3.

Some commonly used terminology in linear programming originates from this manufacturing allocation problem:

- right-hand side constraints b_i $(i = 1, 2, \ldots, m)$:
  amount available of resource b_i;
- coefficients a_{ij} $(i = 1, 2, \ldots, m, j = 1, 2, \ldots, n)$:
  usage of resource limited by b_i, per unit x_j;
- coefficients c_j $(j = 1, 2, \ldots, n)$:
  contribution to profit per unit x_j;
- shadow price of constraint b_i $(i = 1, 2, \ldots, m)$:
  increase of profit Z per unit increase of production capacity b_i;
- reduced cost:
  reduction in cost of a third product x_3 necessary to make it part of the optimal solution, i.e. to let it contribute to profits.

This model does not fit all linear programming problems. The other legitimate forms are the following:

- Minimising rather than maximising the objective function:

$$\text{Minimise} \quad Z = \sum_{j=1}^{n} c_j x_j$$

- Some functional constraints with a greater-than-or-equal-to inequality:

$$\sum_{j=1}^{n} a_{ij} x_j \geq b_i \quad \text{for some values of } i$$

- Some functional constraints in equation form:

$$\sum_{j=1}^{n} a_{ij} x_j = b_i \quad \text{for some values of } i$$

- Deleting the non-negativity constraints for some decision variables:

$x_j$unrestricted in sign, for some values of j

Any problem that mixes some or all of these forms with the remaining parts of the above model is still a linear programming problem as long as they are the only new forms introduced. The interpretation of allocating limited resources among competing activities may no longer apply, but all that is required is that the mathematical statement of the problem fits the allowable forms. In Open Design, all legitimate forms mentioned above may occur. Note that in the professor's time allocation problem the first two of the above legitimate forms are used.

3.2 Extension to Open Design: negotiation of constraints

Let us assume that the professor of the preceding example gets a job offer for an interesting position outside the university for 20 hours per week. Obviously, he cannot accept this offer, while maintaining the constraints $x_1 > 10$, $x_2 > 15$, and $x_1 + x_2 < 40$. If he nevertheless wishes to accept the offer, he has to renegotiate these constraints. The last one, accepting more than 40 hours work per week, would affect his family life which is unacceptable to him. So the professor decides to renegotiate his contract with the university. In the negotiation with the research coordinator and the teaching coordinator it then becomes clear that:

- To be meaningful, research can only marginally be reduced below 15 hours/week.
- Teaching responsibility should be either more than 10 hours or limited to just one elective of say 3 hours/week.

The parties therefore decide on new (renegotiated) constraints:

$$x_1 \geq 3 \tag{3.6}$$

$$x_2 \geq 12 \tag{3.7}$$

$$x_1 + x_2 \leq 20 \tag{3.8}$$

There upon, the professor accepts the outside position and optimises his time as described before within constraints (3.4), (3.5), and (3.6).

In Open Design this process takes place, in essence, in the same way. Initially, the constraints are defined in such a way that no solution is possible: the solution space, also called feasible region, is zero. Contrary to classical linear programming, however, the constraints are not considered to be fixed but negotiable. The negotiations about changes in constraints in order to achieve a non-zero solution space can be limited to those constraints that really matter, i.e. those having the greatest impact on the solution space. These constraints, having major impact, can be identified by a sensitivity analysis of the constraints as initially given.

Herein lies the first major improvement brought about by the Open Design approach: identification and negotiation of the constraints that really matter for achieving a solution at all.

The second significant merit of the Open Design approach is that a higher level of satisfaction can be achieved for all stakeholders. In other approaches certain stakeholders are invariably excluded from the design process. As a result, these stakeholders tend to be dissatisfied with the outcome.

3.3 An urban planning project

An example of the Open Design approach applied in an urban planning project is the Lijnbaan urban renewal project in Dordrecht (Leenman, 1985).

For a number of years attempts had been made to draw up plans for this project, but to no avail. The neighbourhood was deteriorating, sites where factories had been demolished were becoming wastelands and many of the old houses were in a very poor state of repair. The municipal council therefore decided that a breakthrough had to be made. A new project leader was engaged and he was given one year to produce a feasible plan and obtain approval for its implementation. The 'Open Design method' was called upon to provide support for the design process.

The project group based their approach on the 'integration of all the aspects involved' and 'parallel operation' on the assumption that only in this way would it be possible to complete the assignment within the specified time. The group actually succeeded in this. Within three months the integrated solution space had been defined, all the parties involved had formulated their requirements and constraints, and this had all been incorporated into a computer optimisation model. The initial mathematical solution that fulfilled all the requirements could thus be produced.

In the following three months the solution was expanded to become an urban redevelopment programme for the area, which included requirements regarding the type and number of houses, amount of greenery, streets and parking, public and private areas, cost of the land, etc. While this stage progressed well, the following phase stagnated.

The residents' committee and the housing association became aware that within the solution space that had been accepted by everyone more than one design was feasible. The housing association's architect, who was responsible only for designing new housing, presented an overall plan for the area that was completely different from the one produced by the municipal urban development agency (Fig 3.4). In the municipality's plan the housing blocks are located at the inside of the site with roads oriented to the water front. In the architect's plan the housing blocks are placed on the edge of the location oriented to the old city.

A great deal of confusion arose in the group. Communication between the architect and the urban designers became problematic. Both had extremely firm ideas on the land use plan. It had been ascertained on the basis of the computer model that both plans fulfilled the requirements of the redevelopment plan. However, it proved impossible to reconcile the differences related to aspects which are difficult to quantify such as greenery, urban character and living environment.

It emerged at this point that, since the computer model had made the norms, requirements and rules of the relevant disciplines explicit and transparent,

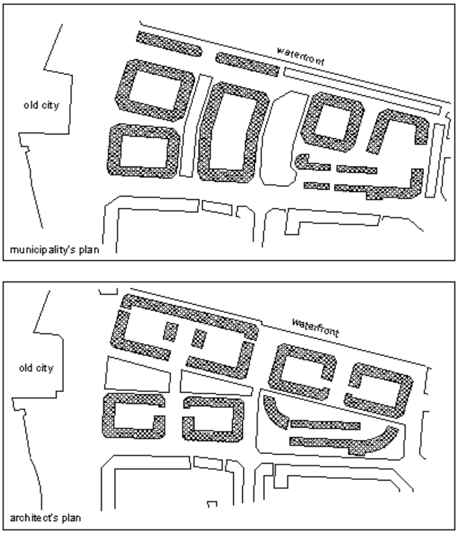


Figure 3.4 Two different plans within one solution space

people could no longer hide behind them. The debate was now about ideas and opinions. Separating in this manner the computer-related aspects and the aspects which are highly individual in nature only intensified the confrontation.

In retrospect, the problem of stagnation was solved fairly easily and logically. The municipal councillor was presented with both land use plans and he asked the future residents and the housing association which one they preferred. They were unanimous in their choice of the architect's plans. These were presented to the council, approved and implemented.

This project contained almost all the elements of 'Open Design' described in this book:

- The shift towards decentralised design

  After the council's decision, the local paper reported that the monopoly of the municipal urban development service had been brought to an end. People then realised that there was no longer one central place where the design was made and decided upon. This had already been proposed in many public consultation documents and political manifestos but it had now become a reality.

- Team design as a multi-party negotiating process

  The residents' committee had participated in the process from the outset. However, as soon as they presented themselves as an independent party with their own views trying to achieve their own goals by means of negotiation with a municipal councillor and the formation of a coalition with the housing association and the architect, the professional designers of the municipality tried to exclude them from the team process.

- Design optimisation as a form of social welfare optimisation

  Because nothing had been done in the Lijnbaan area for years there was a great deal of pressure on the project to produce results fast. There was also a degree of mistrust towards the experts who had not been able to produce a viable plan. However, as the first optimum calculation had incorporated various constraints and requirements, both political and from the residents themselves, the project group could move seamlessly from expert optimisation to social optimisation.

- Acknowledgement of an individual design decision area for each team member

  Some decision areas had been allocated within the municipal urban planning service. That outside participants had their decision areas as well, possibly independent thereof, came as a surprise to the experts.

- The political nature of the multi-party design process

  That the problem of stagnation was solved through political channels would have been logical to the experts if this aspect had been recognised from the outset.

3.4 An office renovation project

An example of the Open Design methodology applied in an office renovation project is the upgrading of the former KLM head office on the Plesmanweg in the Hague (Binnekamp, 1995).

In the year 1979, the building had been in use for ten years by its second owner, the Ministry of Infrastructure. The building badly needed a thorough overhaul including maintenance of the outside of the building, improving the ventilation, modernising the interior and making the office designs of the various wings more efficient. The building no longer met the legislation and user requirements of that era. The total floor area was 27 000 m2. Only 11 000 m2 was used for offices, the remainder being storage rooms, cellars, halls, corridors and staircases (Fig. 3.5).

A renovation plan was made including a calculation of the cost involved. A decision for execution was, however, postponed for years. First, a new wing had to be built. This extension was very urgent, for the Ministry had rapidly grown in its number of employees.

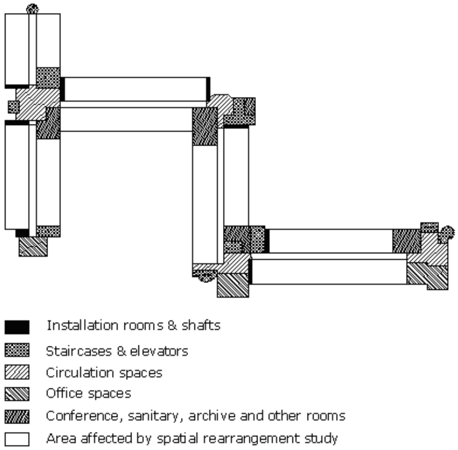


Figure 3.5 Floorplan of former KLM head office

When the new wing had been completed in 1985, the whole building was reviewed in the light of the user's requirements and general norms for offices at that time. It was established that it would be possible – according to generally accepted calculation rules – that the building would accommodate 1 550 persons on a functionally usable area of 21 230 m2, at an average of 13.70 m2/person. Not surprisingly, the new wing already satisfied these modern norms. The old building, as could be expected, came nowhere near.

A preliminary budget was reserved: on the basis of experience with other buildings a budget of € 6.81 million was considered appropriate for both overhaul and achieving an efficient layout.

In 1988 a project team started with the assignment to make a renovation plan related to both technical maintenance and modernisation of the interior. The new layout had to accommodate 1 100 persons. The first plans and calculations indicated that an investment of about € 13.18 million would be required for this. After some negotiation the initial budget of € 6.81 million was increased to € 10.22 million. The cost of the complete renovation had to be kept below this ceiling.

The project team proceeded and made a second plan within the limits of the budget. A detailed design was made for one wing and immediately implemented. At the same time the renovation of the next wing was prepared. It then emerged that another layout was preferred.

This revised layout was actually implemented. In the preparation for the next wing the ideas changed again and these changes were also incorporated. In 1992 the renovation was completed. € 14.55 million had been spent to accommodate only 853 persons.

The owner of the building, the real estate institution of the State, gave the project a negative evaluation. More than twice the budget was spent for 25% fewer accommodated persons than agreed at the start. It was also not clear to what extent the cost had generated commensurate quality. In other words: did the owner get value for his money? The cause of the failure was primarily seen to be the poor monitoring of decisions.

The process of renovation had extended over a number of years. Plans had been revised after each completed phase. As a result, decisions on different parts of the building lacked coherence. Their effect on the functioning of the building as a whole was lost out of sight which made cost control extremely problematic. Cost savings by appropriate integration of sub-projects could not be achieved.

In retrospect, it is understandable that the project was negatively evaluated. The owner had to pay twice the budget for only three quarters of the agreed functional output. Since the cause was primarily seen to be the poor integration of the various sub-projects, the question arose if an Open Design approach could have led to a significantly better result and, possibly, to a positive evaluation by the owner.

To answer this question, an extensive simulation based on the Open Design approach was made. The hypothesis of the simulation was that the failure was not so much the result of budget overruns and under-realisation of anticipated functional output (number of accommodated persons), but of the way new emerging insights and demands had been incorporated.

Starting from the initial specifications and boundary conditions, an integral optimisation model was made to establish the solution space of the renovation project. This model allowed the various steps taken in reality to be simulated and analysed.

It then soon became clear that accommodation of 1 100 persons would never have been feasible. In due time, the organisation of the user had changed: more highly placed executives had to be accommodated requiring more m2 per person. Accommodating 1 100 persons would imply that certain parts of the user's organisation would have to be transferred to elsewhere.

It also was found that the selection of main dimensions for corridors and office rooms had a great impact on the functional output of the building. Alternative layouts could offer impressive improvements in terms of functional output over cost.

The optimisation model allowed the assessing of the consequences of alleviation in relevant constraints, in particular the number of persons and the total budget. Table 3.1 summarises the results that are most relevant to the owner.

The conclusion is that the Open Design approach could have provided a building accommodating more people and requiring substantially lower energy consumption, so lower yearly cost, at only 53% of the price actually paid.

Table 3.1 Comparison initial plan–realisation–Open Design simulation for former KLM head office

	Plan at start	Realisation	Open Design simulation
Number of person accommodated	1 102	853	916
Energy cost per year (€ 1 000)	59	66 (estimated)	54
Investment (€ million)	10.22	14.55	7.27

3.5 Solution space versus solution point

The real life examples of the preceding sections illustrate an important feature of Open Design: by establishing a solution space (or feasible region) in which the architect has complete freedom, the way is paved for the realisation of creative architectural ideas. Ideas that are both valuable in the sense that they increase satisfaction of stakeholders, and feasible in the sense that they fit into the solution space. In conventional design practice, by contrast, the starting point is one feasible design, a solution point. Usually other designs – representing other solution points – are subsequently made to accommodate criticism on the first one. Such alternatives, therefore, tend to be merely incremental deviations from the first design.

In the example of the residential area of Section 3.3, a new architectural concept was generated within the agreed solution space. Without the Open Design approach, this interesting concept would not have survived. The designers of the municipality were actually very surprised that another design, fundamentally different from their own, turned out to be possible within the agreed constraints. They had assumed that within these constraints only slight deviations from their own design would be possible. That this assumption turned out to be wrong was, understandably, a shock to them.

Thinking in terms of a solution space is particularly important when the solution space is made up of several parts which are connected by narrow 'corridors'. For two decision variables, we can represent that situation as shown in Figure 3.6 (one may think of the metaphor of two ponds connected by a narrow channel).

If a solution point in Part 1 is used as the starting point of a trial-and-error process, it is extremely unlikely that any solution in Part 2 of the solution space will ever be found.

Example: Hoorns Kwadrant Delft

> The municipality of Delft wished to build some 2 000 houses on a residential area called 'Hoorns Kwadrant' which was owned by the neighbouring village of Schipluiden (Van Loon et al., 1982). The municipality of Schipluiden was only prepared to sell the site if considerably less houses were to be built. They felt that other-

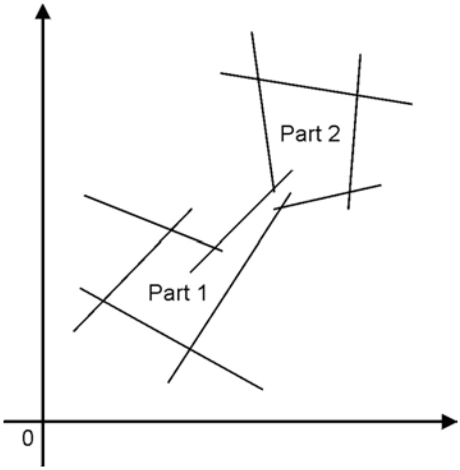


Figure 3.6 Solution space made up of two parts connected by a small 'corridor'

wise the region would get too much 'an urban character'. In a trial-and-error process the number of houses to be built was reduced to 1 650. The municipality of Delft refused to give in any further in view of the financial feasibility of the project. The municipality of Schipluiden still considered the number of houses far too great.

To resolve this stalemate situation – which had lasted for years – the help of open-design consultants was called in. It then transpired that financial feasibility was ensured in two areas:

- In the range of, say, 1 500 to 2 500 houses. Then ground would have to be bought from both farmers and greenhouse owners.
- In the range below 1 200 houses. In that case no expensive ground purchases from greenhouse owners would be needed.

The latter revealed that the implicit assumption the Delft municipality had made – the lower the number of houses the lower the financial feasibility – was not correct. The project was actually implemented for some 1 200 houses.

3.6 Integration of numerical and geometrical modelling

The numerical outcomes of the LP optimisation comprise quantities of resources to be used. Many of these resources are expressed in numbers, surface areas or densities. An LP model is expressed in linear equations (equalities and inequalities), which implies that multiplication or division of two endogenous variables is impossible. For instance, the model cannot calculate the surface area of a spatial entity and simultaneously determine its length and breadth. The LP model does not provide a spatial plan. It leaves open where the various functions in a residential area or in a building will be located. In the LP model for a building, surface areas for various rooms and functions are known, but not their shape and physical location. The model does not say anything about being located at the outside of the building or compliance with rules for escape routes. The LP model can only achieve that certain boundary conditions are satisfied which allow an acceptable spatial arrangement to be made within the numerical outcomes of the model.

The LP model, moreover, does not take into account the requirement that in a layout the various elements have to fit like the pieces of a jigsaw puzzle without overlaps, ugly discontinuities in shape, or useless corners. Requirements related to light and sight cannot be accounted for either.

The conclusion is that, in addition to numerical models, we need geometrical models to generate spatial designs and plans. The numerical models are used to calculate optimum solutions. The geometrical models serve to translate the resulting quantities into spatial plans using classical sequential heuristic methods.

In Open Design, both methods – on the one hand numerical / integral / optimising, and on the other geometrical / sequential / heuristic – are applied in an integrated way. The integration is achieved in an iterative process (Fig. 3.7).

Usually, we have available at the beginning:

1. a *bill of requirements*, which in Open Design is always regarded as preliminary, and *legislation*;
2. a *sketch* of how the building or residential area looks, also regarded as preliminary, and often some *reference designs*.

A numerical (LP) model is built on the basis of the bill of requirements, legislation and physical constraints. The LP model provides a current solution space and an optimum solution point. In parallel, a geometrical model, consisting of 2D and 3D computer drawings is made on the basis of the preliminary sketch and reference designs. The geometrical model provides a list of relevant geometry related parameters – surface areas and volumes – and the current values of these parameters.

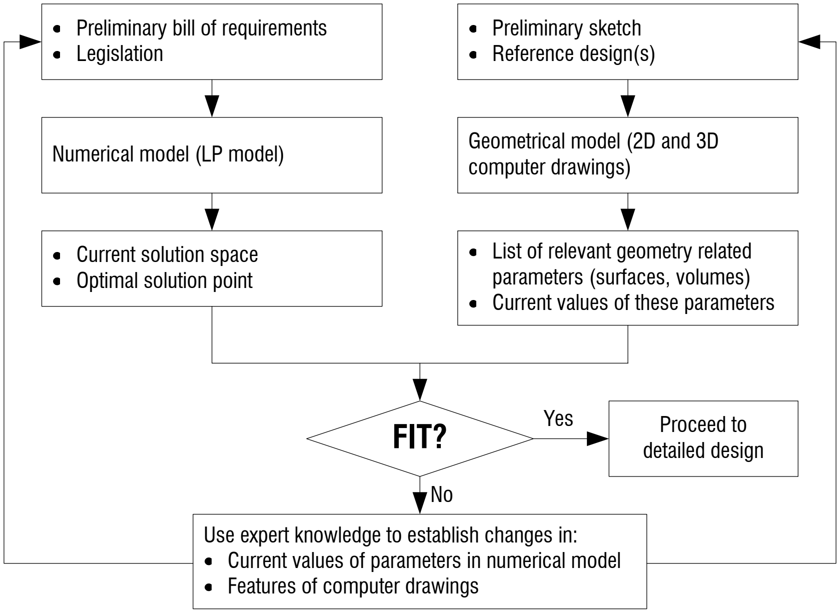


Figure 3.7 Integration of numerical and geometrical modelling through expert feedback

We can then compare these values from the geometrical model with the associated values from the LP model. Initially, they will fit poorly. To get a better fit, expert knowledge can be used to establish desirable changes in:

1. Current values of parameters in the LP model;
2. Features of the computer drawings.

This process is repeated until a satisfactory fit is achieved, upon which we can proceed to detailed design.

Instead of using expert knowledge to change the current values of the constraints concerned in the LP model, we can also do so by conducting a sensitivity analysis (as described in Section 7.1) on the constraints (Fig. 3.8). Conversely, if we wish to correct the geometrical model without calling on expert knowledge, we have to proceed as indicated in Figure 3.9.

In that case the feedback loop consists of two parts:

1. Extend the numerical model with geometry related parameters (which can be derived from the);
2. Conduct a sensitivity analysis (Section 7.1) on these parameters to establish the required changes in the features of the computer drawings.

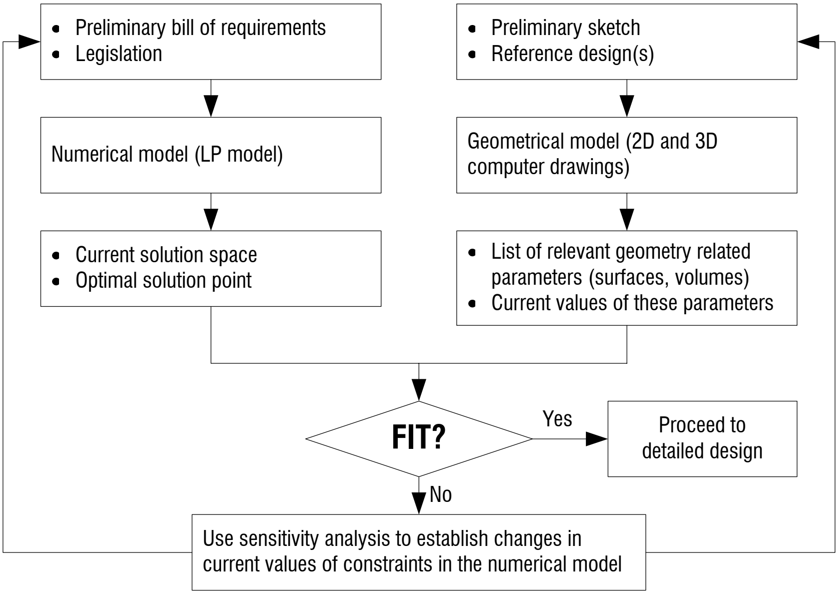


Figure 3.8 Integration of numerical and geometrical modelling through sensitivity analysis of constraints

The integration of the numerical LP model and the geometrical model, as described here, is absolutely essential to ensure that the model concerned has sufficient *reality value*, i.e. the extent to which the model reflects reality. Using a numerical model exclusively may give results which can turn out to be completely unrealistic when it comes to translating them into shapes and physical locations. Conversely, nice drawings – made by pencil or computer drawings – can turn out to be completely unrealistic because they violate physical and financial constraints.

Such loss of *reality value* can be avoided by continuously checking that the results of one model are meaningful in the other and vice versa. Hence, the necessity of integrating numerical and geometrical modelling.

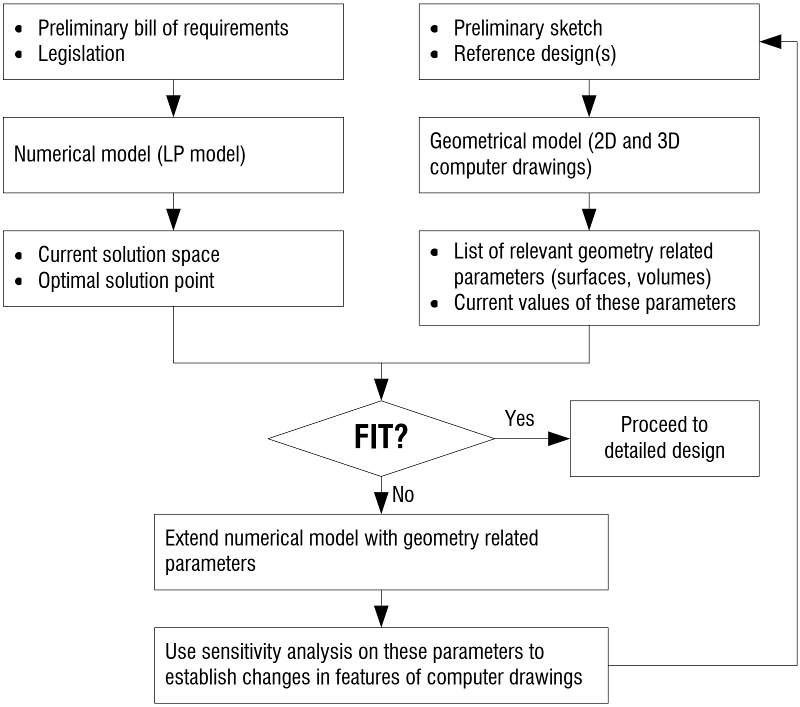


Figure 3.9 Integration of numerical and geometrical modelling through sensitivity analysis of geometry related parameters

3.7 Conclusions

1. In Open Design, as opposed to classical linear optimisation, constraints are not considered to be fixed but to be negotiable amongst stakeholders.
2. The Open Design process is basically the same for urban planning and for complex construction projects.
3. Thinking in terms of a solution space rather than a solution point is characteristic for the open designer. It significantly facilitates the realisation of creative, unconventional architectural ideas.
4. Numerical and geometrical modelling should be done in parallel in order to achieve mutual feasibility, i.e. that outcomes in one model are also meaningful in the other.

4 Uncertainty reduction and risk assessment

The examples given in the preceding chapter illustrate the usefulness of Open Design methodology for resolving stalemate situations as a result of conflicting stakeholder interests, but also reveal some practical shortcomings.

What happens is, in essence, the following. Initially, the constraints of the various stakeholders are accepted at face value. The computer calculation of the LP model with these constraints then invariably gives the result: no solution possible. But it also specifies which constraints are the most important to achieve a positive solution space. The next step is to get the 'owners' of these crucial constraints around the negotiation table and to recalculate with changed constraints until a positive solution space is reached.

In practice, this procedure entails the following problems:

1. It is not known a priori to which extent crucial stakeholders will be prepared to change 'their' constraints.
2. In the LP model only one variable can be optimised. All other variables are constraints. Which variable should be selected as the one to be optimised is open to question.
3. Once a positive solution space has been reached, no further decision support information is provided related to the selection of the final solution (within the solution space).

In this chapter we describe some complementary concepts to resolve these problems (Van Gunsteren, 2000b).

4.1 Uncertainty and risk

Let us first define what we mean by *uncertainty* and *risk*.

- *Uncertainty:* a lack of sureness about something; state of not knowing definitely.

  Uncertainty relates to a situation in which one does not know what could be expected. For instance, in Open Design: not knowing a priori which stakeholders and associated constraints will be crucial for a positive solution space and how stubborn or lenient they will be in the negotiations. Uncertainty, therefore, pertains to the *relevance* a parameter may or may not have.

- *Risk:* the possibility of loss or damage; probability of such loss.

> Risk relates to a situation in which one knows what to anticipate and one can estimate the probability of it becoming reality. For instance, in Open Design: the risk that actual cost of the project will be higher than assumed in the LP calculations. Such probabilities can be taken into account in calculations, hence the expression a *calculated risk*. Risk, therefore, pertains to the values a parameter may have in a particular situation.

4.2 Uncertainty reduction in Open Design

So far, uncertainty reduction in Open Design has been dealt with as follows.

Initially, all stakeholders set the values for their constraints as they wish. With these values the LP model will, in general, not yield a positive solution space. The sensitivity analysis of the computer calculation will indicate, however, which constraints are more important than others. The owners of these crucial constraints can then negotiate amongst themselves, until a positive solution space is reached.

This procedure is, by nature, iterative and unsatisfactory in the sense that not all stakeholders are treated equally. Only a few have to give in. Where should we draw the line for crucial stakeholders' At three, four or five? The higher their number, the more complicated the negotiations will be. We therefore recommend asking each stakeholder to specify three values instead of one for the constraint assigned to the stakeholder:

1. An *ideal value*, as seen from the stakeholder's viewpoint;
2. An *acceptable value*, i.e. the value the stakeholder would accept without much discussion;
3. A *walk-out value*, i.e. the value the stakeholder would only accept when absolutely necessary and after thorough discussion.

This procedure is similar to estimating costs and revenues of investment projects in Monte Carlo simulations. For both costs and revenues three estimates are given:

1. A pessimistic value, defined as having a probability of 10% that reality will be worse than that;
2. A most probable value (best guess);
3. An optimistic value, defined as having a probability of 10% that reality will be better than that.

In general, the probability curve through these three points will not be symmetrical but skewed. The Monte Carlo simulation of the financial return calculation then provides the probability distribution for the financial return (Net Present Value or Internal Rate of Return).

Experience with this procedure shows that calculations with the most probable values as given by experts tend to provide a reasonable outcome, whereas the same calculations based on single values given by experts tend to give weird results. Apparently, when people are asked to give only one value, they will actually give their pessimistic estimate without saying so. A calculation based on such values will always give an unsatisfactory financial return. In practice, the financial analyst has then to challenge the experts or managers involved and ask them if they can do better. They ask the sales manager if he can sell better, ask the production manager if he can produce more efficiently, etc. This goes on until a financial return has been reached which is in line with the company's policy. Calculation with most probable values, by contrast, usually gives a satisfactory result straight away, with the important advantage that managers don't feel manipulated. By accepting their estimates at face value, they feel committed to the outcomes.

The conclusion is that people become a lot more genuine when asked to give three values of the variable concerned. If only one value is asked for, the answer is distorted by the perception of risk of the respondent.

Having the three values for the constraints as defined above, LP calculations can be made for each set of values:

1. The *ideal values*. The solution space will, in general, be zero (no solution possible);
2. The *acceptable values*. In many cases, the solution space will be positive;
3. The *walk-out values*. In general, the solution space will be positive.

A sensitively analysis can be made to establish which constraints are crucial. In this way, a lot more insight can be obtained before going into negotiations to change crucial constraints than in the case of an analysis based on single values.

4.3 The variable to be optimised: financial return

Which variable should be optimised – once the constraints allow a positive solution space – is open to question. In the case of an office building, for instance, we may choose the return on investment, the office space per employee, the parking area, the budget for a prestigious entrance, etc. The problem can be circumvented to a certain extent by assigning weight factors to a limited number of variables and optimise the weighted sum of these. The choice of the weight factors and the selection of the set of variables remain, however, arbitrary. We therefore recommend optimising, ultimately, always the same variable: financial return, either Net Present Value (NPV) or Internal Rate of Return (IRR). At the same time considerations related to variables like the budget for a prestigious entrance or the size of the parking lot should be supported by information from Monte Carlo simulations as described in the next section.

It should be emphasised that our recommendation to select financial return as the variable to be optimised only holds for the *final stage* of the Open Design process. At intermediate stages, in particular to facilitate negotiations among crucial stakeholders, other variables are chosen in the objective function to show the effect thereof to stakeholders. They then can better decide on possible concessions regarding the constraints assigned to them. This will be elaborated in Section 7.2, Multiple Objectives.

4.4 Risk assessment in Open Design

Once the constraints allow a positive solution space, the question arises how to utilise the available financial margin. For instance, should we use it for a prestigious entrance and a large parking lot or should we keep the investment as low as possible? The former – the expensive option – is more risky in the sense that users may not be prepared to pay extra rent for the nice entrance and the parking area. There is also a reasonable chance, however, that they will be prepared to pay more for it than its (discounted) cost. In that case the financial return will be higher than for the inexpensive option (no prestigious entrance and only a limited parking lot).

The probability curves for the financial return of the inexpensive and the expensive options are typically as shown in Figure 4.1.

The (cumulative) probability $\bar{P}$ that the return will be above a minimum threshold $\bar{R}$ is:

$$\bar{P}(\bar{R}) = \int_{\bar{R}}^{\infty} P dR \tag{4.1}$$

This gives us the risk profiles of the two options (Fig. 4.2).

If the investor prefers a moderate but sure return, he should choose option 'X'. Conversely, if he wishes to go for a more ambitious return and is willing to accept the associated higher risk, then he should choose option 'Y'. The difference between the two risk profiles is caused by the associated probability curves of the rent users will be prepared to pay.

Risk assessment by introducing probability distributions for variables entailing risk was already proposed by Hertz (1969) in the late sixties. The probability distributions of the variables determining the return on investment are the basis of Monte Carlo simulations as shown in Figure 4.3.

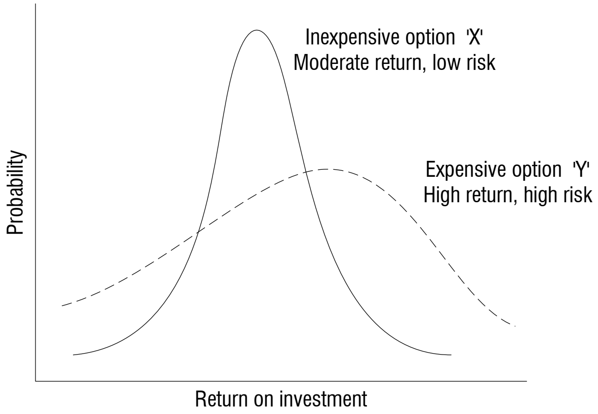


Figure 4.1 The investment dilemma: moderate return, low risk versus high return, high risk

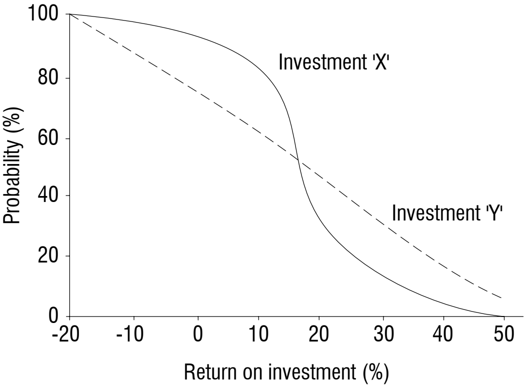


Figure 4.2 Risk profiles (cumulative probability) of two investment options

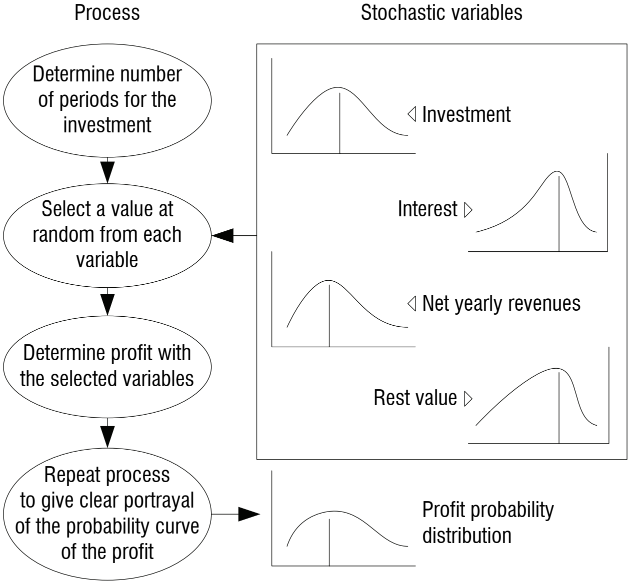


Figure 4.3 Monte Carlo simulation for a real estate investment

As mentioned before, instead of making one estimate for each variable that affects the return of investment, three estimates are made:

1. A pessimistic estimate, defined as having a probability of 10% that reality will be worse than that;
2. A best guess;
3. An optimistic estimate, defined as having a probability of 10% that reality will be better than that.

These three points determine the probability distribution for the variable concerned. With these distribution curves, Monte Carlo simulation finally gives the probability distribution for the return on investment.

The arithmetic of the Monte Carlo simulation is simple: whenever a risk variable enters into the calculation, a random number generated by the computer is corrected with the (skewed) distribution of the variable concerned. The calculation is done, say, 2 000 times. The resulting 2 000 different outcomes for the return on investment provide the probability distribution of the return on investment.

This approach has two important advantages compared to conventional investment analyses based on single values:

1. It allows trading-off *moderate return–low risk* investments against *high return–high risk* investments. The decision support information provided by the two different risk profiles is extremely relevant for an investor.
2. As already mentioned before, by asking experts a range instead of a single estimate, they tend to be genuine. When people are asked to give only one estimate, they tend to give their pessimistic guess without saying so.

An underlying assumption of the Monte Carlo simulation is that de variables involved are *stochastically independent* (see also Section 8.4).

It should be noted that the three estimates asked from experts for risk assessment of the investment are of a different nature than the three values asked from stakeholders for the constraints in the LP calculations. The former give the range in which a variable, such as construction cost, must be expected. The latter determine the uncertainty related to stakeholder negotiations.

4.5 Net Present Value or Internal Rate of Return

Discounted cash flow investment analysis can be done in two different ways:

1. Specify a required interest rate and calculate the net present value (NPV) of the investment, i.e. the total of all future cost and revenues discounted to today with the specified interest rate. The alternative having the highest NPV is best. Inflation can be included in the specified interest rate or be taken into account separately;
2. Calculate the internal rate of return (IRR), i.e. the interest rate giving a zero Net Present Value (NPV$= 0$). The alternative having the highest IRR is best.

The latter is easier to work with because it is a non-dimensional figure, but the NPV can also be made non-dimensional by, for instance, relating it to the upfront investment. The IRR is nevertheless preferable, because it is the criterion that determines how easy or difficult the financing of the project will be. Quite contrary to general belief, there is an overabundance of money in this world along with a shortage of good projects. Investors have to invest, they have to do something with their money. They will, in general, invest into the projects giving the best return, i.e. showing the best IRR.

It should be noted that the NPV criterion and the IRR criterion will produce the same preference when comparing two competing projects as long as the yearly cash flows do not vary too much. Only in the case of widely varying yearly cash flows the NPV criterion is to be preferred. In Open Design practice, the condition of fairly constant yearly cash flows is always satisfied.

4.6 Conclusions

1. In Open Design, the uncertainty related to the willingness of stakeholders to change their constraints can be reduced by asking them to give three values for their constraint:

    1. An ideal value;
    2. An acceptable value;
    3. A walk-out value.

    This enables a far greater insight to be gained from LP calculations before entering into negotiations with stakeholders to change their constraints.

2. The variable to be optimised in the final LP calculations should in general be financial return, preferably the Internal Rate of Return. All other variables are to be treated as (negotiable) constraints.

3. Risk assessment should be done by Monte Carlo simulations. The resulting risk profiles enable the trade-off to be made between *high return–high risk* and *moderate return–low risk* alternatives.

5 How to deal with the overabundance of information

Nowadays the problem of information handling is not a shortage of information, but an overabundance of information. There is more information available than an individual can handle. A concept for dealing with this issue in the Open Design process is described in this chapter.

5.1 Distinction between data and information

Beauty is in the eye of the beholder, and so is information. Information is always related to the purpose the user of that information has in mind. Information is based on data – facts and figures – which only become useful to the user once arranged in such a way that they become meaningful to him.

Data can be stored in databases. To become useful, the data has to be transformed into information. The Open Design process can be seen as the transformation of data into information for a group of stakeholders and designers.

Information has to be reduced to what each individual can handle. In the Open Design process this is a dynamic process, because stakeholders and their constraints as incorporated in the LP model vary over time.

5.2 A typology of information

A typology of information has been proposed by Van Gunsteren (1988) which can be summarised as follows.

Let us consider the design decision of an architect involved in an Open Design process, i.e. in a situation where he has to deal with a multitude of stakeholder interests. If God himself were to make that decision, He could make use of all the information relevant to the matter concerned. This information is labelled *relevant information* (Fig. 5.1).

The architect, of course, receives much more information than he is ever able to use for his particular decision. This information is labelled *information paid attention to*. The part of that information having relevance to the purpose concerned – the design decision – is called *used information*.

Relevant information to which no attention is paid, is labelled *Cassandra information*. (The god Apollo, being in love with Cassandra, the beautiful daughter of King Priam of Troy, gave her a present: the ability to predict the future. When she rejected him in spite of that gift, he could not take it back because a gift from a god is a gift forever. Therefore, he provided her with another: no one would ever listen to her. When she warned the Trojans about the wooden horse, her advice was ignored and the city was subsequently destroyed.)

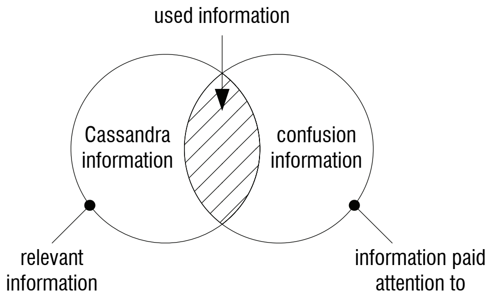


Figure 5.1 Information pertinent to architects

The information paid attention to by the architect that is not relevant is called confusion information, as this type of information tends to confuse the issue.

When dealing with information (in an Open Design process) the architect should, of course, primarily be concerned with Cassandra information. He must strive to reduce the likelihood that relevant information is overlooked or ignored.

In principal, this can be done in two different ways (Fig. 5.2):

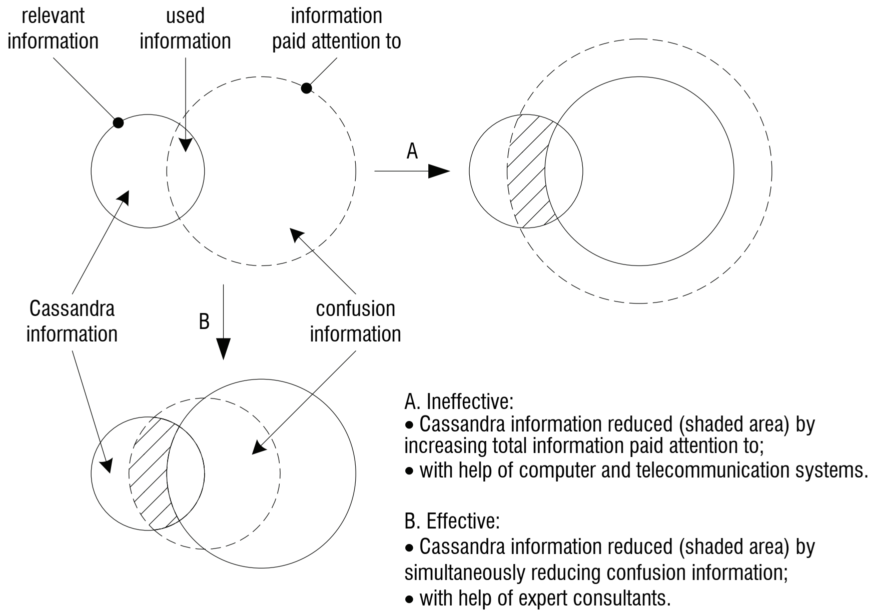
1. Increasing the information paid attention to. It cannot be denied that in this way Cassandra information is indeed reduced, but at the same time confusion information increases. The availability of ever more powerful computers generates a trend in this direction (making the problem of overabundance of information worse than it was already);

2. Reducing Cassandra information along with reducing confusion information. This is what good (expert) consultants (and designers) try to do: telling their client what is relevant to him. No more, no less.

The latter is the essence of the typology: try to simultaneously minimise both Cassandra information and confusion information.

5.3 Information handling in Open Design

In Open Design, the constraints of various stakeholders that are incorporated into the LP model constitute the *information paid attention to*. Initially, the architect keeps the model simple. He or she starts with a limited number of constraints. Sensitivity analysis (giving the effect of a constraint on the solution space) with that simple model reveals which of these constitute *used information* and which can be considered to represent *confusion information*. Whenever



A. Ineffective:
- Cassandra information reduced (shaded area) by increasing total information paid attention to;
- with help of computer and telecommunication systems.

B. Effective:
- Cassandra information reduced (shaded area) by simultaneously reducing confusion information;
- with help of expert consultants.

Figure 5.2 Two approaches to reducing Cassandra information

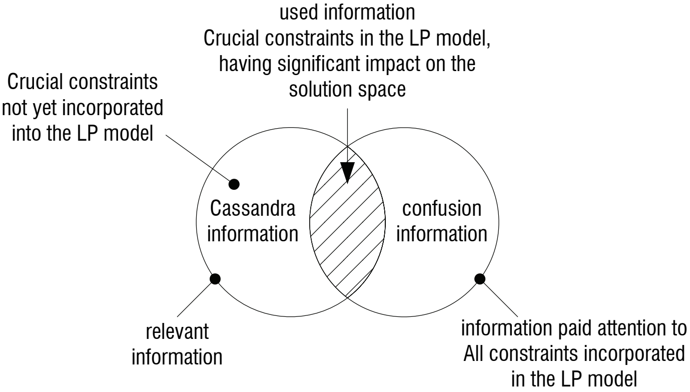


Figure 5.3 In Open Design, both information paid attention to and relevant information change when new constraints are added to the LP model

a new stakeholder with a new constraint is added to the model, it is again sensitively analysis which determines if the new constraint represents *used information* and thereby reduces *Cassandra information*.

In Open Design, therefore, what is *used information* and what is *confusion information* is not constant but changes over time. Actually, it changes every time a new constraint is added to the LP model (Fig. 5.3).

5.4 Conclusions

1. The Open Design process can be seen as transforming data into information meaningful to a group of stakeholders and designers.

2. In Open Design, the problem of overabundance of information is dealt with in a dynamic way. What is *used information* and what is *confusion information* changes every time a new constraint is added to the LP model.

6 How to deal with quality requirements

The demands of stakeholders in an Open Design process can be seen as quality specifications which the final design has to satisfy. Some of such specifications are of a 'hard' nature, such as the area available for a building, or a 'soft' nature, such as the requirement of a 'prestigious' entrance. Some demands are explicit, i.e. specified, while others are tacitly assumed to be valid by stakeholders but not less important. How to deal with such hard or soft and explicit or implicit demands from stakeholders will be described in this Chapter.

6.1 A quality classification

Van Gunsteren (2003) has proposed a quality classification which we will summarise in this Section and extend in the next one to the methodology of Open Design.

What is quality?

- Doing or making something well according to the norms of an evaluator or end user. These norms depend on the purpose one has in mind, hence the definition:
- Quality is fitness for purpose.

That means quality is:

1. Related to a subjective purpose;
2. A perception.

Absolute standards of quality do not exist. What quality is depends on the needs of the user. These needs are not only determined by the user's personal desires and preferences, but whenever new technologies offer new possibilities, the demands of users will also become more exigent.

Quality can be:

- *Relevant* or irrelevant;
- *Realised* or not realised in the product or service;
- *Specified* or not included in specifications.

Combinations of these aspects yield seven categories of quality which we will now discuss.

Quality specifications will never cover exactly all quality which is relevant to the end user (Fig. 6.1). Relevant quality which is covered by specifications

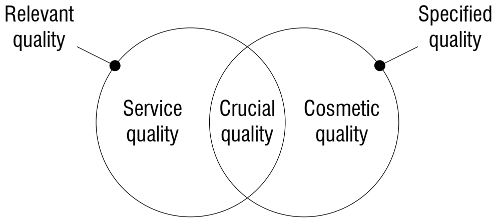


Figure 6.1 Quality specifications never cover exactly all relevant quality

is labelled *crucial quality*, because it is absolutely crucial to realise this type of quality in the product or service. In the case of non compliance, a claim would be justified both formally and also because the user really needs that quality for his or her purpose. Relevant quality which is not specified is called *service quality*, because this quality has to be delivered as a service if the end user's needs are to be properly satisfied. Specified quality that does not serve any purpose of the end user is labelled *cosmetic quality*, which consists of:

- Ritual quality: realised cosmetic quality, and
- Excuse quality: non-realised cosmetic quality.

Specifications and standards are sometimes used as an excuse to exclude a supplier. For instance, the dimensions of car number plates in a certain country were prescribed in such a way that foreign suppliers were handicapped. In another country, an old-fashioned, inaccurate method to measure the dimensions of marine propellers (using templates) was prescribed to protect the backward domestic industry against more advanced competitors.

Cosmetic quality should not be confused with cosmetic measures to give the product an attractive appearance, such as goodlooking packaging. This kind of cosmetics belongs to service quality as it satisfies a real users' need.

Quality realised in the product or service will never cover exactly what is relevant and/or specified. Realised quality which is neither relevant nor specified is labelled *wasted quality*, as it serves no true purpose. Wasted quality is non-existent in the engineer's ideal of Caesar's war chariot which never fails but at the end of its lifetime disappears completely into dust. If one bolt would still remain, then that bolt would have been constructed too conservatively and that would have had adverse weight implications. Unnecessary weight impairs the effectiveness of the chariot, which Caesar would never accept. This completes our classification of the seven categories of quality (Fig. 6.2).

It is in the interest of the buyer (or end user) to be flexible with regard to *cosmetic quality* – i.e. excuse and ritual quality – and to pay due attention to *service quality* – i.e. relevant but not prescribed quality. He should be prepared to exchange some cosmetic quality for extra service quality.

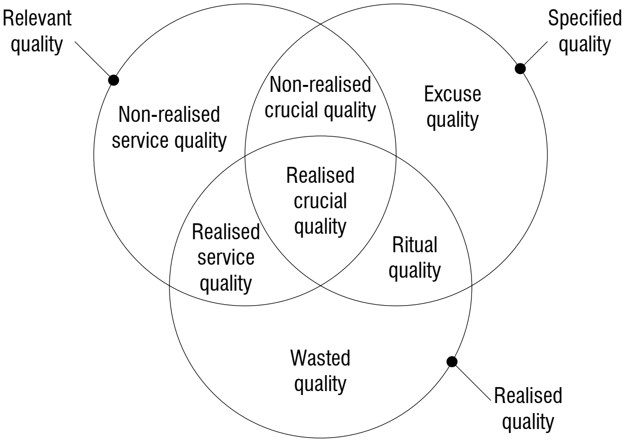


Figure 6.2 Classification of seven categories of quality

6.2 Extension to Open Design: quality incorporated in the mathematical model

Let us extend this quality classification to the methodology of Open Design. To this end we define:

- Relevant quality = quality as relevant to all stakeholders;
- Specified quality = quality as specified in the bill of materials and legislation;
- Realised quality = quality incorporated in the LP model.

In the first version of the LP model only a small part of the relevant and specified quality is incorporated (Fig. 6.3). In the second version some more service quality and specified quality can be accounted for. In the third and later versions still more stakeholder constraints and more rules or specifications are incorporated.

In each new version of the LP model we can vary the values of the constraints. These variations constitute *iterations* of the LP model.

In the example of the professor's time allocation problem of Section 3.1, the first version of the LP model is limited to two variables x_1 and x_2, teaching time and research time. Iterations may pertain to the constraint of his family commitment, for instance 30, 40, or 50 working hours per week.

In a second version of the LP model, the professor may split his teaching time into two parts – time for lecturing and time for individual coaching of

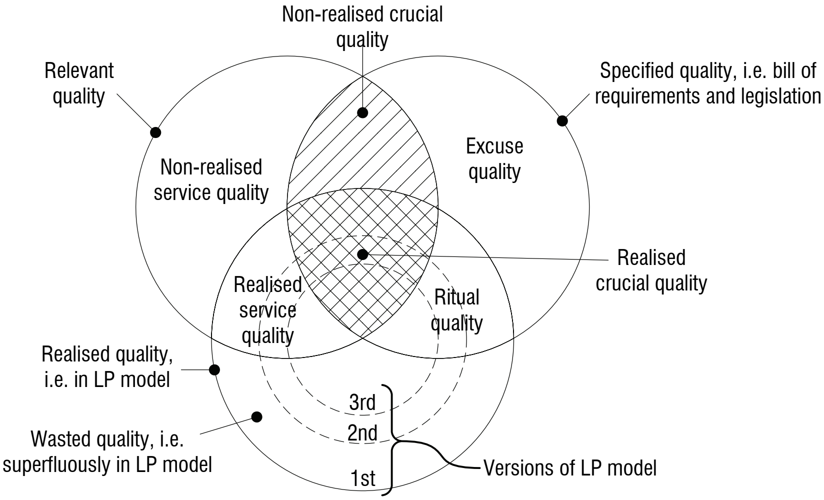


Figure 6.3 In each new version of the LP model mode quality aspects are covered

students – and set constraints for each of them. Within that second version of the model he then can vary the constraints in different iterations.

To summarise, in Open Design we see different *versions* of the LP model being made to accommodate the interests of emerging shareholders. Within these versions, *iterations* are made with different values for constraints in order to achieve a positive solution space.

Nevertheless, it may be that a positive solution space cannot be reached. The designer of the LP model should then look for an opportunity to exchange some cosmetic quality for some extra service quality by asking for exemptions from specifications or rules that are not relevant in the case at hand but a hindrance to getting a positive solution space.

This implies that in Open Design the bill of requirements and building legislation are not considered to be completely fixed. There should be room for exceptions that are reasonable in the light of the specific circumstances. Of course, the effort of obtaining approval from the authority concerned must be justified by the impact on the solution space.

6.3 Quantification of soft variables

Soft variables are related to constraints such as:

- a prestigious entrance;
- an eye-catching appearance;

- environmentally friendly,

Such variables can be taken into account in the LP model by proper quantification. For instance:

- a prestigious instance: extra budget for it;
- an eye-catching appearance: idem;
- environmentally friendly: (specified) constraint for area to be kept green;

Within the extra budgets for the prestigious entrance and eye-catching appearance of the building, the architect has complete freedom. What the green area will look like is up to the landscape designer. When such constraints related to soft variables become roadblocks to achieving a positive solution space, negotiations between stakeholders can take place to alleviate them in the same way as is done with constraints that represent 'hard' variables.

6.4 Reference designs

Let us consider the case of a ship owner who wishes to add a new cargo ship to his fleet. His prime interest is, of course, how much cargo (for which he gets paid) the ship can carry. He further specifies a minimum sustained speed and an action radius (distance the ship can sail without bunkering). How can the naval architect then generate a first design, i.e. establish the main dimensions of length, breadth, and draught of the ship?

The most important constraint in this case is the law of Archimedes: the weight of the ship, including cargo and fuel, equals the weight of the water displaced. This constraint is extremely difficult to cope with because the weight is the sum of a multitude of parts and components.

If the naval architect starts from scratch, i.e. an arbitrary first choice of main dimensions, he will invariably find that the 'design' does not satisfy the law of Archimedes. By variation of main dimensions he can finally arrive at a set of values which satisfies Archimedes' law. In each variation a complete weight calculation, i.e. establishing the sum of all weights involved, has to be done. This is an almost impossible and extremely cumbersome task, because most weight components are not known *a priori*.

The usual approach, therefore, is that the naval architect tries to find some existing ships which more or less satisfy the demands of the owner. He then studies these reference ships – or reference designs – and derives relevant ratios from their designs. For instance the ratio dead weight/displacement (dead weight = the weight of cargo and fuel). Once he has established this ratio for the class of ships concerned, he can apply it to his own design. From the owner's requirements he can establish the dead weight (the fuel can be estimated from the speed and action radius requirements). The dead weight/displacement ratio derived from the reference ships then provides a first estimate for the displacement. The block coefficient for the class of ships concerned, i.e. the displacement over the 'bounding box' around it, can be established in a similar way. Stability requirements determine the ratio breadth/draught, and the requirement of minimum wave resistance provides the ratio of speed over the square root of the length. From these ratios, the naval architect obtains his first set of main dimensions without carrying out any weight calculations. This procedure based on reference designs constitutes an enormous time-saver in the design process.

Similarly, the architect of a building can make use of reference projects by deriving certain ratios from them and applying these ratios to his particular design. For certain categories of buildings the latter has already been done for him. The resulting ratios are published in norm tables, for instance the REN: the Real Estate Norms. Such 'norms' are no more and no less than the result of an extensive regression analysis of a vast number of existing buildings. As in ship design, such empirical ratios are extremely useful for the efficiency of the design procedure. The architect should be aware, however, that these 'norms' are descriptive, not normative. They are no more than averages (weighted with the least squares method) of existing designs. As a corollary, the architect should not be afraid to deviate from these norms when his design problem so requires.

Equally important is to note that the architect can establish his own 'norms' from a limited number of reference designs by carrying out a regression analysis as described in Section 8.5. This is particularly recommendable when the design is unconventional and deviates substantially from the designs underlying the REN norms or other empirical ratios.

Example: Municipality office of The Hague*

> RFPs (Request For Proposal) were directed towards selected construction firms for the municipality building of The Hague in The Netherlands. The design had been made by the American architect Meier. In the RFP, reference was made to several existing buildings designed by Meier, but the construction firm with the winning bid had not paid any particular attention to them.
>
> When the construction firm later complained about excessive quality demands from Meier, the municipality could successfully refuse to pay any extra for this, because the contractor could have been aware of those demands if he had paid proper attention to

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*F. Seyffert, private communication.

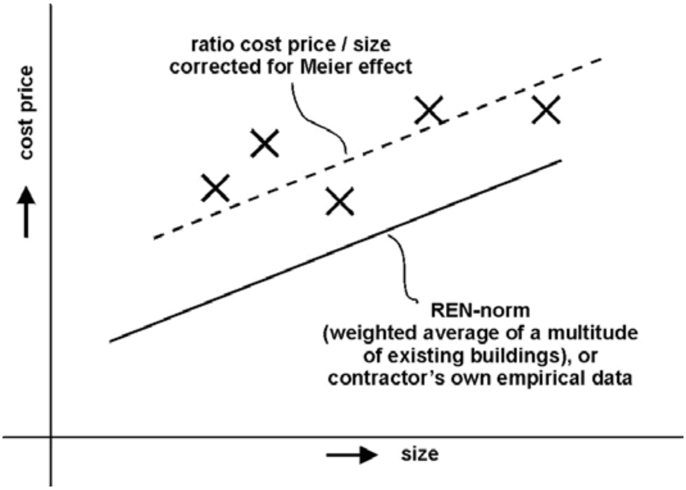


Figure 6.4 Correction of empirical data by regression analysis of reference designs

the reference designs. What the contractor should have done is the following (described here in a simplified way):

- Establish the cost price from the ratio cost price/size according to the REN norms or the contractor's own empirical data (Fig. 6.4). Plot some existing 'Meier designs' in the Figure (indicated by crosses);
- Calculate a correction factor *C* on price for the 'Meier-effect' by a linear regression analysis of the reference designs: cost price 'Meier' = *C* × cost price according to REN norm (or own empirical data). Adjust the bidding price for the 'Meier-effect'.

By doing so, the contractor could have avoided his severe losses and a lot of fruitless dispute.

6.5 Conclusions

1. In Open Design, the bill of materials and building legislation are not considered to be fixed at all cost. Exemptions are always possible provided they can be justified convincingly to the relevant stakeholders and authorities.
2. In the dynamic Open Design process, a distinction should be made be-

tween *versions* of the LP-model having different constraints, and *iterations* with different values of the constraints within one version.

3. When the solution space is zero – i.e. no solution is possible with the current constraints – the open designer should look for possible alleviations in the constraints that are most determinant, regardless of whether they are related to rules and regulations or to the demands of specific stakeholders.

4. 'Soft' variables can always be 'translated' into quantitative variables that can be used in the LP model.

5. Empirical data published in norm tables, such as Real Estate Norms, can be extremely useful in the initial phases of the design process. Such 'norms' are descriptive, not normative, for they represent weighted averages of existing designs. As a corollary, they should never be used in a normative manner. If necessary, the open designer should not hesitate to deviate from them.

6. If the architectural concept at hand differs substantially from the designs underlying the empirical ratios, it is recommendable to derive new ratios by regression analysis of reference designs.

7 How to deal with conflicting requirements in the mathematical model

The requirements from the various stakeholders are almost always conflicting to such an extent that concessions have to be made to make a solution possible at all. In this chapter we describe a methodology to establish the required concessions and their distribution amongst stakeholders. Sensitivity analysis identifies the group of crucial stakeholders that, collectively, has to make concessions to resolve stalemate situations. Multiple objectives or multi criteria optimisation provides a method to distribute the required concessions amongst crucial stakeholders in a manner acceptable to them.

7.1 Sensitivity analysis

How can the open designer find out which constraints are crucial to arrive at a positive solution space and invite their associated stakeholders to the negotiation table? In other words: how can he or she establish the sensitivity of the solution space to variations in the constraints?

If the model is still relatively simple, he or she can vary one constraint – by say 10% – while keeping all other constraints unchanged, and see what happens with the solution space. When the model includes a large number of constraints, however, this primitive method of analysing the sensitivity of the solution space to the various constraints soon becomes very cumbersome if not prohibitive. Fortunately, the Simplex method used to resolve the inequalities of the LP model almost automatically provides the information needed to cope with this problem, as we will describe in this section.

As described in Chapter 4, stakeholders should preferably specify three values for their constraints:

- an ideal value;
- an acceptable value;
- a walk-out value.

During the initial phases of the Open Design process, these values may coincide for certain constraints – that means only one value is used – while for other constraints ranges are given.

Only in exceptional cases will calculating exclusively with ideal values yield a positive solution space. If so, everybody will be happy and some money will still be left. If not, the question arises to what degree constraints will have to be alleviated within the range between the ideal value and the walk-out value.

When the model is relatively simple, in the sense that the number of constraints is limited, a trial-and-error approach may suffice, but in cases involving many constraints this would become extremely cumbersome. In such cases we need to know which constraints have a great impact and which ones are relatively unimportant for achieving a positive solution space. *Sensitivity analysis* provides the answer to this question.

Sensitivity analysis in linear programming is closely linked to the concept of *duality* which will be described below.

Recall that our LP model can be formulated as:

$$\text{Maximise} \quad Z = \sum_{j=1}^{n} c_j x_j \tag{7.1}$$

subject to:

$$\sum_{j=1}^{n} a_{ij} x_j \leq b_i \qquad \text{for } i = 1, 2, \ldots, m$$

and

$$x_j \geq 0 \qquad \text{for } j = 1, 2, \ldots, n$$

We call this the primal problem. The dual problem (connected to this primal problem) is obtained by interchanging the c vector and the b vector and minimising instead of maximising (the a-matrix remains unchanged):

$$\text{Minimise} \quad Y = \sum_{i=1}^{m} b_i x_i \tag{7.2}$$

subject to:

$$\sum_{i=1}^{m} a_{ij} y_i \leq c_j \qquad \text{for } j = 1, 2, \ldots, n$$

and

$$y_i \geq 0 \qquad \text{for } i = 1, 2, \ldots, m$$

See Table 7.1.

From the symmetry apparent from the table, we can derive the *Dual Theorem* (the asterisk refers to optimality):

If

$$(x_1^*, x_2^*, \ldots, x_n^*)$$

Table 7.1 Primal-dual table

			Primal problem					
			Coefficient of				Right side	
			x_1	x_2	$\dots$	x_n		
Dual problem	Coefficient of	y_1	a_{11}	a_{12}	$\dots$	x_{1n}	$\leq b_1$	Coefficients for objective function (minimise)
		y_2	a_{21}	a_{22}	$\dots$	x_{2n}	$\leq b_2$	
		$\vdots$	$\vdots$	$\vdots$		$\vdots$	$\vdots$	
		y_m	a_{m1}	a_{m2}	$\dots$	x_{mn}	$\leq b_m$	
	Right side		$\geq c_1$	$\geq c_2$	$\dots$	$\geq c_n$		
			Coefficients for objective function (maximise)					

and

$$(y_1^*, y_2^*, \dots, y_m^*)$$

are optimal solutions for the primal and dual problems respectively, then:

$$\sum_{j=1}^{n} c_j x_j{}^* = \sum_{i=1}^{m} b_i y_i{}^*$$

In other words: the optimal values of the objective functions of the primal and dual problem are equal.

The optimal dual variables y_i^* are called *shadow prices*, because the shadow price y_i^* for resource i represents the (maximum) unit price you should be willing to pay to increase the allocation of that resource. The shadow price y_i^* (i.e. the optimal value of a dual variable) indicates how much the objective function changes with a unit change in the associated right-hand-side constraint b_i, provided the current optimal basis remains feasible.

The latter implies that the validity of dual values (shadow prices) is limited to a certain range. Outside that range the dual value itself will change as a result of a change to a different optimal solution or the problem will become infeasible.

A corollary of the *Dual Theorem* is the *Theorem of Complementary Slackness*:

Let

$$x_j^* \qquad \text{for } j = 1, 2, \dots, n$$

and

$$y_i^* \qquad \text{for } i = 1, 2, \dots, m$$

be corresponding feasible solutions to the primal and dual problems respectively. Then both are optimal if and only if:

$$y_i^*(\sum_{j=1}^{n} a_{ij}x_j^* - b_i) = 0 \qquad \text{for } i = 1, 2, \ldots, m$$

and

$$x_j^*(\sum_{i=1}^{m} a_{ij}y_i^* - c_j) = 0 \qquad \text{for } j = 1, 2, \ldots, n$$

This implies that whenever a constraint in one of the problems holds with strict inequality, so that there is *slack* in the constraint, the corresponding variable in the other problem equals zero. Or: if there is *slack* in a constraint, i.e. that constraint is not determinant for the optimal solution, the shadow price of that constraint is zero.

The concept of *reduced cost* is similar:

Let $x_j^* = 0$, i.e. activity x_j^* does not contribute to the optimal solution (for instance profit). The dual value of activity x_j^* is then the rate of change in the objective function (for instance profit) if x_j^* were forced into the solution, even though it is not optimal to do so.

Such dual value is called *reduced* cost because it represents the amount by which the cost c_j of activity x_j^* would have to be reduced in order to make it profitable to put it into the solution. If activity x_j^* has a positive value, its dual value will always be zero.

Reduced costs also have a range of validity outside which the optimal solution changes or the problem becomes infeasible.

To summarise: the dual values provide a first indication of the sensitivity of the objective function to changes in the coefficients concerned. *Shadow prices* are related to the sensitivity of the objective function to the right-hand-side constraints bi . *Reduced cost* refers to the changes in the coefficients c_j of the objective function required to force the associated activities into the optimal solution. For instance, in the case of the Open Design of an office, let x_1, x_2, x_3 be the number of one-person, two-person, and three-person rooms respectively, with unit cost c_1, c_2, c_3, and $x_1^* = 0$ (no one-person rooms in the optimal solution). The *reduced price* of x_1 then indicates how much the price of a one-person room c_1 must be reduced to force x_1 into the optimal solution, i.e. to make it worth having some one-person rooms in the office.

Decision variables x_j having a value zero in the optimal solution are called *non-basic variables*. Decision variables x_j having a non-zero value in the optimal solution – i.e. they form part of the optimal solution – are called *basic variables*. Reduced prices can be seen, therefore, as the amount by which the unit cost c_j has to be reduced to change a non-basic variable $x_j = 0$ in the optimal solution into a basic variable ($x_j > 0$ in the optimal solution).

The sensitivity of the objective function Z to changes in the coefficients c_j of the basic decision variables x_j follows from the definition of c_j: contribution to Z per unit of x_j. This is only true however, within a certain range. Outside that range the optimal solution will change, as we will explain for the manufacturing allocation problem with only two decision variables x_1 and x_2 (Figure 3.3).

The slope of the line representing the objective function $Z = c_1x_1 + c_2x_2$ is determined by the coefficients c_1 and c_2, specifically by the ratio c_1/c_2. If we keep c_2 constant, we can change the slope by changing c_1 and vice versa. The line representing the objective function for the optimal solution (x_1^*, x_2^*) will then turn around the point (x_1^*, x_2^*), but no more than until a next corner-point feasible solution is reached. In Figure 3.3, turning anti-clockwise, that point will be the intersection of the lines $a_{21}x_1 + a_{22}x_2 = b_2$ and $a_{31}x_1 + a_{32}x_2 = b_3$. Turning clockwise it will be the point $(b_1/a_{11}, 0)$. The range of validity for c_j, therefore, indicates how much can be changed (keeping all other parameters the same) without affecting the optimal solution (x_1^*, x_2^*). The ranges of validity for the coefficients c_j, of basic decision variables are computed in the Simplex procedure when moving, systematically, from one corner-point feasible solution to a better one until no better one can be found.

Systematic sensitivity analysis related to the coefficients a_{ij} of the matrix is rarely used in Open Design practice. Usually, the expert knowledge of the open designer allows him to identify intuitively the few of these coefficients which might have a large impact on the objective function and could be changed to a certain degree. He can then simply verify his ideas by pilot runs with varying values for the coefficients concerned.

We will now describe how *shadow prices* are used to arrive at a solution at all, i.e. how to come from a zero to a positive solution space.

This involves two steps:

Step 1: modify the model by alleviating all (inequality) constraints b_i until an optimal solution is achieved;

Step 2: tighten the constraints as much as possible whilst maintaining a positive solution space.

In its simplest form, Step 1, modification until an optimal solution is reached, goes as follows:

Recall that objective function Z is financial return; all stakeholders' wishes are expressed in the constraints b_i. We start by alleviating all (inequality) constraints b_i with the same fraction p.

So we can write:

$$\text{Maximise} \qquad Z = \sum_{j=1}^{n} c_j x_j$$

subject to

$$\sum_{j=1}^{n} a_{ij} x_j \leq b_i + p b_i \qquad \text{for } i = 1, 2, \ldots, m$$

and

$$x_j \geq 0 \qquad \text{for } j = 1, 2, \ldots, n$$

We then run several pilots for various values of p between 0 (no alleviation) and 1 (100% alleviation). The resulting p-value is used as starting point for Step 2.

If we wish to establish the alleviation (in all inequality constraints) more precisely, we can let the model itself provide the alleviation (p-value) which is just enough to make the solution space positive. To distinguish it from the previous one, we will denote it with a capital P.

We make P endogenous:

$$\text{Maximise} \qquad Z = \sum_{j=1}^{n} c_j x_j - c_p P$$

subject to

$$\sum_{j=1}^{n} a_{ij} x_j - b_i P \leq b_i \qquad \text{for } i = 1, 2, \ldots, m$$

and

$$x_j \geq 0 \qquad \text{for } j = 1, 2, \ldots, n$$

Of course, if $P = 0$, then no solution is found.

Since we wish to find the lowest possible value for P, we choose an arbitrary but high value for its coefficient c_p in the objective function (in other words: we make the unit cost of P high). With the resulting P-value, we proceed to Step 2.

The first pilot run, with the alleviation (p- or P-value) found in Step 1, provides us with the *slack variables* of the non-basic variables (the decision variables x_j not contributing to the optimal solution); the *slack variables* indicate how much the non-basic variables x_j can be increased without affecting the optimal solution.

Step 2, modification by changing the constraints as much as possible to their original values whilst maintaining a positive solution space, implies that we reduce each constraint b_i to:

- either its original value;
- or until its slack variable becomes zero.

With these constraints b_i ($i = 1, 2, \ldots, m$) we can calculate shadow prices y_i ($i = 1, 2, \ldots, m$) and their ranges of validity.

This information completes our search for crucial stakeholders, i.e. the stakeholders who will have to alleviate their constraints to make a solution possible at all.

At this point we also have a first estimate of the extent to which they will have to give in from their ideal values and what effect this will have on the objective function (shadow prices).

What we do not know at this stage is:

- To what extent each stakeholder will be prepared to give in: how lenient or stubborn he or she will be;
- How a compromise made with one crucial stakeholder will affect the required combined compromises with all the others.

This is the subject of the next section.

7.2 Multiple objectives

So far, we have assumed that the *wishes of stakeholders* are incorporated in the mathematical model through the *constraints*, while choosing *financial return* as the objective to be optimised. The reason for doing so is that in Open Design all stakeholders should be treated equally. Concessions to the wishes of stakeholders should only be asked for if that is necessary to achieve a solution at all, and not because some wishes are, by nature, more important than others. In principle, all stakeholders are equal. The reality is usually quite opposite. Financial return is a boundary condition – it should be sufficient to allow the project to be financed – while a number of stakeholders' objectives have to be optimised. Those stakeholders' objectives are usually conflicting. The situation is like a zero-sum game: the more one stakeholder gives in, the less concessions are required from the others.

The sensitivity analysis described in the preceding section has given us a limited number of crucial stakeholders who will have to make concessions to allow a solution at all. How to deal with the conflicting requirements from these crucial stakeholders will be described in this section on Multiple Objectives, also called Multi-Criteria Optimisation.

In optimisation models for multiple objective problems, we can distinguish *non-preference* and *preference methods* (Radford and Gero, 1988). With the *non-preference approach*, we limit the model to the production of information on non-dominated (Pareto) performances. A non-dominated (Pareto optimal) solution is one for which no other solution exists that is capable of providing a better performance in one criterion and no worse performance in all other criteria. Given criteria that completely express the goals of a design problem and a complete Pareto set of solutions for those criteria, the best solution for the stakeholders concerned must lie within the Pareto set. Which member of the set this *is*, is still open to question.

In the *preference approach*, the designer's trade-off preferences are incorporated in the model. For instance, he can reduce the multi criteria problem to a single-criterion problem by assigning weight factors to the criteria and optimise the weighted sum. The choice of the weight factors remains rather arbitrary however. Even if there were a rationale for a certain choice – quod non – it would be extremely difficult for the open designer to explain why the interests of some crucial stakeholders get less weight than those of others. We therefore recommend that the preference approach – in whatever form – is used only to explore possibilities in the Open Design laboratory, but never in the dialogue between the open designer and the crucial stakeholders.

The general (non-preference) Pareto optimisation problem with n decision variables, m constraints, and p objectives is:

$$\text{Maximise} \qquad [Z_1(x), Z_2(x), \ldots, Z_p(x)]$$

subject to

$$\sum_{j=1}^{n} a_{ij}x_j \leq b_i \qquad \text{for } i = 1, 2, \ldots, m$$

and

$$x_j \geq 0 \qquad \text{for } i = 1, 2, \ldots, m$$

Consider the criteria space for a problem with two criteria, Z_1 and Z_2 (Fig. 7.1). As a corollary of the definition of Pareto optimality, the set of Pareto optimal performances lies along the northeast boundary of the criteria space (indicated with a thick line in Figure 7.1).

The generalisation to the p-dimensional criteria space is similar to generalising a linear programming problem with two decision variables to one with n decision variables.

In Open Design, it is not necessary to generate the complete Pareto set. We are only interested in the range where concessions are made related to *all objectives* (no stakeholder is given a preference position). We can, therefore, iterate to the final solution using the so-called Constraint method in a straight forward manner starting with the outcome of the sensitivity analysis as described in Section 7.1.

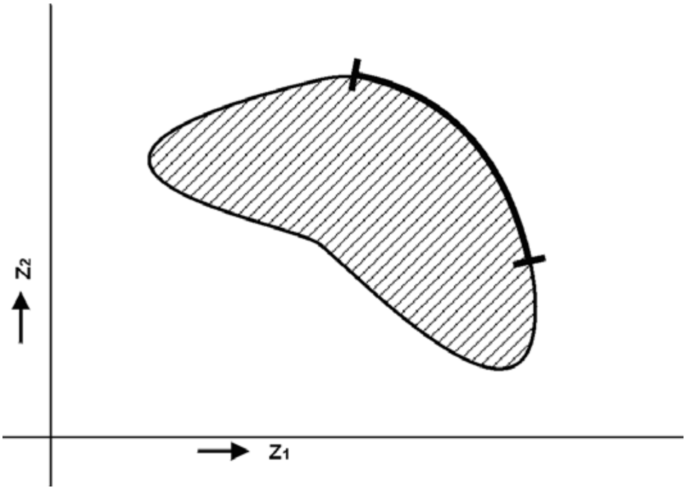


Figure 7.1 Pareto optimal set for a problem with two objectives

The Constraint method retains one objective as primary while treating the remaining objectives as constraints. By doing this in turns for the various objectives, the relevant part of the Pareto set is found.

Let us consider the case of a two-objective problem, for instance:

Z_1 = number of low cost houses to be built on the location;

Z_2 = financial return of the project.

The associated stakeholders are:

- The housing co-operation wishing as many low-cost houses as possible (Z_1);
- The financial institution wishing the highest possible financial return (Z_2).

The two objectives are conflicting in the sense that the more low cost houses are built, the lower the financial return of the project will be (Figure 7.2).

The calculation with the ideal values of the two crucial stakeholders, say $Z_1 = 2\,000$ low-cost houses, and $Z_2 = 0.18$ (IRR) – i.e. the point $(Z_1, Z_2)_0$ – gives no solution. In a first negotiation with the financier the financial return is reduced to IRR$=0.15$ and put into the model as a constraint. The number of low-cost houses is then optimised with result $Z_1 = 1\,400$. This is not accepted by the housing cooperation, which is only prepared to go down (from their

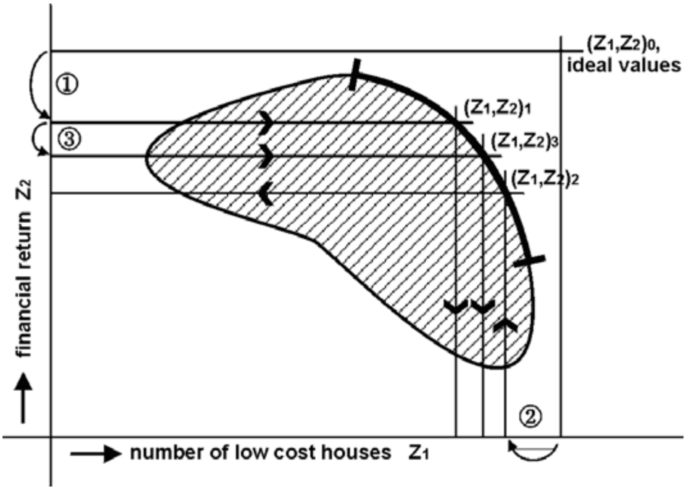


Figure 7.2 Iterative procedure for (two) crucial stakeholders negotiation

ideal of 2 000) to 1 700 houses. This is put into the model as a constraint, while optimising the financial return with result $Z_2 = 0.09$. This is not acceptable to the financier, but he will accept a return of 0.12. This is put into the model as a constraint, while optimising the number of low-cost houses. The result, 1 500 low-cost houses, is finally accepted by the housing cooperation.

To summarise:

$(Z_1, Z_2)_0$ = (2000, 0.18)	ideal values (no solution);
$(Z_1, Z_2)_1$ = (1400, 0.15)	result after first negotiation (with financier);
$(Z_1, Z_2)_2$ = (1700, 0.09)	result after second negotiation (with housing co-operation);
$(Z_1, Z_2)_3$ = (1500, 0.12)	result after third negotiation (with financier): solution acceptable to both parties.

It should be noted that the *shadow prices* related to the objectives that were treated as constraints are the basis for the negotiations (recall: shadow price = change in objective function per unit change of a constraint).

The procedure for more than two objectives is quite similar. In turn, all objectives except one are incorporated into the model as constraints. Shadow prices are used in the negotiations on new values for the objectives which have to be accepted by the stakeholders concerned.

We close by noticing two important observations:

1. The sensitivity analysis takes place in the open designer's laboratory; it can be done as *homework*. The multi-criteria optimisation has to take place in the meeting of Crucial Stakeholders as it is closely intertwined with the negotiations among them;
2. It is completely unpredictable how much individual crucial stakeholders will be prepared to compromise, because their willingness to do so is heavily influenced by the outcomes of the pilot runs, i.e. by the effect they *see* that the compromises requested from them will have on resolving the problem of achieving a solution at all.

7.3 Conclusions

1. To achieve a solution at all, constraints have to be alleviated. Sensitivity analysis of solutions with arbitrarily alleviated constraints allows identification of a limited set of crucial stakeholders who will have to compromise to achieve a positive solution space.
2. The sensitivity analysis can be done as homework in the open designer's laboratory.
3. The actual compromises are made in the meeting of Crucial Stakeholders. The negotiations among them can be facilitated by multiple objectives optimisation. This involves treating, in turn, all objectives except one as constraints. Shadow prices resulting from each pilot run form the basis for the next negotiation on compromises that are required to achieve a solution at all.
4. The multiple objectives optimisation has to be conducted in the meeting of Crucial Stakeholders, because it is closely intertwined with the negotiations amongst them.

8 Open Design Computer Tools

Application of Open Design methodology requires adequate computer software for the following purposes:

- Linear optimisation;
- Geometry computation;
- Financial return computation;
- Monte Carlo simulation;
- Regression analysis (curve fitting).

Software packages for these purposes are described in this chapter.

8.1 Linear optimisation

Optimisation by linear programming requires software to resolve the LP model by means of the Simplex Method or another, faster algorithm.

A widely used software package is the program 'What's Best' by Lindo Systems, Inc. This program provides all relevant information for Open Design problems, including dual values (for sensitivity analysis) and validity ranges. Unfortunately, the validity ranges of the coefficients in the objective function (c-vector) are not provided and shadow prices related to minimum constraints ($\geq$) appear, incorrectly, with a minus sign.

The program must be used in combination with Microsoft Excel. For a description we refer to the user manual.

8.2 Geometry computation

Various (standard) software packages for graphical CAD can be used as a basis for geometrical modelling. Well-known packages are AutoCAD, MicroStation and, in the Netherlands, Arkey.

The software tools for geometrical modelling should satisfy the following requirements:

- The internal representation of geometrical objects should be based on vectors, and not on raster points (also known as pixels).
- The structure of the geometrical data files must allow distinguishing between line chains and closed contours as individual objects of a specific type.

- It must be possible to attach to each graphical object a set of alphanumerical data describing various attributes of that object.
- The capability to insert other graphical files into the current graphic file must also be one of the features of the CAD software.
- The possibility must be included to define composite objects that are composed of single geometrical objects. It must be possible to attach alphanumerical data to these compound objects.
- The program should be able to generate bills of quantities such as number of occurrences, length, surface area and volume. These lists should represent this data for each individual geometric object in the database together with the optionally attached alphanumerical attributes.
- The program should allow Boolean operations – subtraction, intersection, union – on spatially overlapping objects.
- The program should use a macro-language allowing the user to control the features of geometrical objects, or at least include the option to directly transmit the geometrical and alpha-numerical data of the object to spreadsheet or database software.

8.3 Financial return

Financial return on investment, allowing trade-offs between benefits and costs, always plays a role in Open Design problems. As mentioned in Chapter 4, we recommend using discounted cash flow analysis with a preference for using the Internal Rate of Return (IRR) criterion over the Net Present Value (NPV) criterion.

The Net Present Value of a project is:

$$\text{NPV} = \sum_{i=0}^{m} \frac{C_i}{(1+r)^i}$$

where:

C_i = cash flow (positive or negative) in year i;
r = (yearly) cost of capital (as a fraction of that capital);
m = life time of the project in years.

In general, the cost of capital r is closely linked with inflation.
The Internal Rate of Return, IRR, is the value for r which would give $\text{NPV} = 0$:

$$\sum_{i=0}^{m} \frac{C_i}{(1+\text{IRR})^i} = 0$$

In real estate financing, the cash flows can be characterised by:

- A large investment I, i.e. negative cash flow, at the start of the project;
- A yearly net exploitation result E, i.e. the difference between the yearly exploitation revenues and costs;
- A rest value V at the end of the project. In real estate investments V constitutes the selling price at the end of the lifetime.

The formulae for NPV and IRR can then be simplified to:

$$\textsc{npv} = -I + E \sum_{i=1}^{m} \frac{1}{(1+r)^i} + \frac{V}{(1+r)^m} \tag{8.1}$$

and

$$0 = -I + E \sum_{i=1}^{m} \frac{1}{(1+\textsc{irr})^i} + \frac{V}{(1+r)^m} \tag{8.2}$$

The profit P is defined as the return made above the cost of capital (or inflation) r, so:

$$\textsc{irr} = r + P \tag{8.3}$$

Usually, it is this profit P in which we are primarily interested. P should be sufficient to reward the financier for the risk involved compared to investment alternatives. If that reward is too low, the project cannot be financed.

It should be noted that in equation (8.2) the rest value V – i.e. the selling price of the premises at the end of the lifetime – is taken into account by discounting for inflation but not for profit above the cost of capital. The reason for doing so is that we wish to trade off investment against return from exploitation, not from land speculation. To include speculation profit on the sales of premises, the last term in equation (8.2) must be replaced by $V/(1+\textsc{irr})^m$. In practice the difference is negligible.

The profit P has to be found from:

$$0 = -I + E \sum_{I=1}^{m} x^i + \frac{V}{(1+r)^m} \tag{8.4}$$

where

$$x = \frac{1}{1+r+P} \qquad (0 < x < 1)$$

The sum of the geometric series

$$\sum_{i=1}^{n-1} x^i = \frac{1-x^n}{1-x}$$

so:

$$\sum_{i=1}^{m} x^i = \frac{1 - x^{m+1}}{1 - x} - 1$$

which can be written as:

$$\sum_{i=1}^{m} x^i = \frac{x(1 - x^m)}{1 - x}$$

Inserting in (8.4) and rearranging terms gives:

$$x = \frac{Q + x^{m+1}}{1 + Q} \tag{8.5}$$

where

$$Q = \frac{I - \frac{V}{(1+r)^m}}{E}$$

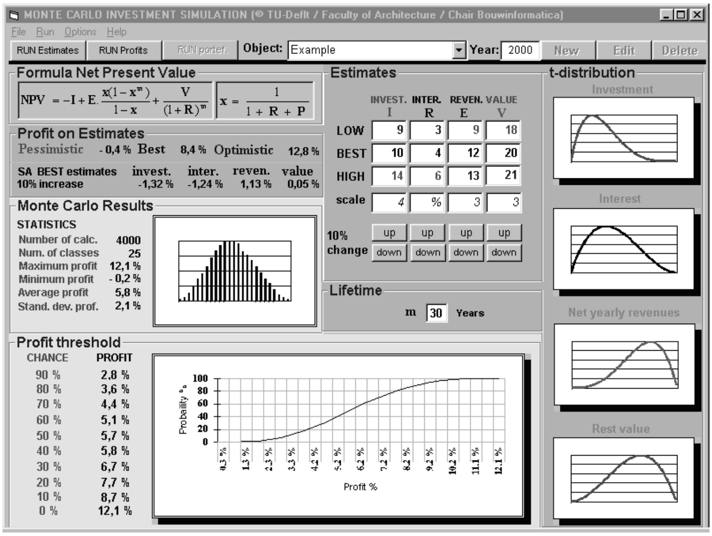
This equation, having the form $x = f(x)$, can be conveniently solved using Wegstein's iterative procedure. For the reader's convenience, we give below the Algol-procedure as published by Wegstein (1958). The procedure computes a value of $g = x$ satisfying the equation $x = f(x)$. The calling statement gives the function, an initial approximation $a \neq 0$ to the root, and a tolerance parameter ϵ for determining the number of significant figures in the solution.

```
procedure   Root(f( ), a, epsilon)=(g)
begin       b=a ; c=f(b) ; g=c
            if (c=a) ; return
            d=a ; b=c ; e=c
Hob:        c=f(b)
            g=(d(c-b(e)/(c-e-b+d)
            if(abs((g-b)/g)=<epsilon) ; return
            e=c ; d=b ; b=g ; go to Hob
end
```

8.4 Monte Carlo simulation

Since the variables investment I, cost of capital r, yearly net exploitation revenues E, and rest value V as defined in the preceding section are stochastically independent, a Monte Carlo simulation can be conducted based on ranges specified for these variables.

We have developed a software package for this purpose (Van Gunsteren and Krebbers, 2000). The input consists of the lifetime m and the ranges (three



Object: Example **Year:** 2000

Formula Net Present Value

$$NPV = -I + E.\frac{x(1-x^m)}{1-x} + \frac{V}{(1+R)^m} \qquad x = \frac{1}{1+R+P}$$

Profit on Estimates

Pessimistic - 0,4 % Best 8,4 % Optimistic 12,8 %

SA BEST estimates 10% increase	invest.	inter.	reven.	value
	-1,32 %	-1,24 %	1,13 %	0,05 %

Estimates

	INVEST. I	INTER. R	REVEN. E	VALUE V
LOW	9	3	9	18
BEST	10	4	12	20
HIGH	14	6	13	21
scale	4	%	3	3
10% change	up down	up down	up down	up down

Lifetime

m 30 Years

Monte Carlo Results

STATISTICS

Number of calc.	4000
Num. of classes	25
Maximum profit	12,1 %
Minimum profit	- 0,2 %
Average profit	5,8 %
Stand. dev. prof.	2,1 %

Profit threshold

CHANCE	PROFIT
90 %	2,8 %
80 %	3,6 %
70 %	4,4 %
60 %	5,1 %
50 %	5,7 %
40 %	5,8 %
30 %	6,7 %
20 %	7,7 %
10 %	8,7 %
0 %	12,1 %

Figure 8.1 Output illustration of Monte Carlo simulation

values) for the before mentioned variables (I, r, E, V). The output gives the probability distribution of the profit P and a sensitivity analysis based on the best guess estimates. An illustration of the output is given in Figure 8.1.

The package includes an option for establishing the risk profile, i.e. the probability distribution of the expected return, for a portfolio of projects with different lifetimes, different starting dates and different risk profiles. This option is also useful for single real estate investment projects which are made up of several parts serving fairly independent markets. For example, a tower consisting of, say, eighty floors with offices, shops and hotels can be processed as a portfolio of three projects with three different risk profiles. The Monte Carlo simulation then provides decision support information to the investor related to the decision how to distribute the available floor area over offices, shops and hotels.

8.5 Regression analysis (curve fitting)

In general, regression analysis of reference designs can be linear, i.e. we draw a straight line through the cloud of points. The line can be represented by the equation:

$$y = a \cdot x + b$$

where the coefficients a and b have to be determined so as to give a 'best fit' through the cloud of points.

Linear least square curve fitting means that we determine the coefficients a and b such that the sum of the squares of the deviations of the points from the regression line is at its minimum.

For n points, having coordinates (x_m, y_m), $m = 1, 2, \ldots, n$, this sum, S, is:

$$S = \sum_{m=1}^{n} \left([y_m - (a \cdot x_m + b)]^2 \right) \tag{8.6}$$

The values for a and b that minimise S are those that satisfy the conditions $\partial S / \partial a = 0$ and $\partial S / \partial b = 0$. Differentiating (8.6) with respect to a and b yields (after rearranging terms and substitution):

$$a = \frac{n \cdot \sum_{m=1}^{n} x_m y_m - \sum_{m=1}^{n} x_m \cdot \sum_{m=1}^{n} y_m}{n \cdot \sum_{m=1}^{n} x_m^2 - \left(\sum_{m=1}^{n} x_m \right)^2} \tag{8.7}$$

and

$$b = \frac{\sum_{m=1}^{n} y_m}{n} - a \cdot \frac{\sum_{m=1}^{n} x_m}{n} \tag{8.8}$$

Most pocket calculators have a routine for computing the coefficients a and b with these equations. For an extensive treatment of single and multiple variable regression analysis, see Chapter 4 (page 263) of *Open Design, Cases and Exercises*.

8.6 Conclusion

Adequate software packages are available which enable application of Open Design methodology with hardly any programming effort on the part of the open designer.

Appendix A
Behavioural theory of Argyris and Schön, a summary

Behaviour is governed by *theories of action*. A *theory of action* is defined in terms of a particular situation, S, a particular consequence, intended in that situation, C, and an action strategy, A, for obtaining consequence C in situation S. The general form of a theory of action is similar to a computer program. If you intend to produce consequence C in situation S, then do A.

A theory of action, whether it applies to organisations or individuals, may take two different forms. By *espoused theory* we mean the theory of action that is brought forward to explain or justify behaviour. The espoused theory of action gives the norms and values people *say* govern their behaviour. By *theory-in-use* we mean the theory of action as can be inferred from observable behaviour, the norms and values that actually determine their pattern of actions. From the evidence gained by observing any pattern of action, one might construct alternative theories-in-use which are, in effect, hypotheses to be tested against the data of observation.

In general, the espoused theory of action and the theory-in-use of individuals or organisations are very different, and one may be aware or unaware of that difference. When Al Capone states that he is an honest businessman, he is very well aware that he is actually a crook. In general, however, individuals are unaware of the difference between their espoused theory of action and their theory-in-use. As a result, they are perceived as defensive when confronted with the divergence between their espoused theory of action and their theory-in-use.

Learning, i.e. detecting and correcting error, whether individual learning or organisational learning, can be *single loop* or *double loop*. These terms relate to the analogy of a control system, for instance a thermostat that controls a heating installation. When the actual temperature drops below a preset value for the desired temperature, the thermostat activates the heating installation. This is a single loop control system in which the desired temperature is kept constant. If in addition to controlling the actual temperature, the desired temperature is controlled, the control system becomes *double-loop*, i.e. it comprises two feed-back-loops. Similarly, we call *single-loop-learning* learning that changes strategies of action in ways that leave the values of a theory of action unchanged.

When a change in the underlying values of a theory of action is involved, we speak of *double-loop learning*. The double loop refers to the two feedback loops that connect the observed effects of action with the underlying strategies, as well as the values determining these strategies. Strategies and assumptions may change concurrently with, or as a consequence of, a change in values.

Double-loop learning may be carried out by individuals, when their inquiry leads to a change in the values of their theory-in-use, or by organisations, when individuals inquire on behalf of an organisation in such a way as to lead to a change in the values of the organisation's theory-in-use.

Organisations continually engaged in transactions with their environments regularly carry out inquiries that take the form of detection and correction of error. Single-loop learning is sufficient where error correction can proceed by changing organisational strategies and assumptions within a constant framework of values and norms for performance. It is concerned with how to achieve existing goals and objectives, keeping organisational performance within the range specified by existing values and norms. In some cases, however, the correction of error requires an inquiry through which organisational values and norms themselves are modified.

It has been found from numerous observations that when human beings deal with issues that are embarrassing or threatening, their reasoning and action conform to a particular model of theory-in-use which is called Model I (Table A.1).

The consequences of governing values and action strategies of Model I behaviour reinforce those values and strategies. In a world of defensiveness, escalating errors, and self-fulfilling processes, it is understandable that individuals should protect themselves by striving even harder to be in unilateral control, to win and not to lose, to deal with the defensiveness of others by attempting to be, and encouraging others to be, 'rational', and to suppress, as best they can, their own and others' negative feelings. Model I theory-in-use, in such circumstances, is *self-sealing*. An example of a self-sealing theory-in-use is the teacher who feels that students are lazy and undisciplined, an opinion he will see confirmed again and again as a result of his own attitude towards them.

Another result of Model I is that social virtues such as concern, caring, honesty, strength, and courage become defined in ways that support Model I theory-in-use. For example, concern and caring come to mean: 'Act diplomatically; say things that people want to hear' – meanings that lead to action strategies such a easing-in, covering-up, and telling white lies. Strength becomes defined in terms of winning, maintaining unilateral control of the situation, and keeping private one's feelings of vulnerability.

There is another factor that powerfully reinforces Model I, increasing the likelihood of anti-learning processes. Individuals are highly skilled in the execution of Model I. Skillful actions usually 'work', in the sense of achieving their intended objectives; they appear spontaneous, automatic and effortless; they are taken for granted; and they require little conscious deliberation.

Model I behaviour, characterised by manipulation of the situation to one's

Table A.1 Model I theory-in-use

Governing Variables	Action Strategies	Consequences for Behavioural World	Consequences for Learning Effectiveness
Define goals and try to achieve them.	Design and manage the environment unilaterally (be persuasive, appeal to larger goals, etc.).	actor seen as defensive, inconsistent, incongruent, controlling, fearful of being vulnerable, withholding of feelings, overly concerned about self and others, or underconcerned about others.	Self-sealing. Decreased long-term effectiveness.
Maximise winning and minimise losing.	Own and control the task (claim ownership of the task, be guardian of the definition and execution of the task).	Defensive interpersonal and group relationship (depending on actor, little help to others).	Single-loop learning.
Minimise generating or expressing negative feelings.	Unilaterally protect yourself (speak in inferred categories accompanied by little or no directly observable data, be blind to impact on others and to incongruity; use defensive actions such as blaming, stereotyping, suppressing feelings, intellectualising).	Defensive norms (mistrust, lack of risk taking, conformity, external commitment, emphasis on diplomacy, power-centred competition and rivalry.	Little testing of theories publicly. Much testing of theories privately.
Be rational.	Unilaterally protect others from being hurt (withhold information, create rules to censor information and behaviour, hold private meetings).		

own ends, is universal and widely accepted in our society. When Model I behaviour prevails, *double-loop learning* becomes impossible. Double-loop learning depends on the exchange of valid information and public testing of attributions and assumptions, which Model I behaviour tends to discourage.

In situations where double-loop learning is essential for effectiveness, an other kind of behaviour, called Model II, is required. The governing variables of Model II are *valid information*, *free and informed choice*, and *internal commitment* (Table A.2).

The governing values of Model II theory-in-use are not opposite to those for Model I.

For example, Model I emphasises that individuals advocate their purposes and simultaneously control the others and the environment in which to ensure that the actor's purposes are achieved. Model II does not reject the skill to advocate one's purposes. It does not reject the unilateral control that usually accompanies advocacy with the typical purpose to win.

Model II couples advocacy with an invitation to others to confront the views and emotions of self and other. It seeks to alter views in order to base them on the most *valid information* possible and to construct positions to which people involved can become *internally committed.*

The behavioural strategies of Model II involve sharing power with anyone who has competence and is relevant to deciding the action at hand. Definition of the task and control over the environment are shared with all the relevant actors. Under these conditions individuals will not tend to compete to make decisions for others or to outshine others for self-gratification. In a Model II world individuals seek to find the people most competent or entitled to the decisions to be made.

If new concepts, such as new buildings or urban developments, are created under Model II conditions, the processes used to develop them are *open to scrutiny by those who are expected to use them*. Equal say is given both to end users and to learned experts. Synthesis – not compromise – is the aim of the Open Design approach under Model II conditions.

Example: Library Technical University Delft

> The budget for the new library of the Technical University was initially, in the early nineties, established at € 20.5 million. This budget had not been made for a particular design, but on the basis of a Bill of Requirements – i.e. a list of functional requirements – and empirical calculation rules to translate these requirements into cost prices. A design contest was held in which three reputable architectural firms participated. One design (Mecano) was elected (which satisfied the Bill of Requirements) and prices were offered for building this design by several construction firms. It then be-

Table A.2 Model II theory-in-use

Governing Variables for Action	Action Strategies	Consequences of Behavioural World	Consequences on Learning	Consequences on Effectiveness
Valid information.	Design situations where participants can be origins of action and experience high personal causation.	actor experienced as minimally defensive.	Disconfirmable precesses.	Increased long-term effectiveness.
Free and informed choice.	Task is jointly controlled.	Minimally defensive interpersonal relations and group dynamics.	Double-loop learning.	
Internal commitment to the choice and constant monitoring of its implementation.	Protection of self is a joint enterprise and oriented toward growth.	Learning-oriented norms.	Frequent public testing of theories.	
	Bilateral protection of others.	High freedom of choice, internal commitment, and risk taking.		

came apparent that the library would cost € 24.5 million, i.e. 20% more than initially anticipated.

A typical Model I discussion evolved, including attributions like 'architects can't calculate', and 'the University is too much on the penny' depending on the view of the particular participant in the discussion. The university's newspaper extensively reported those untested attributions and accusations. Finally, the Board ended the public debate by deciding that the design had to be built and extra finance of € 4.0 million had to be found. With hindsight everyone is extremely satisfied with the result, but the accusations and attributions of various players left their trail of spoiled relationships. Was that really necessary? If conditions would have been more of a Model II nature, the trade-offs between quality and cost could have been kept factual and based on valid information.

The end result would undoubtedly have been of the same quality, however without the bitter aftertaste of the Model I-discussion.

Appendix B

Individual optimum versus collective optimum, consequences for Open Design

When describing matters on which decisions are made in a society (an economic system, a company) economists distinguish between the *individual optimum* and the *collective optimum*, and between *individual (consumer) goods* and *collective (consumer) goods*.

Individual consumer goods can be consumed by one individual in 'separate' units, after which they are no longer available to other individuals. They might be apples, jackets, or private homes. In contrast, collective goods can be consumed by several individuals at the same time. Examples include bridges and parks. The individual optimum is the optimum for one individual, while the collective optimum is the optimum for a number of individuals together. The four terms give four different situations (Table B.1).

a. The individual optimum for individual goods

From an economic point of view the individual optimum for individual goods is relatively simple (Fig. B.1): it is a situation where the consumer surplus (AC_aP) is at a maximum. An individual's consumer surplus is the maximum price the individual would be prepared to pay for a certain quantity of a good (= marginal benefits, AC_aQ_aO) less the amount that he actually pays (= marginal costs, PC_aQ_aO). The marginal benefits are the sum of the price (A) that an individual is prepared to pay per unit. It is assumed here that, after the first item of a certain good has been purchased, each subsequent item will be less satisfying, i.e. will produce fewer benefits than the previous one. Take, for example, rooms in a home: the individual is prepared to pay A_1 for the first room, A_2 for the second, etc. Figure B.1 shows that the optimum will have

Table B.1 Four different situations for the optimum (after: Van den Doel (1993))

	Individual Goods	Collective Goods
Individual optimum	A individual optimum for individual goods	D individual optimum for collective goods
Collective optimum	B collective optimum for individual goods	C collective optimum for collective goods

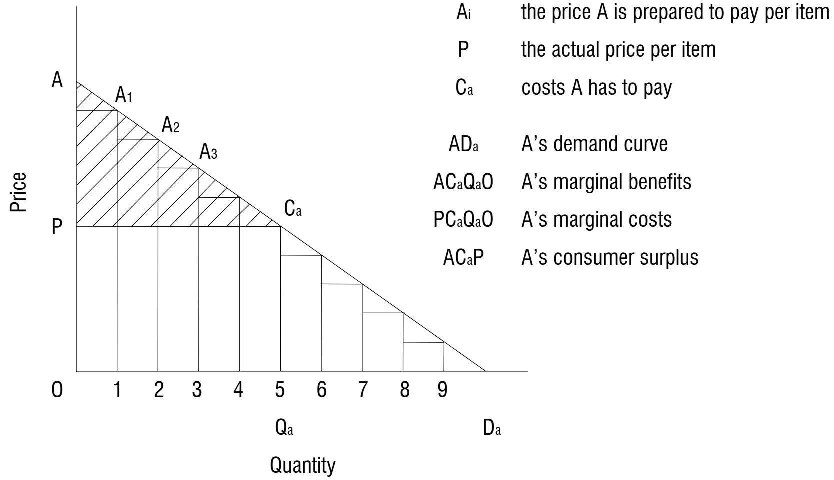


Figure B.1 A's individual optimum for individual goods

been achieved if an individual buys five rooms ($Q_a = 5$), each for the same price P. The sixth room costs more than the buyer is prepared to pay for it. AD_a is the demand curve for rooms.

b. The collective optimum for individual goods

The collective optimum (for several individuals at once) for individual goods is nothing more than the sum of the individual optimums. Let us assume that, in addition to the demand curve of individual A in Figure B.1, individual B also has a demand curve for rooms as shown in Figure B.2.

The collective optimum for A and B is illustrated in Figure B.3: 5 rooms for individual A plus 7 rooms for individual B.

c. The collective optimum for collective goods

To obtain the collective optimum for collective goods, we must not add together the individual demands of consumers, because they do not all need to have their own collective goods (their own road bridges or parks). Instead, we can only usefully add up the willingness of A and B respectively to pay a particular price for these collective goods, which they can use jointly. For instance, A is prepared to pay $A_1 + A_2 + ... + A_n = A_{Total}$ tax a week for bridges and B is prepared to pay $B_1 + B_2 + ... + B_n = B_{Total}$. These two demand curves are presented in Figure B.4.

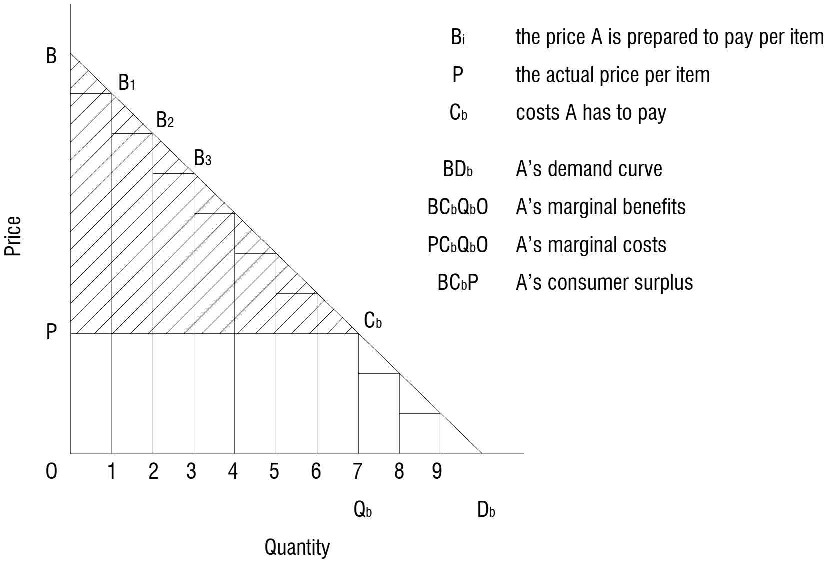


Figure B.2 B's individual optimum for individual goods

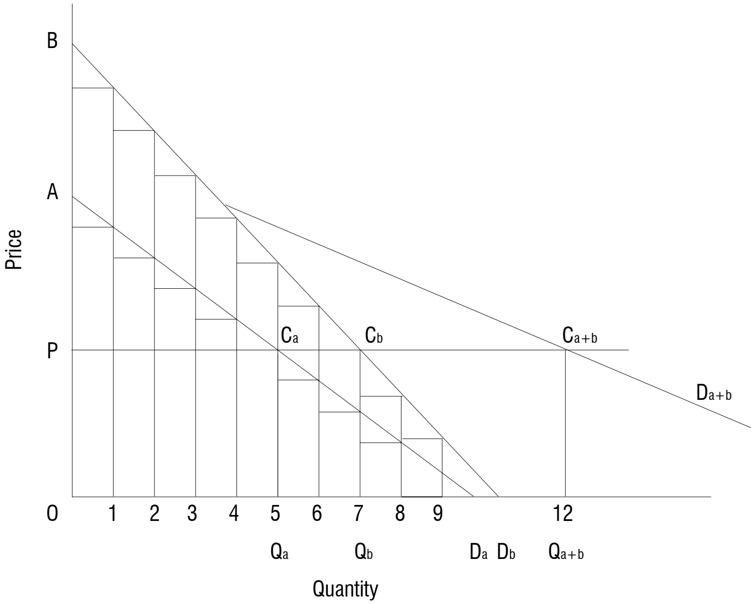


Figure B.3 A and B's collective optimum for individual goods

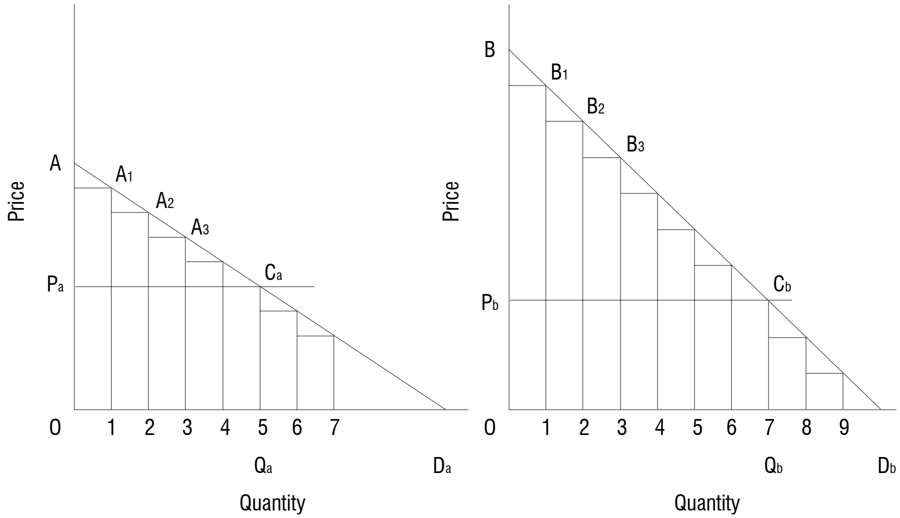


Figure B.4 Demand curves for A and B for collective goods

Adding these demand curves vertically, as in Figure B.5, produces the total demand for bridges: D_{a+b}. If, say, the actual price per bridge is P ($P = P_a + P_b$) tax a week, the optimum is at C: 6 bridges. At this point the maximum price that A and B are prepared to pay together for bridge 6 is the same as the actual price of a bridge. More bridges than 6 would represent a deterioration. Note that the maximum that A is prepared to pay for the first bridge is less than the actual price of a bridge, so A is unwilling and unable to pay for a bridge alone.

d. The individual optimum for collective goods

Figure B.5 also shows the individual optimum for collective goods. As I have said, there is no optimum for individual A. For individual B the optimum is 4 bridges, each at the price P. If A and B do not work together, 4 bridges will be built, which they can both then use. For this privilege, A will pay nothing and B will pay 4 times P_b. A's consumer surplus is thus equal to the area of the quadrangle S_a, and that of B is equal to the area of the triangle S_b. The total consumer surplus is thus equal to the area of the quadrangle $D_{a+b}DC'P$, or to the total benefits (area of quadrangle $D_{a+b}DQO$) less the total costs (area of quadrangle $PC'QO$).

If A and B do cooperate and add together their consumer surpluses through 'collective action', they can construct 6 bridges, as we saw in situation C.

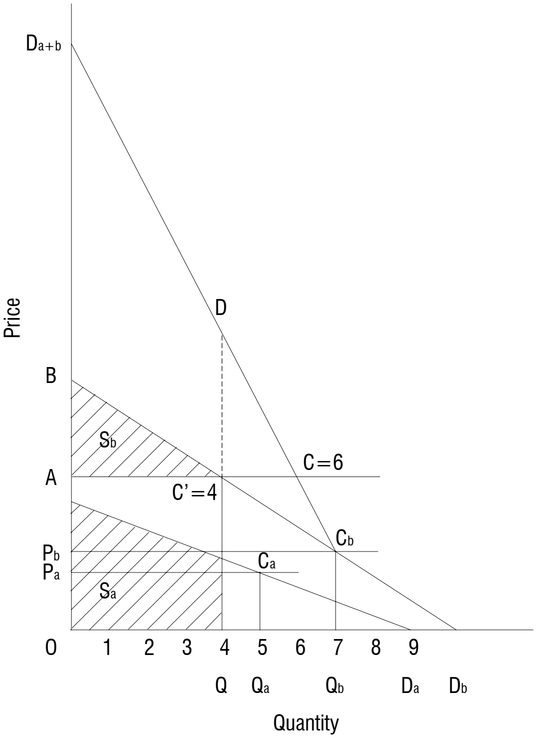


Figure B.5 The collective optimum for collective goods

Van den Doel (1993) concludes, that the *welfare optimum for individual goods* differs in at least two respects from that for collective goods: *firstly*, 'in an optimum situation, different consumers consume different amounts of purely individual goods at the same price. However, in the same situation, different consumers will consume the same amount of purely collective goods at different prices'; *secondly*, 'the optimum for individual goods means that the marginal benefits for each individual consumer will be the same as the marginal costs of the good as a whole. However, the optimum for collective goods means that the marginal benefits totalled up for all consumers is equal to the marginal costs of the goods as a whole.'

Economists have worked out these four situations (*a*, *b*, *c* and *d*) in much greater detail. They have addressed the difficulties of representing the actual demand curve of consumers – in reality this will seldom be straight – and establishing how consumers will value several individual or collective goods in relation to each other in terms of benefits and sacrifices. However, the above descriptions are enough to indicate the essential difference between decision-making methods geared to an individual result, and decision-making methods geared to a group result. The difference between these two methods lies in *the aggregation of the marginal benefits of the individuals*. As indicated in situation *c* (collective optimum for collective goods), this aggregation must now be possible if the optimum group result is to be achieved.

The *classical design methods*, geared to systematic design, have never incorporated this step. They are focused on situation *a*: the individual optimum for individual goods. For a design commission there has to be a principal who decides, as an 'individual consumer', what the optimum is. The designer (this might also be a 'homogeneous' group of designers) designs goods at a particular price that have a certain value for the principal. The principal chooses on the basis of price and value. If there are several principals for the same good then, on the basis of the classic design method, this good will first have to be divided into individual parts, after which each principal will be given a say over his own part. Altogether they determine the optimum combination of these individual parts. This is situation b: the collective optimum for individual goods.

When situation *c* occurs – a group of principals want a number of goods, which they regard as collective goods – then the classic design method will attempt to keep the optimisation of this situation 'outside' the design process. Designers and design teams only need to draw up designs, plans and proposals for collective goods (bridges, parks). It is left to the principal(s) to decide on the number, price and users of these collective goods. In practice this is not possible. The need to design in a decentralised manner – principals (organisations) negotiate via their representative, their own designers, during the design process – means that *collective action* to *aggregate individual marginal* *benefits* can no longer be placed outside the design process.

In welfare theory, the *government* is usually the institution most suitable for performing this aggregation. In Open Design it is the *open designer* who takes care of the aggregation. Just as the government can only have credibility by complying with democratic principles, such as spending money only on matters agreed in parliament, the open designer must be genuine and open in dealing with stakeholders' constraints.

Open Design and Construct Management

Managing Complex Construction Projects through Synthesis of Stakeholders' Interests

Lex A. van Gunsteren
Peter-Paul van Loon

Preface

This book is about managing complexity in the construction industry. More often than not, construction projects that are large and complex tend to get out of control and can only be completed with considerable overruns in time and money, compared to the initial planning and budget. Our perspective is that this state of affairs is not an inevitable reality of life at all, provided we acknowledge that the dynamics of the overall management of such complex projects are fundamentally different from those of pretty straightforward projects. The overall management of these projects has to cope with the same uncertainty and unpredictability inherent to industrial Research and Development (R&D) projects. Best management practices from the world of industrial R&D, therefore, become useful for managing aspects of complexity and uncertainty in complex construction projects as well. Large-scale construction projects are always complex and, therefore, of particular interest to our subject.

Complex projects invariably involve a great number of stakeholders. Open Design methodology, aimed at solving the multi-stakeholder design problem through synthesis of their interests, offers managerial concepts that could also be useful in regard to what we could call the *multi-stakeholder design and construct problem*.

We have adopted the term *Open Design and Construct Management* because openness is a feature of both effective R&D management and Open Design.

These management concepts are only needed when complexity and uncertainty prevail. Sub-projects which are pretty straightforward can be effectively managed using the well-accepted best management practices found in the literature on the subject. Open Design and Construct management is only needed for the overall project.

Cases, presented in this book, where Open Design and Construct management has intuitively been adopted by the project manager concerned show that it is indeed possible to achieve stakeholders' satisfaction without incurring substantial overruns in time and money.

We hope that the concepts offered here will be complementary to those of our earlier book *Open Design, a Collaborative Approach to Architecture*, which was focused on the design rather than on the implementation.

Acknowledgements

The basis of this book originates from the late seventies-early eighties, when the first author was employed by the international contractor Royal Boskalis Westminster Group and at the same time by Delft University of Technology as Professor of Technology (Management of Innovation).

In both working environments – international contracting and supervising graduation projects on managerial issues – the shortcomings of the classical approach towards project management of complex construction projects became more and more apparent. It then also transpired that best R&D management practices could be a key for improvement. In the nineties the collaboration with the second author led to the insight that the Open Design approach and its related tools in the IT domain could further contribute to the formulation of best management practices for large and complex construction projects as described in this volume. We are grateful to those who made these experiences possible for us.

The validation of our theory has, for a part, been made possible by the various graduation theses on the subject by our students, in particular: Tiemen de Lange, Ruud Binnekamp and Wouter Roelofs. We greatfully acknowledge their contributions.

For the other part, the validation of our theory has been made possible by the project managers interviewed as outstanding examples: Mr Frans and Kees Rijnboutt. We have appreciated in particular their open and inspiring attitude in those interviews.

We also wish to express our gratitude to Shell for their kind permission to publish about the Singapore project, thereby contributing to the state-of-the-art of managing complexity which is nowadays more relevant than ever.

Lucia Merema's assistance in gathering relevant information on the Delta works and Jeroen Burger's patience when polishing the English of our manuscript, are highly appreciated. Finally, we thank Marja Landzaad, our management assistant, who enabled us to find the time to complete the book.

Contents

Introduction

Considerable overruns in time and money and often not achieving promised levels of performance are not uncommon in complex construction projects. The relevant question is here how the dynamics of complexity can be properly translated into appropriate construction management practices, and if there are already successful cases in this respect.

The literature on project management is almost endless: on the internet some three hundred book titles on the subject can be found over only the last few years! The library of the authors' university offers some six hundred books on the subject. Apparently, the impact of all that wisdom is piecemeal when it comes to complex projects.

It can be noted that the part of the project management literature that is focused on complex projects is mainly an extrapolation of the best practices for managing simple projects. Such extrapolation can be dangerous, because the issues and problems in both cases are very different, and so are their solutions. Best practices for managing relatively simple projects have become myths of project management, when it comes to complex projects.

As an example of our subject, let us consider the history of the famous Delta Works in the Netherlands. It is 1974. The Dutch prime minister, Joop Den Uyl, presents three options for the Delta Plan, which must prevent a flooding of the province of Zeeland, as happened in 1953, from ever happening again:

A. Cutting off all sea arms by adequate dams and dykes. This option, which would provide the highest safety, was strongly preferred by the Zeeland population, but rejected by environmentalist pressure groups. They feared that valuable ecosystems would disappear.

B. Increasing the height of the existing dykes. The Zeeland population – which had suffered a loss of 1835 lives in the 1953 flood – considered this option not safe enough.

C. A compromise: Option A, but with openings in the main dam. These openings could be closed during storms and spring tides.

Clearly, option C would be acceptable to both the Zeeland population and the environmentalists, but would also be very expensive. The estimates for the three options as presented by the prime minister were:

- Cut off sea arms: € 0.90–1.10 billion.
- Heighten existing dykes: € 0.90–1.10 billion

- Cut-off sea arms with a dam having openings that can be closed: € 1.30 billion

The Dutch parliament accepted option C, and Joop Den Uyl's government was saved. That evening, some engineers, including the first author of this book, were having a beer at their former student's club. Their gut feeling was that the price difference between option A and option C would be much more than was promised by the prime minister. They all wrote their personal estimate on the backside of their beer mat. The beer mats were collected. The average of the cost estimates for option C was € 3.6 billion, so more then twice the number given by the prime minister.

The actual cost turned out to be: € 3.54 billion (source: Ministry of Transport). The actual costs are made up of two parts:

1. The dam itself: € 1.30 billion, price level 1976; € 1.90 billion, price level 1986; € 0.59 billion, budget overrun; € 2.50 billion in total;
2. 'Compartment'-works (Philipsdam, Brouwersdam) necessary elsewhere to make the dam with openings feasible. If the costs of these are added, the total costs become: € 2.27 billion, price level 1976; € 3.27 billion, price level 1986; € 0.27 billion, budget overrun; € 3.54 billion in total.

The engineers also predicted that the technology to develop such a dam would be hard to commercialise and that the maintenance would become a serious problem after the year 2000. In these respects their gut feeling also turned out to be correct: the market in the world for such dams proved to be non-existent, and nowadays maintenance is becoming a serious burden. The reader will undoubtedly remember similar cases.

We take the view that appropriate managerial approaches and best practices for complex construction projects are fundamentally different from those for simple projects. In short, what works on a small scale in a simple and rather predictable situation does not necessarily also work when scale and complexity increase considerably. Most of the literature on project management is implicitly based on the incorrect assumption that what is true for simple is also true for complex.

In this book we offer in Part I, *Theory*, managerial concepts for complex projects, which differ fundamentally from the mainstream in project management literature. The proposition is that complex construction projects can indeed be implemented with less deviation from the promised levels of performance, provided the dynamics of such projects are properly translated into truly appropriate policies and management practices. In Chapter 1 we establish what we mean by *design and construct* and what its purpose is. In Chapter 2 we summarise the concepts of project management as found in the literature, which are actually applicable only to relatively simple projects. In Chapter 3 we present the policies, best practices, and in particular attitudes, that are required for effective project management of complex projects. In Chapter 4 we describe the consequences of applying managerial concepts for simple projects to cases that are actually complex and vice versa.

In the introduction to Part II, *Cases*, Chapter 5 we outline how we validate the theory given in Part I, using on the one hand lessons from failures and on the other experiences from successful projects in which exceptional managers have intuitively applied the managerial concepts (given in Chapter 3) that are appropriate for complex construction projects. In Chapters 6, 7, and 8, we present post-mortem analyses of, respectively, the renovation of the former KLM office in The Hague, the expansion of Schiphol Airport Amsterdam, and the new office for the broadcasting organisation VPRO. These chapters, which describe lessons from failures, are based on material collected by the authors' graduation students. Chapter 9 and 10 deal with lessons from successful projects in which the management practices (given in Chapter 3) appropriate for managing complexity prevailed to a large extent. These Chapters are largely based on interviews the authors held with the project managers concerned. Chapter 9 describes the successful design and construction of a $0.6 billion chemical plant in Singapore by a Shell-Mitsubishi joint-venture. The conclusion of this chapter has been expanded with the experiences from the project manager's subsequent construction project. Chapter 10 describes the renovation of the city centre of The Hague.

We close with Chapter 11 on IT tools in design and construct management of complex projects and a summary of our findings.

Part I

Theory

1 The purpose of design and construct management

In this chapter we establish what we mean by design and construct management and what kinds of design can be distinguished.

1.1 Purpose of design and construct

The design and construct of a piece of engineering work – be it a building, an airport, a ship, a dam, etc. – is always related to the purpose the user of it has in mind. The user can be a group of users or stakeholders such as the population of the province of Zeeland in the case of the Delta works.

That purpose can be described in functional requirements, in this case:

1. Safety against storm flooding;
2. Maintenance friendliness.

These requirements are referred to by the word *functionality*. The object should *function* according to the purpose the user had in mind. Defining the purpose – explicitly or implicitly – and translating it into required functionality is the first step in any construction project.

1.2 Different kinds of design, a classification

Once required functionality is established, a first preliminary design can be made. At first, the 'design' is no more than a rough sketch with a few specifications. In due course the design becomes more specific. As a corollary, there is no such thing as a *frozen design*. Modifications are and should be always possible, although the solution space for changes in the design will narrow down considerably once it comes to actually building.

It is useful to distinguish various phases in the design process according to the different parties that are involved. This leads to the following classification of design:

1. *Conceptual design:* preliminary sketches, main functional requirements.
2. *Contractual design:*contractual design bill of materials, specifications on sub-system performance.
3. *Detailed design:* construction drawings, specifications of sub-systems.
4. *Design modifications during construction:* corrective measures during construction.

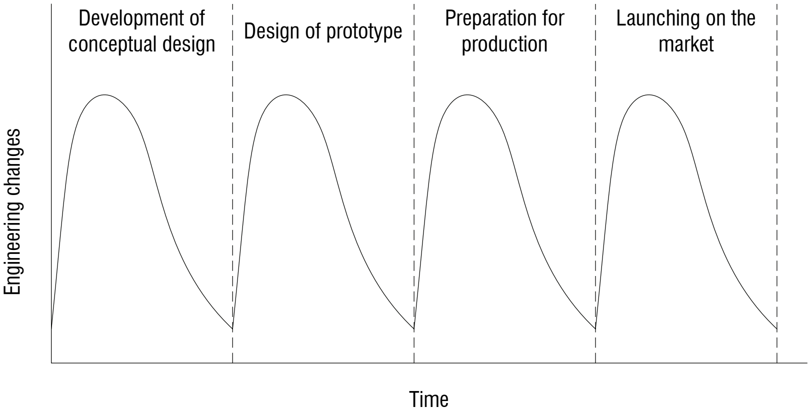


Figure 1.1 Schematic pattern of the frequency of engineering changes tends to show peaks whenever a new group gets involved (Van Gunsteren, 2003, p. 128)

5. *Design modifications after commissioning:* corrective measures after completion.

This classification is similar to the design phases of the development of a new industrial product (Fig. 1.1).

To achieve quality of design on a new industrial product, both available technologies and specific, or latent, wishes of end users must be incorporated into one integrated design of the new product. This requires effective communication with both the relevant scientific community and the end-users. Design changes inevitably occur whenever new players become involved.

Engineers engaged in Research and Development (R&D), by virtue of their technical background, tend to show a genuine interest in advancements in their field of expertise. However, they are usually not good listeners towards non-technical people, including end-users. They perceive the basic wishes of customers, often related to the user-friendliness of the product, as being straightforward, and not very challenging in the technical sense.

As a result, a great number of engineering changes has to be processed in order to make a product acceptable when launched onto the market. The same phenomenon can be observed when a product design is transferred to another group within a company, since these people can be seen as internal customers.

When the development of the conceptual design starts with a rough idea, a lot of modifications take place. The conceptual design is then transferred to the next group, which has to produce the prototype. Contrary to the expectations of the previous group, it then turns out that the product cannot be made within the cost limits dictated by the market.

Another round of modifications emerges before the prototype is completed.

Table 1.1 Involvement of players in different phases

	Players:			
Phase:	Owner	End user	Financier	Contractor
1. Conceptual design	•	•		
2. Contractual design	•	•	•	
3. Detailed design	•	•		•
4. Design modifications during construction	•	•		•
5. Design modifications after commissioning		•		

The project is then transferred to a manufacturing group for production preparation, which in turn introduces another batch of engineering changes. Production of series differs fundamentally from making a single prototype, and these changes are necessary to make the product production-friendly. The project is finally transferred to marketing for introduction into the market. Again, a series of modifications has to be carried out to make the product acceptable to the ultimate customers.

Similarly, the number of design changes in a construction project tends to increase considerably at the beginning of each new phase of the process, when new players become involved (Table 1.1).

To summarise, the design process never ends, but its characteristics change over time. During later phases, design freedom becomes more limited, solution spaces become smaller, but not zero. In different phases other players – actually also *designers* – get involved.

The distinction between design and construction usually made in practice, is artificial. When projects become large and complex, this artificial separation of design and construction can have disastrous effects as paraphrased so convincingly in the fairytale of De Ridder's 'Granny's puzzle' (De Ridder, 1994, pp. IV-VI). See Appendix.

Design and construct, in our view, refers to one continuous process from initial idea to implementation. We see *design and construct* as narrowing down design solution spaces until actual implementation.

1.3 Conclusions

1. The purpose of *design and construct* is to achieve optimal functionality for the stakeholders involved.

2. *Design and construct* refers to the continuous process of narrowing down solution spaces from initial idea to actual implementation.

3. *Design and construct management* refers to how to manage this process in order to indeed achieve functionality and stakeholder satisfaction.

2 Design and construct management of simple projects

In simple construction projects, management focuses not so much on functionality but mainly on how to avoid overruns in time and money. Most of the literature on construction project management addresses this issue, resulting in what are nowadays considered to be the best project management practices for the construction industry. See for instance Gray and Hughes (2001); Kerzner (1998); Ritz (1993); Bennet (1991); Nicholas (2004). In the Dutch literature the most widely used book is *Projectmatig werken* by Wijnen et al. (2001, 1st ed. 1984), as it is used by the country's leading construction management consultant firm as the basis for their consulting. In this chapter we will summarise these practices and discuss their limits of applicability.

2.1 Best practices of project management

In Tables 2.1, 2.2, 2.3 we have summarised, in ten aspects, the best practices for project management and their implications as can be found in the literature on the subject. We call them PI practices, for simple projects, which we distinguish from PII practices, being more appropriate for managing complex projects. These PII practices, will be presented in Chapter 3. They have been summarised in the same ten aspects. Of course, our summary of PI management practices is by no means exhaustive, but we are confident that the most important features relevant to our argument are covered.

2.2 Limits of applicability

In the construction industry, the PI project management practices have indeed been very effective at avoiding overruns in time and money. They were so successful in this domain that, in the eighties and nineties, consulting firms were trying to transfer these practices to the realm of industrial research and development (R&D). Overruns in time and money were a serious problem in that domain as well. The results, however, were disappointing. The R&D scientists involved felt that these practices could not be applied in an R&D environment characterised by uncertainty, complexity, and unpredictability (Van Gunsteren, 2003). For instance, setting goals at the beginning and not changing them during the process is not possible in ambitious, innovative R&D projects (Aspect 1). New insights emerging from the R&D-efforts made so far may give rise to an adjustment of goals and objectives. In addition, dividing the work into small steps with identifiable milestones is often hardly

Table 2.1 Best project management practices, PI: Process related issues

Aspect:	Best practice:	Implications:
1. Goal setting	Before awarding a contract – for design and/or construction – the design brief or the design itself should be frozen and not be unfrozen before commissioning.	• Set goals at the start and do not change them before project completion. • Separate design and construction as rigorously as possible.
2. Leadership	Leadership is provided by the project manager, who is the central figure in the entire process.	• Individual prominence becomes a dominant selection criterion for the project manager (to ensure he or she has sufficient reference power).
3. Conflict resolution	Focus on powerful stakeholders and try to establish compromises between them.	• Define limits of formal and sanction power. • Power structure determines outcome.
4. Design process	Proceed from coarse, preliminary design towards detailed design in a trial-and-error process starting from an arbitrarily chosen first design.	• Focus initially on getting a solution, i.e. a solution point. • Freeze the design or subsystem design when necessary to keep deadlines.

Table 2.2 Best project management practices, PI: Information handling related issues

Aspect:	Best practice:	Implications:
5. Communication	Keep everyone involved informed on design status, approved changes and planning.	• Use bulletin board and internet to give everyone access to status information. • Communication is information oriented.
6. Persuasion of players	Make presentations to convince players who have to accept compromises.	• Pay attention to PR and image building. • Use powerful audio-visual aids.
7. Progress control	Divide the process into small steps with identifiable milestones against planned deadlines.	• Separate object from process to make it. • Focus on process for project control.

Table 2.3 Best project management practices, PI: Structure related issues

Aspect:	Best practice:	Implications:
8. Divisions of tasks	Define division of tasks and associated responsibilities in job and function descriptions.	• Control of progress on predetermined tasks. • Responsibility for right information at the right place determined by job description: information push.
9. Integration and coordination of tasks	Integration and coordination of tasks is a prime responsibility of the project manager.	• White spots, unexpected problems, are resolved by the project manager who uses formal and sanction power to do so. • Little reliance on personal initiatives from people involved.
10. Standardisation	Standardisation where possible, because standardisation reduces complexity.	• Trend towards uniformity. • Seasoned project managers tend to reject new concepts that are hard to standardise.

possible or desirable in R&D (Aspect 8). And in R&D, standardisation is postponed as much as possible to avoid unnecessary exclusion of new concepts (Aspect 10).

The literature on management of technological innovation offers concepts and recommended practices that are fundamentally different from those on which PI project management practices are based. See, for instance, Blake (1978); Twiss (1992); Van Gunsteren (2003); Mintzberg (1979).

Urban planners made the same observations regarding the project management approach from the construction industry: that it was not applicable in an urban planning environment. This often happened when the actual urban planning problem concerned a new infrastructure development or an inner city redevelopment situation (Van Loon, 1998). Due to the technical complexity of these kinds of problems, engineers from the construction industry became dominant in these planning processes. At the start of such processes they came with already completed designs for the infrastructure and the buildings to be realised (Aspect 1). Their attention was on the persuasion of the decision makers for their well-worked-out ideas (Aspect 6).

For urban planners, it was hard to fit these proposals into their broader planning issues such as social welfare in the city, economic improvement of the urban area, and social justice in housing distribution. There was no real solution space in these designs for combinations with the objectives of other stakeholders than the construction firms and the real estate owners (Aspect 4).

The literature on planning theory and planning methodology offers concepts to overcome this gap and methods to develop an appropriate project management approach for complex urban construction projects. See, for instance, Faludi (1973); Van Loon (1998); Schön and Rein (1994); Kingdon (1995).

2.3 Conclusions

1. The mainstream of project management concepts and recommended best practices from the construction industry (PI) are actually only applicable and useful in relatively simple and predictable situations.
2. For construction projects that are characterised by a great deal of uncertainty and complexity, these PI practices are not appropriate or are even counter-productive. In such cases the concepts and practices of the management of technological innovation and the practices of urban planning are more appropriate than those of straightforward construction management.

3 Design and construct management of complex projects

If best practices for project management as recommended in the mainstream literature are inappropriate in complex construction projects, what should then be considered best practices for managing these complex projects? Our approach to answer this question has been twofold:

1. As the realm of industrial R&D is also characterised by uncertainty and unpredictability, we have investigated to what extent best practices in industrial R&D are also recommendable in the management of complex construction projects.
2. As complex construction projects invariably involve a large number of stakeholders with conflicting interests, we have paid attention to the managerial concepts from Open Design methodology, which is aimed at multi-stakeholder planning and design problems.

3.1 Best practices of Open Design and Construct management

In Tables 3.1, 3.2, and 3.3 we summarise the best practices of Open Design and Construct management as can be derived from R&D management practice (Van Gunsteren, 2003) and from Open Design methodology (Van Loon, 1998; Van Gunsteren and Van Loon, 2000). We call these PII best practices for complex projects.

Management of technological innovation and management of the multi-stakeholder design process according to the Open Design methodology both require an open, non-manipulative managerial approach. We therefore speak of *Open Design and Construct management*, because transparency is their characteristic feature. In this chapter we will explain what we mean by this by discussing the ten aspects of project management from the preceding chapter for situations characterised by uncertainty and unpredictability, as well as discussing their limits of applicability.

In essence, Open Design and Construct management requires an open and constructive attitude aimed at respecting the interests of *all* stakeholders involved, and not only the powerful or knowledgeable ones.

3.2 Limits of applicability

Adoption of PII practices is not necessary, and even undesirable, in projects that are not characterised by uncertainty, unpredictability and a multitude of

Table 3.1 Best practices (PII) of Open Design and Construct Management: Process related issues

Aspect:	Best practice:	Implications:
1. Goal setting	Nothing is fixed in advance; be prepared to adjust goals when circumstances change and insight improves.	• Re-evaluation of project objectives at regular intervals. • Adjustment of goals and deadlines according to new insight.
2. Leadership	Aim at leadership focused at defending relevant stakeholders' interests.	• Give project management authority to make connections to all stakeholders. • Select non-manipulative person as project manager.
3. Conflict resolution	Aim at open synthesis (not closed compromise), i.e. choices aimed at satisfaction of stakeholders concerned.	• Equal treatment of powerful and less powerful stakeholders and of experts and laymen. • Valid information rather than power structure determines outcome.
4. Design process	Proceed from ideal constraints of stakeholders to alleviated constraints to achieve a solution at all.	• Think in terms of solution space, not solution point. • Respect constraint ownership; no change without stakeholder consent.

Table 3.2 Best practices (PII) of Open Design and Construct Management: Information handling related issues

Aspect:	Best practice:	Implications:
5. Communication	Respond to information needs and demands of decision-makers (designers, stakeholders).	• Be open in communication; provide valid info to whoever needs it. • Be honest about slacks and margins, i.e. the solution space. • Communication is decision oriented.
6. Persuasion of players	Persuade by supplying valid and relevant information.	• No hidden agenda or window dressing. • Accept consequences of being honest no matter how painful these may be.
7. Progress control	Pay attention to both ‘hard’ and ‘soft’ information on progress.	• Pay equal attention to formal and informal information to anticipate pro-actively. • Value and appreciate initiatives from players to warn in time for forthcoming disasters.

Table 3.3 Best practices (PII) of Open Design and Construct Management: Structure related issues

Aspect:	Best practice:	Implications:
8. Divisions of tasks	Think in roles rather than tasks, using only broad job descriptions.	• Rely on mutual adjustment rather than sharp division of tasks. • Make groups responsible, also for information they need: information pull.
9. Integration and coordination of tasks	Create a climate for mutual adjustment of tasks.	• Allow project manager to delegate part of the coordination tasks to people he or she trusts. • Promote integration of tasks by emphasis on functional performance achieved collectively.
10. Standardisation	Standardisation only where functional and genuinely accepted by stakeholders.	• Do not push uniformity. • Be, selectively, open to new concepts.

stakeholders with conflicting interests. It should be emphasised that complex projects can often be subdivided into smaller sub-projects that are relatively straightforward. Application of PII practices should then be limited to the overall project, whilst managing the straightforward sub-projects according to traditional PI project management practices, as summarised in Tables 1, 2 and 3.

The project manager will largely take care of the management of the overall project himself, preferably applying the Open Design and Construct approach, and delegate the management of the subprojects to others who can manage those in the classical way. In this way, not everybody involved has to embrace the open stakeholder-oriented management style.

3.3 Conclusions

1. Best practices for complex projects (PII) can be derived from the best practices in industrial R&D and from Open Design methodology aimed at solving the multi-stakeholder design problem.

2. These practices should only be applied where complexity and conflicting interests of stakeholders so require, whilst managing straightforward sub-projects according to widely-accepted traditional project management practices (PI).

4 Consequences of applying best practices for simple projects to complex projects and vice versa

In the preceding chapters we described two categories of best practices of project management:

1. For straightforward and relatively simple projects (PI);

2. For complex projects characterised by uncertainty and unpredictability (PII).

This raises the question of what happens if the first category of best practices, PI, is applied in a complex, unpredictable situation SII. Conversely, what will happen if the second category of best practices, PII, is applied in a relatively simple, predictable situation, SI. These questions will be discussed in this chapter.

4.1 Applying PI practices to a complex situation SII

This mismatch between managerial approach and situation is quite common. The best practices PI, which in reality are only effective in relatively simple and predictable situations, are so widely accepted that quite often we see them being used in very complex and large construction projects as well. What usually happens then is:

1. A loss of functionality;

2. Overruns in time and money.

Ultimately, the project is completed in spite of the inappropriate managerial approach. Everybody is then glad that the problems in the execution were finally overcome, and there is little incentive to spoil the feelings of achievement by a post-mortem analysis. As a result, the inappropriate application of project management practices PI tends to be continued: a self-sealing process. Post-mortem analyses of three cases are given in Chapters 6, 7 and 8 from which we may conclude that inappropriate application of PI can seriously decrease functional performance and cause a waste of time and money.

4.2 Consequences of applying practices PII for complex and unpredictable situations to an actually simple and predictable situation SI

As we have mentioned before, PI practices are also needed in complex projects to implement subprojects that are relatively straightforward. Only those aspects that are complex and uncertain need to be managed with PII practices.

This implies that the project manager can go too far with Open Design and Construct PII practices. What might then happen is that efforts are wasted because players abuse the freedom given to them by the PII approach of the project manager.

For instance, if the design of certain details is left to the contractor on the basis of functional requirements only, he may choose solutions that are best for him but not desirable from other stakeholders' points of view.

Such abuse of freedom is quite common in RI-contracts (re-imbursable cost contracts) with a relatively weak owner. Such contracts tend to start with honeymoon enthusiasm but end in frustration when cost and time overruns due to hobbyism become unavoidable. Examples are government contracts on the maintenance of infrastructure and nuclear installations.

4.3 Conclusions

1. Inappropriate application of PI practices for simple and predictable circumstances in complex and unpredictable situations, SII, causes loss of functionality and overruns in time and money, along with frustration and value destruction through bad reputation. In extreme cases it may even lead to non-completion of the project.

2. Conversely, inappropriate application of PII practices, suited for complex and uncertain circumstances, in quite straightforward situations, SI, can lead to abuse of freedom, as often happens in re-imbursable cost contracts with a weak owner.

3. In projects characterised by complexity and unpredictability both practices are needed: PII for managing the over-all project and PI for managing relatively straightforward sub-projects.

4. The Open Design and Construct project manager and also the owner should have a feel for where to apply PII and where to rely on PI practices. Unbalance, either way, will cause waste of effort and money.

Part II

Cases

5 Validation through cases

The validation of our point of view cannot be done by designing a controlled laboratory experiment. We have to resort to inductive investigation of carefully selected cases. Our point of view is that straightforward, predictable projects require a different managerial approach than complex projects involving a lot of uncertainty and that a mismatch between them results in:

1. Loss of functionality;
2. Overruns in time and money.

This point of view is exposed in Table 5.1 below. We are, of course, interested in particular in the lower line of the Table: mismatch or appropriate matching in the case of complex, unpredictable situations, SII. Will an appropriate matching, SII, PII, indeed yield satisfactory functionality and no or only limited overruns in time and money? So, the assumption to be tested is:

1. SII, PI:
    - unsatisfactory functionality;
    - substantial overruns in time and money.
2. SII, PII:
    - satisfactory functionality;
    - no or only limited overruns in time and money.

Cases related to situation 1 – lessons from failure – are described in Chapters 6, 7, 8:

1. Former KLM office in The Hague;
2. Expansion of Schiphol Airport Amsterdam;
3. The office for the broadcasting organisation VPRO.

These cases describe post-mortem analyses based on material collected by graduation students of the authors.

As to situation 2 – lessons from success – we have chosen the following approach:

1. Select some real life large construction projects characterised by a high degree of complexity and uncertainty (SII) which yielded satisfactory functionality (high degree of stakeholders? satisfaction) and no or only limited overruns in time and money.

Table 5.1 Matching of managerial approach with nature of project

		Project management style	
		Best practices PI	Best practices PII
Nature of project	Simple, predictable situation SI	Appropriate	Mismatch
	Complex, unpredictable situation SII	Mismatch	Appropriate

2. Investigate whether, to a high degree, the project managers involved actually managed the overall project in a PII-manner. If so, the hypothesis is confirmed.

Two cases were selected:

1. Shell-Mitsubishi, Singapore, a petrochemical process plant;
2. Renovation of a central part of the city The Hague, an urban redevelopment project.

These cases, described in Chapters 9 and 10, are largely based on interviews with the project managers concerned.

6 Renovation of the former KLM head office in The Hague

In 1979, the former KLM head office in The Hague had been in use for ten years by its second owner, the Ministry of Infrastructure (Fig. 6.1). The building badly needed a thorough overhaul including maintenance of the outside of the building, modernising the interior, and making the office plan more efficient. The building no longer met the legislation and user requirements of that era.

The renovation of the building, extending over a period from 1979 to 1992, was negatively evaluated – unsatisfactory functionality along with substantial overruns in time and money – so appropriate to test our assumption.

The decisions made during the renovation process over the subsequent decade were later analysed by Binnekamp (1995). He made a computer simulation of the overall design decision-making process. The conclusion was that interconnections between decisions were very poor. This led to missing essential combinations of sub-solutions, as will become apparent from the description of the case.

6.1 What happened?

The total floor area was 27 000 m2. Only 11 000 m2 was used for offices, the remainder being storage rooms, basement, halls, corridors, staircases, and the like (Fig. 6.2). A renovation plan was made including a calculation of the costs involved. A decision for execution was, however, postponed for years. First, a new wing had to be built. This extension was very urgent, for the Ministry had rapidly grown in its number of employees.

When the new wing was completed in 1985, the whole building was reviewed in the light of the user's requirements and general norms for offices at that time. It was established that it would be possible – according to generally accepted user norms and floor space calculation rules – for the building to accommodate 1 550 people (in the new wing and old building) on a functionally usable area of 21 230 m2, at an average of 13.70 m2 per person. Naturally, the new wing already satisfied these modern norms. The old building, as could be expected, came nowhere near.

A preliminary budget was reserved in 1985: on the basis of experience with similar buildings a budget of € 6.81 million was considered appropriate for both renovation and achieving an efficient layout. In 1988, a project team started with the assignment to make a renovation plan related to both technical maintenance and modernisation of the interior. The new layout had to accommodate 1 100 people in the old building. The first plans and calculations

Figure 6.1 Former KLM head office, Plesmanweg, The Hague (Binnekamp, 1995, p. 1)

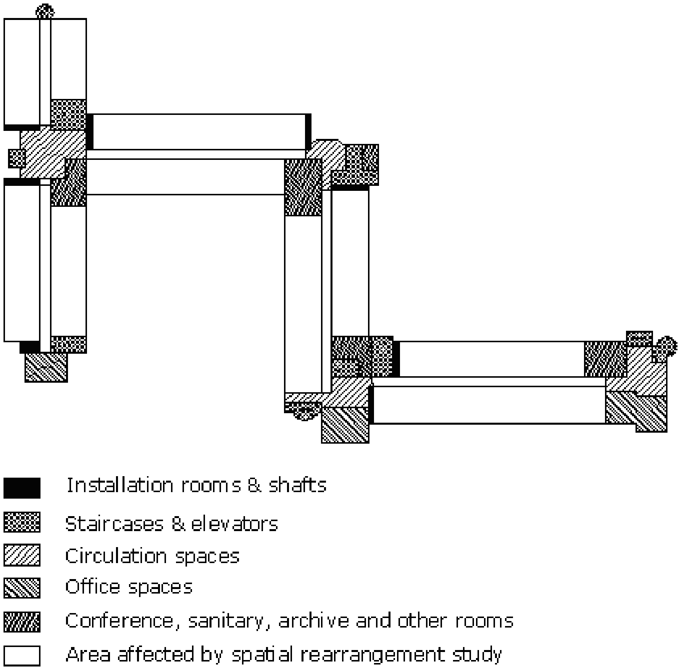


Figure 6.2 Floorplan of former KLM head office

indicated that an investment of about € 13.18 million would be required. After some negotiation, the preliminary budget of € 6.81 million was increased to € 10.22 million. The cost of the complete renovation had to be kept below this ceiling.

The project team proceeded and made a second plan within the limits of the budget. A detailed architectural design was made for one wing and immediately implemented. At the same time, the renovation of the next wing was prepared. It then emerged that another layout was preferred as a result of an internal reorganisation.

This revised layout was actually implemented. In the preparation for the third wing the ideas changed again and these changes were also incorporated. The renovation was completed in 1992. € 14.54 million had been spent to accommodate only 853 people. The renovation process extended over a number of years. Plans had been revised after each completed phase. As a result, decisions on different parts of the building lacked interconnection. The effects of decisions on the functioning of the building as a whole, was lost out of sight, which made cost control extremely difficult. Cost savings through appropriate combination between new desirable office layouts, alternative allocations of budgets, and specific distributions of workplaces across the building could not be achieved. Such combinations were not even considered by the project team, because – in line with the prevailing PI project management approach concerning goal setting (Aspect 1) – the project team was not allowed to redefine goals and objectives during the process. These were set at the start.

This gave rise to a design process in which initially agreed design solutions could not be changed. Consequently, standardisation was dominant, well-known solutions for office layouts were chosen (Aspect 10). New solutions and new combinations of these solutions were not considered, as they would have made the project more complicated. Conflict resolution was simplified by using the hierarchic power structure to resolve stale mate situations. In other words, when there is a renovation problem, just spent more money to solve it instead of aiming at synthesis based on valid information (Aspect 3).

In retrospect, it is understandable that the project was negatively evaluated. The owner had to pay twice the budget for only three quarters of the initially agreed functional output.

6.2 Open Design simulation

The focus of Binnekamp's analysis of this case was whether the application of Open Design methodology could have prevented many of the disappointing results. He focused his analysis on two process related aspects: Goal setting (Aspect 1) and Conflict resolution (Aspect 3), and on one structure related aspect: Standardisation (Aspect 10).

An extensive Open Design simulation of the overall multi-stakeholder decision making process was made. The assumption was that the failure was not so much the result of budget overruns and under-realisation of anticipated functional output (number of accommodated people), but of the way new emerging insights and user demands had been incorporated and combined in new office designs and upgrading measures.

Starting from the initial objectives and constraints, an integral floor space optimisation model including construction costs was made to establish an overall solution space for the renovation project. And within this space a possibility of various combinations of sub-solutions was studied. This model allowed the various steps taken in reality to be simulated and analysed.

The simulations soon made it clear that the accommodation of 1 100 people would never have been feasible. In due time, the organisation of the user had changed: more highly placed executives had to be accommodated, requiring more floor space per person. Accommodating 1 100 people of the Ministry would imply that certain parts of the user's organisation would have to be transferred elsewhere.

It was also found that the selection of main dimensions for corridors and office rooms had a great impact on the functional output of the building. Alternative layouts could offer impressive improvements in terms of functional output over cost. How could it happen that these efficient alternative layouts were overlooked? To a large extent this was caused by the concept of 'divisional losses' (Fig. 6.3). This concept entails evaluating office floor surfaces against the floor space norms of the Rijks Gebouwen Dienst (RGD). 'Divisional loss' means a difference between the designed layout and the numerical floor-space capacity calculated using these norms. A floor space norm is a highly misleading term since these 'norms' actually constitute empirical averages of existing buildings.

The architect's answer to the 'divisional loss' criticism was to utilise the 'redundant' spaces for storage (Fig. 6.4). Trading-off with spaces for traffic and minimise on the aggregated difference between actual lay-out and calculated floorspace use based on the norms, as done in the Open Design simulation, was not considered.

The simulation allowed the assessment of the consequences of relaxing relevant objectives, specifications, and constraints, in particular the number of people, the area office space, and the total budget for renovation. Table 8 summarises the results that were most relevant to the owner.

The conclusion was that the Open Design approach on the aspects of non-fixed goals (Aspect 1), less standardisation (Aspect 10), and aiming at synthesis based on valid information of experts (Aspect 3), could have provided a building accommodating more people and requiring substantially lower energy consumption, hence lower costs, at only half of the price actually paid.

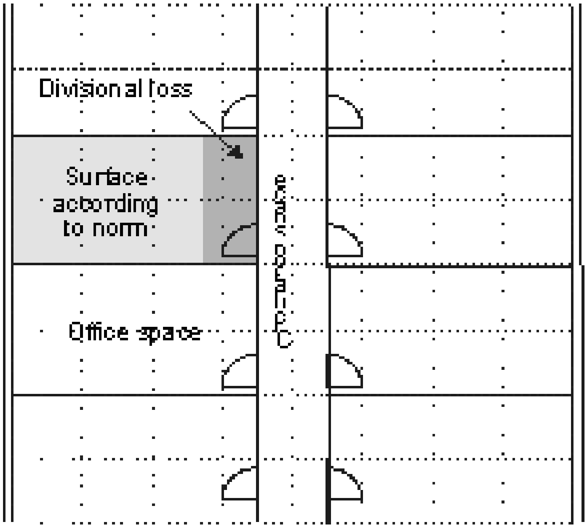


Figure 6.3 ‘Divisional loss’ according to RGD norm (Binnekamp, 1995, p. 23)

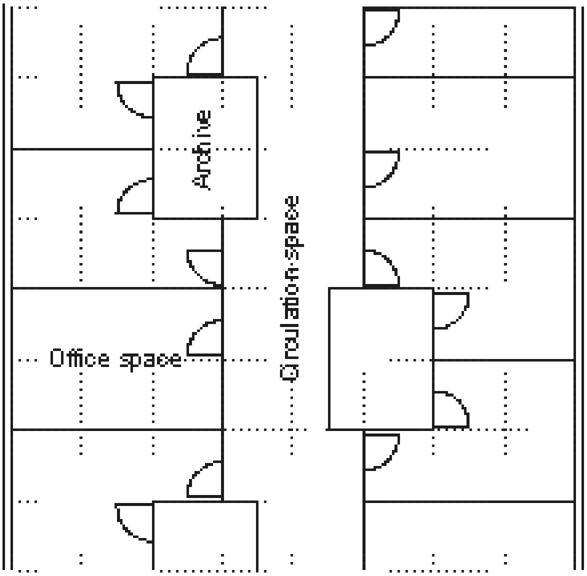


Figure 6.4 Architect’s answer to ‘divisional loss’ criticism (Binnekamp, 1995, p. 23)

Table 6.1 Comparison initial plan – realisation – Open Design simulation for former KLM head office

	Plan at start	Realisation	Open Design simulation
Number of person accommodated	1 102	853	916
Energy cost per year (€ 1 000)	59	66 (estimated)	54
Investment (€ million)	10.22	14.55	7.27

Table 6.2 Application of best practices in renovation of former KLM head office

Aspect:	PI / PII:
1. Goal setting fixed vs. floating	PI
3. Conflict resolution compromise vs. synthesis	PI
8. Divisions of tasks job descriptions vs. roles	PI
10. Standardisation where possible vs. where functional	PI

6.3 Significance for Open Design and Construct management

The very fact that an Open Design approach would have been appropriate also suggests that Open Design and Construct management would have been required for this complex case.

From the case description it becomes apparent that best management practices PI (for simple and predictable situations SI) were predominantly applied (Table 6.2). Goals were kept fixed over considerable periods of time and only adjusted a long time after they had obviously become unattainable. Stakeholders were only involved in the design process in a very indirect manner. Conflicts were resolved by compromises (increased budgets). Coherence of the project as a whole was lacking, as a result of subdividing it into well-defined sub-projects as is recommended in the PI repertoire (Aspect 8).

The conclusion is that not only Open Design methodology, but also application of best practices PII for the overall management of the project would have produced much better functionality for roughly half of the actual cost.

7 Expansion of Schiphol Airport in the eighties

In the eighties, Amsterdam Airport Schiphol realised an expansion and upgrading of facilities which more than doubled its capacity, along with considerably improving functionality.

The management of the project, or rather series of projects, was investigated by De Lange (1987). The conclusion of this study was that PI practices – no matter how useful they may be for straightforward construction projects – can become counterproductive for large, complex projects involving a lot of uncertainty and extending over a relatively long period of time. We summarise the findings of the study here, and its implications for PII practices.

7.1 The Schiphol Group

Schiphol Group is a company responsible for developing, maintaining, and providing infrastructure to accommodate air traffic, both at Amsterdam Airport Schiphol and at other airports in and outside the Netherlands. It has a turnover of €0.6 billion and a staff of 2 000 employees. Amsterdam Airport Schiphol accommodates about 430 000 flight movements and about 40 million passenger movements per year.

Originally a governmental organisation, the Schiphol Group was privatised in 1958. As a private company, Amsterdam Airport Schiphol is responsible for financial return on investment, but also has to meet societal demands such as stimulation of the economy and employment, and control of noise hindrance. Amsterdam Airport Schiphol offers a sophisticated product and has special know-how in the field of airport development.

7.2 Management of the expansion

In 1985, Amsterdam Airport Schiphol stood at the beginning of major expansion activities in its infrastructure. The capacity of the airport for both passengers and cargo was going to be doubled. The organisation of Amsterdam Airport Schiphol at that time was not ready to manage these huge expansion activities within the required limits of time and money. Up till 1985, there was little awareness that such enormous expansion needed organisational changes concerning communication, accounting, and working methods. Because of the attention needed for these organisational changes, the management could not focus fully on the preparation of the expansion. A consultancy firm was asked to propose and implement a suitable approach to meet the demands of the organisation.

Specific needs of the organisation, as formulated by the management, were the following:

- There was too much overrun in time and budget of projects;
- Specifications and demands were constantly changing;
- The decision-making processes needed to be fundamentally improved:
  - Decisions should be better prepared and not be constantly changed;
  - Better reasons for decisions should be given;
- The quality of staff should be improved;
- Information supply towards senior management had to be improved.

The consultancy firm came to the conclusion that the organisation was lacking a structured project management approach. Their consultants introduced a course and a handbook on project management which were based on PI practices based on the first edition of Wijnen et al. (2001, 1984). This consultancy firm acted as an 'expert' consultant and focused on enlarging leadership by the project managers (Aspect 2). Their consultants worked with an attitude of 'we know how to tackle such problems in organisations' and 'we teach the project leaders this knowledge'. They consulted with a very small group of senior managers about their approach. The pitfall of this was that it caused resistance and dissatisfaction among employees at lower levels. They felt ignored and misunderstood. These employees, however, where crucial for the implementation of the new project management approach.

The consultancy firm also selected and implemented a software tool for Planning & Control of running activities. This caused a lot of opposition however, and did not appear to be successful. The software was aimed at a constant information flow on the project progress to everyone involved (Aspect 5). It was assumed that this information-oriented communication would provide so much insight, that every task in the project would be fulfilled as prescribed and scheduled (Aspect 7).

Meanwhile, another consultancy firm was involved in improving the implementation of smaller projects by the Technical Department and the Operational Department. They were acting in a completely different way. This consultancy firm acted not as an expert, but as a 'process' consultant (Schein, 1969). They worked in close co-operation with technicians on the work floor, providing them with valid and relevant-for-them information about the progress of colleagues in the projects (Aspect 5). The employees in these departments were satisfied with this approach and experienced that such an approach was what they really needed.

After two years of trying to implement the Planning & Control approach without any success, an internal project manager was assigned to evaluate and improve the situation. He was an inspiring manager, with great insight and zeal. He brought the most critical factor of the current approach up for discussion: the fact that crucial employees at lower levels were not involved.

The new project manager changed the management approach by turning the top-down approach into a bottom-up approach. He also enlarged the contribution of the actual users to the Planning & Control system. He implemented all this by establishing a pilot group in the most urgent department to stimulate imitation elsewhere. In fact, he changed the currently applied 'planning' strategy into an 'entrepreneurial' strategy to give project managers authority to make connections to all stakeholders (Aspect 2). He defined the project tasks in such a way that it became possible for the project groups to be responsible for their own tasks and own information need (Aspect 8).

As in R&D, user involvement inevitably means that goals cannot be fixed, as demanded by the first management consultant (Aspect 1). When new insights emerge as a result of new end user demands, goals have to be adjusted. The change in approach, effected by the internal project manager, turned out to be crucial for the later success of the project.

7.3 Lessons learned

The change in approach turned out to be crucial for the later success of the project (Table 7.1). The following lessons can be learned from this case:

- A centralised management culture does not match with a company with a sophisticated product and know-how, such as Schiphol Airport.
- Information exchange and communication are essential: avoid taboos, make sure everything is debatable.
- Don't be afraid of uncertainties, identify and learn to deal with them.
- Senior management should take decisions on policy and provide frameworks. Middle management should work within these frameworks using their experience and know-how. The organisation then becomes a cell structure in which each cell is responsible for a clear task. It is important that senior management creates an atmosphere of freedom and encourages the cells to be productive.
- There should be a relationship between problem identification, proposals for solution and implementation towards results. All three should be close to employees.
- Goals and objectives must be adjusted when new insights so require.

Table 7.1 Application of best practices in the expansion of Amsteram Airport

Aspect:	PI / PII:
2. Leadership boss focused vs. stakeholder focused	PI / PII*
5. Communication information oriented vs. decision oriented	PI / PII*
7. Progress control hard info oriented vs. soft info oriented	PI / PII*

* Transition from PI to PII effected by new project manager

7.4 Implications for Open Design and Construct management

Initially, the project showed the characteristics making it an appropriate case for our purpose: doubtful functionality along with considerable overruns in time and money. The first approach to overcome these problems was to introduce typical PI best practices as advocated by the expert consultancy firm. When this approach turned out to have limited success, the managerial concept was changed by a new project manager, very much in the direction of PII best practices. This change turned out to be successful in the sense that functionality (stakeholder satisfaction) and avoiding overruns in time and money were significantly improved. So our assumption was confirmed in this case as well.

We close this section with an aerial view at the time of writing (Fig. 7.1).

Figure 7.1 Aerial view of Schiphol Airport

8 The VPRO office

The new office for the broadcasting organisation VPRO, called 'Villa VPRO', was completed in June 1997. The dissatisfaction of the most important stakeholder – the people who have to work in the building – has been extensively documented in a booklet published three years after commissioning (Paans, 2000) as well as in the press (e.g. national newspaper, Volkskrant, 2001).The design by MVRDV architects, was based on an audacious architectural concept, which required innovative solutions from all parties involved. The main characteristic feature of the design was the architectural open space concept: open floor areas with open views from one floor to an other. Two of the architects involved – Maas and Van Rijs – had previously worked at the Office of Metropolitan Architecture (OMA) of Rem Koolhaas, who had applied a similar open space concept in his design for the competition in 1993 for the Bibliotheque Jussieu University in Paris. MVRDV stands for the initials of Maas and Van Rijs and the third founder Nathalie De Vries. How the design team developed innovative solutions has been described by Roelofs (2001).

8.1 Appropriateness of the case

The architectural concept was the architect's answer to special demands by the owner in regard to the desired architectural character of the new building. It had to provide the users with the same feeling that they were accustomed to in their old premises: a variety of freestanding houses mostly built in the thirties, referred to by the employees as their 'urban villas' (Fig. 8.1). The new building had to be a home rather than an office. Table 8.1 shows how this requirement was incorporated in the bill of requirements.

The owner, who realised that such ambitious architectural objectives would require not only functional concessions but also more money, made a budget of € 18.18 million available, some sixty percent more then what would be required for a standard office building. A standard office building for the spatial requirements as listed in Table 8.2 would have cost about € 11.60 million.

Deadlines in the design phase were extended several times, but this hardly affected the date of commissioning. We will, therefore, consider only the criterion of functionality and investigate if in this extremely complex case inappropriate application of PI practices led to a loss of functionality that could have been avoided by adoption of PII practices. As we will see, that is indeed the conclusion of our analysis.

Figure 8.1 Villa 65, one of the old office villas (all figs. from Wennekes (1997))

Table 8.1 Architecture and associative identity of the building

Apart from being an association with idealistic objectives, the VPRO self-image is that they are an organisation of programme makers for television and radio. The architecture has to be in line with the identity of the VPRO and, preferably, reinforce it.

Concessions with regard to functionality and efficiency of the building needed in view of architectonical demands are discussable with the owner. There is freedom in the choice of materials.

The associative meaning of the building is described by:

- opinionated
- daring, beautiful
- exclusive
- stylish, tasteful
- sober, but not prestigious
- classic, no office façade towards the highway
- open, informal
- low building, pavilion structure (like old existing buildings)
- atmosphere as in the former villas
- exceptional forms, materials, norms
- ‘the home of VPRO’.

Table 8.2 Spatial requirements

Working stations	353
area per employee (m2)	26.3
gross floor space (m2)	9 562
parking places	165 (115 in partial basement, 50 in the grounds)

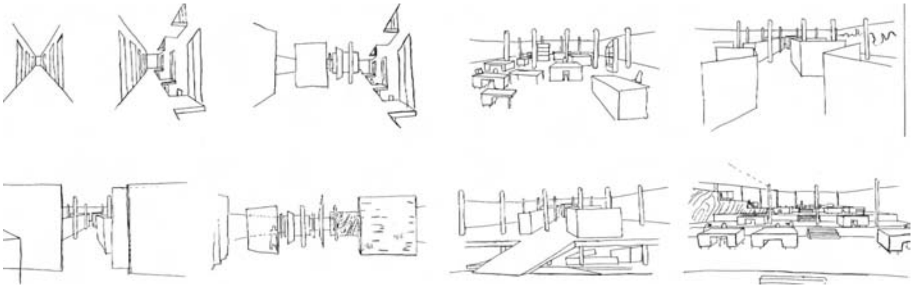
8.2 The Open Space concept

The open space concept entails the combination of a variety of office types, functions, different materials, and so forth, integrated into one compact building without any physical separations (Fig. 8.2a to 8.4b). Transparency of the building as a whole, aimed at integrating it with its environment, is an important aspect of the open space concept. (For an extensive description, see Wennekes (1997).

Obviously, the following key issues would have to be resolved for the realisation of this concept (Roelofs, 2001):

- First, there is the issue of fire protection and escape routes. Once ignited, a fire could spread through the building very quickly. Corridors with fire doors would clearly be in conflict with the open space concept.
- Second, the daylight distribution in the building constituted a serious problem. The daylight in some working locations would not meet the prevailing regulations for daylight at the working place at all.
- Third, certain areas would have to be protected against too much sunlight.
- Fourth, the installations for ventilation and heating would have to be designed in such a way that all the connected open spaces would be properly ventilated and heated.
- Finally, noise hindrance and acoustics are critical in such an open, connected space. A broadcasting company is quite different from a software development firm where people are quiet behind their computer screens. A lot of verbal communications and telephone conversations are inherent to the mission of a broadcasting organisation such as VPRO.

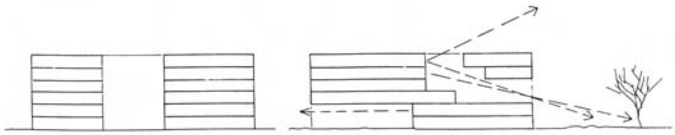
Since straightforward, standard approaches for these issues would soon result in severe clashes with the open space concept, specific design solutions had to be invented. This meant less standardisation and more openness for new concepts (Aspect 10).



(a) A variety of office types was provided

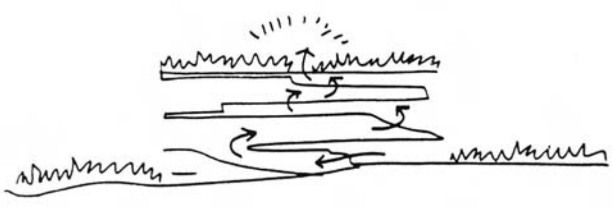
(b) Combinations of various office types in one building

(c) Floorspace at six layers of the building

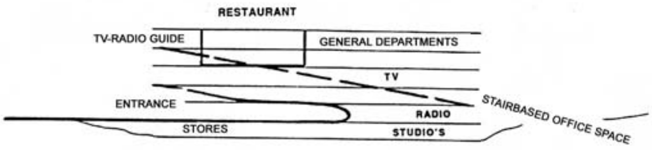


(d) Vides with view to the outside

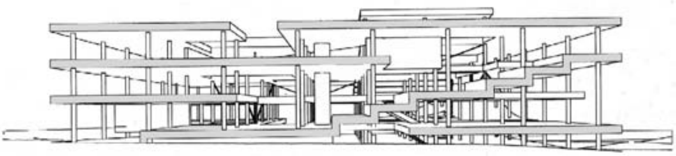
Figure 8.2 Elements of the open space concept I



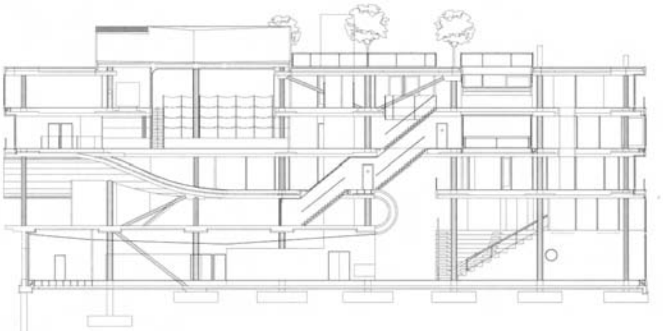
(a) Geological profile



(b) Various functions combined in one compact building

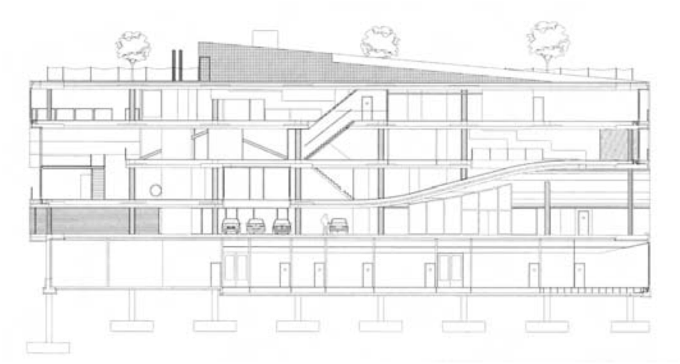


(c) Structural design (South side)

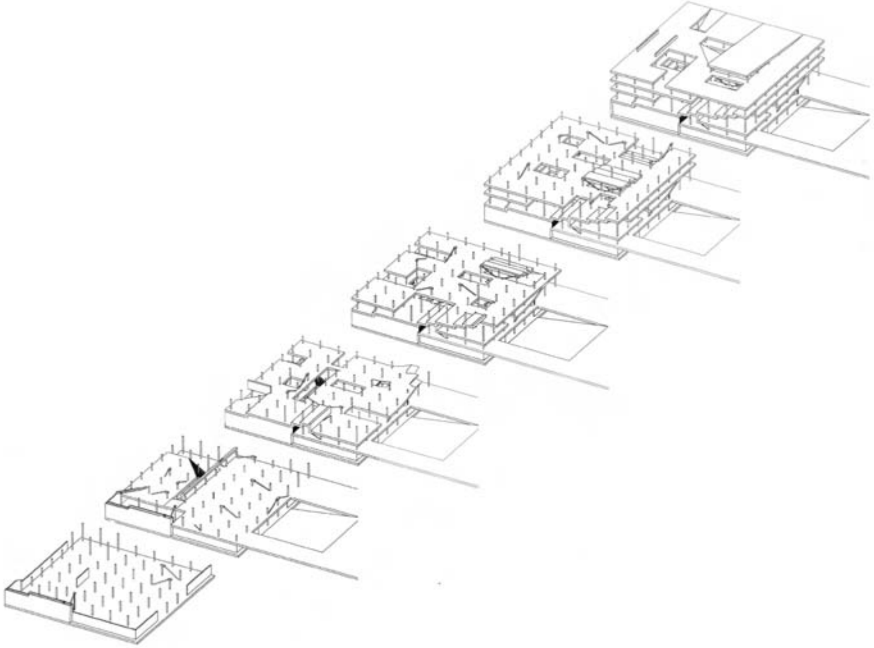


(d) Section West

Figure 8.3 Elements of the open space concept II

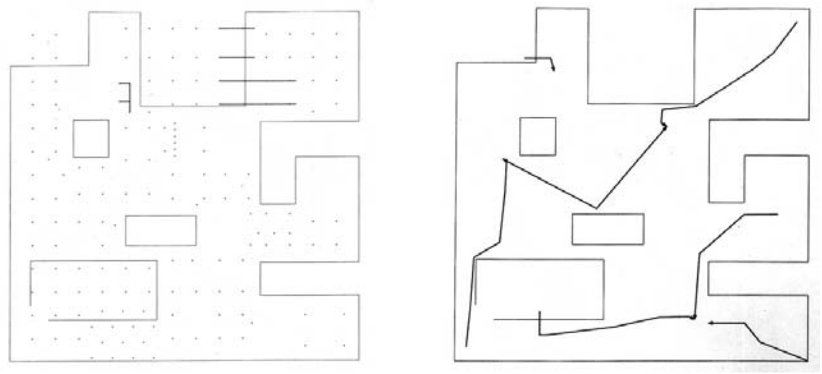


(a) Section East



(b) 3D representation of floor composition

Figure 8.4 Elements of the open space concept III



(a) Sprinkler plan for 2nd layer (b) Escape routes for 2nd layer

Figure 8.5 Fire protection plans

The first four key issues were actually addressed in the spirit of PII practices, and with success. Specialists were challenged to produce innovative solutions that would leave the architectural concept intact. They applied PII practices by means of adjusting of goals when circumstances changed, by means of conflict resolution based on synthesis and not on compromise, and by means of creating a climate of mutual adjustment of design sub-solutions (Aspects 1, 3, and 9).

In the first issue, fire protection, the solution turned out to be the installation of a sprinkler system that would detect smoke and flush water at the very beginning of any fire (Fig. 8.5a). Sprinklers are unusual for such buildings. Escape routes were kept to a minimum, although some concessions to open space concept were unavoidable (Fig. 8.5b). The daylight issue was resolved by creative solutions such as reflecting walls to lead the daylight to spots that needed more light and light domes at carefully selected locations (Fig. 8.6). Many innovative solutions were also generated for the issue of solar protection (Fig. 8.7). The issue of heating and ventilation was resolved by using the space in the floors as a *plenum* (Fig. 8.8).

The fifth key issue, noise hindrance and acoustics, was not addressed in a PII way. It was considered sufficient to provide for some silence rooms and for an extra budget, which would allow corrective measures to be taken after commissioning, such as the application of noises damping materials at critical locations. The result has been that most of the people who have to work in the building are extremely dissatisfied and disappointed.

How could this happen? Four of the five key issues were successfully resolved in an innovative manner that deserves only admiration and respect. The fifth issue, by contrast, was almost completely ignored in the design of

Figure 8.6 Floor height domes to provide sufficient daylight

the building, making it unsuited to its purpose: providing an adequate working place for an organisation of (top) programme makers for television and radio. The architects persisted in their view that the design reflected the practical requirements of the users, who in turn maintained that quite the opposite was true. At the time of writing, the issue is still unresolved.

8.3 Noise hindrance and acoustics, the ignored key issue

Noise hindrance and acoustics had been identified as an important issue right from the beginning. Relevant buildings with open offices were visited in the country and abroad. On January 5th, 1994, the board of directors of VPRO paid a visit to the open office spaces of the headquarters of the insurance company Centraal Beheer in Apeldoorn. Their reaction was: reserved enthusiasm. This was, however, interpreted as 'quite well' in the minutes of the design team meeting of January 6th, 1994.

In the minutes of the next meeting it is noted: 'Acoustics are extremely important: people are busy, lots of walking, talking and telephone conversations.' In the steering committee of February 10th, 1994 the architects of MVRDV present a note: 'Noise absorption inside the building' in which they write: 'Conclusion: noise absorption is solvable with 60% mats (on the floor), with furniture and with curtains.'

The VPRO organisation, however, was not convinced and decided to conduct a test. In the existing villa's, ten new lodgings were commissioned with openings instead of doors. The reaction of the personnel concerned was negative. The minutes of the steering committee meeting of September 8th, 1994

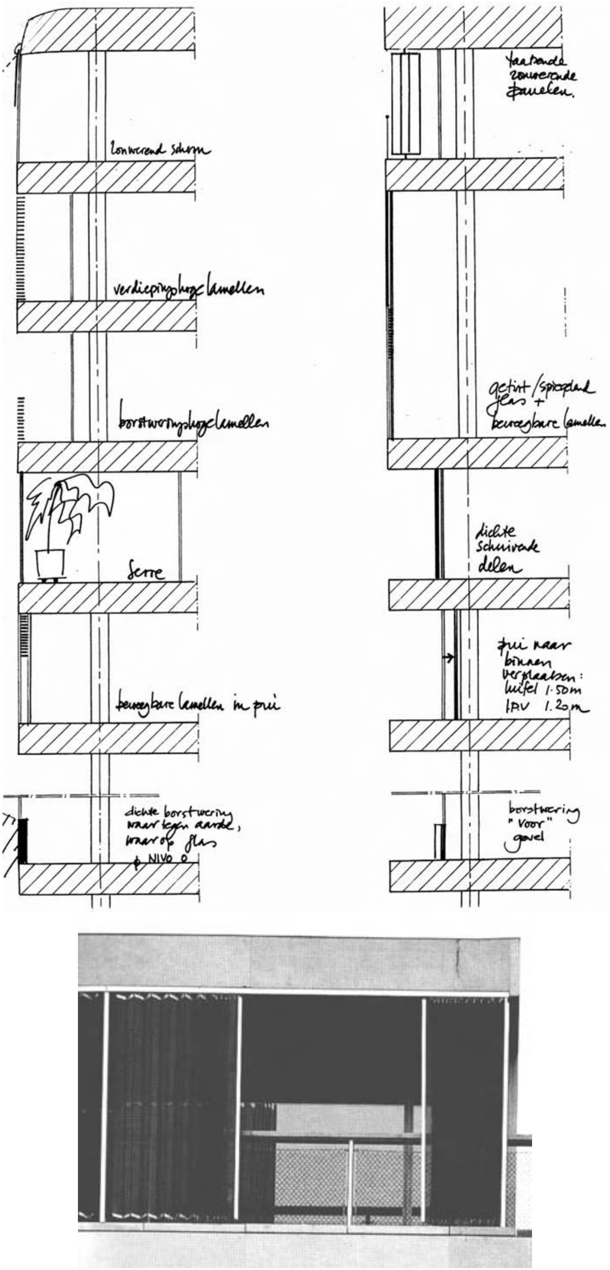


Figure 8.7 Sun protection propositions

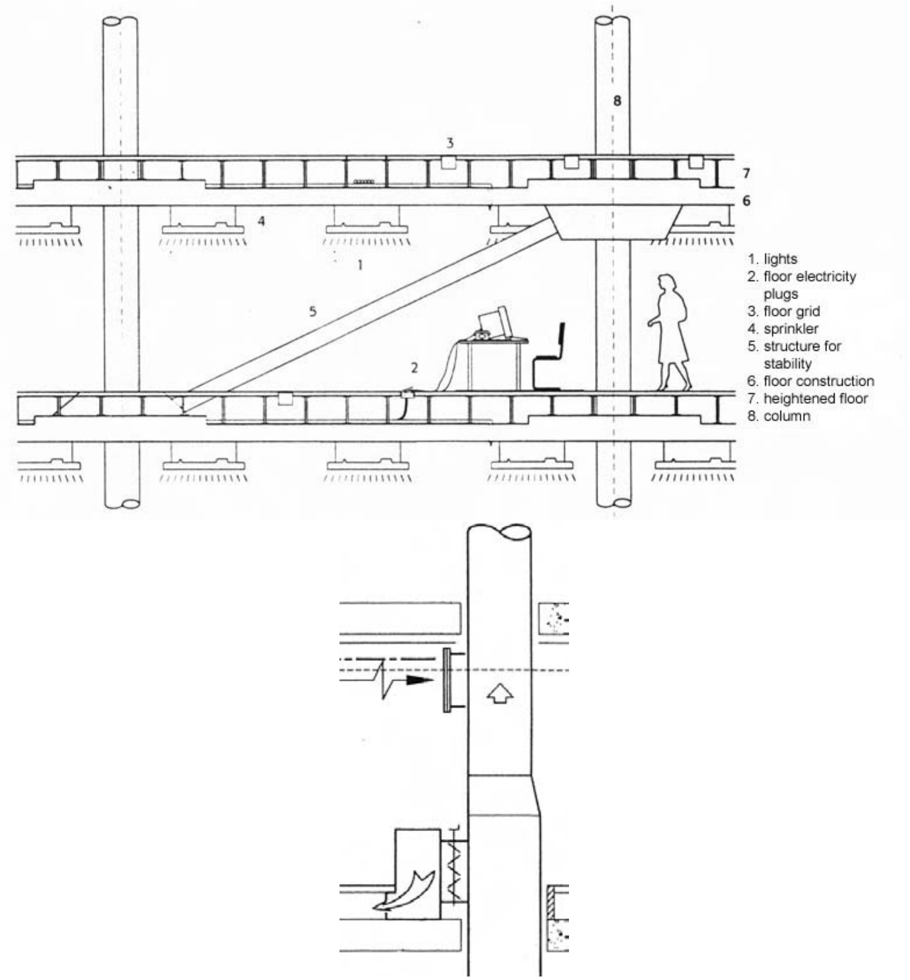
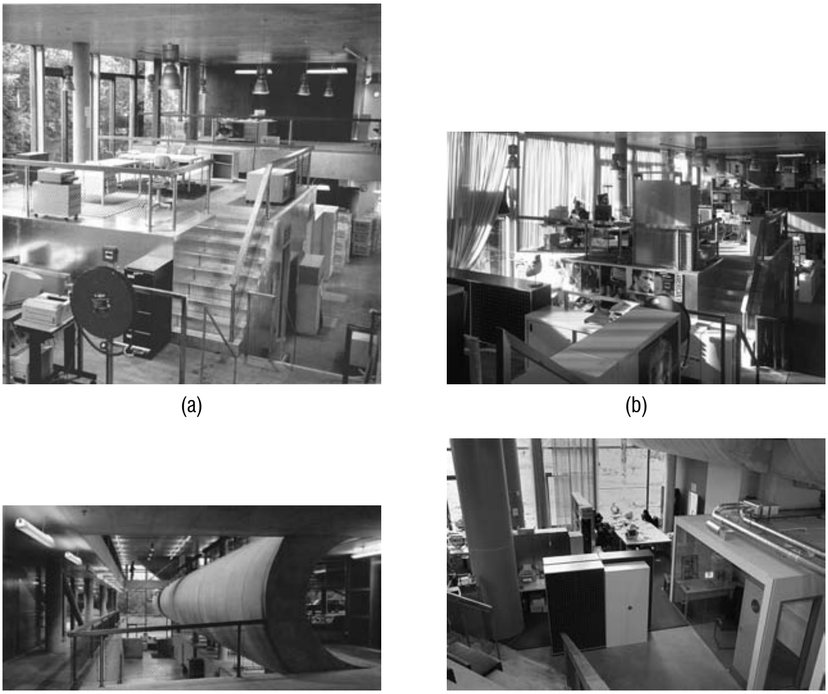


Figure 8.8 Integration ventilation and heating into floors



(a) (b) (c) (d)

Figure 8.9 The same working areas before and after modification by users: cupboards and curtains, closed working units with separate ventilation system

mention: 'Walls: the highest floor of the new villa had loose walls without doors. This evoked quite some resistance from the personnel. They indicated to prefer a door to protect one's own working place, even if that door would be open most of the time!'. That was the last time reference was made to the test. Clearly, the open space concept goes a lot further, for not only the doors are left out but also the walls.

Immediately after the commissioning of the building in June 1997, a stream of serious complaints from the users about noise and lack of privacy began. Employees started to correct the situation right away by building their own 'walls' with cupboards, boxes and curtains (Fig. 8.9). Some employees started working at home to avoid the disturbances and distractions at their official work location.

As the stream of complaints continued, a meeting between architects and personnel was arranged on October 2nd, 1999. The meeting was organised as a Symposium under the title 'Working in a piece of art: architects contra


(a) (b)

Figure 8.10 The building exterior (a) and the building interior modified by users (b)

users or users contra architects.' This confrontation between architects, or rather artists, and users did not generate any solutions to the serious problems raised by the users. The architects persisted in their view that the design reflected the practical requirements of the users, who in turn maintained that quite the opposite was true (Paans, 2000). At the time of writing, the issue is still unresolved (Fig. 8.10).

The fact that the key issue of noise and acoustics – and to a certain extent also the lack of privacy – was largely ignored and played down during the design phase of the project was not just a coincidence. The ambition of realising a daring architectural concept brought with it that anything that could kill it was taboo: undiscussable because of too painful consequences.

The architects could not ignore the other four key issues. Fire protection and escape routes concern personal safety with which no one is prepared to compromise. Daylight distribution and sun protection affect the very nature of the work of an architect: playing with space and light. Installations for heating and ventilation simply cannot be left out.

Noise hindrance and privacy, by contrast, do not affect safety and are subjective in the sense that different individuals perceive them differently. They are, therefore, linked to the mission and culture of the organisation concerned. It is quite possible that the building would have been suited for a software development company or for a library. For a broadcasting organisation it is definitely not, as is illustrated by the following comments from users:

- As a clubhouse or factory it is quite good, but thinking for a moment from time to time, having an undisturbed telephone conversation or writing an article, is not possible.
- Building is beautiful, but old-fashioned. No flexible workplaces; every one chained to his or her workstation.
- The building has changed our way of working. In-depth research is hard

Table 8.3 Application of best practices in the VPRO office

Aspect:	PI / PII:
1. Goal setting fixed vs. floating	PII
2. Leadership boss focused vs. stakeholder focused	PI
3. Conflict resolution compromise vs. synthesis	PII
9. Co-ordination of tasks project manager's co-ordination vs. mutual adjustment	PII
10. Standardisation where possible vs. where functional	PII

> to sustain over longer periods of time. When I have complicated telephone calls, I am exhausted after three hours. One gets a constant input of impressions from which one cannot shut oneself off. The depth of the work is being undermined. That is alarming, for it affects the quality of our programmes. In addition, it should be noted that little flexibility is provided for future organisational changes. For instance, the trend is to work increasingly with multimedia: TV, radio, digital, guide and to organise units, also physically, according to subject.

8.4 Lessons related to Open Design and Construct management

The taboo on anything that could kill the architectural concept has led to a design in which the interests of the most important stakeholder – the people who have to work in the building – have largely been ignored (Table 8.3). The design does not match the mission and the culture of the user organisation VPRO.

One may wonder:

1. Could this extremely serious fault have been avoided by appropriate PII-practices?
2. If so, would the architectural concept have survived?

The answer to the first question must be affirmative, because excluding a crucial stakeholder is a 'deadly sin' in the realm of PII practices. User demands related to noise hindrance and privacy would have received equal weight as architectural beauty.

Whether the open space concept would have survived is hard to say. Far reaching concessions would probably have been necessary. On the other hand, the concept did not really survive anyway if we consider the improvised measures taken by the users, such as building glass walls around units, and placing partition-like cupboards, curtains, decorations, and wooden movable walls (Fig. 8.10b). What is preferable, the concept being killed in the design phase or after commissioning?

9 Shell-Mitsubishi petrochemical plant in Singapore

This chapter describes the case of a US$ 0.6 billion petrochemical process plant for the joint venture between Shell and Mitsubishi on Seraya Island in Singapore, which was designed and constructed in the period 1990-1997. The construction of this petrochemical plant was managed by 'Mr Frans', as he was called on the site. He was interviewed in depth by the authors to surface the underlying principles of his managerial approach.*

At the end of this chapter we have added the relevant management experiences of Mr Frans of his subsequent construction project during the period 2001–2006: a US$ 4.3 billion Joint Venture between CNOOC and Shell for a chemical plant in Guangdong Province of P. R. China, known as the Shell Nanhai project.

9.1 Historical review

1990-1992 Birth of the Seraya Island Projects Singapore

Since its start-up in 1984, the $ 2 billion Singapore Petrochemical Complex ('Complex I') had established itself as a competitive and reliable petrochemical supplier of high quality, superior grade products in Asian countries with an average turnover of over $ 1.8 billion per year.

Demand for petrochemical products in the Far East, especially China was expected to increase considerably. Singapore, having been a base for Shell for a century, was considered by the chemical division in Shell to be the appropriate bridgehead for the expansion of its chemical business in the region. Compounding factors were the political stability and the economic policy of the Singapore Government and related authorities to actively stimulate the petrochemical business after the refining business had matured.

For Shell Chemicals, not yet having a large manufacturing presence in the Far East, a joint venture with a reputable Asian company was considered desirable. Both Sumitomo and Mitsubishi Chemical had shown their commitment in the first chemical complex. They had invested in the first cracker project, led by Sumitomo, and the downstream Ethylene Oxide project, led by Shell. The second cracker project was led by Sumitomo with a 50% share held by Shell and the downstream Seraya project was led by Shell.

Shell technology, based on its Moerdijk and Pernis experience in The Netherlands, was chosen for the Seraya projects. Therefore, the technology-related

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*The views expressed by the authors in this chapter are their own or the personal views of Mr Frans. They do not necessarily represent the views of management in general of any Shell company.

aspects were managed from Holland. Shell Singapore provided not only the project finance, but also a large part of the resources in the widest sense including staff and operator training.

At this stage Phillips Petroleum (USA) was still participating in one of the six projects, together constituting the second petrochemical complex, but later – in July 1993 – pulled out of the project because financial priorities had shifted to upstream activities (They joined again later after the Singapore Government took up 20% share).

1992-1994 Project preparation

Sixty service agreements were put into place to arrange the required legal/services set-up of a new (70%-30%) venture between Shell and Mitsubishi Chemical.

The project specification – fifty volumes, some four meters of books – was developed in Holland with various Shell departments, contractors and input from Shell Singapore and Mitsubishi Chemical.

The other two Japanese-led parts of the development of the island were a year ahead as a result of their different execution strategy. In order to catch up one year in the schedule, it was decided to avoid a bidding step. Chiyoda (Japan) was chosen as main contractor for the execution of the project on a lump sum basis. The lump sum was negotiated in a depressed market allowing the joint venture to benefit from a relatively low capital expenditure. This was in line with Shell's practice to invest counter-cyclically, if justified on a long-term basis. Chiyoda was chosen because of its proven performance for Shell in Singapore as well as its acceptability to Mitsubishi.

1994-1995 Project execution

The project was manned with staff already on board in the preparation phase, staff with roles in the operation phase, staff having particular Singapore and Shell expertise, and Mitsubishi staff.

The detailed engineering was executed in Yokohama, Japan, with help from a Seraya resident team of five persons. Each month an alignment meeting was held in Yokohama with the project and operational management.

Meanwhile, the authority approvals were requested in Singapore, both for the execution of the project on site as well as for the logistic infrastructure, e.g. parking spaces and ferries to reach the Seraya Island.

At the site in Singapore the soil removal and site preparation were executed based on soil investigations by Singaporean and Dutch firms in the preceding phase.

The Seraya joint venture company was registered and structured using the full support of Shell Singapore and its good reputation in Singapore.

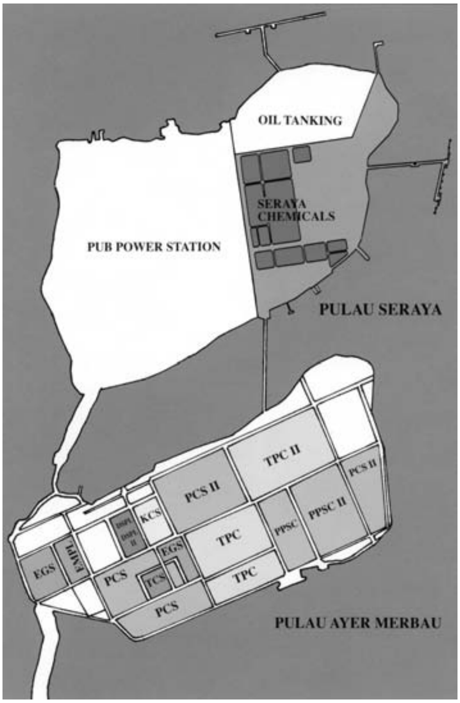

Figure 9.1 Map of integrated first and second petrochemical complexes (Seraya Chemicals)

1996-1997 Construction and commission

In 1996 the plant was constructed with completion in 1997. Commissioning and successful start-up took place in May 1997.

A map of the integrated complex is shown in Figure 9.1. Its location with respect to Singapore is given in Figure 9.2. An aerial view is shown in Figure 9.3.

9.2 Project manager's story

Appropriateness of the case

The project satisfies to a great extent the main criteria for successful complex design and construction management:

1. High degree of stakeholder satisfaction on most of the achieved levels of performance.
2. Project completed on time and (substantially) below budget.

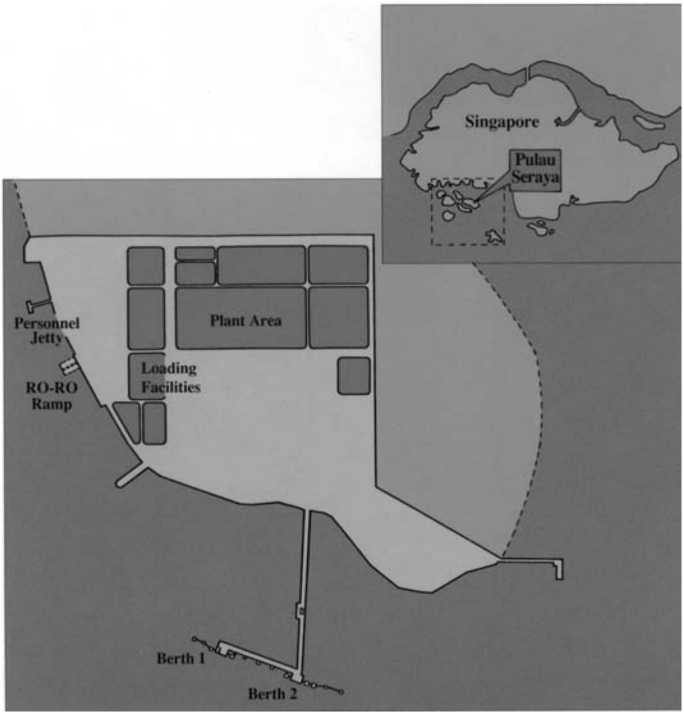

Figure 9.2 Location of plant with respect to Singapore (Seraya Chemicals)

Figure 9.3 An aerial view of Seraya Chemical complex (Shell Venster, 1994, p.21)

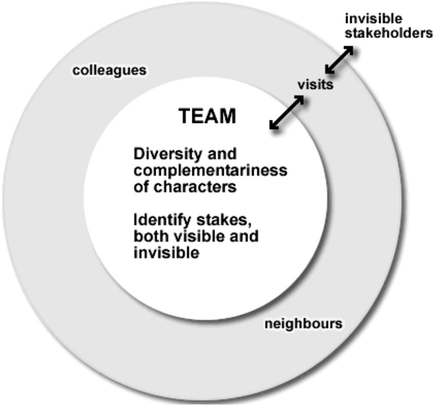

Figure 9.4 Team composition should cover visible as well as invisible stakes

After completion the key elements of these criteria were benchmarked by an independent party (Independent Project Analysis Inc.) and the shareholders Shell and Mitsubishi.

Project management team

The project manager Mr Frans: 'How did I manage the project?'

First of all, I did not manage it alone. The project was actually managed by a duo of Arjen, the designated plant manager, and myself. Arjen had been involved from 1990. I joined in mid 1992. We were complementary not only in personal capabilities, but also in our relationships with essential stakeholders (Table 8.1).

It should be noted that the relevance of various stakeholders changes over time. Relationships with stakeholders should preferably be established well before the stakeholder concerned becomes relevant to the project.

Arjen was the process co-ordinator, because he came from Chemicals. After completion of the project he would become the plant manager, so we had the future user in the team. In view of our different roles, we agreed to emphasise that difference in the last year before hand-over and start-up.

Diversity in the team and relationships with stakeholders were not only criteria for selection of the leaders of the team, but also for choosing other team members (Fig 9.4).

Origin of the project

After the Second World War, Shell had made great efforts to diversify downstream, i.e. in the petrochemical business, but the financial results had al-

Table 9.1 Relationships of project managers with stakeholders

	Arjen	Frans
Dutch connection		
Shell:		
• Chemicals	•	
• Process	•	
• Operations	•	
• Technology	•	
• Moerdijk/Pernis	•	•
• Staff chemicals	•	
Shell top management:		
• Mr X		•
• Mr Y	•	
Oil and Gas:		
• Mr Z		•
• Staff		•
• Support		•
Marketing:	•	
Japan connection		
• Mitsubishi Corporation	•	
• Mitsubishi Chemical		•
• Chiyoda (contractor)	•	
• Yokogawa (contractor)		•
Singapore connection		
• Bukom		•
• Shell management Singapore		•
• Chinese community in general		•

Table 9.2 Scores on cultural dimensions of some countries according to Hofstede (1980, 1994)

	PDI	UAI	IDV	MAS	LTO
Singapore	*74*	*8*	20	48	48
The Netherlands	38	53	80	*14*	44
Great Britain	35	35	89	66	*25*
Japan	54	*92*	46	*95*	80
Hong Kong	68	29	25	57	*96*
United States	40	46	91	62	*29*
India	*77*	40	48	56	61
China					118
Mean	52	64	50	50	
Standard deviation	20	24	25	20	

ways been rather disappointing. So, there was a need for a big project in Shell Chemicals, which could bring the result so long hoped for. Where should it be? From strategic planning, Singapore finally emerged as the logical choice, mainly because of three reasons:

1. Long term corporate strategy to expand in the Far East;
2. Local business practices were in line with Shell's Business Principles;
3. Entrepreneurial climate.

The latter becomes apparent from Hofstede's work on the culture of various countries.

Hofstede (1980, 1994) describes the culture of a country in five dimensions:

1. Power distance acceptance, PDI;
2. Uncertainty avoidance, UAI;
3. Individualism, IDV;
4. Masculinity, MAS;
5. Long term orientation, LTO (Confucian dynamism).

Originally, only the first four dimensions were included. The dimension of long term orientation or Confucian dynamism, was later added to account for this characteristic feature of eastern countries which largely explains their successful economic growth over the past decades.

Scores for some relevant countries are given in Table 9.2 (Hofstede, 1980, 1994).

The relevance to the project of some particular scores is listed in Table 9.3.

Table 9.3 Relevance to the project of some scores on cultural dimensions

Relevance to the project of scores in italics in Table 9.2

1. Singapore low UAI:
    - Entrepreneurial government
    - Flexibility in day-to-day decision-making on site
2. Singapore and India (a large part of the work force was from India) high PDI:
    - Acceptance of top-down decision-making
3. Netherlands low versus Japan high MAS:
    - Requires special approach in safety issues
4. USA and Great Britain low LTO:
    - Brings along opportunistic decision-making (f.i. Phillips Petroleum pulling out)
5. Japan high UAI and high LTO:
    - Natural emphasis on being a reliable and long-term partner
6. Hong Kong, typical for Chinese business community, high LTO:
    - Long term relationship is sine-qua-non

In regard to Uncertainty Avoidance, Singapore scores lowest of all investigated countries! Accordingly, the Singapore Government operates in an entrepreneurial manner. After the successful investments in crackers, the government wished to get a petrochemical business off the ground which suited well with Shell's desire for the same. Another advantage of Singapore's low Uncertainty Avoidance score is that it provides flexibility in day to day decision making on the site. Initially, there was a lot of reluctance to go ahead with the Singapore-option. The prevailing prejudice was: those Singapore Chinese know everything better. You know what? They do indeed know better!

I was sent to Singapore by Shell Senior Management, who had confidence in me because of previous experience, on a two month mission to reconcile conflicting positions on the division of work between Singapore and Holland and on the contracting strategy.

At that time I formulated the contractors' philosophy, i.e. determining who does what. This is what shareholder stakeholders are always primarily interested in. For example, the choice of Chiyoda as main contractor was a must. They already belonged to the Mitsubishi family and had done big projects in the Bukom area before and they were capable of catching up on the time schedule for the development of the island.

To summarise, Shell was in need of a big petrochemical project, there was a dormant project in Singapore, I came along and was, with Arjen, trusted by some key managers in this process to solve two major issues:

1. *Division of work:* should the project be run from Holland or from Singapore?
2. *Contracting strategy:* which contractors to involve to make it possible to catch up a year's delay as compared to other investments on the island by the Japanese companies Sumitomo and Mitsubishi?

The contracting strategy was established mid 1992. Comprimo was chosen for the engineering design. They started in September 1992. I had required that as from January 1, 1992 Chiyoda would be present in the Comprimo offices in Amsterdam. Such involvement before contract is exceptional and was only possible because we could build on the results of our objectives meeting in which we had identified our common interests. The Chiyoda executives in the Comprimo offices – some twenty people – would only pick up information already available. They were not allowed to ask for information that would require extra engineering hours.

The twenty Chiyoda people wired all their information to their headquarters in Japan. This went on during six months. The ITB (Invitation To Bid) went out in April, so also in the period that we were still engaged in basic design.

I wanted to reach agreement on 01-07-1993 based on a bid from 01-06-1993. This was only possible because the form of their bid was such that we could analyse it and make comparisons with our computer programs in a fortnight. Everything was presented in formats convenient for us. When I then went to Japan – as always first to Mitsubishi and subsequently to Chiyoda – we did not reach agreement on the price. Their price was some twenty percent higher than ours, probably due to Chiyoda's belief that we had no other options. And then Phillips Petroleum (USA) pulled out putting the whole project on ice. All of a sudden we were not in a hurry anymore. Chiyoda, eager to get the ball rolling again, made concessions and on 03-09-1993 we reached agreement.

We had a fixed price well below the Shell estimate. This provided financial margin to get the project financed with the help of EDB – Singapore's Economic Development Board – as a temporary substitute for the investment of Phillips. Singapore was very interested in the project in view of its effect on the long-term development of the country.

In January 1994, Singapore's ambassador in Brussels asked Shell's president one question: 'Give me the reason why you would not approve the project'. Just one question. If the answer is: 'I am going to approve', she would have done her job. If a reason for not approving were given, her answer would be: 'We'll solve that for you'. There could always have been a hidden reason for not approving. Why did the president approve? Shell had obligations towards the Singapore government, towards Sumitomo, and towards Shell Chemicals who had their homework in order. Mitsubishi was on board as a partner. There was no reason for not approving, so it was approved on 25-02-1994.

At this stage, I learned that the Dutch connection can also be a disadvantage. Comprimo was excluded from the execution at a very late stage. Why? The Chinese in Singapore had historically been dominated by English and Dutch expatriates. By the English in regard to marketing and sales and by the Dutch in regard to technology. Nowadays there is no inferiority anymore in either of these, but the grudge from the past is still there. If something went wrong, the Comprimo Singapore residents tended to turn to their headquarters in Amsterdam and complain about their Singapore counterparts whom they had to collaborate with. I consider that to be a deadly sin, but I did not listen well enough to some people who warned me when I tried to involve Comprimo in the execution as well.

In November 1992 a decision had to be made on the form of contract – lump sum/turn key or reimbursable plus incentives*. The latter would be in line with previous experience in Pernis (The Netherlands) but the question was if that would be possible with Japanese contractors in Singapore. A two day meeting was arranged with two Japanese main contractors – Chiyoda and JGC. Their view was politely communicated to me: In Singapore there is only one possibility: lump sum /turn key. This later turned out to be a blessing. Once the contract is signed, there is for three years no quarrelling about money. The contract gives a financial boundary within which management can manoeuvre. There is rest and focus on collectively achieving results, in particular through mutual aid, helping each other where possible. This is an enormous advantage.

Disadvantages of the lump sum contract were that we did not have the upperhand in the management control and vulnarability of scope changes. In general, Chiyoda has not misused the contract form. Only in a few cases delay had to grow significantly before we could get them act.

We had four objectives meetings with Chiyoda to establish what our common interests were and what our conflicting interests were. It turned out that our only conflicting interest was money. That issue was settled by the lump sum/turn key contract and a strict and formal change order procedure. After signing we could fully concentrate on our common interests: safety, efficient working procedures, etc.

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*Lump sum/turn key means that a fixed price is agreed for a well-defined end result. Reimbursable plus incentives means that efforts, i.e. man hours and costs, are paid along with bonuses for specific results. The problem of lump sum/turn key is that it is often impossible to describe the required end result in detail at an early stage.

9.3 Key Issues Matrix

In the management of the project the concept of a Key Issues Matrix played an important role in focussing attention on the right issues and addressing them with appropriate management tools. On the horizontal axis are placed the management tools addressing the key issues, such as communication, continuity of staff, delegation procedures and lessons from other projects. On the vertical axis are placed the key issues put forward by the project managers. Then the question was asked: what can each management tool contribute to each of the key issues? The answers to this question provided the courses of action that make up the matrix. In retrospect it can be noted that the Key Issues Matrix enabled to match PI best practices for subprojects with PII best practices related to complex aspects of the project as a whole.

The project manager explained the role of the Key Issues Matrix as follows: at the beginning of the project a two-day objectives meeting was held with the responsible managers to identify the key issues deserving special management attention. It was called an 'objectives meeting', because the shareholders' long-term objectives, not necessarily the contract objectives, played a major role. Stakeholders who could not be present in person, for instance the business manager of Shell or Mitsubishi, were represented by someone playing that role, i.e. people who could be trusted to know the views of the real stakeholders sufficiently well.

At first, any issue could be tabled. Next, all issues were discussed to establish if they were special to this case or normal for such projects. For instance, the issue 'planning & scheduling' is always a problem in any construction project and was, therefore, removed from the list.

Finally, only four key issues remained:

1. Interlinkage: the five projects in the second petrochemical complex, with five different shareholders (Sumitomo, Shell, Phillips Petroleum, Mitsubishi and Denka) were interconnected and also connected to the first petrochemical complex. Connectedness of a multitude of parties involved with different cultural backgrounds, different interests, etc. Linkage to parties around us, to our neighbours on the site, and to Bukom.

2. Joint venture: a two bosses situation, fundamentally different from a Shell-only situation. For Mitsubishi the joint-venture was the entry into a new market (of polyols).

3. Technology: there is always a need to apply advanced technology, but also the experience that new technology invariably seems to generate disasters. For instance, an effluent water treatment problem surfaced that could only be solved by applying new technology.

Table 9.4 Key Issues Matrix: Key Issues and Management Tools *

Key Issue 1: Interlinkage	Key Issue 2: Joint Venture	Key Issue 3: Technology	Key Issue 4: Project management for new company in green field
Management tools:			
Mutual aid			
Nurture informal mutual aid e.g. marine help to TPC and OTS lay down area	Balance between board meetings MPCL secondees		Whole team to focus on overall project objectives and build up SCSL corporate identity
Communication			
Monthly meetings with PCS and EGS Formalise contacts with marketing organisations (SECL+YSPL)	Formal progress / and support of PA only by SCMD/CLX	Centralised filing to enable project history & avoid recycle Look for best timing of unavoidable changes Licensor in Hague	SCMD and CLX split roles but same office Short lines of communication Weekly video conference to avoid bureaucracy by timely decision of SCSL management
Build on Shell Singapore Bukom			
Use experience with PUB and ENV and PSA		EWT experience CW intake experience Material selection	Use mix of Bukom engineers SICM-CMF manufacturing Start with Shell finance systems for finance and personnel
SICM support			
Liaison EGS–AS2 Project Support Standards for EO line and pipebridge	SMPO restricted information Project monitoring in steering committee	Licensors in The Hague Nurture daily contact Training start-up from Moerdijk/Pernis	Bukom engineers and chemical expertise

* Unabridged. As a result the matrix contains some unexplained abbreviations, which are not relevant in the present context.

Continued opposite

Continuity of staff			
Continuity in focal points Old hands to help new hands	SCMD/CLX take over from GLN Nakayama is central focal point - MPCL SICM continuity: vd Weerd/Dee	Dee/Driesson to stay on project	Use PCS/EGS/TPC experience with authorities Check interference with Bukom on e.g. HSE
MPCL secondees			
Japanese connection	Use MCPL and when SCSL	Auditor role	Use secondees as well as agreement at source to avoid recycle at higher levels
Clear flexible roles in team			
Formalise differentiated points for OTS and PUB Keep shareholders role of Shell outside project	Secondees as required for	No change policy, but bring and use experience by "ASK FOR TASK" and focus on overall project objectives	
Management tool: Delegation procedures			
Focal PCS, EGS Formalise budgets for: SCSL, SSPL, SECL	Board info and SMPO restricted info to be handed by SCMD only. Project progress report by CLX.	Strict change management No implementation or anticipation before full change authorisation	Use SCFN, CLX/3/4/5 to write procedures Avoid bureaucracy by accepting non-perfect first issues
Management tool: Audit plan			
CL to check quarterly on project approval and progress: SCLD, MK, EGS, PCS, TPC	IPA check Jan 1994 Use SCFN and CLX/5 as internal auditor		SCFN and CLX/5 to prepare plan
Management tool: Lessons other projects			
PCS-1 EGS experience SMDS/MLNG/BLOT (BINTULU) experience	TPC/PCS/EGS/SMDS	Use Moerdijk Pernis experience on SMPO/POD Supervise EWT scope closely	SMDS. Bintulu, Malaysia Rayong, Thailand Use Bukom experience for handling Chiyoda

4. A new company in green field: the organisation for which a company name, logo and culture still had to be established, on a new site without any infrastructure and which could only be reached by ship. Historically, the largest contractor's claims are soil-related. So a green site represented a large risk of contractor's claims.

We then asked ourselves: what can each management tool contribute to each of the four key issues? The answers to this question provides the courses of action that make up the matrix. But first I have to explain these management tools.

Mutual aid means that if something can be resolved for $ 1 by one partner, whereas it would cost the other one $ 10, the former will solve it, regardless which one of the two is the problem owner in terms of guilt or responsibility. Let me give an example of mutual aid: the soil problem mentioned before. We had a soil investigation report which had been made in the standard manner. Far insufficient to avoid contractor's claims later on. The soil investigation had to be translated into a foundation advice. But I had no budget for that. So I went to Chiyoda and asked if they would be prepared to pay it as an aid to Shell and myself in the realm of our relationship. They did so! They actually paid the foundation advice, thereby reducing their own chances for successful claims. I promised them that they would be refunded in the case the project would be abandoned. This solution was only possible because we had agreed on mutual aid. Of course, we have also helped them (Chiyoda) in situations where we were in a position to do so, for instance in relations with Singapore authorities.

Communication is essential to build trust. Both formal and informal communication have to be managed. One without the other is not enough.

Build on Shell Singapore Bukom. I am convinced that we would have failed without the support from Bukom. But how to get it? The prevailing attitude was: this is a chemical project that has nothing to do with refinery. To overcome this prejudice, I used the financial argument by pointing out that the project had been financed by cash flow from Bukom. Without Bukom there would not have been a project at all. On this argument the involvement of Bukom was accepted. Bukom had too many people – since staff reductions were ongoing because of efficiency improvements and outsourcing – so a number of them were transferred to our project. In the realm of our mutual aid agreement with Bukom, we could require that these people were the best and not the people they wanted to get rid of anyway. This is exceptional. Why did they comply with our request? It was seen as a Singapore project, – in which the EDB participated – not as a separate chemical project. Here you see the link with the shareholders. It also helped, of course, that I had worked before in Bukom. I knew these people. The subcontractors really made an effort, because they saw it as a Shell project, not as something directed from Holland.

In 1992, during the preparatory phase of determining the scope when I was in Singapore once a month, I had a dinner with Chiyoda, the two most important subcontractors and some Bukom executives. Just a dinner. I told them that when this project were to get the green light, they would be invited by everyone, but that I wanted to agree with them that they would work for us. Unspoken, they did as I expected. Without their Bukom clients amongst them at the table this would not have been possible. The message was: you belong to us and we need you. We expect you to help us, like we would help you when necessary. This is the Chinese way of working. At the end of the project one of those subcontractors had a dispute with Chiyoda, who understandably kept their subcontractors under tight financial control. Reference to our objectives meetings and to the importance of long-term relationships resolved the issue: the subcontractor was paid. Without the Bukom-relationship this intervention would not have been possible.

The next of the management tools – *SICM (i.e. Shell International, The Hague) support* – was expected to be problematic in the sense that for this downstream project little support capacity would be available because of a number of huge upstream projects: Perplus ($ 2 billion), China – Nan Hai – also some $ 3 billion, grassroots Rayong refinery project in Thailand, Oman LNG in preparation, Nigeria LNG in preparation. The solution was again *mutual aid*: I accepted some under-qualified people, but the corporate HRM manager promised me extra support when things would really go sour as a result of it. An example is utilities. When it turned out that the design for the cooling water system was poor – it could not even be started up – I got all the support for redesign and even implementation support to Chiyoda, who was responsible for design and construction.

Continuity of staff was also a management tool that needed special attention. Training of operators was a major problem. Without any experience, fresh from school, Singapore youngsters had to be trained to become reliable operators. We built, at the start of the project, an expensive simulator to enable them to learn almost everything on the simulator and we tried to get the most experienced instructors possible, who would stay with the project after start-up.

Instrumentation is another example of the staffing issue. Analysis of some five construction projects (lessons) revealed commissioning problems due to lack of qualified instrument staff. I had to wait for half a year to get the person I wanted (after I had turned down three candidates). When he finally came and worked marvellously with his counterpart from Bukom, the issue of instrumentation was never critical anymore.

As a result of my approach of being so selective, my team had about half the size of what was usual in Shell's large projects, as my chief in The Hague once noticed. I replied that on a trawler, a coaster or a supply boat the working atmosphere tends to be fine, whereas on a big tanker it is always a problem. When people have just a bit too much work, they have no time to quarrel and to criticise each other. Having too much time available for the work to be done is unhealthy and poison to the working climate. I only wanted people in the team with end responsibility. They could get help from whoever they would like, but they remained ultimately responsible. Within the team I tried to get balance between people from Bukom, Pernis, Moerdijk, etc. in view of links with other experts they would have access to.

Continuity of staff is, of course, always a problem. In addition to having future users in our team, we took some special measures to ensure a smooth transition from construction to operation. For instance, we had a common filing system. Usually, the construction team destroys its files after commissioning. We did not. Even the administrator of the files was transferred to operations after commissioning. This facilitated close-out considerably. When things go wrong after commissioning, the usual thing to do is to blame the contractor. But when everything is well documented, most things can be resolved without blaming anyone. Our files were used until the first shutdown. This was unusual, the construction team always used to dump their files after commissioning without after-care.

Mitsubishi secondees proved to be very useful as they were part of the Japanese connection. They could work well with Sumitomo, our neighbour on the site, and with main contractor Chiyoda. They were very knowledgeable. I insisted that they would do the auditing of technology, not Shell technologists who could easily be perceived as biased. Mitsubishi appointed a very experienced former plant manager who did a splendid job. He became our internal challenger, auditor and ad hoc problem solver. He liked the job because it provided him with new knowledge and he felt part of the success. Secondees are also important to keep shareholders satisfied. For this reason I wanted a financial controller from Mitsubishi.

The next two management tools, *clear flexible roles in team* and *delegation procedures*, are helpful in dividing the work to be done without losing sight of who should do what and who is responsible. Optimum use of the small number of team members achieved flexibility in roles, clear definitions of end responsibilities and continuity in our team.

Audits, constitute a useful management tool and are not at all a nuisance as is often the perception. I always wanted the best auditors possible and audits early rather than late. I see audits as opportunities to learn and to anticipate better on future problems. They are also important for shareholder relations. As explained before, I had to accept under-qualified people at several key positions. By having the audits done by the unit responsible for their assignments, recognition was given for the job done, taking into account these personnel limitations. Audits took place in various areas: civil works, rotating equipment, instrumentation, electrical; but also for safety and the project management by myself. I felt that my project management also had to be subjected to auditing. I wanted the best auditor available in order to learn as much as possible. This was the former Moerdijk plant manager, who was also a seasoned project manager. Together with an experienced project accountant, he investigated during three intensive days how Arjen and I had managed the project. An extremely useful learning experience not only for me, but also for the auditor himself. He used the audit to prepare himself and make a plan for the Oman LNG project of which he was the project manager and Chiyoda later became the main contractor. In view of that connection, Chiyoda was pleased having him as an auditor to whom they could show their performance. So, the audit was good for Chiyoda, good for the auditors, and good for me. A win-win situation created by a non-defensive attitude towards audits. I also insisted to have an audit on contract close-out, which had never been done so far. The best contract man within Shell came three months before commissioning to establish where the contract had loopholes that could still be closed before commissioning. I was so focussed on technical aspects and implementation that I could easily overlook important contractual issues. I told him that I saw him as my conscience in regard to contractual changes that had to be negotiated in this final stage. So, I used audits to get relevant expertise available elsewhere into the project. This is why a good audit plan is important, if executed by the right auditors, at the right time, with the right scope.

The same holds for *lessons learned*, not only from Shell projects, but also from projects of Sumitomo and other Japanese projects. These projects are factual and can be referred to using the results of the objectives meeting to establish what is relevant to our current project. It can provide – free of charge – new effective approaches and concepts that are complementary to conventional project management practices.

Rules of conduct for effective Design and Construct management

As a means to live up to the intention of effective collaboration, I have established rules of conduct that are short, so easy to memorise and to refer to (Table 9.5).

Rule one – *openness, everything on the table, without procrastination* – is undoubtedly the most important. We had weekly change meetings in which changes on plans were decided upon. In these meetings anything relevant could be tabled and discussed. At the start of our collaboration Arjen and I had agreed, personally, *everything on the table*. He has lived up to that better than I did. That is his merit. During the basic engineering phase in 1992/1993 we had a weekly lunch meeting with the whole team. We had started with the basic design in September and at Christmas (1992), Arjen came with a message of doom: 'I am stuck, I am completely stuck. Effluent water treatment

Table 9.5 Rules of conduct for effective design and construct management

1. Openness, everything on the table
    - Anything relevant to the mission and objectives – hard or soft information – should be discussible, no hidden agendas.
2. Mind your client
    - Respect your external or internal customer.
3. Relieve your chief
    - Be selective in using your chief as a resource.
4. Dig deep, report short
    - Think twice before communicating your view
    - Avoid contaminating your message by exhibitionism (spoiling the signal-to-noise ratio by showing off how clever you are)
5. Solve self
    - Do not pass the buck.
6. File few
    - If relevance is not clear: in the waste basket!
7. Grind your grudge
    - Accept decisions made wholeheartedly (a Dutch weakness difficult to monitor).
8. Use reaction for pro-action
    - Turn problems into opportunities
9. Complete in order not to repeat
    - Finish a job completely, to avoid recycling of problems.
10. Use your radar
    - Listen to non verbal messages
11. A job well done is fun
    - Striving for excellence in both small and large matters gives satisfaction.

is becoming an unsolvable problem. The requirement is 100 ppm COD affluent water. To achieve that, we get an enormous amount of waste we can't get rid of. I don't dare to continue, we have to stop here.' In the realm of our personal mutual aid agreement, I offered to solve this problem. The effluent water treatment was removed from the scope of Chiyoda. So Chiyoda could move on and was instructed to do so. A task force was appointed, chaired by Arjen, to cope with the problem. New technologies were investigated and finally a satisfactory solution was found. The new technology applied for this problem was freezing to get the pure water separated. The pure water coming free could be re-used in the process, thereby reducing the water consumption, which was welcome due to Singapore being water limited.

Mind your client means that you show respect for the interests of both your external and internal clients. That respect should prevail in the entire organisation and will enhance mutual aid.

Relieve your chief. As manager of such a big project I am inevitably overloaded. People reporting to me should never waste my time. This is well understood in the Singapore culture. One of my people from Singapore had applied on his own initiative. He wanted to join because, as he put it, 'it felt good; in one way or the other, your undertakings seem to succeed'. I later entrusted him with the task of taking care of the relations with the Singapore authorities. He performed this delicate task with extremely selective use of his chief as a resource.

Dig deep, report short. Have depth in your analysis, but report concisely. All issues open in our monthly report and all key issues addressed in our quarterly report. No surprises by hiding.

Solve self. Don't pass the buck. This is related to *relieve your chief.* No upward delegation, nor creating bureaucracy and mistakes due to miscommunication and misunderstanding.

File few. As much as possible in the waste basket to relieve your administrative filing. We initiated central filing to be used by all parties, the technologists, engineers, operators and support staff. Those files should not be contaminated by irrelevant data.

Grind your grudge. Genuinely accept decisions. To accept decisions that are contrary to one's own view is particularly difficult for high performers with a strong character, and especially for Dutchmen. We are a country of Calvinistic ministers and professors. In the 17th century, we were traders, hence our understanding of the Chinese. We only became an industrial nation some time after Great Britain, Germany and USA did. As a result, we have an enormous middle class valuing individual views. This makes *grind your grudge* so difficult for Dutch people.

Use reaction for pro-action means that one should always try to turn a problem into an opportunity. The Dutch have a proverb on this: 'van de nood een

Table 9.6 Criteria for selection of team members

1. Listening;
2. Convincing, inspiring;
3. Learning ability;
4. Initiative, creativity;
5. Persistence.

deugd maken′ (turn *need* into *virtue*).

Complete in order not to repeat is related. If you take care of something, finish it completely. Not an answer for tomorrow, knowing that the problem will emerge again the day after tomorrow. Solve it in such a way that is also solved for the longer term. If you do that in dealing with your contractor, you will get less and less problems in the relationship with him.

Having everything that is relevant on the table means that you need a *radar screen*. Listen to non-verbal messages in particular. Knowing everything is impossible. We designed the Smokeshed between Chiyoda and our project team. It served the informal exchange of information. Also the safety rounds were used to get feedback on hidden shortcomings.

A job well done is fun. After a celebration on an achievement, see it as a collective success rewarded by the satisfaction of a job well done is fun. Don′t ask for individual bonuses and the like.

The above rules of conduct are reflected in our criteria for the selection of people for our team (Table 9.6).

Listening is the absolutely number one criterion. Listening, especially to messages one cannot read and cannot hear (as the Chinese say: keep your eyes on things you cannot see). Then, *convincing* and *inspiring*. One must have an own opinion or conviction to be self-driven and achieve results. Next, *learning ability*. Extremely important to grind your grudge. *Initiative* and *creativity* are only valuable when combined with *persistence*. Otherwise initiative and creativity become a luxury without tangible results.

In the selection of personnel, not only the candidate′s capabilities – in terms of knowledge, skills and experience – are of importance, but also his or her *ambitions* and *hobbies*. *Ambitions* reveal the learning experiences the candidate would like to get from the job, and *hobbies* indicate where one may expect intrinsic motivation from the candidate. Let me give an example.

The project required a highly qualified expert on rotating equipment at the beginning and at the end. In the intermediate period the expert would have to perform other tasks. The ideal candidate for the job was offered a number of possibilities for work in the intermediate period, but none of them appealed to him. Reluctant to turn him down for that reason, I asked him what he liked to do most. He replied: 'Taking photographs'. His hobby was photography, in which he had skills at a professional level. So we made him our photographer. He was authorised to take pictures where ever he wanted. He took some four thousand photographs. Our photo-archive was very useful in several respects. For instance, distortion of historical facts in defending claims was strongly discouraged by the availability of photographs on almost everything. So, the personal hobby of our rotating equipment expert considerably increased both his usefulness and his job satisfaction.

Importance of floating goals

Once the technical solution for the water treatment problem was available, it had to be re-introduced into the contract with Chiyoda. This was difficult for me, but was achieved in May 1994. The time to solve this problem was available due to the delay as a result of Phillips pulling out. Both issues – the pulling out and the unexpected water treatment problem – were dealt with in an integral way. In a management concept of fixed goals this would not have been possible. You have to accept floating goals. A solution using new technology had to be executed with great care and that requires extra time, which is never available in a fixed goals management concept. Experience in Shell has been that new technology is the number one cause of financial disasters. We could, therefore, never propose a scope which entailed a technology risk. In this water treatment issue, some new technology was unavoidable. Acceptance thereof was only possible by 1) a floating goals concept, and 2) people in the team capable of working with floating goals. This in particular is important to managing the four key issues. This has been my management philosophy as from 1990. I see my role, primarily as, first, identifying what is not 'normal', and second, making clear how to manage that.

Decisiveness through delegation

The number one rule, *openness, everything on the table*, has to be organised. In the construction phase – and even at commissioning – we had a weekly change meeting in which decisions were made on required modifications to the design. This speed of decision-making on changes was unusual. The decisiveness it generated enabled Chiyoda to proceed without any delays longer than a week. Every Friday our project engineer, our cost controller, Arjen and myself convened to cope with questions from whoever had a problem. We called these meetings Doctor's hours: every Friday from 9 to 10 o'clock. Often an on-the-spot inspection was made by the person to which we had delegated authority to decide on the matter. For instance, a pipe going through a foundation or a support. Always only one person was entrusted with the decision which, once taken, was accepted without further discussion.

For instance, when we had a serious problem with polyols we asked ourselves: Who is our expert on this? Then, whatever that expert says will be done, since we know he would only act if convinced his superior and colleagues would support his line of action.

Arjen as future operator and myself as project manager had full authority. We, in turn, empowered the people we trusted. In the execution, of course, procedures had to be respected; a round had to be made to properly administer the changes made, get drawings adapted, etc. Traceable and auditable procedures and records are, of course, indispensable.

Stop scope, if dead end

An essential responsibility of the highest ranked authority is: *stop scope, if dead end*. This is a most difficult thing to do since it involves acceptance of *sunk cost*, i.e. expenditure made in vain for something. You get warnings that things are going wrong on almost everything. So you need the ability to judge what is really going wrong, what is really unsolvable.

You then have to stop, put a halt to it, as soon as you are sure. People are inclined to circumvent and postpone issues they cannot resolve. If you see a potential dead end on your radar screen, you have to act, for instance by putting a special team on the issue (such as was done with the effluent water problem).

Managing different cultures

The three connections we had to deal with were:

- The Singapore connection (including the Chinese community);
- The Japanese connection;
- The Dutch connection.

Three completely different cultures (see Table 9.3), constituting both a problem and an opportunity.

The Japanese tell you what you want to hear, so they actually tell you nothing. Mutual aid then does not work. There was only one Japanese executive I could talk to about this: Chiyoda's project manager. All others saw their Chiyoda boss as their only boss. So, if I wanted to get something done I had to involve their Chiyoda boss. For instance the issue of safety. When I made my rounds on the site and made direct remarks about safety violations that I noticed, nothing happened. The Chiyoda construction manager had been bypassed, which is not acceptable in the Japanese culture. In a safety objective meeting he proposed that I would tell him everything I wanted to be acted upon. He promised that he would then personally make sure action was taken the very same day. That worked perfectly. So, for years, we saw each other every day at one o'clock and he made sure that action was taken that same afternoon. In the Dutch culture it is quite acceptable to address people directly on safety matters, tell them to put on their safety glasses, etc. In the Japanese culture that is totally unacceptable. I often used Mitsubishi executives in the Japanese connection to understand those sensitivities. All three connections had to be managed taking into account the considerable cultural differences.

The Dutch, Japanese and Singaporean nationalities with their inherent cultures were by no means the only ones. Indian, Malay and Chinese work force brought along that – in line with their respective religions – we had to pay due attention to consecration ceremonies.

In our change management, the rule was: trust operators! We had some seasoned operators who were so serious that they would not sleep for a night if a suggestion from them was rejected. You could blindly rely on their recommendations. Technologists, by contrast, had to be treated with scepticism. They were inclined to be creative and reinvent the wheel. As a rule, we asked them twice to check their homework and more often than not the proposed changes turned out to be unnecessary.

For monitoring cultural aspects, the coffee machine was quite useful. I had my room in front of the coffee machine. Door open, I could see everyone coming for a cup of coffee. I saw them and they saw me; also at an early hour, for I am always early. In this way, I could keep an eye on things that otherwise could not have been seen. The day chiefs only come there early in the morning. If they wanted to draw my attention to something, they dropped in and briefly told me what they wanted me to know.

Personal motivations

To manage effectively, one has to know the personal motivators of the people involved. For instance, some stakeholders are interested in approval of the project whilst others are more interested in efficient implementation. Such interests may change over time. Particular attention deserve those stakeholders who have a long-term interest. Three different kinds of interest play a role:

- Company interest;
- Project interest;
- Personal interest.

These interests vary from person to person and change over time. Sometimes you can identify a problem at an early stage, but not prevent it. In our first objectives meeting we observed that Chiyoda's construction manager was not really on board and was only paying lip service to the mutual-aid principle.

Ultimately, this damaged Chiyoda particularly. He optimised on cost and opted for 2D piping computer software, so the 3D aspects had to dealt with manually. The time schedule was pretty relaxed, so this was not impossible. I did not demand 3D for I would then also get the invoice for it. I had to give the contractor the freedom to keep his cost price as low as possible. As could be expected, a lot of problems arose on site as a result of the manual 3D engineering. These problems were solved by the excellent subcontractors working for us, but nevertheless caused a delay of three months.

The Chiyoda construction manager had informed his boss that no liquidated damages were to be expected for this. Ultimately, the liquidated damages had to be paid by Chiyoda as the decision on the 3D engineering of the piping had been their own choice exclusively. The incident resulted in a (temporary) demotion of Chiyoda's board member who had trusted the construction manager too much, and did not empower Chiyoda's project manager enough.

Part of the delay was recaptured by a creative measure, which enabled welding to be done intermittently with transport of inflammable liquids. Any mixture of the two would, of course, be disastrous, so the quality control on keeping these activities separated had to be absolutely watertight. Both Chiyoda's construction manager and his colleague, the project manager, cooperated fully in this phase.

Normally a sequential order is followed of mechanical completion, construction and commissioning. During three months we had overlaps between them, allowing us to catch up two months on the schedule. Permits to weld were given by Arjen to a task force including the most senior Japanese manager on site with some twenty years experience. We made him quality manager having authority over everything. He would personally make sure that the safety rules on this matter were lived up to. He had his desk in the most critical area, in the full tropical sun, a hardship he accepted knowing it was necessary to gain those two months.

Inseparability of process from object

The case of 2D versus 3D piping software illustrates that separation of process from object, as advocated by some writers on project management, is absolutely impossible. The two are always closely intertwined. You can only come to good solutions – to synthesis – by really understanding, by having the matter explained without avoiding complexities. In a sense, it is a pleasure for me if something goes wrong, because it justifies that I study the matter in depth. When I ask technical questions, the answer is sometimes: 'That is too much technical detail for a director.' My reaction then is: 'Why? How can I come to a sound judgement without a certain depth of investigation?' The solution always comes from combining a good explanation of what the problem is about, with your own knowledge and experience. Separation of process from object, therefore, is simply impossible.

Awareness of personal strengths and weaknesses

Reflection on one's own strengths and weaknesses as well as those of the team is important to avoid unpleasant surprises as a result of a blind spot. It will help to be decisive when one can build on strengths and hold back when weaknesses are involved. Let me illustrate this point with an experience from the time I worked at Bukom.

The operations manager of the refinery got a phone call informing him of a collision that had occurred in the bay of Singapore. A 2 000 ton LNG tanker, coming from Bukom, had collided with a Russian freighter. The ship was making water through a large hole amidships. I offered to help with my expertise as a naval architect, which was gratefully accepted. From the drawings of the ship and the location of the damage, I concluded that the ship would not sink or capsize, provided no further cracking would occur.

I could draw that conclusion based on my experience as the Dutch representative during more than five years on the board of the IMO (International Maritime Organisation). I had been involved in hundreds of calculations on damaged stability of LNG tankers. So, I was pretty sure that the ship could be kept afloat with the reported damage. When I arrived at the ship, tugboats were already on the spot to tow the ship to a shallow spot where she could be put aground. The charter was Shell, so I told our Shell man to take over the command, which he did. Next, we put watchmen at the critical bulkheads and used our own tugboats to keep the ship on stream. No more than just that, to prevent the structure from cracking by pulling too hard. Then the representative of the salvage company came to me and ordered the ship to be beached. Our conversation was brief. 'Are you saying the ship is not sinking?' 'Yes, that's what I am saying.' 'I'll sue you in court and your are going to prison.' He had already phoned to the port authorities that the ship had to be beached. At my request, our man who had taken over the command, forced him to leave. The ship was then saved without beaching. The damage was temporarily repaired by the salvage company with wood. Against unit rates, for there was no crisis situation anymore. When the Hongkong owner of the tanker later paid me a visit to thank me, the thought occurred to me that each bow he made represented about a million dollars. Of course, the good ending was also good for Shell's reputation in the area.

Such incidents are not without risk. One has to be critical of oneself and to be aware of one's own limitations. For that reason, I have always insisted that my management was audited like everything else. In our team we identified individual strengths and weaknesses, so that we knew where team members were complementary and where we were vulnerable as a team because no one had the strengths required for the issue at hand.

Managing milestones

In project management, deadlines on milestones to be reached are crucial. Especially when tasks can only be performed sequentially. A deadline for completion is never met completely; there is always a list of outstanding items. What matters is if these outstanding items affect the subsequent tasks. We therefore always made it a joint matter between the two parties with sequential tasks.

In the spirit of *mutual aid* we would take decisions earlier than strictly necessary, if that could improve the profit margin of the subcontractor.

In choosing subcontractors we had agreed amongst us that we would ignore price differences below 5%. When it became difficult to choose in a particular case, someone proposed to award to the lowest bidder who was 2% cheaper. But I insisted that we would decide on other criteria. These policies, and others in the same spirit, facilitate managing milestones.

Key Issues that were missed

Let us return to the Key Issues Matrix. In hindsight, we realised that we missed one very important issue: authorities, or rather *permits issued by authorities*. We had underestimated delays due to authorities. It is interesting to note that this key issue is actually ethics driven. In comparison to other Far Eastern countries, Singapore is unique in fighting corruption. For instance: Ministers are paid like captains of industry in order to remove any need to be corrupt. Such measures, combined with severe prison sentences for violation, made Singapore's anti-corruption policy exceptionally successful. Prior to our project, a number of serious accidents had occurred. A drilling platform had collided with a cable car because the tide had been miscalculated. A hotel had collapsed due to compromising with the quality of the concrete that was used. As a result of the investigations into those accidents, a whole network had been established of authorities issuing permits. Understandably, these authorities wished above all to preserve their image of being independent by taking their jobs of approving extremely serious, in other words: by being more Catholic than the Pope. As a result, we were faced with all kinds of unexpected delays in obtaining permits for things we had to build. Business ethics made any attempts for compromises to speed up counter-productive. Plans for buildings could often not be submitted in the required complete form when they included systems that were also used in the plant. Details on plant related systems were seldom available at such an early stage. If we would promise to add the lacking information later on, the application would be put at the bottom of the pile. We should have foreseen this situation. With the admission of a serious mistake from our part, we addressed ourselves to the Singapore Economic Board to get priority which was then indeed given to us. You have to be extremely selective with such interventions. You cannot bother the EDB more than once or twice. When we asked them for help, we emphasised that we had done everything we could to solve the problem ourselves.

Two other issues we missed – although less critical – were bombs and thunderstorms. The site had been a firing range for the British Army, so bombs in the ground were to be expected. Nowadays, almost any site entails such a risk. A bomb was found, which made the whole site immediately suspect and was reason for Chiyoda to submit a claim. First, we tried to put the issue in a reasonable perspective. For instance, by pointing out that another bomb that was found had been put there by our neighbours. To get such relevant information you need your radar screen! Chiyoda demanded extensive soil investigations, but we only agreed to have them at one spot where chances of finding something were highest. The issue was resolved in the framework of mutual aid: we agreed to be responsible for any man-made objects that were to be encountered in the soil. So, we only paid for the removal of some scrap encountered, for no more bombs were found.

We have had a fatality with a thunderstorm. In such a flat area any object would attract the lightning in the case of a thunderstorm. A pick-up truck was struck by lightning, killing a man in the back of the truck. After that incident we put up a mast to monitor approaching thunderstorms. Chiyoda's highest safety executive was given authority for thunderstorm alarm to ensure that within five minutes after the alarm everyone had moved to safe shelters, spread over the site. If we had consulted the meteorological institute in the area at an early stage, we would have known that the site was located in a critical area for thunderstorms.

Of course, with hindsight one can always point to disasters that could have been prevented, but that is never an excuse for not anticipating where possible and paying appropriate attention to post-mortem analyses of comparable cases.

9.4 Implications for Open Design and Construct management

Having heard the project manager's story, we can now establish:

1. To what extent did the project manager apply what we have called best practices PII as defined in the ten aspects of Chapter 3?

2. What other management concepts did the project manager use that are additional to our list of ten best practices?

Based on the project manager's view of the relation between his management tools and the four key issues (Table 9.4), it can be noted that a PII approach played an important role on the following aspects of Open Design and Construct management.

Firstly, in managing the key issue 'interlinkage', the PII best practice of *conflict resolution* by means of 'mutual aid' (Aspect 3) played a crucial role. Mutual aid means that if something can be resolved for € 100 by one partner, whereas it would cost the other one € 10 000, the former will solve it regardless which one of the two is the problem owner in terms of guilt or responsibility. Secondly, the PII best practice of *division of tasks* by means of roles rather than job description (Aspect 8) proved to be effective in regard to continuity in staff with changing roles in various phases.

In managing the key issue 'joint venture structure', the PII best practice *integration and coordination of tasks* by means of clear and flexible roles was important in the team and in the delegation procedures (Aspect 9). The shareholder representatives were fully integrated at source in the project team and the finance function to the satisfaction of the minority shareholder.

In managing the key issue 'technology' the PII best practice on *progress control*, paying attention to both 'hard' and 'soft' information (Aspect 7), was implemented through self-imposed audits which were helpful as opportunities to learn and anticipate better on future problems. By having the audits done by the best available experts, aware of global best practices and problems, information becomes available, which better enables problems to be anticipated. In doing so the informal global experience was used to be pro-active.

In managing the key issue 'new company in green field', the PII best practice of creating a climate for *mutual adjustment of tasks* (Aspect 9) was followed, in addition to extensively making use of advice from trusted individuals from the nearby Shell refinery.

So, our hypothesis has been confirmed by this case. There are, however, two important aspects that have to be added to the ten best practices PII of Chapter 3:

1. Selection of key personnel;
2. Commitment.

Selection of key personnel: The project team members must understand PII best management practices or the project leader will become isolated in his approach (a prophet in the desert). The spirit of Open Design and Construct management has to prevail in the whole project team. That requires special attention when selecting team members on the five criteria of Table 9.6.

Commitment: For about five years, the project manager worked on the project with full commitment. At the site he joined the gymnastic exercises with the Chiyoda staff every day at 8 o'clock (Fig. 9.5). Especially in the beginning, Frans and Arjen worked some fourteen hours per day which included

Figure 9.5 Gymnastic exercises at the site

an almost endless variety of activities, ranging from meetings to solve serious problems to rituals like gymnastics and well over sixty consecration ceremonies. Working intelligently helps, but it is not enough. There simply is no replacement for hard work.

Mr Frans's subsequent project: the Shell Nanhai project

A few years later Mr Frans was assigned as construction manager to another large complex construction project: a US$ 4.3 billion joint venture between CNOOC and Shell for a chemical plant in the Guangdong Province of P. R. China, known as the Shell Nanhai project. Successful start-up took place in early 2006. The great complexity of the project stems not only from the technologies and cultures involved, but in particular from its huge size:

- 428 hectares plot size,
- 25 000 person peak workforce,
- 100 million hours of direct construction labour,
- 16 million cubic meters of earthwork,
- 4 100 pieces of major equipment,
- 547 000 cubic meters of concrete,
- 50 000 tons of steel,

- 1.4 million linear meters of pipe,
- 38 000 instruments,
- 16 000 piles,
- 5.3 million meters of electrical cable,
- 56 buildings,
- 40 km of roads.

In this section, we summarise similarities and differences between the two projects.

Similarities with the Seraya project

The managerial approach of the Seraya project was also followed in the Nanhai project:

- Start with establishing the overall objectives of the project, based on the stakeholders' long term objectives.
- Identify key issues for important problem areas that are unique for the project concerned.
- Compile a key issue matrix of problem areas (issues) and management tools to address the identified issues.
- Apply PII best management practices where appropriate.

The resulting key issue matrix for the Nanhai project is given in Table 9.7. The boxes 1.1, 1.2, etc. of the matrix were systematically filled in and translated into concrete managerial actions (of which a description would be beyond the scope of this book).

Differences of Nanhai with Seraya project

In hindsight two fundamental differences with the Seraya project can be identified:

1. Size;
2. Degree of uncertainty.

Table 9.7 Resulting Key Issue Matrix Nanhai

Key Issue 1: Leadership	Key Issue 2: Human resources	Key Issue 3: Open to nonconformance	Key Issue 4: Communication	Key Issue 5: Lesson	Key Issue 6: Control
Management Tools:					
1. Project management for new company in green field					
1.1	2.1	3.1	4.1	5.1	6.1
2. Huizhou DB infrastructure and experience with petro-chem industry					
1.2	2.2	3.2	4.2	5.2	6.2
3. Chinese EPC methods					
1.3	2.3	3.3	4.3	5.3	6.3
4. Mindset and language					
1.4	2.4	3.4	4.4	5.4	6.4
5. Technology					
1.5	2.5	3.5	4.5	5.5	6.5
6. Size					
1.6	2.6	3.6	4.6	5.6	6.6

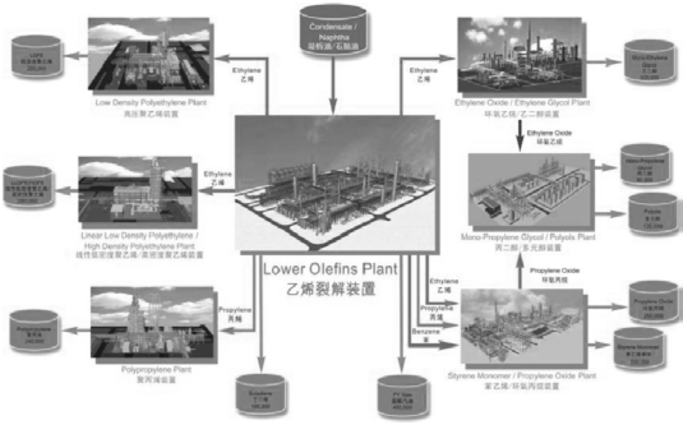

Figure 9.6 Nanhai project divided into eleven ‘silos’

The *size* of the project is enormous, which brings along that the project has to be subdivided into manageable sub-projects, referred to as ‘silos’. The co-ordination of the eleven silos constituted a major planning problem (see also Chapter 3 of *Open Design, Cases and Exercises*).

The *degree of uncertainty* was relatively low in the Seraya project. There were risks as addressed by the key issue matrix, but few *unknown* dangers. The environment was stable and known from experience. In the Nanhai project, by contrast, the environment was both to a large extent unknown and changing rapidly during the construction phase. (For the difference between uncertainty and risk see Chapter 4 of *Open Design, a Collaborative Approach to Architecture*.) The unknown and rapidly changing environment brought along unforseen issues on-the-run which could not have been anticipated by means of the key issue matrix. Among the issues which arose:

- Overheating of Chinese economy in 2004 resulting in:
    - matéral cost increase (50%)
    - labour cost increase (average 30%, welders 100%)
    - Shop Loading (some in LOP 6 months late)
    - power and water shortage
- Rate of Exchange
- SARS epidemic and typhoon in 2003
- Sinopec Design Office and Construction Contractors overloaded in 2003, 2004, 2005

- Crude oil price increase in 2005, hurting commissioning budget

How could these issues be addressed? Basically by *a redundancy of capable people and other resources*. All these unforseen issues required a PII approach to resolve them. A comparison of the application of PI and PII practices for the Seraya and Nanhai projects is shown in Table 9.8.

The Nanhai project satisfied all stakeholders' performance criteria:

HSE	Health very good
	Safety acceptable
	Environment very good
Cost	Within budget of feasibility 1997
Schedule	As planned
Quality	Above expectation
Reputation	Pro-actively managed and delivered

In retrospect, this can be attributed to a large extent to the application of an optimal mix of PI and PII best practices in addressing emerging problems on-the-run.

Table 9.8 Application of best practices in Seraya and Nanhai

Seraya	Nanhai
Aspect:	
1. Goal setting – fixed vs. floating	
The strategic scope and set up of the project was set and fixed according PI practices.	The strategic scope was according PI practices, the implementation according PII practices, especially in 2005, prior to start up.
2. Leadership – boss focused vs. stakeholder focused	
Mutual support played the important role and non-manipulative cooperation in a PII manner, to align contractor and owner.	Vulnerable leadership based on PII practices in unknown territory.
3. Conflict resolution – compromise vs. synthesis	
The shareholder alignment was successful according PII practices.	Special risk of joint ventures in china required daily PII approaches.
4. Design process – solution point vs. solution space	
A PII scope, omissions managed on the run (offices).	Outsourcing air separation unit after approval project scope reduction (Rail).
5. Communication – information oriented vs. decision oriented	
Weekly meetings by Arjan and Frans on information needs as PII.	PII weekly metrics/trends plus 'light management' mitigation.
6. Persuasion of players – window dressing vs. valid and relevant information	
A good and open PII approach.	Tried to achieve decisions based on facts (PII) rather than power play (PI).
7. Progress control – hard info oriented vs. soft info oriented	
PI hurdle by construction ignoring metrics, PII recovery by parallel commission & construction.	PII engagement key to 'mood' and hard results: PI Blocks in construction die-hards.
8. Divisions of tasks – job descriptions vs. roles	
Arjan/Frans working in PII allowed overlapping roles resulting in quick decisions and effective teamwork.	PII the same as in Seraya, and very effective in off-site scope.
9. Co-ordination of tasks – project manager's coordination vs. mutual adjustment	
The same experiences as with Aspect 8.	Owner on board, PMC after two years, contractors never.
10. Standardisation – where possible vs. where functional	
PI technical flaw originated from oil standards applied to chemicals; PII solved on the run.	Technical deviation on the run, 2004/2005 PII.

10 Renovation 'De Resident', The Hague

This chapter describes the case of 'De Resident', a city-centre renovation project in The Hague, close to the Central Station, in the period 1989-1998. Kees Rijnboutt – at that time 'Rijksbouwmeester' – played a central role in the organisation of the project. As Rijksbouwmeester he was responsible for the architectural quality of all government buildings that were built. That position gave him direct access to all cabinet ministers and provided authority to play the essential mediating role between the various parties involved. This central role was reason for the authors to interview him on the managerial aspects of the project.

The architectural aspects of this case, which are extremely interesting, have been extensively documented in the book *Stadsbouwkunst: de stedelijke ruimte als architectonische opgave, Rob Krier in Den Haag: De Resident* by Van Rossem (1996). For our purpose it suffices to note that the project constituted an almost unsolvable problem:

- a very high building density;
- a great and complex variety of functions;
- a mixture of offices, shops and houses;
- a tramway right through the area;
- a rich history of unresolved political discussions.

The approach of solving this 'unsolvable' problem by means of a collective design effort was new at the time. As a result of its success, the approach has also been adopted in subsequent urban development projects, such as the renovation of the centre of Amstelveen and the 'Kop van Zuid' in Rotterdam.

10.1 The challenge

In the year 1990 the renovation of the centre of The Hague was largely completed, but the heart, the Lavi-area of the Spui quarter, still had to be developed (Fig. 10.1).

The area was called Lavi because the intention had been to build the offices of the Ministry of 'Landbouw en Visserij' (Lavi) there. This idea was abandoned in 1987 by the Rijksgebouwendienst (institution responsible for all governmental buildings). This decision affected not just one building, but also Carel Weeber's vision of the whole area as expressed in his urban plan of 1982. To avoid an impasse, a collaboration agreement was signed between the

Figure 10.1 Lavi-area of Spui quarter, The Hague, anno 1990 (Van Rossem, 1996, p. 56)

Governmental Pension Fund (ABP), the Railways (NS), the Rijksgebouwendienst, and the municipality of The Hague.

The Austrian urban architect Rob Krier was hired to develop concepts. He was supported in the background by Ton Meijer, director of MAB, a real estate development company based in The Hague, which had a successful track record in complex urban real estate developments in various European countries. Although Krier's third proposal of mid 1990 had hardly any chance to survive in the political arena, the new alderman Peter Noordanus and the newly (September 1989) appointed Rijksbouwmeester Rijnboutt took the wise decision to continue the collaboration with him. The question was: how?

The challenge was almost unlimited. First, there was the dominant presence of the Central Station, the former Staatsspoor. Already in 1908 Berlage had argued that for a healthy urban development the station had to be integrated with the other railway station in The Hague, Hollands Spoor, at only a few miles distance. In 1946 Dudok had again pointed at the nonsense of having these two stations at such a short distance. In the seventies, Weeber finally accepted it as a reality, but alleviated the architectural ugliness of the associated fly-over by projecting buildings over it.

Second, huge buildings had arisen at the circumference of the site, as becomes apparent from Figure 9.1. It was clear that it would be an enormous challenge to create a plan that would be in harmony with these historical constraints.

10.2 'Resident' story told by the 'Rijksbouwmeester'

Let me first point out that simple, straightforward projects are nowadays the exception rather than the rule. Complexity and conflicting stakeholder interests are encountered in relatively small projects as well. For instance, the design of a building for the Court of Justice is extremely complex: various parties – lawyers, judges, prisoners, the press, etc. – should never meet each other before the court session. Security – personal safety, leaking of confidential information, etc. – is an extremely complex issue. As a result of this trend towards more and more complexity, management practices to cope with it will become more and more important.

Back to the 'Resident'. How could we meet the enormous challenge we were confronted with? Actually, by putting two important (process) constraints upon ourselves, to make the work a real collective effort:

- To develop a master plan with few people (about 7) in a short time (3 months), under the supervision of Rob Krier;
- To have the brains at the 'table' for all team members, which meant that there was no delegation allowed.

Names were tossed around. We had agreed to aim at a mix of older and younger architects. Candidates would have to be loyal to Rob Krier's ideas or decline the invitation. Some actually did so, others were immediately enthusiastic. After a last check on names with the ministers Hans Albers and Hedie d'Ancona, we ended up with a team of Rob Krier, myself and the following architects:

- Sjoerd Soeters,
- Gunnar Daan,
- Bert Dirrix,
- Peter Drijver.

The first two architects were in their late forties, the second two in their early thirties. Somewhat later Karelse Van de Meer Architects joined for the design of two blocks of houses and CHE Partners for the design of open spaces.

An agreement on our intended modus operandi was signed by all parties involved. The agreement also specified the total office floor area, number of parking places, number of houses, etc. An extremely important item was that we would not decide a priori who would design which building. The master plan had to be the brainchild of all of us. The master plan was generated in six workshops, each lasting 48 hours. The municipality had made a villa available for us, which was at walking distance from a hotel for our guests from abroad.

After three months we had indeed completed a master plan. A few dozen maquettes were made for the presentation. Sjoerd Soeters turned out to be a virtuoso in this. The presentation was given to some 35 people seated in the living room of our villa.

The reaction of the ABP, one of the financing parties, was one of complete rejection. It then paid off that we had generated the master plan as a team: each of us felt responsible for the whole. As a result, we did not change anything because of the harsh criticism of ABP, but we decided to continue without them. At a later stage ABP tried to get in again, but then it was too late.

We then involved project developer MAB. It took about one year to overcome their emotional backlog, which means to get them at an equal level of understanding and emotional commitment. From this experience we learned the lesson that it is essential to involve the project developer from the start (which we have done in all subsequent projects).

Ton Meijer, director of MAB, had a very good liaison with Rob Krier, which made it possible to correct our managerial mistake of involving the project developer only after the basic concept had already been established.

After a year, a financial agreement was reached involving a guarantee from the Government to hire some 55 000 m2 office space. We had our regular meetings to monitor progress with about one hundred people. This brought along with it, of course, quite some bureaucracy.

When we were well underway, Ton Meijer came with the message of doom that his company did not wish to continue with the architects of our team. The future users wanted the involvement of some international 'big shots'. The issue was resolved in the sense that our team was extended with some internationally well reputed architects from abroad:

- Michael Graves (USA),
- Adolfo Natalini (Italy),
- Cesar Pelli (USA).

They were prepared to work according to our agreed modus operandi, including loyalty to Rob Krier's vision. We actually learned a lot from them. For instance, the American architects were always focused on the client. They would never trust that a drawing would be enough for the client and would always make maquettes for presentations.

Each of the architects, including Rob Krier himself, was finally entrusted with the design of a specific building. To ensure coherence of the project as a whole, however, all detailed drawings were made by one and the same office Arcadis (Grabowsky & Poort), under the supervision of Sjoerd Soeters.

We were lucky in the sense that we could focus on quality without being concerned about budget constraints. The project was initially scheduled over

Figure 10.2 'De Resident' (Van Rossem, 1996, p. 74)

a period of 10 years which eventually became 13 years. The increase of prices of real estate in those three years only improved profits. As a result we could afford to monitor progress on time rather than on budget.

Whether we reached our goal of quality should be left to the judgement of the users, once the construction is completed.

10.3 Implications for Open Design and Construct management

Having heard the 'Resident' story, we can establish:

1. To what extent were best practices PII as defined in the ten aspects of Chapter 3 applied in the project?
2. What other management concepts were used that are complementary to our list?

In retrospect, a PII approach can be recognised on the following three aspects.

First, the division of tasks (Aspect 8), which was done by means of role description. Subsequently all members of the team were pointed at their role as a professional, and not at their formal job descriptions. Collaboration on professional roles gave space to mutual adjustments during the design process.

Second, the coordination of tasks (Aspect 9), which was done by means of emphasis on functional performance achieved collectively. The incident with ABP shows how important it is to build confidence and trust in each other that you can rely on for about half a decade. Such confidence and trust will erode if not nourished by new impulses from time to time.

Third, conflict resolution (Aspect 3), which was done by means of synthesis. With so many strong characters, of course, a lot of conflicts had to be resolved.

Table 10.1 Application of best practices in renovation 'De Resident', The Hague

Aspect:	PI / PII:
3. Conflict resolution compromise vs. synthesis	PII
8. Divisions of tasks job descriptions vs. roles	PII
9. Co-ordination of tasks project manager's co-ordination vs. mutual adjustment	PII

This was done by always focussing on the content of the matter, in other words: playing the ball, not the person. In this way synthesis was achieved as opposed to a compromise resulting from a power game. The team could focus on quality.

Table 10.1 shows that all ten best practices PII were applied which we consider appropriate for large, complex construction projects. So, our assumption has been confirmed by this case.

Also in this case, some important aspects have to be added to the ten best practices PII of Chapter 3:

1. Selection of key people;
2. Team building;
3. Commitment to a common cause;
4. Ability to turn problems and crises into opportunities.

Commitment to a common cause was crucial when ABP dropped out as a shareholder. The ability to turn a crisis into an opportunity saved the project when the project developer insisted on 'big shots'. Instead of adopting a defensive attitude, the team wholeheartedly accepted the architects from abroad and was prepared to learn from them.

We note that these aspects are the same as those emerging from the case of the chemical plant in Singapore. Apparently, they are absolutely essential for successful Open Design and Construct management of complex construction projects.

11 Concluding remarks

11.1 IT tools for Open Design and Construct management

The lessons from our cases – both the failures and the successes – show that in complex situations SII, management practices PII are required that are focused at the interest of all stakeholders, the powerful as well as the less powerful ones.

The cases also show how difficult it is to live up to this requirement. As the VPRO-case of Chapter 8 illustrates, it is very tempting, but ultimately disastrous, to exclude at early design stages important, but rather powerless stakeholders whose interests bring along difficult constraints.

The current management technique to cope with multi-stakeholders issues is called *framing*, because it systematically frames the issues of the various stakeholders (Schön and Rein, 1994). Framing helps to put stakeholders interests into a balanced perspective, but it does not assist in weighing those interests against each other. How much weight should be given to the various stakeholders interests usually requires a *quantification* of essential parameters. Such quantification is provided by Open Design methodology (*Open Design, A Collaborative Approach to Architecture*) which incorporates stakeholders interests into a mathematical model. The model enables the establishment of solution spaces within which solutions are possible or – if the solution space turns out to be zero – assessing how much demands from crucial stakeholders will have to be alleviated to allow a solution at all.

The mathematical modelling of stakeholders' interests adds a completely new domain to IT-based assistance in project management (Table 11.1).

For many years, Open Design methodology has mainly been limited to using linear programming with negotiable constraints. In recent years new mathematical models, in particular incorporating stakeholders' preferences and allowing for risk and mitigations-on-the-run in network planning, were added to the repertoire of Open Design (*Open Design, Cases and Exercises*, Chapters 3, 5, 6, 11, 13, 14).

These IT applications are of great importance to stakeholders oriented Open Design and Construct management. Framing – providing a qualitative analysis – is useful, but not enough. Quantification, as provided by Open Design methodology, is essential for achieving a synthesis of interests.

11.2 Summary of findings

The cases, both the failures and the successes, demonstrate that the overall management of complex construction projects requires an approach focused

Table 11.1 IT in design and construct management

To support PI, straight forward project management	To support PII, stakeholder-oriented over-all project management
• Data bases on: – parties involved (addresses, features, etc.) – cost prices • Administration: – electronic filing – financial reporting • Calculations: – cost prices – scheduling • 'Drawings': – 2D – 3D • Communication: – bulletin board – *information push*	• Open Design methodology: – quantitative integration of stakeholders' interests – establishing solution spaces within which solutions are possible • Information: – emphasis on relevance – *information pull* (asking decision-oriented relevant questions) • Mathematical modelling of relevant issues: – linear programming (with negotiable constraints) – Monte Carlo simulations – preference ranking techniques

on a synthesis of all the stakeholders' interests. This implies that it cannot be governed by contractual or formal limitations. Stakeholders that are not mentioned in any contract can be as important for success as those that are well-represented. To ensure that such a stakeholder-oriented approach is genuinely lived up to, the selection of the project management team is crucial. Members of that team have to understand and wholeheartedly endorse this approach.

A non-manipulative, stakeholder-oriented approach has to be followed in all key issues of complex projects. If one key issue is treated in a manipulative manner, it can spoil the whole project, as happened in the case of the VPRO office. If stakeholders are not enabled to interconnect their decisions, mutual aid will not take place, as happened in the case of the former KLM office. If a bottom-up approach based on stakeholders' knowledge is not adopted, overruns in time and money will occur, as was the case in the Schiphol airport expansion.

Mitigations-on-the-run, managerial measures for coping with unexpected events, are always necessary in complex projects to ensure that progress is maintained according to schedule. How to allow for mitigations-on-the-run in the network planning of the project, including allowance for limited human resources, is described in Chapters 3 and 11 of *Open Design, Cases and Exercises*. Various classes of possible mitigations are suggested by Heerkens (2001), which enables a systematic approach whenever disasters are looming.

PII best practices in the overall management of complex construction projects can lead to stakeholder satisfaction without overruns in time and money. Together with the requirement of a committed and genuinely stakeholder-oriented management team, these best practices constitute the required approach for managing complexity. Subprojects that are pretty straightforward could be managed with conventional PI best practices. The project management team must develop a feel for where to apply the stakeholder-oriented best practices (PII) and where to rely on control-oriented traditional management practices (PI).

11.3 Relationship with welfare theory

In analysing the cases we searched for practical opportunities and advantages offered by the PII best practices for complex construction projects. However, there are also drawbacks to these practices. We would like now to take a look at two of these drawbacks often occurring in open group processes: the risk of exploitative behaviour and the risk of an unfair group optimum.

The risk of exploitative behaviour

The Open Design and Construct Management approach tends to ignore the risk that in the group (which consists of free, independent individuals), exploitative and parasitical behaviour might occur (Van den Doel, 1993). This is because the concept of openness assumes that cooperation is voluntary and that everyone will cooperate of his own volition. But there might be individuals who avoid making their contribution, or attempt to pass on the costs to others. Sub-groups might also form that try to 'vote down' those in the minority, or lend unfair weight to their own preferences. Openness in itself offers no opportunities for preventing this kind of behaviour, or curbing it once it has occurred.

To address this problem, welfare theorists devised a number of additions to the concept. The best known and most commonly used states that, once decisions on the production of collective goods and services and on the division of the costs of implementation have been taken, they must be declared binding on all members of the group. Everyone is thus forced to cooperate with the implementation of the decisions, and no one is able to avoid making his contribution. This will be acceptable to the individual members if they know that the decision-making process has been democratic, everyone has had his say, and the costs and benefits have been fairly divided.

However, it is often difficult to force people to implement decisions, even if all the conditions mentioned above have been met, particularly when it comes to larger groups. If the decisions have the support of only a small minority of the group, or if they have been taken by 'representatives' of the group who failed to convince the 'represented' - all the members of the group - of the merits of their choices, mutual cooperation can be enforced only by a strong (central) authority. Coercion of this type undermines the free and individual nature of methodological individualism.

Two other additions taken from welfare theory do not rely on a central authority (Pellikaan, 1994). One bases mutual cooperation on the social norms in the group and the associated mutual commitment between individuals. This could be sufficient to curb parasitical behaviour. The other bases mutual cooperation on the willingness of individuals to devote themselves to the whole only on a conditional voluntary basis. Here, individuals state when and under what conditions they are prepared not to act in an exploitative manner towards others.

These two additions also prove somewhat difficult in practice, particularly in pluralistic groups, where different norm systems are applied and individuals feel a commitment to several different sub-groups. Conflicts between norm systems can disrupt cooperation within the group. It is also difficult, in pluralistic groups, for individuals to see whether their conditions for participation have been met, particularly when it comes to complex issues. The absence of such an overview can hamper cooperation.

Some time later, welfare theorists came up with a fourth addition to the concept of openness. It is in fact an alternative to the other three and is referred to as the 'actor's viewpoint' (see Chapter 1 of *Open Design, a Collaborative Approach to Architecture*, page 12). The first three additions all assume that each individual is selfish and that this can only be kept in check by coercion from a central authority, and by morals and social norms. The actor's viewpoint holds that actors can also be cooperative without coercion, since when an individual strives for maximum utility he is not necessarily seeking to achieve selfish ends. People are not egoistic by definition (Pellikaan, 1994, p. 265). This implies that individuals have their own subjective preferences, their own vision of the best outcome and that in a group there will always be several orders of preference for one and the same distribution issue. It only becomes clear in practice whether mutual cooperation that appears difficult on paper actually turns out to be so in reality. And, conversely, an issue that appears perfectly straightforward on paper can turn out to be a problem in practice.

The risk of an unfair group optimum

The concept of openness makes no comment as to the ethical and social value of the group optimum. It does not allow us to say whether the actual level of welfare in a community and the actual distribution of scarce resources among its members is good or bad. It is not possible to make pronouncements on the fairness, justice and social value of the community's welfare at a particular moment on the basis of openness (Sen, 1995, p. 12). It also says nothing about the squandering of raw materials, uneven growth in welfare, or the social acceptability of the outcomes.

Welfare theorists initially sought solutions to these drawbacks in a more refined definition of collective welfare, incorporating into the criterion dimensions beyond the economic. But they continued to assume that the level of welfare in a community can be clearly and neutrally established, and that all the members of the community will therefore agree on what constitutes a change in welfare, whether it represents an increase or decrease of individual and collective welfare and whether the change is good and fair.

For this refined definition, the Pareto criterion is often used (Chapter 1 of *Open Design, a Collaborative Approach to Architecture*, page 13). This criterion is applied largely to issues where welfare is expressed in measurable economic units such as purchasing power, income, and possessions. It therefore offers little opportunity to involve aspects of welfare that cannot be unambiguously identified, such as cultural and historical value, ethics, and fashion.

It was eventually concluded that it was in principle impossible to make a substantive (normative) assessment of welfare purely on the basis of the individual utility criterion. The distinction between the economic view of human behaviour (man as homo economicus who seeks to maximise his own advantage) and the sociological view (man as homo sociologicus who is led by values, norms and ethics) had to be abandoned. The concept of welfare had to be expanded to include aspects other than utility, such as opportunity, distribution and cooperation. This was done in welfare theory on the basis of methodological individualism Sen (1995); Pellikaan (1994) (Chapter 1 of *Open Design, a Collaborative Approach to Architecture*, page 14).

In Open Design methodology, using this methodological individualism we have expanded Pareto's criterion, so that the benchmark is no longer the actual welfare of each individual, but the level of welfare each individual finds acceptable. This allows him to set his own limits during the process regarding what he regards as fair, balanced, and a good way of conserving what already exists. Since this methodology lies at the base of our PII practices, the drawback of the unfair group optimum can be prevented by involving this individual benchmark in Open Design and Construct Management.

Appendix A
'Granny's puzzle'

On the request of the first author (who was a member of the Committee) Hennes A.J. De Ridder (1994) wrote a fairy tale to make clear what his Ph.D. thesis was all about. The story illustrates so well that the separation of Design and Construct (D&C) is artificial, that we feel that it deserves to be added as an unabridged appendix to this book.

A Client's grandmother, who is fond of puzzles but who is too old for puzzling now, is celebrating her birthday. Client wants to surprise grandmother. He owns her favourite jigsaw puzzle of about 500 pieces (estimated). The Contractor is asked to solve the puzzle, paste the puzzle on a board, cut it in four pieces and send it to Client's grandmother. All to be done within 6 hours.

This can be considered a D&C project. A design process is a search process and can be compared to solving a jigsaw puzzle. The number of pieces can be seen as the number of requirements. The pasting and mailing can be seen as construction.

Two Contractors ('A' and 'B'), both specialists in pasting puzzles, are invited to bid. In order to estimate the price, both Contractors set up a working plan: (1) make the puzzle on a board, (2) put a board on the finalised puzzle, (3) turn the ensemble, (4) lift the puzzle board, (5) spread glue on the back of the puzzle, (6) put the puzzle board on the puzzle, (7) wait 5 minutes, (8) cut the edges, (9) cut it into pieces, (10) put the pieces in an envelope and (11) bring it to the mailbox. The working plan has two main phases. The first phase involves solving the puzzle, an activity which does not belong to the primary process and should therefore be done as fast as possible. The second is the pasting phase in which the 'real and risky' job should be done.

Contractor 'A' awards the contract with a very low fixed price. His time schedule is as follows: 3 hours for solving the puzzle (those puzzlers!) and 3 hours for the 'real job' (pasting, cutting and mailing). The most experienced poster of the company is appointed project manager and the organisational structure is sketched in Figure A.1.

Now the work can start. The Contractor is fully aware of the five golden rules for a successful production: (1) cluster elements according to location, material and process, (2) the more people, the more progress, (3) time pressure works, (4) competition is preferable (sub-optimisation = optimisation) and (5) no trials and certainly no errors! All team members are trained according to these rules.

However, the five golden rules for jig saw puzzling are: (1) clustering the pieces (colour, edges), (2) limit the number of puzzlers, (3) preferably no ex-

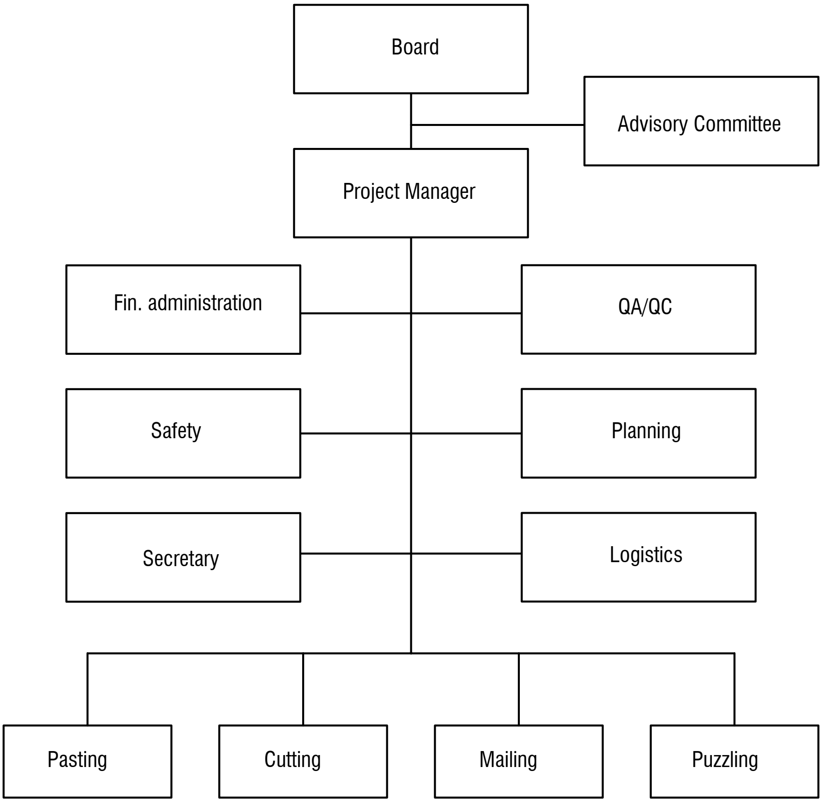

Figure A.1 'Granny's puzzle'

treme time pressure, (4) no competition between the puzzlers (sneaky shifts of difficult pieces towards neighbours) and (5) stimulate trial and error! Unfortunately, none of the team members has ever heard of these puzzling rules. They merely had a pasting education and specialisation.

After 3 hours, not even 20% of the puzzle is ready. The 20% refers to the easiest parts of the puzzle (edges and buildings). In a corner of the table a large number of pieces with identical colour (blue sky) is paced in front of a shy junior puzzler. The manager becomes a little nervous and walks around the table, calling his head office for eight extra puzzlers, which is materialised immediately. After 4 hours not even 30% of the puzzle is ready.

At this moment the pasting people start their job, because they cannot wait anymore. They take away the edges of the puzzle and other small clusters, which are pasted on the board. Implicitly the working plan has changed! After a while, it becomes apparent that the puzzlers did not put some pieces in the right place. Therefore, it is necessary to soak off some pieces. The organisation is chaotic and the state of mind of the participants is rather bad.

At that moment, Contractor's controllers count 700 pieces instead of 500 pieces. The project manager (out of his mind) grabs about 200 pieces from the table and throws it into the dustbin shouting: 'My contract covers a 500 pieces pasting job and not a 700 pieces pasting job. Not one piece above the contractual 500 pieces will be pasted!' However, after three hours of trial and error, it becomes apparent that the pieces in the dustbin are necessary to solve the puzzle.

Unfortunately, a lot of empty coffee cups have been thrown into the dustbin. The manager himself separates the puzzle pieces from the dirt, cleans the pieces and asks the Client for extra time and extra money due to the additional 200 pieces.

The Client is fully aware of this big problem and gives the contractor one extra hour. The Client, however, does not pay extra money, since the number of pieces was defined as 'about 500'.

After 12 hours the puzzle is ready and after 15 hours the puzzle is mailed. At that moment, Granny's birthday celebration has been over for a few hours already.

One month after the project is finished, the Contractor claims additional money, which is fully rejected by the Client. After two years the claim is put into arbitrage. The outcome is that the Client must pay 50%. With this outcome the project has two losers: (1) the Contractor who disturbed his own working method and delayed the puzzling activities by throwing away the 200 pieces, (2) the Client, who missed his goal (the birthday surprise) and who has to pay a substantial part of the Contractor's extra activities.

Open Design, Cases and Exercises

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Preface

The purpose of this book is to enable the reader to become familiar with the mathematical tools and associated computer programs that can be used in Open Design methodology. The principles behind Open Design have been set out in our previous publications in this series, *Open Design, a Collaborative Approach to Architecture* and *Open Design and Construct Management*.

Open Design methodology enlarges the freedom of the architect to apply innovative architectural ideas, because it can identify which concessions are necessary, and *to which extent* they have to be made to make any new concept feasible.

In urban planning, Open Design methodology is particularly useful in resolving stalemate situations, as it can identify the few crucial stakeholders who have to make concessions and *how much* they, collectively, have to alleviate their constraints.

It is not sufficient to know the tools offered by Open Design methodology. To use them effectively in practice, one has to develop *skills* in using them. Such skills can only be learnt through practice. This book is intended to assist in developing those skills by offering cases and exercises that can be studied by the reader before applying the methodology to his or her own problems.

Our hope is that anyone who has worked through the exercises and cases in this book will be able to apply the concepts and computer programs in actual practice.

Acknowledgements

The contributions of the following graduate students are gratefully acknowledged. Their theses form the basis of the Chapters mentioned.

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Contents

Introduction

What is Open Design?

Open Design is made up of two equally important ingredients:

A set of design related norms and values: The design process of creating a new building or a new urban area should, as far as possible, be open and transparent. All stakeholders are to be treated equally. Powerless stakeholders and laymen get the same 'rights' in the design process as powerful stakeholders and experts. Constraint ownership is respected, meaning that a constraint can only be relaxed with the consent of the stakeholder concerned. Manipulation and abuse of knowledge power has to be avoided where possible.

A set of decision-oriented mathematical models and associated computer programs: Linear Programming with negotiable constraints, Monte Carlo Simulation in project planning and in investment analysis, Regression Analysis in cost calculations and as an input to Monte Carlo simulations, Preference Measurement to incorporate soft variables concerning style, beauty, and form, Multi Criteria Optimisation for group decision making, Nonlinear Programming for exponential preference behaviour, Geometrical Modelling to represent surfaces and volumes and to optimise space related parameters, and the appropriate combination of these tools.

A characteristic feature of Open Design is the concept of floating goals, which is well known in industrial Research & Development and which plays an important role in urban planning. The purpose of having a goal in the future is that it gives direction to actions of today. When insight progresses as a result of those actions, however, a better goal can often be defined. Redefining goals when insight improves is accepted practice in industrial R&D, but rejected in the mainstream literature on construction project management. The same can be observed in urban planning where redefining goals is often neglected when it comes to the operational management of infrastructure projects and the preparation of the development of urban areas. Open Design enables working with goals and constraints that are never considered to be fixed.

Open Design has become a powerful tool for architects, construction engineers, and urban planners, which has been made possible by the spectacular progress in computer technology over the past decades: in memory capacity, in speed of processing and, most importantly, in user friendliness.

It is an unfortunate, but widely prevailing misconception that Open Design limits the freedom of designers and planners. The opposite is true. Open

Design enlarges the the possibility of finding unique solutions and combinations of sub-solutions.

The notion of a solution space, as opposed to a solution point, enables designers and planners to trade off the features of their solutions. If they wish to apply a new but expensive concept, Open Design analysis can reveal where concessions would help to make it affordable.

Open Design analysis can also identify concessions in the new designs and plans themselves, which could bring them within budgetary constraints. For instance, a designer made a design for a building consisting of an arrangement of dozens of rectangular blocks, of two different types: blocks of building space and blocks of open air. The design turned out to be too expensive. Open Design analysis then revealed that the concept would become feasible, if the designer were to limit the arrangement of blocks to four or five larger spaces of each kind. The knowledge of how much the new concept had to be changed enabled the designer to decide to accept the required concession. In this case, the computer drawing showed that the beauty of the concept had not suffered at all. If it had, the architect would have been free to discard it entirely.

In urban planning issues, Open Design can help to identify not only which stakeholders have to make concessions to make a plan feasible, but also to which extent they, collectively, have to make those concessions. This feature of Open Design opens ways to solutions that otherwise would not be possible.

Why then, one may wonder, is Open Design in urban planning predominantly applied only after everything else had failed? The reason appears to be that expert stakeholders, such as urban planners, perceive a loss of power to the benefit of laymen stakeholders, such as the future inhabitants of the urban area concerned, the local politicians, the investors, and the real estate owners.

Open Design's structuring of a design problem

The structuring commonly used in design problems for the purpose of mathematical optimisation originates from the domain of operations research (OR). In that domain, reference is made to 'design' problems and 'decision(-making)' problems. By doing so, OR experts do not recognise the obvious relationship between a design problem and a decision problem. After all, one cannot make a decision about something without having 'conceived' (designed) it first. Design problems and decision problems are connected, so it would be more accurate to refer to 'design-decision problems'.

Operations research bases the structuring of a problem on the collection of all the alternatives available to the decision-makers. This collection (A) contains the possibilities from which a choice must be made. It is assumed that this collection is finite and discrete. It is formally represented as:

$$A = \{a_1, a_2, \ldots, a_n\}$$

Table 1 Alternative factors

Type of property	Price (NLG)	Site area (ha)	Number of units
a_1	5×10^6	0.5	25
a_2	3×10^6	0.2	40
a_3	4×10^6	0.3	30

Table 2 Preference score

Type of property	Price	Site area	Number of units
a_1	6	8	7
a_2	9	7	6
a_3	9	6	8

Every alternative a_i is an element of the collection A:

$$a_i \in A$$

For example, an architect who wants to decide what type of residential block is best could take as a basis the following collection of alternatives:

a_1 = a block of semi-detached residential units
a_2 = an apartment block
a_3 = a block of terraced housing

$$A = \{a_1, a_2, a_3\}$$

In order to make a choice based on the collection, the architect must arrange the alternatives in order of preference, thus allowing him to select the one that is most preferable.

Of course this example is very simple. In practice, each alternative will have many attributes, for instance price, site area, and number of units. These are shown in Table 1.

In mathematical terms the price, site area, and number of units are the variables, and a_1, a_2, and a_3 are the vectors. In this example each vector has three components (the permitted value for each variable).

To render this problem – what is the best type of housing? – open to a decision and therefore to (formally) solve it, the components will have to be assigned a preference score (Table 2). If the order of dominance is price, site area, and number of units, type a_2 will receive highest preference.

In practice, the number of alternatives and of components might be so large that the issue of choice becomes too complex. This can be resolved by accepting Simon's 'satisficing' principle, that a decision-maker will be happy to consider only a limited number of alternatives – the alternatives with which

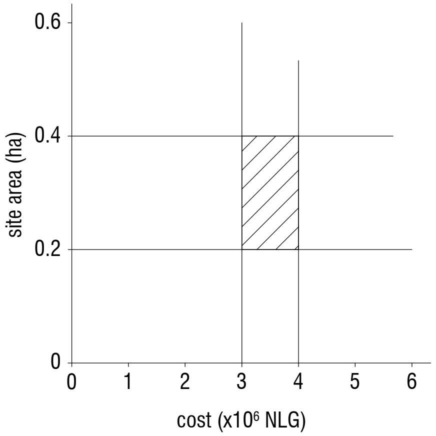


Figure 1 The realisation area (shaded)

he will be satisfied. It is then possible to make the best choice from this limited number. In mathematical terms this is represented in the form of constraints applied to the vectors, which divides the decision-making area into a 'permitted' (or realisation) area and a 'forbidden' area. Figure 1 shows an example in which the cost of the residential property must be between 3 million and 4 million guilders, and the site area between 0.2 and 0.4 hectares.

In OR, the following formula is used for a general (symbolic) notation of the structure of a decision-making problem (Ackoff and Sasieni, 1968, page 9):

$$U = f(X_i, Y_j) \tag{1}$$

where:

U = the utility or value of the system's performance
X_i = the variables that can be controlled
Y_j = the variables (and constraints) that are not controlled but do affect U
f = the relationship between U and X_i and Y_j

This indicates that a decision-making problem consists of two types of elements (variables): the elements X_i that can be determined by the decision-maker, and the elements Y_j that the decision-maker cannot determine. The elements Y_j are given, they come from 'outside' and are immutable as far as the decision-maker is concerned. Furthermore, it is indicated that these two groups of elements are 'ordered' in such a way (in the function f) that the whole has a value, or utility U. The decision-maker has the task of selecting the 'free' elements in such a way that the whole, together with the 'fixed' elements, produces the best outcome (design). Expressed mathematically, the decision-maker has the task of finding the values of the variables X_i that, with the given function f and the given values of the variables Y_j, produces the desired, best value of the variable U.

In Open Design, the variables X_i are split into two groups: the decision variables D_i, which are the variables whose value can be influenced outside the model; and the result variables R_k, whose values are determined by the model. Expressed as a formula (Y_j has been replaced by fixed variable F_j):

$$U = f(D_i, R_k, F_j) \tag{2}$$

where:

D_i = decision variables; input variables which can be influenced outside the model
R_k = result variables; output variables resulting from the model
F_j = fixed input variables

We label this function the *modified Ackoff-Sasieni utility function*. By considering the values of the decision variables D_i to be negotiable, a feasible solution space can be found.

Structure of the book

As explained before, the modified Ackoff-Sasieni utility function (see Equation 2) describes the structure of a decision-making problem. Table 3 shows how each part of the book relates to this formula.

Table 3 Structure of the book

Exercises Chapter	Cases Chapter	Chapter title	Relationship to formula
1	9	Linear programming with negotiable constraints	Input variables D_i are considered to be negotiable outside the model.
2	10	Monte Carlo simulation	Some of the input variables F_j are considered to follow probability curves, yielding the probability distribution of the utility.
3	11	Project Network Planning	The input variables F_j are considered to follow probability curves, yielding the probability of the utility. Some of the input variables F_j can be influenced by mitigations to improve the probability of a minimum required utility value (maximum acceptable throughput time).
4	12	Regression analysis	The relationship f is established on the basis of multiple regression analysis.
5 & 6	13 & 14	Preference measurement	Preference measurement is used to incorporate soft variables quantitatively as input variables F_j.
§1.5	15	Multi Criteria Optimisation	Input variables D_i are considered to be negotiable outside the model.
7	16	Non-linear optimisation	The relationship f is considered to be non-linear.
8	17	Geometric modelling	The input variables F_j are partly Boolean (0/1).

Part I

Exercises

1 Linear Programming with Negotiable Constraints

To use linear programming (LP) software effectively, the Open Designer has to be familiar with the mathematical model for the general problem of allocating resources to activities. He or she can then 'play' with the program without violating its underlying logic. It is not necessary to have detailed knowledge about how the program uses the Simplex Method (or faster procedures that are nowadays available) to find the optimum. It is sufficient to be aware of its essence, namely that it moves in an iterative process, systematically, from one corner-point feasible solution to a better one, until no better corner-point feasible solution can be found. That last corner-point solution is the optimum solution.

For the description of the general mathematical model, we will use the nomenclature and the standard form adopted in the Operations Research textbook of Hillier and Lieberman (2005). This model is used to select the values for the decision variables $x_1, x_2, \ldots, x_n$ so as to:

$$\text{Maximise} \quad Z = c_1x_1 + c_2x_2 + \cdots + c_nx_n \tag{1.1}$$

subject to the restrictions:

$$\begin{array}{rcl} a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n & \leq & b_1 \\ a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n & \leq & b_2 \\ & \vdots & \\ a_{m1}x_1 + a_{m2}x_2 + \cdots + a_{mn}x_n & \leq & b_m \end{array}$$

and

$$x_1 \geq 0, x_2 \geq 0, \ldots, x_n \geq 0$$

For the sake of brevity, we use $\sum$ notation and write:

$$\text{Maximise} \quad Z = \sum_{j=1}^{n} c_jx_j \tag{1.2}$$

subject to:

$$\sum_{j=1}^{n} a_{ij}x_j \leq b_i \qquad \text{for } i = 1, 2, \ldots, m$$

Figure 1.1 What's Best! toolbar

and

$$x_j \geq 0 \qquad \text{for } j = 1, 2, \ldots, n$$

This is adopted as the *standard form* for the linear programming problem. Any situation whose mathematical formulation fits this model is a linear programming model.

The function Z being maximised, $c_1x_1 + c_2x_2 + \cdots + c_nx_n$, is called the *objective function*. The *decision variables* – the x_j – are sometimes referred to as the *uncontrolled* or *endogenous* variables. The input variables – the a_{ij}, b_i, and c_j – may be referred to as *parameters* of the model or as the *controlled* or *exogenous* variables. The restrictions are referred to as *constraints*. The first m constraints, $b_1, b_2, \ldots, b_m$ (those with a function $a_{i1}x_1 + a_{i2}x_2 + \cdots + a_{in}x_n$ representing the total usage of resource i, on the left) are called *functional constraints*. The $x_j \geq 0$ restrictions are called *non-negativity constraints*.

In traditional linear programming, the constraints $b_1, b_2, b_3, \ldots, b_m$ are considered to be fixed. Often they represent physical constraints that indeed cannot be changed, such as the dimensions $(b_1, b_2, \ldots, b_m)$ of land available to grow various vegetables $(x_1, x_2, \ldots, x_n)$. In Open Design, by contrast, at least some of the constraints $b_1, b_2, \ldots, b_m$ are considered to be negotiable. This is a fundamental difference with traditional linear programming, which has far reaching consequences in practice. It means that the mathematical outcome *infeasible* can be changed into *feasible* after all.

1.1 Linear Programming using What's Best!

A convenient way of creating models to solve linear programming problems is to use the What's Best! add-in for Microsoft Excel. A demo version of What's Best! is available from Lindo Systems. After installation, the What's Best! toolbar becomes available in Excel (Fig. 1.1). Decision, uncontrolled, or endogenous variables are called *adjustable cells* in What's Best!. The value of the objective function is called the *best cell*.

A linear programming model can be constructed by transcribing the standard LP form described by Equation (1.1) and its restrictions into Excel, as shown in Figure 1.2. We will use this representation throughout the book.

	A	B	C	D	E	F	G
1	Endogenous variables	var1	var2		var$n$		
2	Outcome	x_1	x_2	$\cdots$	x_n		
3							
4	Objective Function	c_1	c_2	$\cdots$	c_n		Z
5							
6	Constraint 1	a_{11}	a_{12}	$\cdots$	a_{1n}	<=	b_1
7	Constraint 2	a_{21}	a_{22}	$\cdots$	a_{2n}	<=	b_2
8		$\vdots$	$\vdots$		$\vdots$		$\vdots$
9	Constraint m	a_{m1}	a_{m2}	$\cdots$	a_{mn}	<=	b_m

Figure 1.2 The standard LP form represented in Excel with What's Best!

A handy way of quickly building a model is by following this ABC:

A. Define the *Adjustable cells*. These are the cells in the worksheet of which What's Best! is allowed to change the values. Simply select the cells that hold these variables and click the 'Make Adjustable' button on the toolbar. The contents of these cells turn blue as a visual reminder.

B. Define the *Best cell*. This is the cell that holds the outcome of the objective function. Select the cell that holds this value and then click on the 'Minimize' or 'Maximize' button on the toolbar. This cell is then named WBMAX or WBMIN depending on whether you have chosen to minimise or maximise. The cell turns blue to indicate that it is to be optimised by What's Best!.

C. Define the *Constraints* that have to be met. These are the cells that define the relationship between cells that hold required resources and available resources in the model. The mathematical relationships are set with the 'Constraint Less Than', 'Constraint Greater Than', and 'Constraint Equal To' buttons on the toolbar.

We will illustrate this procedure in detail with the exercises that follow.

1.2 The project developer's problem

A project developer wants to develop houses of type A and B. (See Fig. 1.3) He knows that he will make a profit of € 30 000 on type A and of € 50 000 on type B. The municipality has limited the number of houses of type A to a maximum of 60 and the number of type B to a maximum of 50. Every type A needs 1 parking place while type B needs 2 parking places. The municipality has limited the total number of parking places to 150. The project developer

(a) Type A

(b) Type B

Figure 1.3 Two house types

wants to know which combination of houses he should develop to make the greatest profit.

We use the modelling ABC to build the model:

Define the Adjustable cells

	A	B	C	D	E	F
1	Endogenous variables	N_A	N_B			
2	Outcome	0	0			

In this case the Adjustable cells are the number of houses of type A and B. In Excel we create the entries as shown above. The cells B2 and C2 are the adjustables. Select these and click the 'Make Adjustable' button on the What's Best! toolbar.

Define the Best cell

	A	B	C	D	E	F
1	Endogenous variables	N_A	N_B			
2	Outcome	0	0			
3						
4	Objective function	30000	50000	0		

The Best cell would be the total profit given the numbers of houses of type A and B. In Excel we expand the model as shown. Select cell D4 and click the 'Maximize' button on the What's Best! toolbar to identify this cell as the cell that needs to be maximised.

Cell D4 must be the outcome of B4 times B2 plus the outcome of C4 times C2. This is in fact a representation of Equation (1.1). In Excel there is the *sumproduct* function, which we can use to simplify the modelling. There are two ways to create the *sumproduct* function depending on the Excel version you are using. The difference is in the use of semicolons or commas to separate ranges of cells. The version we are using accepts the semicolon. Should you get an error message, try using a comma instead. So, in cell D4 we type:

```
=sumproduct(B2:C2;B4:C4)
```

To make it possible to copy this formula to other rows later on, we make the relationship to row 2 absolute instead of relative. This is done by preceding the reference with a dollar (string) sign. So the formula in cell D4 becomes:

```
=sumproduct(B$2:C$2;B4:C4)
```

Define the Constraints that have to be met

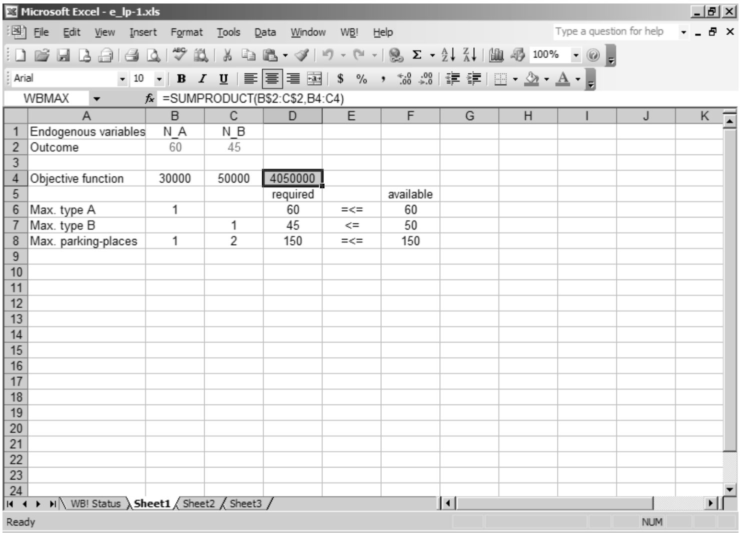
	A	B	C	D	E	F
1	Endogenous variables	N_A	N_B			
2	Outcome	0	0			
3						
4	Objective function	30000	50000	0		
5				required		available
6	Max. type A	1		0	<=	60
7	Max. type B		1	0	<=	50
8	Max. parking-places	1	2	0	<=	150

The Constraints are the restrictions given by the municipality. These are in fact representations of the restrictions to which Equation (1.2) is subject. Note that the formula created in cell D4 can be copied into cells D6 to D8. All other cells contain no formulas, just values entered. We have used the 'Constraint Less Than' button on the What's Best! toolbar to define the relationship between the required resources and available resources.

The model is now ready to be solved. Just click the 'Solve' button to start the solving process. Figure 1.4 shows a screenshot of the solved model with the result: developing 60 houses of type A and 45 houses of type B will yield the highest profit, namely € 4 050 000. [○ e_lp-1.xls] (see page viii).

Check these things if your model did not solve:

- Select the adjustable cells, here cells B2 to C2, and (re-)click the 'Make Adjustable' button;
- Select the best cell, here cell D4, and (re-)click the 'Maximize' button;
- Check for errors in the sumproduct formulas in the best cell and the constraints, here cells D4 and D6 to D8;
- Make sure you did not type in <=, >=, or = instead of using the toolbar for creating these relationships.



WBMAX =SUMPRODUCT(B$2:C$2,B4:C4)

	A	B	C	D	E	F
1	Endogenous variables	N_A	N_B			
2	Outcome	60	45			
3						
4	Objective function	30000	50000	4050000		
5				required		available
6	Max. type A	1		60	=<=	60
7	Max. type B		1	45	<=	50
8	Max. parking-places	1	2	150	=<=	150

Figure 1.4 Screenshot solved model (project developer's problem)

1.3 The municipality's problem

On a terrain of one point four hectares, a housing association wants to build a number of housing complexes and service units (e.g. shops, social-cultural buildings) within sixteen months. A housing complex takes one thousand square metres, and a service unit takes two thousand square metres. The areas mentioned include park and traffic infrastructure. The construction time of a service unit is one month, that of a housing complex is two months. A service unit costs five million euros, a housing complex costs eight million euros. A budget of eighty million euros is available for the whole project. The terrain need not be built up completely. From a poll amongst potential residents, it is apparent that the occupants' appreciation for the new neighbourhood is in the ratio of five housing complexes to three service units. The council has decided to maximise the compliance with this appreciation ratio for the future residents.

Once again, we use the modelling ABC to build the model.

Define the Adjustable cells

	A	B	C	D	E	F
1	Endogenous variables	N_HOUS	N_SERV			
2	Outcome	0	0			

In this case the Adjustable cells are the number of houses and service units. The cells B2 and C2 are the adjustables.

Define the best cell

	A	B	C	D	E	F
1	Endogenous variables	N_HOUS	N_SERV			
2	Outcome	0	0			
3						
4	Objective function	5	3	0		

The Best cell would be the total compliance given the numbers of houses and service units. Cell D4 is the cell that needs to be maximised. Cell D4 must be the outcome of B4 times B2 plus the outcome of C4 times C2.

Define the constraints that have to be met

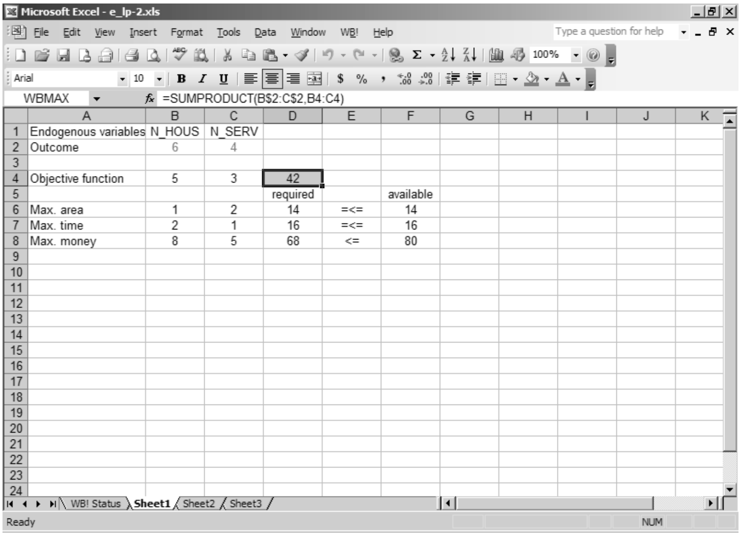
	A	B	C	D	E	F
1	Endogenous variables	N_HOUS	N_SERV			
2	Outcome	0	0			
3						
4	Objective function	5	3	0		
5				required		available
6	Max. area	1	2	0	<=	14
7	Max. time	2	1	0	<=	16
8	Max. money	8	5	0	<=	80

The Constraints are the restrictions in time, area, and money.

The model is now ready to be solved. Figure 1.5 shows a screenshot of the solved model with the result: building 6 housing complexes and 4 service units yields the highest resident's compliance, of 42. [○ e_lp-2.xls]

1.4 The facility manager's problem

A facility manager needs to replace the flooring of an office. He has the choice of two types of flooring. The one is less expensive but has high annual maintenance costs. The other is costly but has low annual maintenance costs. Material A costs € 60 per square metre and has an annual maintenance cost of € 10 per square metre. Material B costs € 90 per square metre and has an annual maintenance costs of € 8 per square metre. The total flooring area is 1 250 square metres. At least the entrance area, which is 125 square metres, should be made of material B. The cost of capital is 5%. The manager has a budget of € 100 000. The total lifespan of each material is 20 years. The manager wants wants to know which combination of materials would result in the lowest life



WBMAX =SUMPRODUCT(B$2:C$2,B4:C4)

	A	B	C	D	E	F
1	Endogenous variables	N_HOUS	N_SERV			
2	Outcome	6	4			
3						
4	Objective function	5	3	42		
5				required		available
6	Max. area	1	2	14	=<=	14
7	Max. time	2	1	16	=<=	16
8	Max. money	8	5	68	<=	80

Figure 1.5 Screenshot solved model (municipality's problem)

cycle costs (initial investment plus the net present value of the maintenance costs). The maintenance costs need to be paid at the end of every year.

Define the Adjustable cells

	A	B	C	D	E	F
1	Endogenous variables	A_A	A_B			
2	Outcome	0	0			

In this case the Adjustable cells are the quantities of the materials A and B. The cells B2 and C2 are the adjustables.

Define the Best cell

	A	B	C	D	E	F
1	Endogenous variables	A_A	A_B			
2	Outcome	0	0			
3						
4	Objective function	184.62	189.70	0		

The Best cell would be the total life cycle costs given the areas of type A and B. Cell D4 is the cell that needs to be minimised.

Cell D4 must be the outcome of B4 times B2 added to the outcome of C4 times C2. This is a representation of Equation (1.1). In this case the c in Equation (1.1) stands for the life cycle costs per square metre of material A and B. These are made up of both the initial costs and the present value of the annual maintenance costs. The net present value (NPV) of m annual payments C at interest rate r is (See Section 2.3):

$$NPV = C \cdot x \left\{ \frac{(1 - x^m)}{1 - x} \right\} \tag{1.3}$$

where:

$$x = \frac{1}{1 + r} \tag{1.4}$$

Therefore, in cell B4 we type:

```
=60+10*(1/(1+0.05)*(1-1/(1+0.05)^20))/(1-1/(1+0.05))
```

and in cell C4 we type:

```
=90+8*(1/(1+0.05)*(1-1/(1+0.05)^20))/(1-1/(1+0.05))
```

Define the Constraints that have to be met

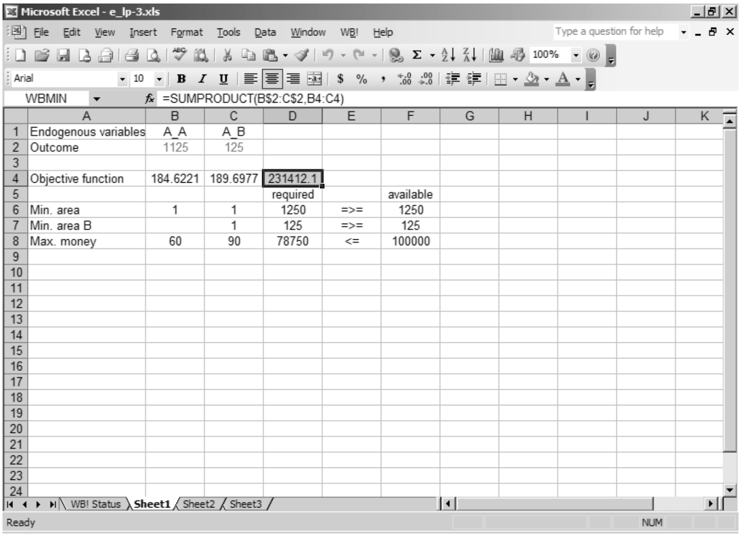
	A	B	C	D	E	F
1	Endogenous variables	A_A	A_B			
2	Outcome	0	0			
3						
4	Objective function	184.62	189.70	0		
5				required		available
6	Min. area	1	1	0	>=	1 250
7	Min area B		1	0	>=	125
8	Max. money	60	90	0	<=	100 000

The Constraints are the restrictions in area and money.

The model is now ready to be solved. Figure 1.6 shows a screenshot of the solved model with the result: using 1 125 square metres of material A and 125 square metres of material B yields the lowest life cycle costs, of € 231 412. [○ e_lp-3.xls]

1.5 LP and multi-criteria optimisation

In this section the *Constraint method* (see Chapter 6) in multi-criteria optimisation is used for allocating different types of houses to a residential area. The municipality has come into contact with a project developer interested in developing four types of houses (see Fig. 1.7). The types of houses differ mainly



WBMIN =SUMPRODUCT(B$2:C$2,B4:C4)

	A	B	C	D	E	F
1	Endogenous variables	A_A	A_B			
2	Outcome	1125	125			
3						
4	Objective function	184.6221	189.6977	231412.1		
5				required		available
6	Min. area	1	1	1250	=>=	1250
7	Min. area B		1	125	=>=	125
8	Max. money	60	90	78750	<=	100000

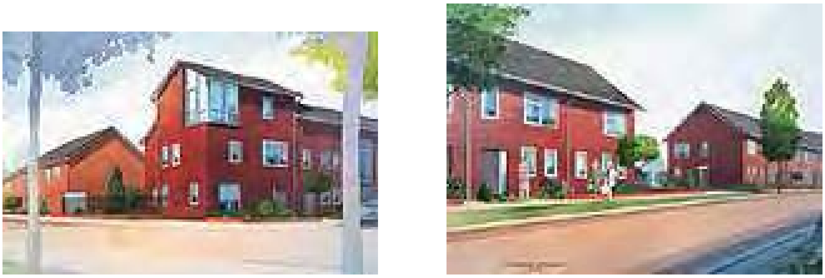
Figure 1.6 Screenshot solved model (facility manager's problem)

Table 1.1 Data of four types of houses

Type	Selling price	Minimum	Maximum	Developer's fee
A	225 000	20%	30%	11 250
C	275 000	-	-	13 750
L	300 000	-	-	15 000
M	225 000	15%	20%	11 250

in the selling price, ranging from affordable to expensive houses. The municipality has limited the total number of houses to between 200 and 260. The selling prices have been established, as has the developer's fee. The municipality wants to make sure that not only the expensive types of houses (with the largest fees) will be built. This is done by restricting the minimum and maximum percentages of the affordable types (as percentages of the total number of houses built). Note that contrary to the previous examples, there are now two stakeholders instead of one. All data is summarised in Table 1.1.

(a) Type A (b) Type C



(c) Type L (d) Type M

Figure 1.7 Four house types

Define the Adjustable cells

	A	B	C	D	E	F	G	H	I
1	Endogenous variables	N_A	N_C	N_L	N_M	N_TOT			
2	Outcome	0	0	0	0	0			

In this case the Adjustable cells are the number of houses of type A, C, L, and M. Because there are also restrictions in regard to the total number of houses, we also create an adjustable cell for this. The cells B2 to F2 are the adjustables.

Define the Best cell

	A	B	C	D	E	F	G	H	I
1	Endogenous variables	N_A	N_C	N_L	N_M	N_TOT			
2	Outcome	0	0	0	0	0			
3									
4	Objective function	1			1		0		

The municipality wants to build as many affordable houses (type A and M) as possible. The project developer, however, wants to make as much profit as possible. In LP terms: the two stakeholders have objective functions made up of different units (houses and euros). An objective function cannot be made up of different units. An advanced way to resolve this, using Preference Modelling, is described in Chapter 6. A less advanced, but very effective, way is to first optimise using one stakeholder's objective function and to then add this outcome as a restriction to the model. We will assume that the municipality's objective function is used for the first optimisation. The Best cell would then be the total number of affordable houses. Cell D4 is the cell that needs to be maximised.

Define the Constraints that have to be met

	A	B	C	D	E	F	G	H	I
1	Endogenous variables	N_A	N_C	N_L	N_M	N_TOT			
2	Outcome	0	0	0	0	0			
3									
4	Objective function	1			1		0		
5									
6	Min. houses					1	0	>=	200
7	Max. houses					1	0	<=	260
8	Min. houses A	1				-0.2	0	>=	0
9	Max. houses A	1				-0.3	0	<=	0
10	Min. houses M				1	-0.15	0	>=	0
11	Max. houses M				1	-0.2	0	<=	0
12	Total houses	-1	-1	-1	-1	1	0	=	0

The Constraints are the restrictions given by the municipality. One special restriction needs to be added, defining the total number of houses as the sum of all different types of houses (row 12).

The model is now ready to be solved. Figure 1.8 shows a screenshot of the solved model with the result: a maximum of 130 affordable houses can be built. [○ e_lp-4.xls]

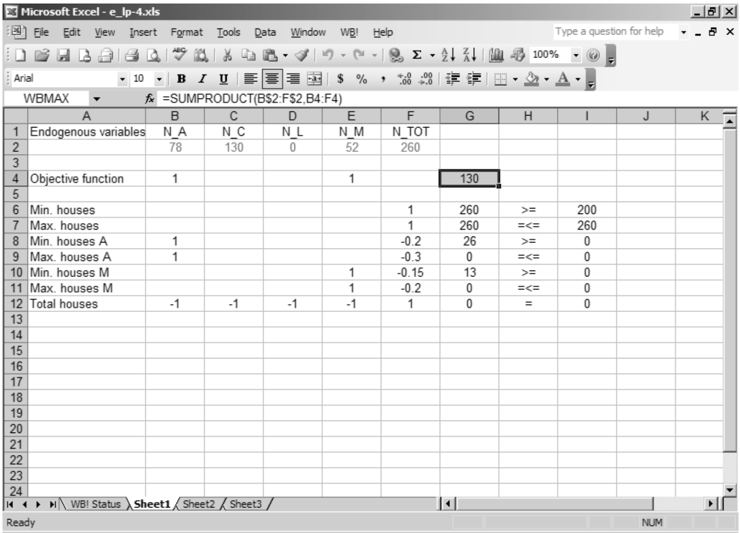
The municipality's optimum is then added as a minimum restriction to the model. The objective function is also changed: the project developer's fee is maximised. Figure 1.9 shows a screenshot of the solved model, with the added restriction and altered objective function. The developer's optimal fee turns out to be € 3 412 500.

Note that the only difference between the two outcomes is the number of houses of type C and type L. In the first run, it did not really matter how the number of houses of type C and L were distributed because the objective function was aimed at maximising the number of affordable houses. In the second run this did matter because the objective function was aimed at maximising the developer's fee and the fee of type L was higher than that of type C. Also note that both outcomes are in essence acceptable. The second outcome is better however, due to the higher profit the developer will make.

1.6 Conclusions

1. The concept of linear programming with negotiable constraints constitutes a powerful tool to address the combinatory explosion problem in architecture and urban planning.

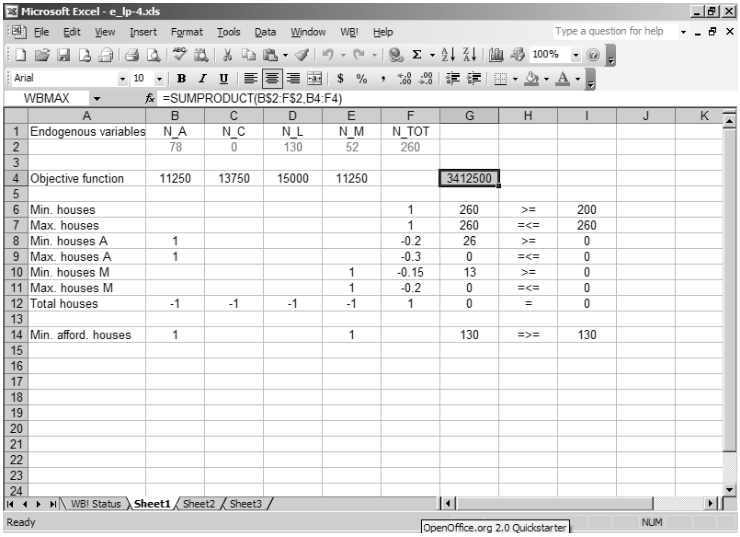
2. The concept can be extended to multi-criteria optimisation.



WBMAX =SUMPRODUCT(B$2:F$2,B4:F4)

	A	B	C	D	E	F	G	H	I
1	Endogenous variables	N_A	N_C	N_L	N_M	N_TOT			
2		78	130	0	52	260			
3									
4	Objective function	1			1		130		
5									
6	Min. houses					1	260	>=	200
7	Max. houses					1	260	=<=	260
8	Min. houses A	1				-0.2	26	>=	0
9	Max. houses A	1				-0.3	0	=<=	0
10	Min. houses M				1	-0.15	13	>=	0
11	Max. houses M				1	-0.2	0	=<=	0
12	Total houses	-1	-1	-1	-1	1	0	=	0

Figure 1.8 Screenshot solved model (maximising the number of affordable houses)



WBMAX =SUMPRODUCT(B$2:F$2,B4:F4)

	A	B	C	D	E	F	G	H	I
1	Endogenous variables	N_A	N_C	N_L	N_M	N_TOT			
2		78	0	130	52	260			
3									
4	Objective function	11250	13750	15000	11250		3412500		
5									
6	Min. houses					1	260	>=	200
7	Max. houses					1	260	=<=	260
8	Min. houses A	1				-0.2	26	>=	0
9	Max. houses A	1				-0.3	0	=<=	0
10	Min. houses M				1	-0.15	13	>=	0
11	Max. houses M				1	-0.2	0	=<=	0
12	Total houses	-1	-1	-1	-1	1	0	=	0
13									
14	Min. afford. houses	1			1		130	=>=	130

Figure 1.9 Screenshot solved model (maximising the project developer's fee)

2 Monte Carlo simulation for real estate and infrastructure investments

Financial return on investment, which allows trade-offs between costs and benefits, always plays a role in Open Design problems. As mentioned in Chapter 4 of *Open Design, a Collaborative Approach to Architecture*, we recommend using discounted cash flow analysis with a preference for using the Internal Rate of Return (IRR) criterion over the Net Present Value (NPV) criterion.

The net present value of a project is:

$$NPV = \sum_{i=0}^{m} \frac{C_i}{(1+r)^i} \tag{2.1}$$

where:

C_i = cash flow (positive or negative) in year i;
r = (yearly) cost of capital (as a fraction of that capital);
m = life time of the project in years.

In general, the cost of capital r is closely linked with inflation. The internal rate of return is the discount rate which would give $NPV = 0$:

$$\sum_{i=0}^{m} \frac{C_i}{(1+IRR)^i} = 0 \tag{2.2}$$

The internal rate of return can be considered to be made up of two parts:

1. Cost of capital r without risk allowance,
2. Profit p representing the reward for accepting the risk of the investment.

In real estate financing, the cash flows can be characterised by:

- A large investment I, i.e. negative cash flow, at the start of the project;
- A yearly net exploitation result E, i.e. the difference between the yearly exploitation revenues and costs;
- A rest value V at the end of the project. In real estate investments V constitutes the selling price at the end of the lifetime.

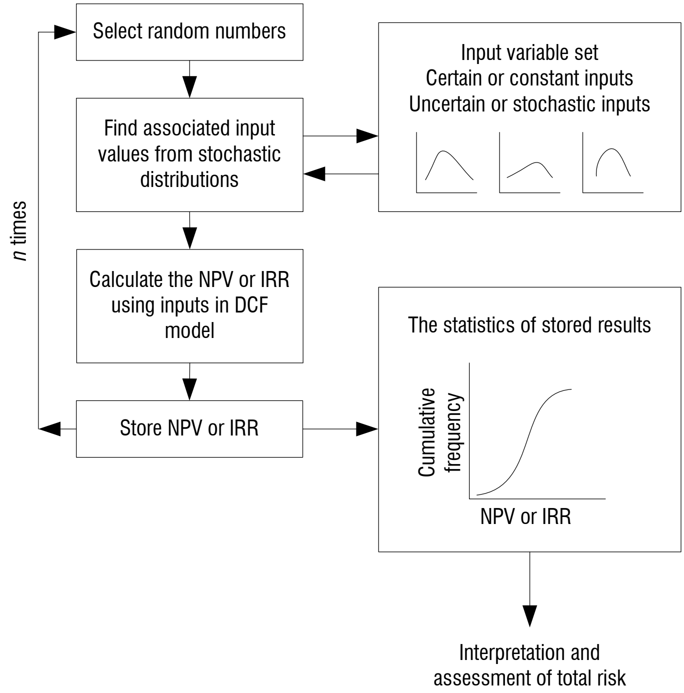


Figure 2.1 Monte Carlo simulation for a real estate investment

In the real world, the variables I, r, E and V will never have the same values as assumed in the investment calculation. We can, however, estimate risk profiles for these variables, i.e. probability distributions for their occurrence. The probability distributions of the variables determining the financial return on the investment are the basis of Monte Carlo simulations as shown in Figure 2.1.

Instead of making one estimate for each variable that affects the return on investment, three estimates are made:

1. A pessimistic estimate, defined as having a probability of 10% that reality will be worse than that;
2. A best guess; in general, this value represents the outcome of a cost-benefits calculation;
3. An optimistic estimate, defined as having a probability of 10% that reality will be better than that.

These three points determine the probability distribution for the variable concerned. With these distribution curves, Monte Carlo simulation finally gives the probability distribution for the financial return.

The arithmetic of the Monte Carlo simulation is: whenever a risk variable enters into the calculation, a random number generated by the computer is corrected with the (skewed) distribution of the variable concerned. The calculation is done, say, 2 000 times. The resulting 2 000 different outcomes provide the probability distribution of the financial return on the investment.

This approach has two important advantages compared to conventional investment analysis based on single values:

1. It allows moderate return–low risk investments to be traded off against high return–high risk investments. The decision support information provided by the two different risk profiles is extremely relevant for an investor;
2. By asking experts a range instead of a single estimate, they tend to be genuine. When people are asked to give only one estimate, they tend to give their pessimistic guess without saying so.

An underlying assumption of Monte Carlo simulation is that the variables involved are stochastically independent.

The trade-off of a moderate return-low risk against a high return-high risk alternative often boils down to choosing between an inexpensive option ‘X’ and an expensive option ‘Y’. For instance, should we spend extra money for a prestigious entrance and a large parking lot or should we keep the investment as low as possible? The former – the expensive option – is more risky in the sense that users may not be prepared to pay extra rent for the nice entrance and the parking area. There is also a reasonable chance, however, that they will be prepared to pay more for it than its (discounted) cost. In that case the financial return will be higher than for the inexpensive option (no prestigious entrance and only a limited parking lot).

The probability curves for the financial return of the inexpensive and the expensive options are typically as shown in Figure 4.1 of Open Design, a Collaborative Approach to Architecture (page 49). The probability that the return will be above a minimum threshold is as shown in Figure 4.2 of Open Design, a Collaborative Approach to Architecture (page 49).

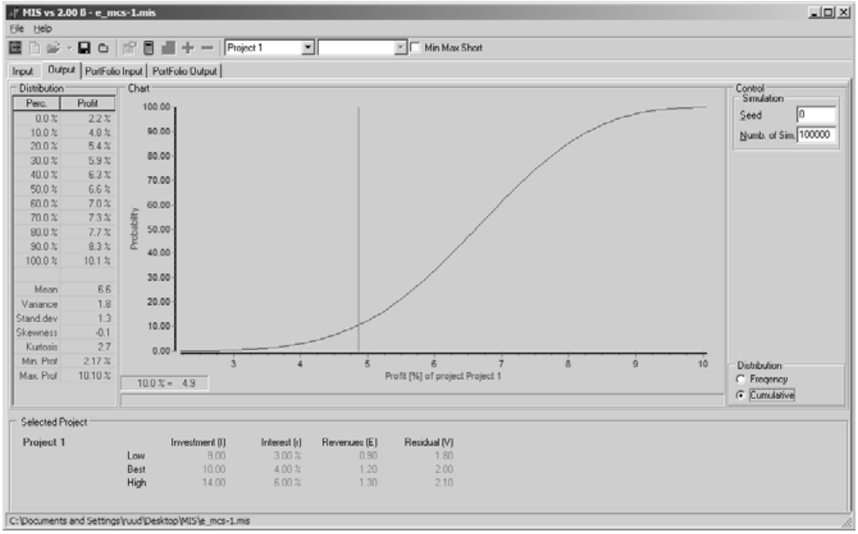
If the investor prefers a moderate but sure return, he should choose option 'X'. Conversely, if he wishes to go for a more ambitious return and is willing to accept the associated higher risk, then he should choose option 'Y'. The difference between the two risk profiles is caused by the associated probability curves of the rent users will be prepared to pay. Since the variables investment I, cost of capital r, net exploitation revenues E, and rest value V as defined in the preceding section, are stochastically independent, a Monte Carlo simulation can be conducted based on ranges specified for these variables.

We have developed a software package for this purpose. The input consists of the lifetime m and the ranges (specified by three values) for the variables investment, cost of capital, yearly net exploitation E, and rest value V. The output gives the probability distribution for the profit p and a sensitivity analysis based on the best guess estimates. The internal rate of return (IRR) distribution is obtained by setting the input variable cost of capital r at zero (three times).

2.1 Risk assessment example: single project

As an investor you are offered a real estate project with the following characteristics:

- The expected lifetime is 30 years.
- The investment is estimated at € 10 million. You think that there is a 10% chance that the investment will be more than € 14 million and you think here is a 10% chance that the investment will be less than € 9 million.
- The cost of capital is estimated at 4%. You think that there is a 10% chance that the cost of capital is more than 6% and you think there is a 10% chance that the cost of capital is less than 3%.
- The yearly net exploitation result is estimated at € 1.2 million. You think that there is a 10% chance that the yearly exploitation result is more than



Distribution

Perc.	Profit
0.0 %	2.2 %
10.0 %	4.0 %
20.0 %	5.4 %
30.0 %	5.9 %
40.0 %	6.3 %
50.0 %	6.6 %
60.0 %	7.0 %
70.0 %	7.3 %
80.0 %	7.7 %
90.0 %	8.3 %
100.0 %	10.1 %
Mean	6.6
Variance	1.8
Stand.dev	1.3
Skewness	-0.1
Kurtosis	2.7
Min. Prof	2.17 %
Max. Prof	10.10 %

Simulation

Seed: 0

Numb. of Sim: 100000

Distribution: ○ Freqency ● Cumulative

Selected Project

Project 1

	Investment (I)	Interest (i)	Revenues (E)	Residual (V)
Low	9.00	3.00 %	0.90	1.80
Best	10.00	4.00 %	1.20	2.00
High	14.00	6.00 %	1.30	2.10

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Figure 2.2 Output illustration of Monte Carlo simulation

€ 1.3 million and you think here is a 10% chance that the yearly exploitation result is less than € 0.9 million.

- The rest value is estimated at € 2 million. You think that there is a 10% chance that the rest value is more than € 2.1 million and you think here is a 10% chance that the rest value is less than € 1.8 million.

You are interested in the risk associated with this project. You want to approve the project if it will have an 80% probability that its profit will be at least 5%. Input the data into the program or open the file [○ e_mcs-1.mis]. Press the 'Perform Project Simulation' button to start the simulation.

The output (Fig. 2.2) shows a mean profit of 6.6% with a standard deviation of 1.3%. The probability $\bar{P}$ that the profit will exceed a threshold $\bar{R}$ according to formula (4.1) (page 48) of *Open Design, a Collobarative Approach to Architecture*, is represented in the S-shaped graph. Note that the mean of 6.6% corrresponds with a 50% probability that the profit will exceed that value.

The project meets the criterion for approval (20% probability that the profit will be less than 5.4%).

Table 2.1 Characteristics of two real estate projects

	Project A			Project B		
	Low	Best	High	Low	Best	High
Investment [€ billion]	9	10	14	7	12	17
Interest [%]	3	4	6	3	4	6
Revenues [€ billion]	0.9	1.2	1.3	1.1	1.3	1.6
Rest value [€ billion]	1.8	2.0	2.1	1.8	2.0	2.2

Table 2.2 Risk profiles project A and B

Probability (cumulative)	Project A	Project B
90%	4.8%	3.4%
80%	5.4%	4.3%
70%	5.9%	5.0%
60%	6.3%	5.6%
50%	6.6%	6.3%
40%	7.0%	7.0%
30%	7.3%	7.9%
20%	7.7%	9.0%
10%	8.3%	10.5%

2.2 Risk diversification example: two projects

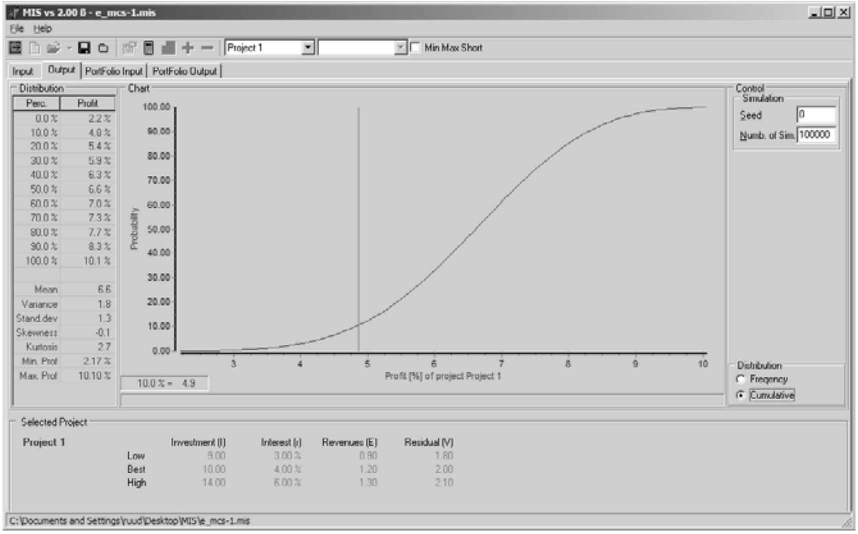
As an investor you are offered 2 real estate projects with the characteristics as shown in Table 2.1.

You already have many projects in your portfolio that have moderate but sure returns so you want this project to have a more ambitious return and you are prepared to accept the higher risk involved (risk diversification).

Input the data into the program or open the files [○ e_mcs-2.mis]. Press the 'Perform Project Simulation' button to start the simulations.

Running both simulations yields the profit thresholds shown in Figures 2.3 and 2.4. The output is summarised in Table 2.2.

As can be seen from the results, the profit of project A ranges from 4.8% to 8.3% whereas the profit of project B ranges from 3.4% to 10.5%. Project A has a standard deviation of 1.3 whereas project B has a standard deviation of 2.7. This indicates that project B is more risky but could also yield a higher profit. There is a 10% probability that project A will have a profit of more than 8.3% whereas project B has a 10% probability of yielding a profit of more than 10.5%. This means that project B fits better into the current portfolio of projects than project A.



Perc.	Profit
0.0 %	2.2 %
10.0 %	4.0 %
20.0 %	5.4 %
30.0 %	5.9 %
40.0 %	6.3 %
50.0 %	6.6 %
60.0 %	7.0 %
70.0 %	7.3 %
80.0 %	7.7 %
90.0 %	8.3 %
100.0 %	10.1 %
Mean	6.6
Variance	1.8
Stand.dev	1.3
Skewness	-0.1
Kurtosis	2.7
Min. Prof	2.17 %
Max. Prof	10.10 %

10.0 % = 4.9

Simulation

Seed: 0

Numb. of Sim.: 100000

Distribution

○ Freqency

● Cumulative

Selected Project

Project 1

	Investment (I)	Interest (r)	Revenues (E)	Residual (V)
Low	9.00	3.00 %	0.90	1.80
Best	10.00	4.00 %	1.20	2.00
High	14.00	6.00 %	1.30	2.10

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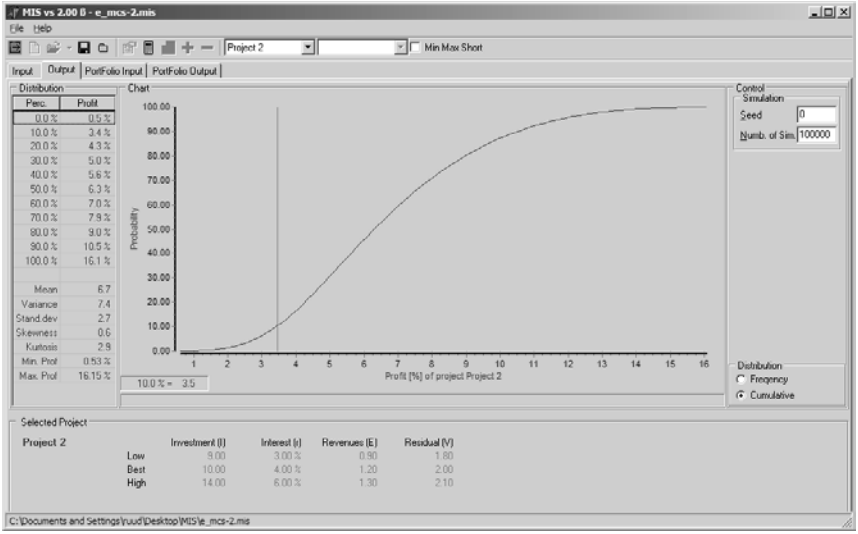
Figure 2.3 Output illustration of Monte Carlo simulation project A



Perc.	Profit
0.0 %	0.5 %
10.0 %	3.4 %
20.0 %	4.3 %
30.0 %	5.0 %
40.0 %	5.6 %
50.0 %	6.3 %
60.0 %	7.0 %
70.0 %	7.9 %
80.0 %	9.0 %
90.0 %	10.5 %
100.0 %	16.1 %
Mean	6.7
Variance	7.4
Stand.dev	2.7
Skewness	0.6
Kurtosis	2.9
Min. Prof	0.53 %
Max. Prof	16.15 %

10.0 % = 3.5

Simulation

Seed: 0

Numb. of Sim.: 100000

Distribution

○ Freqency

● Cumulative

Selected Project

Project 2

	Investment (I)	Interest (r)	Revenues (E)	Residual (V)
Low	9.00	3.00 %	0.90	1.80
Best	10.00	4.00 %	1.20	2.00
High	14.00	6.00 %	1.30	2.10

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Figure 2.4 Output illustration of Monte Carlo simulation project B

2.3 Monte Carlo simulation of a portfolio of real estate investments

Real estate investors are primarily interested in the risk profile (probability distribution of expected return) of their portfolio of projects. What we need, therefore, is a method to conduct a Monte Carlo simulation for a portfolio of projects with different starting dates, different lifetimes and different risk profiles.

Any project, j, of a portfolio of N projects has a past (indicated by subscript P) and a future (indicated by subscript F).

The NPV is the sum of the NPV over the past and the NPV over the future:

$$NPV = NPV_P + NPV_F \tag{2.3}$$

The NPV_{Pj} over the past - at the present time, in money units of the present time - of project j is:

$$NPV_{Pj} = y^{L_{Pj}}(-I_{Pj} + V_{Pj}) + E_{Pj} \sum_{i=1}^{L_{Pj}} y^i \tag{2.4}$$

where:

y = $1 + r_P$;
r_P = cost of capital over the past lifetime of project j;
L_{Pj} = past lifetime of project j;
I_{Pj} = investment made at the start of project j, in money units of that point in time;
V_{Pj} = rest value of project j, at the end of its lifetime, in money units at the start of the project; selling price of premises at the end of L_{Fj} is $V_{Pj}(1+r)^{L_{Pj}+L_{Fj}}$;
E_{Pj} = yearly net exploitation result of project j over the past lifetime L_{Pj}, in money units at the start of the project.

The sum of the geometric series

$$\sum_{i=0}^{n-1} x^i = \frac{1 - x^n}{1 - x} \tag{2.5}$$

so:

$$\sum_{i=1}^{m} x^i = \frac{1 - x^{m+1}}{1 - x} - 1 \tag{2.6}$$

which can be written as:

$$\sum_{i=1}^{m} x^i = \frac{x(1-x^m)}{1-x} \tag{2.7}$$

Inserting sum formula 2.7 for the geometric series gives:

$$NPV_{Pj} = y^{L_{Pj}}(-I_{Pj} + V_{Pj}) + E_{Pj}\frac{y(1-y^{L_{Pj}})}{(1-y)} \tag{2.8}$$

The net present value NPV_{Fj} over the future of project j is:

$$NPV_{Fj} = E_{Fj}\sum_{k=1}^{L_{Fj}} x^k \tag{2.9}$$

where:

$$x = \frac{1}{1+r_F+p} \tag{2.10}$$

where:

L_{Fj} = future lifetime of project j;
r_f = cost of capital over the future lifetime of project j;
p = profit;
E_{Fj} = yearly net exploitation result of project j over the future lifetime L_{Fj}, in money units at the start of the project.

Inserting sum formula 2.7 for the geometric series of the last term gives:

$$NPV_{Fj} = E_{Fj}\frac{x(1-x^{L_{Fj}})}{1-x} \tag{2.11}$$

We are interested in the profit p for $NPV = 0$. This means that we have to find the root x from:

$$0 = \sum_{j=1}^{N} NPV_{Pj} + \sum_{j=1}^{N} E_{Fj}\frac{x(1-x^{L_{Fj}})}{1-x} \tag{2.12}$$

Rearranging terms gives:

$$x = \frac{NPV_P^* - \sum_{j=1}^{N} E_{Fj}x^{L_{Fj}}}{NPV_P^* - \sum_{j=1}^{N} E_{Fj}} \tag{2.13}$$

Table 2.3 Characteristics portfolio of real estate projects

Project	Estimate	D	Eh	Tw	Ad	Rd	Nk
Investment	low	9	9	9	9	9	9
	best	10	10	10	10	10	10
	high	13	12	14	14	14	14
Interest	low	3%	3%	3%	2%	3%	3%
	best	4%	4%	4%	3.5%	5%	5%
	high	5%	5%	5%	5%	6%	6%
Revenues	low	1.2	1.2	1.2	1.0	1.2	1.2
	best	1.4	1.3	1.35	1.1	1.3	1.3
	high	1.5	1.4	1.5	1.3	1.4	1.4
Rest value	low	1.8	1.8	1.8	1.8	1.8	1.8
	best	2.0	2.0	2.0	2.0	2.0	2.0
	high	2.1	2.1	2.1	2.1	2.1	2.1
Life time (Past/Future)		4/26	6/34	5/25	9/31	9/31	4/46

where:

$$NPV_P^* = \sum_{j=1}^{N} NPV_{Pj} \tag{2.14}$$

The Equation 2.13, of the form $x = f(x)$, can be solved using Wegstein's iterative procedure (Wegstein, 1958). The routine can also be found in *Open Design, a Collaborative Approach to Architecture* (page 80).

The Monte Carlo simulation for the entire portfolio can then be conducted in the same way as for a single investment project. The input for this option of our software package consists of the number of projects N and for each project:

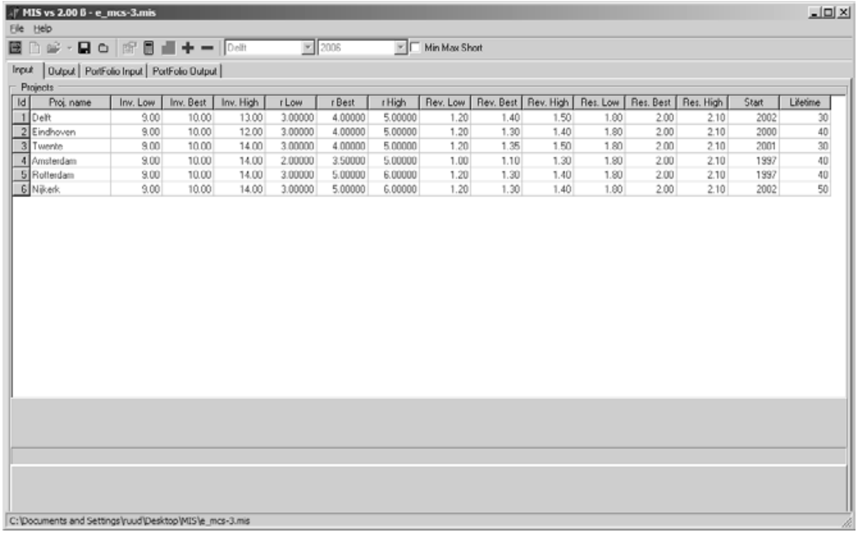
1. $L_P, L_F, I_P, E_P, V_P, r_P$ (single values).
2. Ranges (three values) for E_F and r_F .

The output gives the probability distribution of the expected return (profit) for the portfolio.

2.4 Risk diversification example: portfolio of projects

As an investor you have a portfolio with real estate objects with estimated characteristics as shown in Table 2.3.

You first add the portfolio characteristics to the MCS software or alternatively open the sample project [○ e_mcs-3].



Id	Proj. name	Inv. Low	Inv. Best	Inv. High	r Low	r Best	r High	Rev. Low	Rev. Best	Rev. High	Res. Low	Res. Best	Res. High	Start	Lifetime
1	Delft	9.00	10.00	13.00	3.00000	4.00000	5.00000	1.20	1.40	1.50	1.00	2.00	2.10	2002	30
2	Eindhoven	9.00	10.00	12.00	3.00000	4.00000	5.00000	1.20	1.30	1.40	1.80	2.00	2.10	2000	40
3	Twente	9.00	10.00	14.00	3.00000	4.00000	5.00000	1.20	1.35	1.50	1.80	2.00	2.10	2001	30
4	Amsterdam	9.00	10.00	14.00	2.00000	3.50000	5.00000	1.00	1.10	1.30	1.80	2.00	2.10	1997	40
5	Rotterdam	9.00	10.00	14.00	3.00000	5.00000	6.00000	1.20	1.30	1.40	1.80	2.00	2.10	1997	40
6	Nijkerk	9.00	10.00	14.00	3.00000	5.00000	6.00000	1.20	1.30	1.40	1.00	2.00	2.10	2002	50

C:\Documents and Settings\ruud\Desktop\MIS\e_mcs-3.mis

Figure 2.5 Portfolio characteristics

You can check the portfolio's characteristics by clicking either the 'Input' or 'PortFolio Input' tab. This will show output as shown in Figure 2.5.

You can then click the 'Perform Portfolio Simulation' button to calculate the probability distribution of the expected return (profit) for the portfolio.

The output (Fig. 2.6) shows that the portfolio has a mean profit of 41% with a standard deviation of 0.6%. The probability $\bar{P}$ that the profit will exceed a threshold $\bar{R}$, given by formula (4.1) (page 48) of *Open Design, a Collaborative Approach to Architecture*, is represented in the S-shaped graph. Note that the mean of 41% corrresponds with a 50% probability that the profit will exceed that value.

Adding a new project to the portfolio should result in a higher standard deviation and a higher profit. We choose a profit threshold having a 90% (cumulative) probability, in this case a profit of 42%.

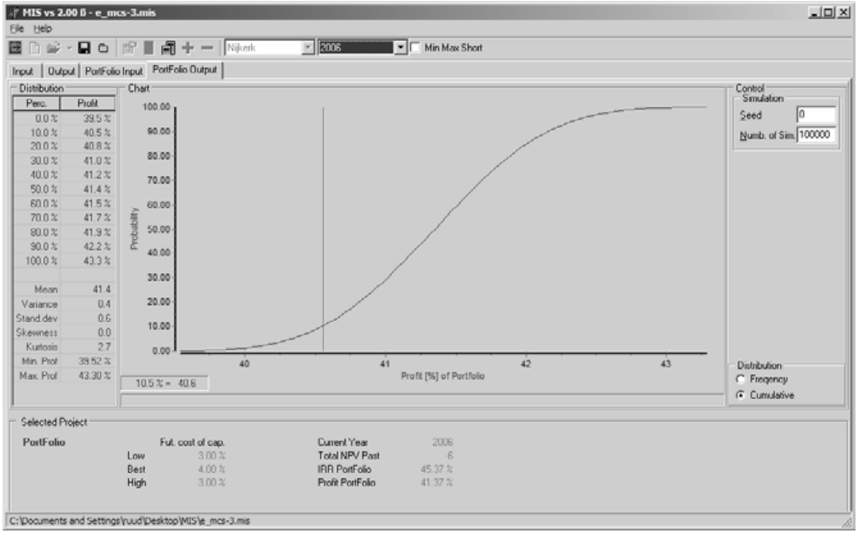
A new project is offered with the characteristics as shown in Table 2.4.

After adding this project to the existing portfolio, the probability distribution of the expected return (profit) for the portfolio can be calculated again (alternatively, open the sample project [○ e_mcs-4]).

The output is shown in Figure 2.7.

Adding the new project to the portfolio indeed results in a higher standard deviation and a higher profit. The standard deviation has risen from 0.6 to 0.8. The profit threshold having a 90% probability, has risen from 42% to 58%.

The portfolio could mainly consist of projects that are near the end of their



Perc.	Profit
0.0 %	39.5 %
10.0 %	40.5 %
20.0 %	40.8 %
30.0 %	41.0 %
40.0 %	41.2 %
50.0 %	41.4 %
60.0 %	41.5 %
70.0 %	41.7 %
80.0 %	41.9 %
90.0 %	42.2 %
100.0 %	43.3 %
Mean	41.4
Variance	0.4
Stand.dev	0.6
Skewness	0.0
Kurtosis	2.7
Min. Prof	39.52 %
Max. Prof	43.30 %

10.5 % = 40.6

Seed 0

Numb. of Sim. 100000

○ Freqency

● Cumulative

PortFolio

	Fut. cost of cap.
Low	3.00 %
Best	4.00 %
High	3.00 %

Current Year 2006

Total NPV Past -6

IRR PortFolio 45.37 %

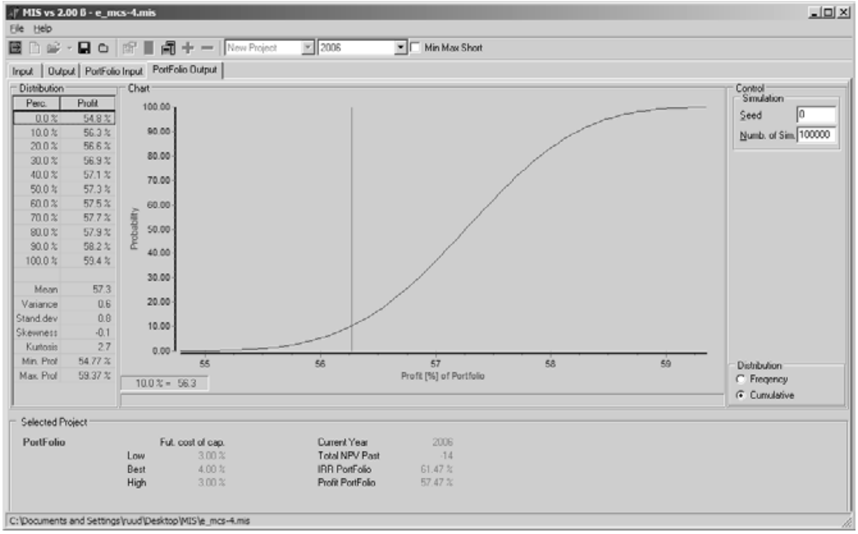
Profit PortFolio 41.37 %

C:\Documents and Settings\ruud\Desktop\MIS\e_mcs-3.mis

Figure 2.6 Output of Monte Carlo simulation on portfolio, before adding new project

Table 2.4 Characteristics new real estate project

Project	Estimate	New
Investment	low	8
	best	10
	high	15
Interest	low	3%
	best	5%
	high	6%
Revenues	low	1.0
	best	1.3
	high	2.0
Rest value	low	1.8
	best	2.0
	high	2.1
Life time		50



2006

☐ Min Max Short

Perc.	Profit
0.0 %	54.8 %
10.0 %	56.3 %
20.0 %	56.6 %
30.0 %	56.9 %
40.0 %	57.1 %
50.0 %	57.3 %
60.0 %	57.5 %
70.0 %	57.7 %
80.0 %	57.9 %
90.0 %	58.2 %
100.0 %	59.4 %
Mean	57.3
Variance	0.6
Stand.dev	0.8
Skewness	-0.1
Kurtosis	2.7
Min. Prof	54.77 %
Max. Prof	59.37 %

10.0 % = 56.3

Seed: 0
Numb. of Sim.: 100000

Distribution
○ Freqency
● Cumulative

PortFolio

	Fut. cost of cap.		
Low	3.00 %	Current Year	2006
Best	4.00 %	Total NPV Past	-14
High	3.00 %	IRR PortFolio	61.47 %
		Profit PortFolio	57.47 %

Figure 2.7 Output of Monte Carlo simulation on portfolio, after adding new project

life time. It is then likely that the portfolio, as a whole, has passed it's pay-back period. This implies that the profit, as an internal rate of return, is impossible to calculate. The program then calculates the net present value of the portfolio. This also implies that choosing between a moderate return, low risk project and a high return, high risk project becomes irrelevant. In effect one is adding projects to a (virtually) new portfolio.

2.5 Conclusions

1. Monte Carlo simulation of real estate and infrastructure investments enables the trade-off to be made between low-risk/moderate-return and high-risk/high-return alternatives.

2. Monte Carlo simulation of a portfolio of real estate investments allows the impact on the risk profile of the entire portfolio to be evaluated when adding a new project.

3 Project Network Planning and Risk Assessment

The current state-of-the-art of decision modelling for construction projects is characterised by the following three techniques, which are widely in use:

1. Gantt or bar chart, which shows the start and finish times of the project's activities.

2. Critical Path Method (CPM), which allows the interdependence of the activities to be taken into account, and the identification of the Critical Path of subsequent activities in which any delay in an activity causes a delay in the total project duration.

3. Program Evaluation and Review Technique (PERT), which is similar to CPM, but allows estimated probability distributions for the duration of the activities to be accounted for.

CPM was developed by Kelly and Walker in 1957. PERT originates from the Special Projects Office of the U.S. Navy and was developed in the late fifties for the Polaris missile program.

The Gantt chart is most frequently used because of its simplicity, but does not show the relationships between the activities that are needed to complete the project (Fig. 3.1).

CPM is better for the larger and more complex jobs in that the network shows the interdependence of the various operations (Fig. 3.2).

The initial real-life experiences with CPM in manufacturing scheduling were disappointing, in that actual project durations tended to considerably exceed the predictions according to the model. The variability in expected activity times had to be accounted for. In its simplest form, this can be done by adding

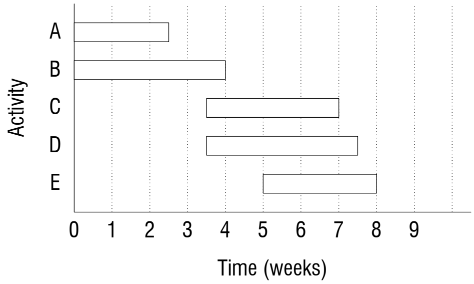
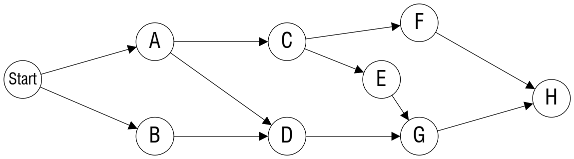


Figure 3.1 Example GANTT chart



Arrows show precedence relationships

Figure 3.2 Example CPM

an estimated margin to each expected activity time, to allow for unforeseen delays.

PERT is similar to CPM, but it allows three estimates for the duration of an activity to be provided: a pessimistic, a best guess and an optimistic estimate.

In this chapter we will first describe the traditional critical path method, the probabilistic approach of PERT, and Monte Carlo simulation on a priori selected paths through the network, which represent the current state-of-the-art. We will then show how to conduct Monte Carlo simulation without any a priori selection of paths through the network. Subsequently, the concept of path ranking is introduced in two different rankings: slack (or float) ranking and risk ranking. The latter is to be preferred for large and complex projects, see Chapter 11. Finally, we describe how to allow for mitigations on-the-run, including constraints due to limited human resources.

3.1 Deterministic network planning: CPM

Modelling a construction planning using LP software is in essence no more than translating the (graphical) relations between the different activities into mathematical equations. The relation between two activities in a construction planning can easily be translated into a mathematical formula. We will restrain ourselves to Finish-to-Start relations with a relation-duration of zero. In the critical path method the activity-duration is considered invariable.

Consider the part of an AON* construction planning shown in Figure 3.3.

This Finish-to-Start relationship means that activity B cannot start earlier than the earliest finish of activity A. In a mathematical equation:

$$x_1 \geq x_2 \tag{3.1}$$

where x_1 represents the earliest start of activity B and x_2 represents the earliest finish of activity A. We know the duration of activity A so the equation can be

---

*Of the two approaches for representing a network, Activity On Node (AON) and Activity On Arrow (AOA), the former is most commonly used because of its clarity and possibilities. The nodes are rectangles representing activities, the arrows represent the relationships.

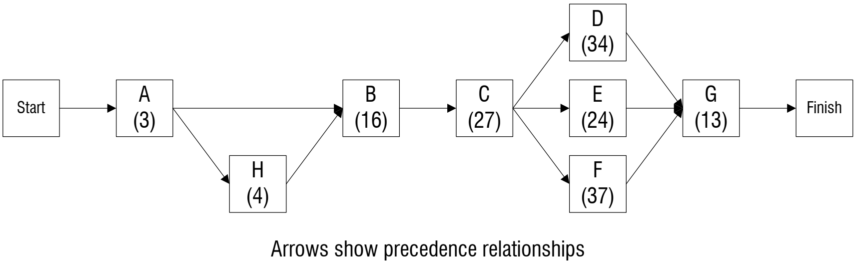


Figure 3.3 Illustration of part of a construction planning

rewritten as:

$$x_1 \geq x_2 + b_1 \tag{3.2}$$

where x_1 represents the earliest start of activity B and x_2 represents the earliest start of activity A and b_1 represents the duration of activity A. This equation can be rewritten as:

$$x_1 - x_2 \geq b_1 \tag{3.3}$$

This equation follows the standard form of a constraint from an LP model, as described in Chapter 1:

$$\text{Maximise} \quad Z = \sum_{j=1}^{n} c_j x_j \tag{3.4}$$

subject to:

$$\sum_{j=1}^{n} a_{ij} x_j \leq b_i \qquad \text{for } i = 1, 2, \ldots, m$$

and

$$x_j \geq 0 \qquad \text{for } j = 1, 2, \ldots, n$$

In critical path planning we are interested in the shortest total project duration. So the objective function is to minimise the total project duration. We will explain this using the following example.

Consider a simple network planning with two parallel activities A and B. Activity A has a duration of 5 days and activity B has a duration of 3 days. The Start and Finish activities are artificial activities that define the project's start and the project's finish. We want to build a model to calculate the shortest project duration. This simple example is just to illustrate the modelling of a critical path planning.

We use the modelling ABC to build the LP model in Excel:

	A	B	C	D	E	F	G	H
1	Endogenous variables	ES_ST	ES_A	ES_B	ES_FI			
2	Outcome	0	0	0	0			

Figure 3.4 Defining 'Adjustable' cells

	A	B	C	D	E	F	G	H
1	Endogenous variables	ES_ST	ES_A	ES_B	ES_FI			
2	Outcome	0	0	0	0			
3								
4	Objective function	-1			1	0		

Figure 3.5 Defining 'Best' cell

A. Define the 'Adjustable' cells. In this case these are the earliest start dates of the different activities, following Figure 3.4. The cells B2 through E2 hold the adjustables.

B. Define the 'Best' cell. This would be the total project duration given the earliest start dates of the different activities. In Excel we create the entries following Figure 3.5, where cell F4 is the cell that needs to be minimised.

   This might be confusing so we will explain this in more detail. The total project duration equals the earliest start of the artificial start-activity subtracted from the earliest start of the artificial finish-activity:

$$Z = -x_1 + x_4 \tag{3.5}$$

   where x_1 represents the earliest start of the artificial start-activity and x_4 represents the earliest start of the artificial finish-activity. Cell F4 must be the outcome of B4 times B2 added to the outcome of C4 times C2 added to the outcome of D4 times D2 added to the outcome of E4 times E2 or in mathematical terms:

$$Z = c_1x_1 + c_2x_2 + \cdots + c_nx_n \tag{3.6}$$

   In Excel, using the sumproduct function, we type in cell F4:

```
=sumproduct(B$2:E$2;B4:E4)
```

C. Define the 'Constraints' that have to be met. These are the restrictions that represent the relationships between the different activities. In Excel we create the entries following Figure 3.6.

	A	B	C	D	E	F	G	H
1	Endogenous variables	ES_ST	ES_A	ES_B	ES_FI			
2	Outcome	0	0	0	0			
3								
4	Objective function	-1			1	0		
5						required		available
6	St FS A	-1	1			0	>=	0
7	St FS B	-1		1		0	>=	0
8	A FS Fi		-1		1	0	>=	5
9	B FS Fi			-1	1	0	>=	3

Figure 3.6 Defining 'Constraints'

These are in fact representations of the following mathematical equation:

$$a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n \leq b_1 \tag{3.7}$$

Row 8 states for instance that the artificial finish-activity cannot start earlier than the earliest start of activity A added with the duration of activity A:

$$x_4 \geq x_2 + 5 \tag{3.8}$$

Where x_4 represents the earliest start of the artificial finish-activity, x_2 the earliest start of activity A and 5 equals the duration of activity A. We can rewrite this equation to meet the standard matrix layout:

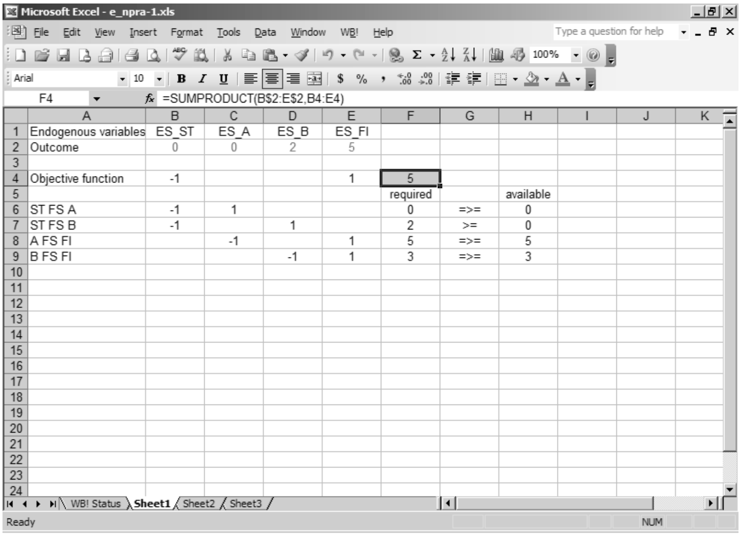
$$x_4 - x_2 \geq 5 \tag{3.9}$$

Note that the formula created in cell F4 can be copied into cells F6 to F9. All other cells contain no formulas, just values entered.

The model is now ready to be solved. Figure 3.7 shows a screenshot of the actual solved model. As you can see the minimal project duration is 5 days. [○ e_npra-1.xls]

3.2 Probabilistic network planning: PERT

PERT allows three estimates for the duration of an activity to be provided: a most pessimistic estimate (p), a most likely estimate (m) and a most optimistic estimate (o). When using PERT, it is usually assumed that activity times follow the beta probability distribution (Fig. 3.8).



F4 =SUMPRODUCT(B$2:E$2,B4:E4)

	A	B	C	D	E	F	G	H	I	J	K
1	Endogenous variables	ES_ST	ES_A	ES_B	ES_FI						
2	Outcome	0	0	2	5						
3											
4	Objective function	-1			1	5					
5						required		available			
6	ST FS A	-1	1			0	=>=	0			
7	ST FS B	-1		1		2	>=	0			
8	A FS FI		-1		1	5	=>=	5			
9	B FS FI			-1	1	3	=>=	3			

Figure 3.7 Screenshot of solved model

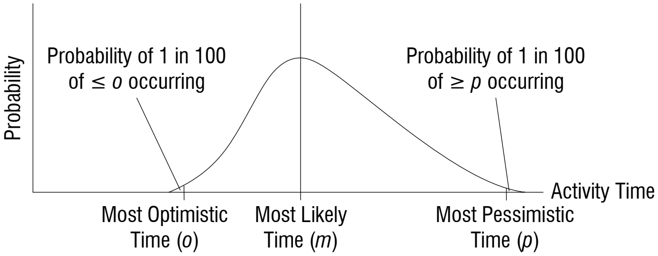


Figure 3.8 Beta probability distribution with three estimates

With two more assumptions — total project completion times follow a normal distribution and activity times are stochastically independent — answers can then be given to questions regarding the probability of finishing the project on time. For more detailed information on CPM and PERT, reference is made to Render et al. (2003) Chapter 7 and Hargitay and Yu (1993) Chapter 8.

The probabilistic approach of PERT constitutes an improvement compared to the deterministic CPM approach, but it brings along a fundamental shortcoming: it only provides information on activities on the Critical Path that was established using the expected mean times (m) of the activities the project is composed of. It may very well be, that the Critical Path for achieving, say, a 90% probability of completion before the end date of that path, is different from the one calculated with the estimated means of the activities.

3.3 Risk assessment in network planning through Monte Carlo simulation

As a solution for this problem, Lanza (2003) proposes a Monte Carlo approach. In essence, this involves the following steps:

1. Establish most optimistic/most likely/most pessimistic estimates for the duration of all project activities;
2. Calculate the Critical Path using the most-likely-estimates. So far the procedure is the same as in traditional PERT planning;
3. Establish one or more other paths through the network that may actually become critical paths as a result of high variability in the duration of activities in those paths;
4. Conduct a Monte Carlo simulation on each of these paths.

The resulting probability distributions for the project duration according to these paths provide answers to relevant questions related to the risk involved, such as:

1. Which project duration can be achieved with a 90% probability and what is the associated path of activities through the network?
2. What is the probability of meeting the deadline for completion of the project as required by the financing party and what is the associated path of activities through the network?

In both cases the critical path may be different from the Critical Path calculated with the most-likely-estimates. The Monte Carlo approach constitutes an improvement over the traditional CPM and PERT techniques because it provides additional information that is relevant to both the project manager and the financing stakeholder. The project manager's attention is drawn to activities that are not on the Critical Path but nevertheless may become critical and the financing stakeholder gets an estimate of the probability of financing problems due to a substantial delay in project completion.

The Monte Carlo approach proposed by Lanza leaves, however, one important question unanswered: Are the considered paths through the network really the most relevant ones?

When the network is extensive and complicated, a path of (statistically) critical activities could easily be overlooked. This difficulty can be avoided by applying Monte Carlo simulation in such a way that (statistically) critical paths are identified in a systematic way. This is achieved by conducting Monte Carlo simulation on the entire project instead of on one path of the network only.

3.4 The concept of path ranking

We define two different rankings of relevant paths through the network:

- Slack (or float) ranking;
- Risk ranking.

Slack ranking

Keeping in mind that other paths through the network than the Critical Path calculated with the most-likely-estimates may become critical when variability of activity durations is accounted for, we define the following paths:

1. Primary Path. This is the Critical Path calculated with the most-likely-estimates. The slack (or float) of the activities on this path is zero.
2. Secondary Path. This is the path with the least total slack compared to the Critical Path.
3. Tertiary Path. This is the path which has the least total slack after the Secondary Path.

This ranking will be referred to as *slack ranking*. The Secondary Path follows from the dual values (shadow prices) as described in Chapter 7 of *Open Design, a Collaborative Approach to Architecture*. By removing the slack from the Secondary Path, it becomes part of the Critical Path. The dual values then identify the Tertiary Path.

Risk ranking

If the slack in the secondary and tertiary paths is small and the variability of activity durations substantially more than in the primary path, the secondary and tertiary paths may become more relevant to project control than the primary path. In other words: if variability of activity durations is taken into account, a ranking of the various paths can be established reflecting the risk involved. We will call this the *risk ranking* of the various paths of the network. The risk ranking and the associated risks are found in the following way.

For all activities the project is composed of, three estimates are made for the duration of the activity concerned: a most pessimistic, a most likely (best guess) and a most optimistic estimate. The pessimistic and optimistic estimates are defined as having a 10% probability of being exceeded. Whenever an activity duration is estimated in this way, a skewed probability distribution, such as the beta distribution, is assumed through the three given estimates. The Monte Carlo simulation is then conducted by carrying out a critical path calculation, say, 2 000 times, using activity durations that are obtained from the skewed distributions (by drawing a random number which is corrected for the skewed distribution). The frequency distribution of the 2 000 calculations provides the probability distribution for the duration of the entire project. A counter keeps track of how many times (out of the 2 000) a given path through the network was the critical path. This provides the risk ranking of the paths and the associated risks, that is, the likelihood that they will be the critical path in reality.

As will be shown in Chapter 11, the path ranking on slack can be very different from the path ranking on risk (frequency of being the critical path in the Monte Carlo simulation).

The risk ranking of the paths, with their associated risks, is important to the project manager as it indicates how much attention should be paid to monitoring activities on the various paths. The probability distribution for the completion of the entire project is, of course, of great interest to the financial stakeholder.

3.5 Numerical examples

Two numerical examples serve to illustrate the methodology and associated software:

1. The example from Lanza's paper (slightly adapted);
2. An actual case from the construction industry.

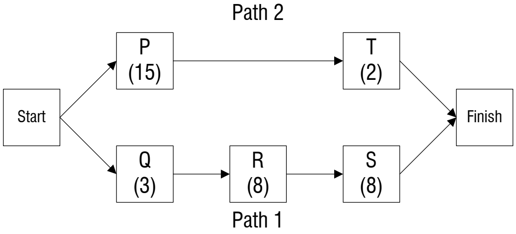


Figure 3.9 Network planning of Lanza example

Table 3.1 Input for the Monte Carlo simulation

Task	Minimum Duration	Optimistic Margin	Expected Margin	Pessimistic Margin	Path 1	Path 2
P	12	0	1	13		13
Q	2	0	1	2	3	
R	4	1	4	5	8	
S	5	1	3	5	8	
T	1	0	1	11		2
Total					19	15

Example from Lanza's paper

Figure 3.9 shows the network Lanza used in his paper.

In this network there are two paths, Path 1 (St-Q-R-S-Fi) and Path 2 (St-P-T-Fi). Table 3.1 shows the minimum duration required anyway for each activity and three margin estimates:

- A most likely estimate (best guess) for the required margin on top of the minimum duration;
- A most pessimistic estimate for that margin, defined as having a 10% probability of being exceeded;
- A most optimistic estimate for that margin, defined also as having a 10% probability of being achieved.

Calculating with the minimum durations and most likely required margins (best guesses), Path 1 turns out to be the Critical Path (Primary Path). Activities on this path would get the most attention from the project manager. Activities on Path 2 (Secondary Path) would get less attention because, based upon this calculation, this path has 2 weeks more slack than the Critical Path.

Figure 3.10 Output of Monte Carlo simulation (Lanza example): probability distribution of total project duration for Path 1

The results of a Monte Carlo simulation carried out for Path 1 and Path 2 separately, according to the approach from Lanza, are given in Figure 3.10 and Figure 3.11 respectively.

If only Path 1 (Primary Path) is considered, the financial stakeholder, who requires an 80% probability of meeting the completion deadline, would be advised to base the financing on a project duration of 20.4 weeks. If Path 2 (Secondary Path) is also considered, the financing should be based on a duration of 22.0 weeks.

A Monte Carlo simulation with our new methodology results in a probability distribution of the total project duration as presented in Figure 3.12.

The graph shows the distribution of the project durations derived from all Monte Carlo runs. The column in the left side of the graph shows the probability of completing the project in the associated completion time. In this example, an 80% probability is associated with a completion time of 22.3 weeks. In this simple case the difference with the aforementioned Path 2 of Lanz's example is, admittedly, small. In more complicated cases, however, the difference can be significant, in particular when a relevant secondary or tertiary path remains unidentified.

The output also gives the frequencies of occurrence of the Primary and Secondary Paths in the Monte Carlo simulation. As can be seen from the 'Percentage' row under 'Simulation Paths', Path 1 (St-Q-R-S-Fi) was critical in 55% of all runs whereas Path 2 (St-P-T-Fi) was critical 45% of all runs. The latter means that the Secondary Path 2, although still second in the risk ranking, has a probability as high as 45% of being critical in reality. This constitutes important information for the project manager, who gets a warning to pay appropriate attention to monitoring the activities on Path 2.

Figure 3.11 Output of Monte Carlo simulation (Lanza example): probability distribution of total project duration for Path 2

Table 3.2 Input for the Monte Carlo simulation

Task	Minimum Duration	Optimistic Margin	Expected Margin	Pessimistic Margin	Path A	Path B	Path C
A	2	0	1	2	3	3	3
B	15	0	1	4	16	16	16
C	25	0	2	5	27	27	27
D	30	0	4	10	34		
E	22	0	2	4		24	
F	34	0	3	7			37
G	12	0	1	2	13	13	13
H	3	0	1	4	4	4	4
Total					97	87	100

From the probability distribution for the completion of the entire project Figure 3.12 the financial stakeholder can see that the project has a probability of 80% of being completed within 22.3 weeks, which means that the financing should be based on a 22.3 week project duration, and not on 20.4 weeks as follows from the traditional PERTcalculation.

Example from the construction industry

Our second example is a simplified actual case from the construction industry. Figure 3.13 presents the Gantt chart of the project planning.

Table 3.2 shows the minimum duration required anyway for each activity and three estimates for the required margin.

The network planning of the activities is given in Figure 3.14.

Figure 3.12 Output of Monte Carlo simulation (Lanza example): probability distribution of total project duration and frequencies of occurrence in the simulation of primary and secondary paths

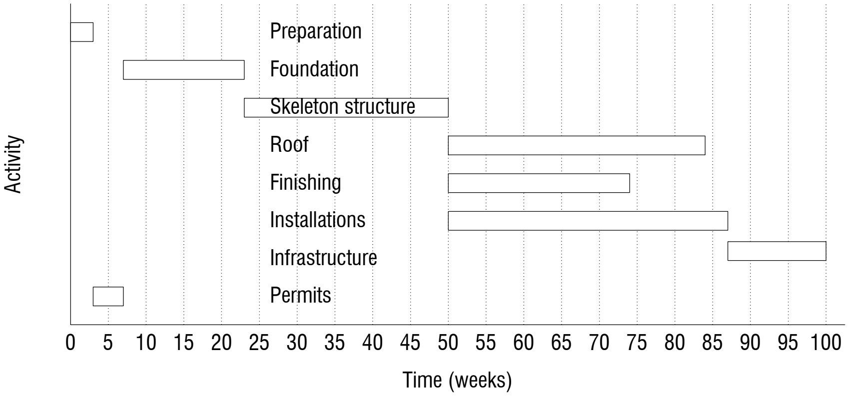
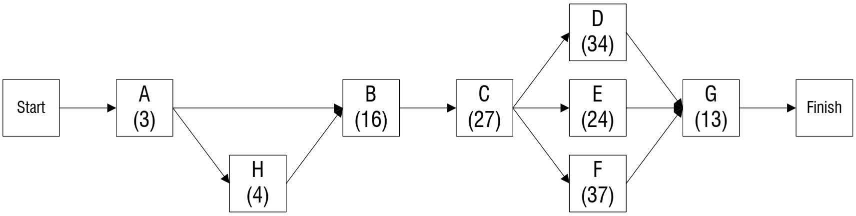


Figure 3.13 GANTT chart of construction industry example



Arrows show precedence relationships

Figure 3.14 Network planning of construction industry example

Figure 3.15 Output of Monte Carlo simulation (construction industry example)

The output of the Monte Carlo simulation according to our new methodology is given in Figure 3.15.

The frequency of the Secondary Path being critical in the Monte Carlo simulation is significant: 29%. This means that, in the later stages of the project, the project manager should not only pay attention to activity F (installations) on the Primary (Critical) Path, but also to activity D (roof) on the Secondary Path. If the financial stakeholder requires an 80% probability of completion on time, the project financing should be based on a 106.5 week project duration.

3.6 Allowance for mitigations in probabilistic network planning

Probabilistic network planning, as described in Section 3.2 and Section 3.3, can be regarded as current state-of-the-art. The use of Monte Carlo simulation and the concept of risk ranking of various paths of the network provides useful information to the project manager as well as to the financing parties of the project, but further refinement is needed.

Testing the usefulness of the methodology for a $ 4.3 billion project revealed the following:

1. The probability of completion on time according to the Monte Carlo simulation of the entire project is extremely low, in the order of a few percent.

2. This does not reflect reality, because the implicit assumption that no corrective measures – mitigations – are carried out is not realistic. In practice, a lot of measures are taken during execution, sometimes at considerable cost, to remove blocks to progress.

The following mathematical model describes how such mitigations can be allowed for in the (probabilistic) network planning.

Mathematical model

For each of the n activities A_i $(i = 1, 2, \ldots n)$ three estimates for the duration t_i are made:

1. Pessimistic estimate (probability of 0.1 that reality will be worse);
2. Best guess;
3. Optimistic estimate (probability of 0.1 that reality will be better).

Running the network planning three times will, in general, yield:

1. Run with pessimistic estimates: completion too late;
2. Run with optimistic estimates: completion on time;
3. Run with best guesses: low probability of completion on time, say $p = 0.03$.

The latter is unacceptable, so measures have to be taken to increase the probability of completion on time. Extra resources have to be mobilised, in particular trustworthy project managers (from the main contractor, the subcontractors or other sources). These are limited in number.

Let us assume that $m \leq m_0$ measures can be taken. Each measure results in reducing activity times by Δt_i at cost C_i, $i = 1, 2, \ldots m$.

In each Monte Carlo run, a Linear Programming optimisation is conducted:

$$\text{Minimise} \quad \sum_{i=1}^{l} C_i \tag{3.10}$$

subject to:

$$t_e \leq t_0 \quad (t_e = \text{throughput time}; t_0 = \text{target completion time}) \tag{3.11}$$

$$l \leq m \tag{3.12}$$

with relaxed activity durations: $t_i = t_i - \Delta t_i, i = 1, 2, \ldots l$.

If no solution can be found, the constraint t_e of the completion duration has to be relaxed. This can be done in steps until a solution becomes feasible.

A counter keeps track of how often an activity duration is relaxed by corrective measures (Figure 3.16).

We then assume that, say, the most frequent four are indeed carried out.

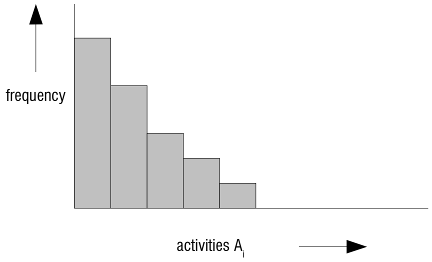


Figure 3.16 Output graph showing which activities needed corrective measures most frequently

Table 3.3 Mitigations $C_i, \Delta t_i$ and required skills S

		S_1	S_2	S_3	S_4
C_1	Δt_1	x			
C_2	Δt_2		x	x	
C_3	Δt_3	x	x		x

With these activities reduced durations, a new Monte Carlo simulation is conducted. If the probability of completion turns out to increase to, say, over $p = 0.5$ the measures can be considered to be sufficient.

This procedure can be repeated at later stages of the project to assess what mitigations are then desirable.

In this way the probability of timely completion can be kept at an acceptable level during the whole execution of the project or, when this becomes infeasible, the target completion time can be relaxed at an early stage.

3.7 Allowing for limited human resources

Each mitigation $C_i, \Delta t_i$ will require human resources R having one or more skills S (Table 3.3).

With this input, the Monte Carlo simulation of the preceding section not only can provide the set of mitigations $C_i, \Delta t_i$ required to meet the deadline t_0 for completion at an acceptable probability p but also the associated set of skills S required for implementation.

The distribution of skills S over a pool of persons R can be specified in an input table (Table 3.4).

Table 3.4 Distribution of skills S over pool of human resources R

	S_1	S_2	S_3	S_4
R_1		x		
R_2			x	
R_3	x			x

With this input, the minimum required project team can be obtained from:

$$\text{Minimise} \quad \sum_{k=1}^{K} R_k \tag{3.13}$$

subject to the restriction:

$$a \leq a_0 \tag{3.14}$$

where:

a = the number of allocations per person,
a_0 = the maximum number of allocations per person,

Which means that we minimise the size of the project team with the constraint that one person can be assigned to maximum a_0 mitigations. This maximum a_0 should never exceed four because it has been established (Peltz and Andrews, 1976) that even a very competent person cannot handle more than four tasks simultaneously.

The rationale for choosing the objective function 3.13 is that the smaller the project team is, the better it is. Each project team member brings along costs – and opportunity costs – related to mobilisation and demobilisation and time to get familiar with the project. Multi-skill persons, therefore, should be preferred above single-skill specialists, which is achieved by the objective function 3.13.

The output of this LP-run provides the composition of the project team needed to carry out the mitigations (output of the first LP-run).

Let us assume that one or more persons R of this project team cannot be made available. The first step then is to remove those $C_i, \Delta t_i$ mitigations which require skills S that are no longer available in the Table 3.4.

With these corrected inputs the Monte Carlo simulation is repeated which reflects the situation of reduced human resources.

When too much persons are removed from Table 3.4, no solution will be found, indicating that either the deadline t_0 for completion has to be relaxed or more human resources have to be provided.

3.8 Conclusions

1. The traditional network techniques CPM and PERT can be significantly improved by the use of Monte Carlo simulation.
2. Monte Carlo simulation of the entire project should be preferred above Monte Carlo simulation related to just one path – established a priori – through the network of activities.
3. It is useful to pay attention to Secondary and Tertiary Paths which have the least total slack compared to the Primary Path (which has zero slack), in view of the variability in activity durations.
4. The frequency of occurrence of other paths than the Primary Path in the Monte Carlo simulation, reflecting the risk involved, is relevant for the project manager's decision as to how much attention has to be paid to activities on those paths.
5. The outcome of the Monte Carlo simulation of the entire project – the probability distribution of the project duration – constitutes important information for the financing party who has to estimate the risk of financing problems due to late completion of the project.
6. If the probability of completion on time is very low, a limited number of mitigations to reduce the duration of critical activities can be accounted for. This enables to keep the probability of timely completion at an acceptable level during all project stages.
7. Allowing for limited human resources in the project team can reveal at an early stage if the deadline for completion has te be relaxed or, alternatively, more human resources have to be made available.

4 Regression analysis of construction projects from the past

The purpose of regression analysis, or curve fitting, is prediction. Regression analysis is aimed at the development of a statistical model that can predict the values of a dependent variable based on the values of at least one independent variable. It plays an important role in the construction industry. Estimates of cost prices, in particular, are often based on rules of thumb derived from historic cost prices, that is a regression analysis of past projects. In this chapter we limit ourselves to the particular use of regression analysis in the domain of architecture and construction, referring to standard textbooks for the mathematical foundation (for instance Berenson and Levine (1996), Aczel (2002), Vose (2000)).

4.1 Linear, single variable, regression analysis

Consider a firm of architects that has data on 30 types of houses from a project. The database has data on the cost price and on both the gross and usable floorspace per house. Table 4.1 shows the content of the database. For instance, type 3A has a cost price of € 98,352 and has a gross floorspace of 163 m2 and a usable floorspace of 122.2 m2.

The firm wishes to develop a formula to predict the cost price of a (similar) house based on either the gross or usable floorspace.

Figure 4.1 shows a graph with the cost price on the X-axis, the gross floorspace on the Y-axis and all data points that can be derived from Table 4.1. It can be seen that there is a relation between the cost price and the gross floorspace. A line can be drawn by hand through all of these points as shown in Figure 4.2.

This line through the cloud of points, is represented by the equation:

$$y = \beta_0 + \beta_1 x + \epsilon \qquad (4.1)$$

Where:

x = independent variable
y = dependent variable
ϵ = error term
β_0 = intercept of line $y = \beta_0 + \beta_1 x$
β_1 = slope of line $y = \beta_0 + \beta_1 x$

Table 4.1 Cost price vs. floorspace

Type	Cost price [€]	Gross floorspace [m²]	Usable floorspace [m²]
3A	98,352	163	122.20
3AK	117,887	163	122.20
3B	121,408	173	122.20
3C	106,772	163	128.10
8A	95,422	142	111.40
8B	108,140	168	132.70
8C	107,689	161	125.30
5B	104,175	178	133.70
5C	121,962	188	133.70
5E	112,513	178	139.20
6A	100,905	158	122.70
6B	114,288	194	151.90
6C	122,941	167	122.90
6D	131,675	172	126.40
7A	95,360	147	121.10
7AK	112,445	147	121.10
7B	117,433	195	148.20
7BK	134,518	195	148.20
7E	114,288	194	151.90
7F	113,625	147	121.10
1A	139,567	169	153.00
1AK	177,639	169	153.00
1AK2	184,950	204	184.60
4A	136,986	210	171.70
4B	191,438	215	192.80
4C	192,753	235	203.00
4D	167,405	215	182.40
5A	118,838	194	161.70
5AK	140,294	194	161.70
5D	147,366	203	166.80

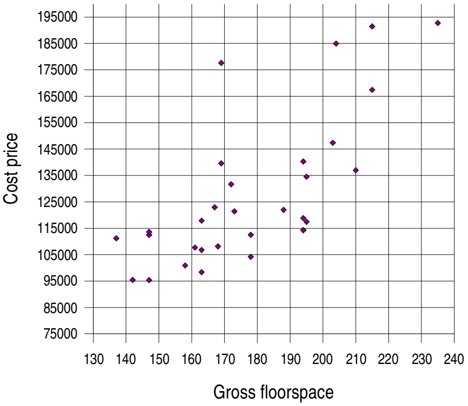


Figure 4.1 Graph showing all data points

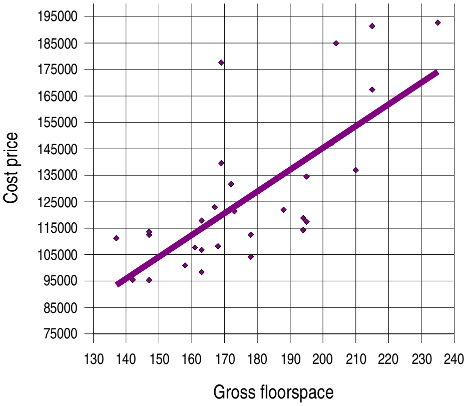


Figure 4.2 Graph showing a line that fits the data points

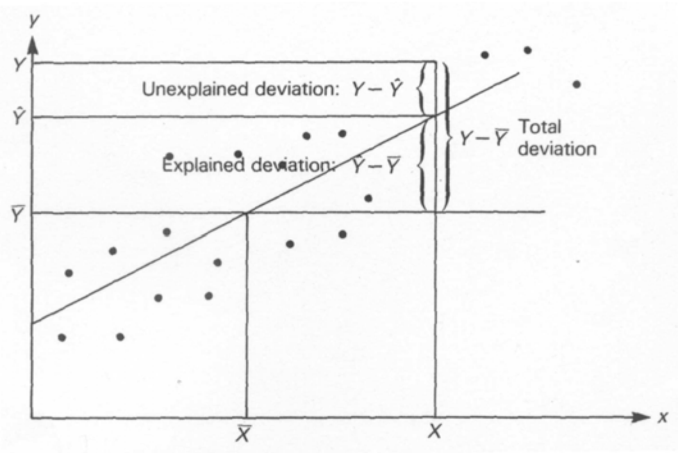


Figure 4.3 The three deviations associated with a data point (Source: Aczel (2002))

This is a theoretical relationship which we presume to exist. The error term is by chance, so every point in the cloud of points contains some error. However, we can make an estimate of the theoretical relationship by means of statistical estimation techniques. We construct a straight line that fits the cloud of points best (the vertical squared distances from the different points to the line are minimal – the method of least squares). In this way we can find the best estimates for the unknown beta's with the associated statistical properties, such as standard errors.

In practice, this equation can be calculated from the data set by a computer or a hand calculator with a built in routine for linear regression.

Once we have established that a linear relationship exists between the two variables, the question arises: How strong is the relationship? In other words: To what extent are deviations from the mean explained by the regression?

For any data point (x, y) we can distinguish three deviations from the mean $\bar{y}$. See Figure 4.3:

$$(y - \bar{y}) = (y - \hat{y}) + (\hat{y} - \bar{y}) \tag{4.2}$$

In words: The total deviation equals the unexplained deviation (error) plus the explained deviation (regression).

Squaring and summing over all n points (cross terms drop out) yields:

$$\sum_{i=1}^{n}(y_i - \bar{y})^2 = \sum_{i=1}^{n}(y_i - \hat{y})^2 + \sum_{i=1}^{n}(\hat{y}_i - \bar{y})^2 \tag{4.3}$$

$$TSS = SSE + SSR \tag{4.4}$$

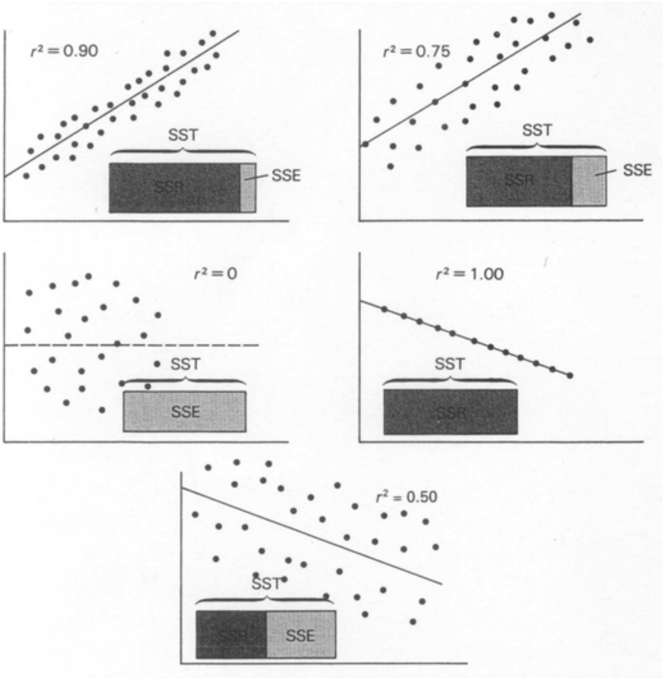


Figure 4.4 Coefficients of determination in different regressions (Source: Aczel (2002))

Total sum of squares = Sum of squares for error + Sum of squares for regression.

In words: The total variation (TSS) equals the unexplained variation (SSE) plus the explained variation (SSR).

The ratio explained variation divided by total variation is called the coefficient of determination:

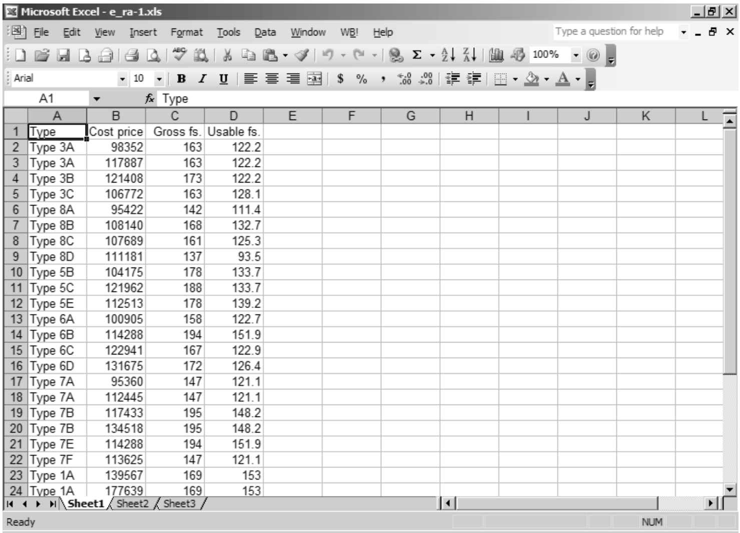
$$r^2 = \frac{SSR}{TSS} = 1 - \frac{SSE}{TSS} \tag{4.5}$$

r = correlation coefficient; $-1 \leq r \leq 1$, so $0 \leq r^2 \leq 1$.

Between the two extremes, $r^2 = 0$ (no fit at all) and $r^2 = 1$ (perfect fit), values of r^2 give an indication of the relative fit of the regression model to the data. The higher r^2, the better the fit and the higher our confidence in the regression (Fig. 4.4).

To carry out the regression analysis we first add the data to an empty Excel-sheet as shown in Figure 4.5.

Because there are two candidate independent variables (gross and usable floorspace) we first carry out a correlation analysis to find out which of these



	A	B	C	D
1	Type	Cost price	Gross fs.	Usable fs.
2	Type 3A	98352	163	122.2
3	Type 3A	117887	163	122.2
4	Type 3B	121408	173	122.2
5	Type 3C	106772	163	128.1
6	Type 8A	95422	142	111.4
7	Type 8B	108140	168	132.7
8	Type 8C	107689	161	125.3
9	Type 8D	111181	137	93.5
10	Type 5B	104175	178	133.7
11	Type 5C	121962	188	133.7
12	Type 5E	112513	178	139.2
13	Type 6A	100905	158	122.7
14	Type 6B	114288	194	151.9
15	Type 6C	122941	167	122.9
16	Type 6D	131675	172	126.4
17	Type 7A	95360	147	121.1
18	Type 7A	112445	147	121.1
19	Type 7B	117433	195	148.2
20	Type 7B	134518	195	148.2
21	Type 7E	114288	194	151.9
22	Type 7F	113625	147	121.1
23	Type 1A	139567	169	153
24	Type 1A	177639	169	153

Figure 4.5 Data from database in spreadsheet

fits the data best. In cell C33 we type:

=correl(B2:B32,C2:C32)

In cell D33 we type:

=correl(B2:B32,D2:D32)

This shows that the usable floorspace has a larger correlation coefficient ($r = 0.83$) than the gross floorspace ($r = 0.71$). This suggests we should carry out the regression analysis using the usable floorspace rather than the gross floorspace as the independent variable. The larger correlation coefficient means that the points fit the line through the cloud of points more closely. Figure 4.6 shows a graph with the cost price on the X-axis, the usable floorspace on the Y-axis and all data points that can be derived from Table 4.1.

Comparison of Figure 4.6 with Figure 4.2 shows that the points related to the usable floorspace indeed fit the line more closely than the points related to the gross floorspace.

To carry out a regression analysis the data analysis toolpak must be installed. To check whether this is the case, select the menu-item ‘Tools/Add-Ins’ and make sure that the list item ‘Analysis Toolpak’ is checked as shown in Figure 4.7.

If the toolpak is installed select the menu-item ‘Tools/Data analysis’ and then select ‘Regression’ from the list as shown in Figure 4.8.

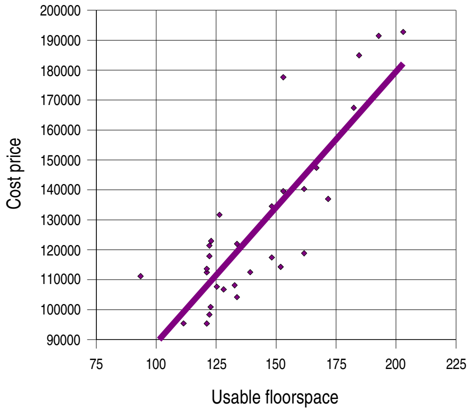
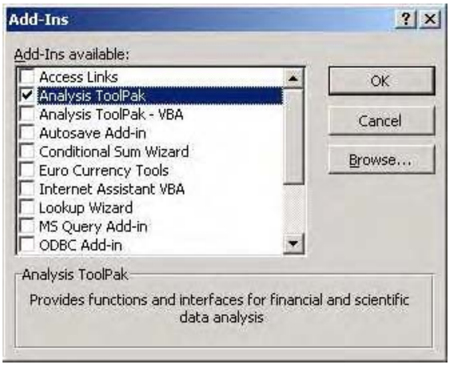


Figure 4.6 Graph showing a line that fits the data points



☐ Access Links
☑ Analysis ToolPak
☐ Analysis ToolPak - VBA
☐ Autosave Add-in
☐ Conditional Sum Wizard
☐ Euro Currency Tools
☐ Internet Assistant VBA
☐ Lookup Wizard
☐ MS Query Add-in
☐ ODBC Add-in

Analysis ToolPak

Provides functions and interfaces for financial and scientific data analysis

Figure 4.7 Add-Ins dialog

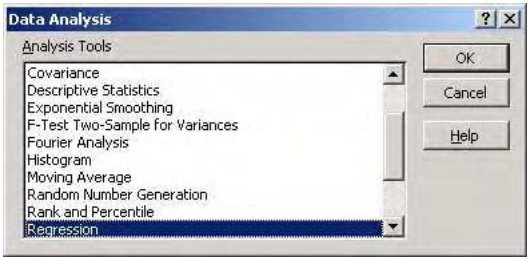
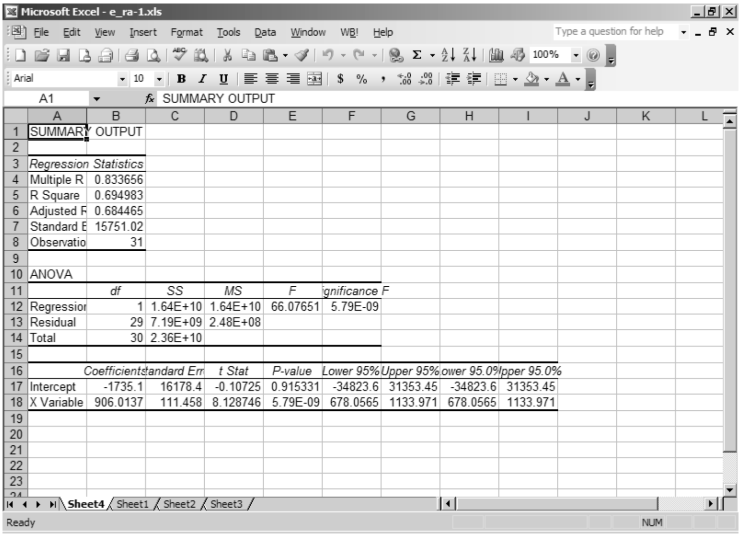


Figure 4.8 Regression option



	A	B	C	D	E	F	G	H	I
1	SUMMARY OUTPUT								
2									
3	*Regression Statistics*								
4	Multiple R	0.833656							
5	R Square	0.694983							
6	Adjusted F	0.684465							
7	Standard E	15751.02							
8	Observatio	31							
9									
10	ANOVA								
11		*df*	*SS*	*MS*	*F*	*ignificance F*			
12	Regressior	1	1.64E+10	1.64E+10	66.07651	5.79E-09			
13	Residual	29	7.19E+09	2.48E+08					
14	Total	30	2.36E+10						
15									
16		*Coefficients*	*tandard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
17	Intercept	-1735.1	16178.4	-0.10725	0.915331	-34823.6	31353.45	-34823.6	31353.45
18	X Variable	906.0137	111.458	8.128746	5.79E-09	678.0565	1133.971	678.0565	1133.971

Figure 4.9 Single regression analysis output in spreadsheet

This opens up a new window where you have to select the 'Input Y range' and the 'Input X range'. The 'Input Y range' is the range of cells containing the cost prices, in this case cells B2 through B32. The 'Input X range' is the range of cells containing the usable floorspace, in this case cells D2 through D32.

After adding these ranges, press the 'OK' button to carry out the analysis. This output shows the results on a new worksheet as shown in Figure 4.9

The equation to predict the deviation can be derived from the 'Intercept' (cell B17) and the 'X Variable' (cell B18). The equation is:

$$y = -1735.1 + 906.0137x \tag{4.6}$$

where:

y = cost price
x = usable floorspace

With this formula any estimate of the cost price can be made. Figure 4.10 shows a graph with both the actual and estimated cost price per type of house.

The question arises: How 'good' is the resulting equation? Let us first look at plausibility. According to the equation an increase of one square metre floor space results in an increase of the cost price of €906,- (units) which seems reasonable. The output shows that $R^2 = 0.69$ (cell B5) so a fair amount of the variance in cost price is explained by the floorspace. We would expect

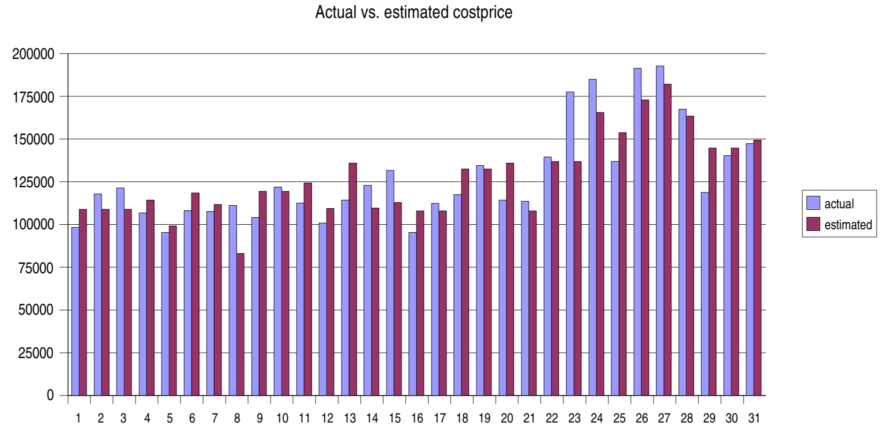


Figure 4.10 Actual cost prices (left columns) compared to estimated cost prices (right columns)

however, that almost all variance in cost price could be explained. So a higher R^2 could be obtainable. To this end we should incorporate more variables in the analysis. Statistical significance is in order as far as the X-variable is concerned, since the p-value is small and the |t-statistic|, being in the order of 8, exceeds the critical threshold.

Examining the data more closely, one can see that type 3A and 3AK houses have identical values where the usable floorspace is concerned but the cost prices differ. It can be noticed that this is true for all other types with a 'K' in them. This is a clear indication that the usable floorspace is probably just one of more independent variables that explain the cost price. The K-types turn out to be the types that are situated at the end of the blocks of houses. For that reason their surface area is larger, hence their facade is larger. This accounts for the fact that they have the same floorspace but higher costs as the facade is more costly than dividing walls. To allow for this, we have two options:

- Remove these types of houses from the input data set;
- Perform a multiple variable regression analysis (also taking the surface area of the facade into account).

The first option will result in an equation that will better fit the data points. Carry this analysis out for yourself and see how the value of R^2 will increase. It comes at a price, however, because your prediction does not apply to houses situated at the end of a block.

A multiple variable regression analysis, also based on this example, is carried out in the next section.

4.2 Multiple variable regression analysis

In multiple variable regression analysis, the dependent variable y depends on various independent variables $x_1, x_2 \ldots x_k$:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k + \epsilon \tag{4.7}$$

where:

x_k = k-th independent variable
y = dependent variable
ϵ = error term or residual
β_k = regression slope for variable x
β_0 = y-axis intercept

Least squares multiple variable regression analysis is similar to the single variable case outlined in Section 4.1.

The estimated regression equation is:

$$y = b_0 + b_1 x_{1,j} + b_2 x_{2,j} + \ldots + b_k x_{k,j} + e \tag{4.8}$$

This equation can also be calculated from the data set by a computer.

The firm of architects from the single variable regression analysis example wants a regression model that better fits the data. To this end more properties of the houses are added to the database. The database now has data on the following properties of each house:

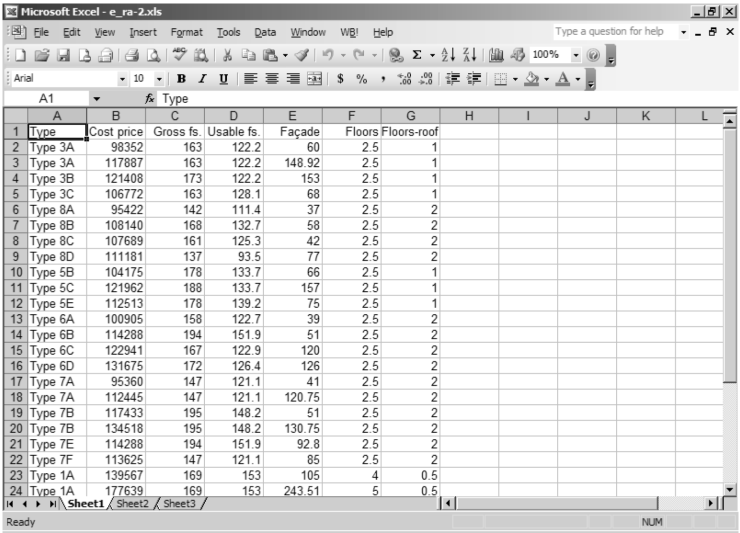
- Cost price;
- Gross floorspace;
- Usable floorspace;
- Surface area of the façade;
- Number of floors;
- Number of floors the roof spans.

Table 4.2 shows the content of the database.

As shown in the single regression example the usable floorspace has a larger correlation coefficient than the gross floorspace. Still, the question arises whether both should be taken into account when performing the multiple regression analysis. This should be done if both variables do not correlate to each other. Both describe more or less the same property of a house, so caution is warranted to prevent multi-collinearity. We therefore carry out a test

Table 4.2 Cost price vs. house properties

Type	Cost price [€]	Gross floorspace [m^2]	Usable floorspace [m^2]	Surface area façade [m^2]	Number of floors	Number of floors roof spans
3A	98,352	163	122.20	60.00	2.50	1.00
3AK	117,887	163	122.20	149.00	2.50	1.00
3B	121,408	173	122.20	153.00	2.50	1.00
3C	106,772	163	128.10	68.00	2.50	1.00
8A	95,422	142	111.40	37.00	2.50	2.00
8B	108,140	168	132.70	58.00	2.50	2.00
8C	107,689	161	125.30	42.00	2.50	2.00
8D	111,181	137	93.50	77.00	2.50	2.00
5B	104,175	178	133.70	66.00	2.50	1.00
5C	121,962	188	133.70	157.00	2.50	1.00
5E	112,513	178	139.20	75.00	2.50	1.00
6A	100,905	158	122.70	39.00	2.50	2.00
6B	114,288	194	151.90	51.00	2.50	2.00
6C	122,941	167	122.90	120.00	2.50	2.00
6D	131,675	172	126.40	126.00	2.50	2.00
7A	95,360	147	121.10	41.00	2.50	2.00
7AK	112,445	147	121.10	121.00	2.50	2.00
7B	117,433	195	148.20	51.00	2.50	2.00
7BK	134,518	195	148.20	131.00	2.50	2.00
7E	114,288	194	151.90	93.00	2.50	2.00
7F	113,625	147	121.10	85.00	2.50	2.00
1A	139,567	169	153.00	105.00	4.00	0.50
1AK	177,639	169	153.00	244.00	5.00	0.50
1AK2	184,950	204	184.60	125.00	5.00	0.50
4A	136,986	210	171.70	80.00	3.50	2.00
4B	191,438	215	192.80	228.00	3.50	2.00
4C	192,753	235	203.00	183.00	3.50	2.50
4D	167,405	215	182.40	121.00	3.50	2.00
5A	118,838	194	161.70	74.00	2.50	1.00
5AK	140,294	194	161.70	179.00	2.50	1.00
5D	147,366	203	166.80	200.00	2.50	1.00



	A	B	C	D	E	F	G
1	Type	Cost price	Gross fs.	Usable fs.	Façade	Floors	Floors-roof
2	Type 3A	98352	163	122.2	60	2.5	1
3	Type 3A	117887	163	122.2	148.92	2.5	1
4	Type 3B	121408	173	122.2	153	2.5	1
5	Type 3C	106772	163	128.1	68	2.5	1
6	Type 8A	95422	142	111.4	37	2.5	2
7	Type 8B	108140	168	132.7	58	2.5	2
8	Type 8C	107689	161	125.3	42	2.5	2
9	Type 8D	111181	137	93.5	77	2.5	2
10	Type 5B	104175	178	133.7	66	2.5	1
11	Type 5C	121962	188	133.7	157	2.5	1
12	Type 5E	112513	178	139.2	75	2.5	1
13	Type 6A	100905	158	122.7	39	2.5	2
14	Type 6B	114288	194	151.9	51	2.5	2
15	Type 6C	122941	167	122.9	120	2.5	2
16	Type 6D	131675	172	126.4	126	2.5	2
17	Type 7A	95360	147	121.1	41	2.5	2
18	Type 7A	112445	147	121.1	120.75	2.5	2
19	Type 7B	117433	195	148.2	51	2.5	2
20	Type 7B	134518	195	148.2	130.75	2.5	2
21	Type 7E	114288	194	151.9	92.8	2.5	2
22	Type 7F	113625	147	121.1	85	2.5	2
23	Type 1A	139567	169	153	105	4	0.5
24	Type 1A	177639	169	153	243.51	5	0.5

Figure 4.11 Data from database in spreadsheet

to see whether these properties correlate to each other. If they do, only one should be taken into account.

To carry out this test, in cell D33 we type:

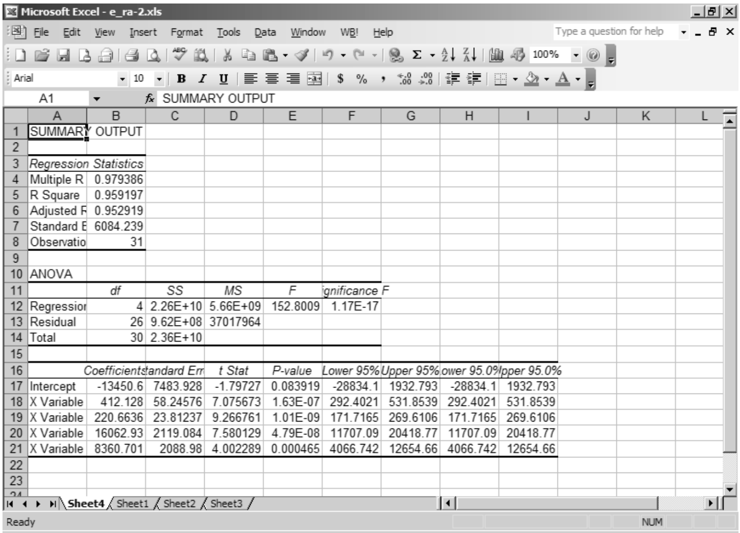
```
=correl(C2:C32,D2:D32)
```

This shows the correlation coefficient ($r = 0.93$) from which you can conclude that they indeed correlate. This means we should not take both into account but only the one that best correlates to the cost price. From the previous example we know that the usable floorspace correlates best to the cost price.

To carry out the regression analysis we first add the data to an empty Excel-sheet as shown in Figure 4.11.

Select the menu item 'Tools/Data analysis' and then select 'Regression' from the list. This opens up a new window where you have to select the 'Input Y range' and the 'Input X range'. The 'Input Y range' is the range of cells containing the cost prices, in this case cells B2 through B32. The 'Input X range' is the range of cells containing the data on the different properties, in this case cells D2 through G32. After adding these ranges press the 'OK' button to carry out the analysis. This will output the results on a new worksheet as shown in Figure 4.12.

This output shows that the model now fits the data much better because the value of 'R Adjusted' (cell B6) equals 0.95.



	A	B	C	D	E	F	G	H	I
1	SUMMARY OUTPUT								
2									
3	*Regression Statistics*								
4	Multiple R	0.979386							
5	R Square	0.959197							
6	Adjusted R	0.952919							
7	Standard E	6084.239							
8	Observatio	31							
9									
10	ANOVA								
11		*df*	*SS*	*MS*	*F*	*ignificance F*			
12	Regressior	4	2.26E+10	5.66E+09	152.8009	1.17E-17			
13	Residual	26	9.62E+08	37017964					
14	Total	30	2.36E+10						
15									
16		*Coefficients*	*tandard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*lpper 95.0%*
17	Intercept	-13450.6	7483.928	-1.79727	0.083919	-28834.1	1932.793	-28834.1	1932.793
18	X Variable	412.128	58.24576	7.075673	1.63E-07	292.4021	531.8539	292.4021	531.8539
19	X Variable	220.6636	23.81237	9.266761	1.01E-09	171.7165	269.6106	171.7165	269.6106
20	X Variable	16062.93	2119.084	7.580129	4.79E-08	11707.09	20418.77	11707.09	20418.77
21	X Variable	8360.701	2088.98	4.002289	0.000465	4066.742	12654.66	4066.742	12654.66

Figure 4.12 Multiple regression analysis output in spreadsheet

The equation to predict the deviation can be derived from the 'Intercept' (cell B17) and the 'X Variable' (cell B18 and B19). The equation is:

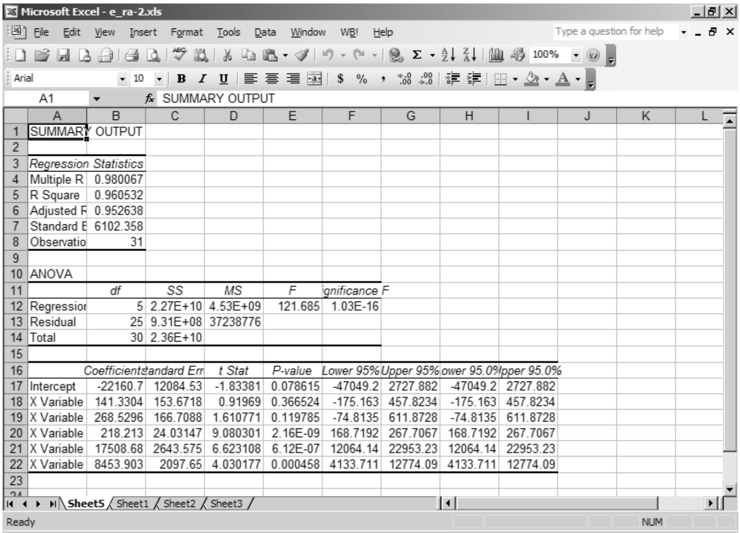
$$y = -13450.6 + 412.128x_1 + 220.6636x_2 + 16062.93x_3 + 8360.701x_4 \quad (4.9)$$

where:

y = cost price
x_1 = usable floorspace
x_2 = surface area façade
x_3 = number of floors
x_4 = number of floors the roof covers

If you examine the different factors of the equation, you will notice that the first two factors regarding the usable floorspace and surface area of the façade have a substantially lower magnitude in comparison to the last two factors regarding the number of floors and the number of floors the roof covers. This is quite plausible because it is likely that an increase of the number of floors or the number of floors the roof spans with one floor has a substantially bigger effect on the cost price than an increase of the amount of usable floorspace or an increase of the surface area of the façade with one metre.

The better fit of the model (higher 'R Adjusted') is due to the fact that more properties affecting the cost price have been taken into account. The fact that



	A	B	C	D	E	F	G	H	I
1	SUMMARY	OUTPUT							
2									
3	*Regression*	*Statistics*							
4	Multiple R	0.980067							
5	R Square	0.960532							
6	Adjusted F	0.952638							
7	Standard E	6102.358							
8	Observatio	31							
9									
10	ANOVA								
11		*df*	*SS*	*MS*	*F*	*ignificance F*			
12	Regressior	5	2.27E+10	4.53E+09	121.685	1.03E-16			
13	Residual	25	9.31E+08	37238776					
14	Total	30	2.36E+10						
15									
16		*Coefficients*	*tandard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
17	Intercept	-22160.7	12084.53	-1.83381	0.078615	-47049.2	2727.882	-47049.2	2727.882
18	X Variable	141.3304	153.6718	0.91969	0.366524	-175.163	457.8234	-175.163	457.8234
19	X Variable	268.5296	166.7088	1.610771	0.119785	-74.8135	611.8728	-74.8135	611.8728
20	X Variable	218.213	24.03147	9.080301	2.16E-09	168.7192	267.7067	168.7192	267.7067
21	X Variable	17508.68	2643.575	6.623108	6.12E-07	12064.14	22953.23	12064.14	22953.23
22	X Variable	8453.903	2097.65	4.030177	0.000458	4133.711	12774.09	4133.711	12774.09
23									

Figure 4.13 Multiple regression analysis output in spreadsheet

types 3A and 3AK have the same gross and usable floorspace, but differ in cost price is explained by the difference in surface area of the façade. The difference is due to the fact that these houses are placed at the end of a block of houses and therefore its façade surface area is larger. The number of floors, and the number of floors the roof covers further adds to the precision of the model.

Finally, to illustrate the effect of multi-collinearity, we carry out the regression analysis including the gross floorspace. Remember that we established a correlation between the usable and gross floorspace. The results of this analysis are shown in Figure 4.13.

This output shows that adding the extra variable 'gross floorspace' does not yield a better fit of the model because the value of 'R Adjusted' (cell B6) being 0.95 equals the value found in the previous analysis. Even worse, the output shows that statistical significance has decreased because the p-value, which was nearing zero in the previous analysis, now has risen to 0.37 and 0.12 respectively. The drop in statistical significance is due to the fact that the variables 'gross floorspace' and 'usable floorspace' are measures for more or less the same property. This results in the model 'having difficulty' distinguishing between the effects of both variables on the cost price of the house. The model therefore yields a lower significance. This phenomenon is called multi-collinearity and is the reason why we used only one of both variables in the regression analysis.

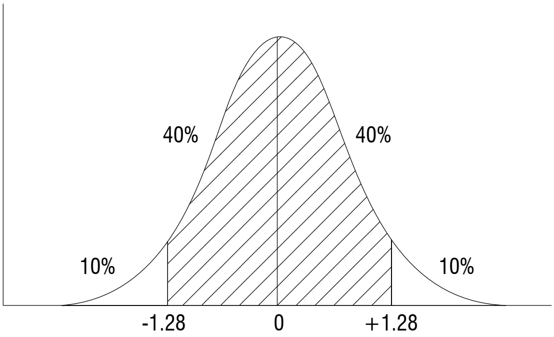


Figure 4.14 Optimistic, pessimistic estimates for Monte Carlo simulation related to standard deviation from regression analysis

4.3 Regression analysis as input for Monte Carlo simulation

The input required for Monte Carlo simulation, as described in Chapter 2, consists, for each expected value of a variable, of three estimates:

1. Pessimistic estimate, defined as having a probability of 0.10 that the reality will be worse than that;
2. Best guess;
3. Optimistic estimate, defined as having a probability of 0.10 that the reality is better than that.

The estimates can be provided by experts, but also by a regression analysis of data related to the past. The processing of the experts experiences to arrive at their estimates can be seen as an informal regression analysis taking place in their brains.

If formal regression analysis is used, as input for Monte Carlo simulation, then:

1. The best guess = $x, \hat{y}$ (value on the regression line);
2. Pessimistic or optimistic estimate = best guess plus or minus 1.28 × standard deviation from the regression analysis (line 7 in Figure 4.13). See Figure 4.14.

4.4 The use of multiple variable linear regression analysis in architectural design

In general, cost prices depend on much more than one variable. To derive rules of the thumb for cost prices calculations we have to conduct multiple variable (linear) regression analysis of databases on past construction projects.

Most cost price calculation procedures, for instance SVINSK which is in use in our faculty, are based on regression analysis. The so-called REN-norms, giving cost price calculation rules, for office buildings, constitute another example. The term 'norms' is misleading, because they represent actually no more than averages of executed building projects. As a result, they tend to be used as norms for evaluating designs in terms of efficiency, ratios on usable floor space, etc.

The result is that, whenever an architect presents a design outside of these 'norms', it is considered to be 'inefficient' and undesirable. This criticism actually boils down to the requirement that each new design must be as 'efficient' as previous designs from other architects. When the new design, however, constitutes a new and appealing concept, the future owner of the building could very well be prepared to accept some 'inefficiency' in return. In such situations, the REN-norms are counter-productive to the realisation of innovative architectural designs.

The REN-norms should, therefore, never be used as 'norms' but only to provide the information as to how a design performs in terms of efficiency, use of floor space, etc. compared to what has been achieved by others in the past.

If cost price estimates should not be based on general 'norms' like REN-norms and SVINSK data, how can an architect make a cost price estimate other than by detailed offers from suppliers? To resolve this issue, we introduce the concept of 'architectural repertoire' which will be explained in the next section.

4.5 The concept of architectural repertoire

A building can be considered to be a system which consists of a variety of subsystems:

- Construction;
- Kitchens;
- Ventilation and heating;
- Facade;

- Roofs;
- Windows;
- Etc.

An architect, or rather a firm of architects, will always display certain preferences as to the choice of these subsystems. These preferences determine to an important degree how they distinguish themselves from their colleagues. The reputation of an architect depends not only on his conceptual designs but also on how he deals with the 'nuts and bolts' that are involved. To make a reliable cost estimate for his design, the architect needs to be informed on the cost prices of his 'preferred repertoire' of subsystems. Cost prices of subsystems he never applies are irrelevant to him.

Let us assume that some dozen of past projects of an architects firm are properly documented including historical cost prices of the various preferred subsystems. A multiple variable (linear) regression analysis of these historical cost prices can then provide a basis for a cost price estimate of a new design which includes the typical extra cost or cost savings of the firm's preferred architectural repertoire.

The multiple variable regression analysis provides a probability distribution of the cost prices of the various subsystems of the new design. These probability distributions serve as an input for a Monte Carlo simulation of the cost price of the new building. The output of the Monte Carlo simulation provides the important information of the probability of deviations (plus or minus) from the expected cost price.

4.6 Ethical considerations

Statistical analysis can be misleading. Hence expressions like: how to lie with statistics. A simple example is prediction outside the range of the original data. To avoid such mistakes, the model designer should always keep in mind where the underlying data came from, accept the associated limitations and, above all, use his or her common sense. When building or evaluating a regression model, plausability questions should always be asked, such as:

- Are the signs and values of the regression coefficients in line with a priori intuition? This can be of importance to identify invisible multicollinearity.
- Is the fit of the data in line with expectations? A bad fit could be improved by refining the model. An extremely nice fit could point at modelling a trivial relationship or at deleting too many observations that do not fit nicely.

- Can observations that do not fit be explained? If not, is the adopted theoretical framework underlying the regression possibly incorrect?

In short, the modeller should always display genuine self-criticism.

Ethical considerations come into play when the model designer is deliberately manipulating when constructing the regression model (Berenson and Levine, 1996). The key here is intent. Unethical behaviour occurs when regression analysis is used to:

1. Forecast a response variable of interest with the wilful intent of possibly excluding certain variables from consideration in the model;
2. Delete observations from the model to obtain a better model without giving reasons for deleting these observations;
3. Make forecasts without providing an evaluation of assumptions when he or she knows that the assumptions of least squares regression have been violated.

Such manipulations are in the longer term disastrous, as even without them it is already difficult enough to achieve that layman decision makers will accept the outcomes from computer models presented by experts.

4.7 Conclusions

1. Multiple regression analysis is an essential tool for the development of cost price estimation formulas in the construction industry.
2. Regression analysis enables the architect to make cost estimates of his or her favourite architectural concepts, systems, and constructions: his or her architectural repertoire.
3. Regression analysis can provide the input for Monte Carlo simulations of the future, provided sufficient historical data are available.

5 Preference Measurement: The key to incorporating soft variables

Scepticism about the usefulness of computer modelling in Architecture and Urban Planning is often based on the argument that soft variables* such as architectural beauty cannot be measured. This is actually a misconception. The beauty itself indeed cannot be measured, but the preference of stakeholders for one design in comparison with other designs can be established without much difficulty. Otherwise, awards from juries for architects, authors, musicians, composers, etc., including Nobel prizes, would not make any sense. By measuring the preferences of the relevant stakeholders *in a correct way*, soft variables, like architectural beauty, can be accounted for.

It should be noted that what people say their preferences are – their espoused preferences – may be different from what these actually are as can be inferred from their observable behaviour – their preferences-in-use. For instance, individuals may say that they value quality much more than cost, but when it comes to paying they go for the cheapest alternatives. For further discussion on this issue we refer to Appendix A of *Open Design, a Collaborative Approach to Architecture*.

In this chapter, we describe preference measurement for Multi-Criteria Decision Making as advocated by Barzilai (1997, 2005). In Chapter 6 we will show how preference measurement can be integrated into LP optimisation.

5.1 Scaling of preferences

A reputable construction company used to address their customers with a yearly survey to measure their perception of the quality of the firm. Respondents were requested to give a grade, on a scale of 1 to 10, for the performance of the company in regard to various criteria that were considered to be relevant:

- Communication;
- Reliability;
- Delivery times;
- Eye for customer's interests;
- Quality control;

---

*A *soft variable* is a variable determined by the subjective view of one or more individuals.

- Image.

On all criteria the company scored well above seven, so everything seemed to be in order. Until, that is, one of our graduates (Sneekes, 2003) raised the question: 'How do you know that your major competitors don't score an eight?' After all, to be selected in a bidding procedure, to be 'good' is not good enough. One has to be perceived as better than the competing candidates. The answer was: 'We don't know, but we cannot ask our customers how we score compared to specific competitors.' This problem was resolved by asking each respondent to provide three scores per criterion:

- Score of the firm;
- Score of the worst competitor the respondent had ever experienced;
- Score of the best competitor ever experienced.

There was no need to disclose the identities of those worst and best performing competitors. This simple change in the survey, made it possible to establish how the company scored in comparison to the competition. The company's objective was to score at least in the top quartile in all criteria. With the assumption that performance of competitors follows a normal distribution, the relative position of the firm on each criterion could be assessed. It turned out that on two criteria the firm scored just below the top quartiles, suggesting a need for managerial measures in those areas.

This example from practice shows how easily one can fool oneself if the measurement scales of preferences are not properly defined. The earlier survey results were completely meaningless, if not misleading. As becomes apparent, there exists no independent scale on which preference can be measured. There is no (known) zero-point (origin) representing the lowest preference. One cannot say: 'I like my new car twice as much as my old one.' To measure preference correctly, measurements have to be taken relative to two arbitrarily chosen reference points. What is measured is the ratio of differences and this operation is independent of the chosen origin (zero-point) and selected unit of measurement.

5.2 Assessment of the order of preference through trade-offs and weight factors

Once the preferences for various alternatives according to conflicting criteria have correctly been established, the stakeholder's order of preference for the available alternatives can be calculated by means of weight factors, determined by trade-offs defining how much the stakeholder is prepared to sacrifice on one criterion to achieve a certain gain in another one. A software package for this purpose is available. This procedure can be summarised as follows (for details see Barzilai (1997)).

Given a number of m Alternatives A_i and a number of n Criteria C_j, the preferences $p_{i,j}$ of each alternative A_i under criterion C_j can been specified by the stakeholder. We want to calculate the total preference P for alternative A_i*:

$$\forall_i P(A_i) = \sum_j w_j p_{i,j} \tag{5.1}$$

We have to determine the weight factor w_j of criterion C_j, for $j = 1, 2, 3, \ldots, n$. The weight factors can be derived using 'trade-offs'. This means the ratio of two weight factors $r_{j,k} = \frac{w_j}{w_k}$ must be calculated. The criteria will be compared pairwise, asking the stakeholder concerned how much 'gain' in one criterion must compensate for a 'loss' in the other one or vice versa.

Example: Let $P_{1,j}$,$P_{1,k}$,$P_{2,j}$ and $P_{2,k}$ be the preferences of alternatives A_1 en A_2 according to the criteria C_j and C_k, then:

$$P(A_1) = w_j p_{1,j} + w_k p_{1,k} \qquad P(A_2) = w_j p_{2,j} + w_k p_{2,k} \tag{5.2}$$

These are equally preferred alternatives:

$$w_j p_{1,j} + w_k p_{1,k} = w_j p_{2,j} + w_k p_{2,k} \tag{5.3}$$

which gives the ratio between the weight factors w_j and w_k:

$$r_{j,k} = \frac{w_j}{w_k} = \frac{p_{2,k} - p_{1,k}}{p_{1,j} - p_{2,j}} \tag{5.4}$$

When a stakeholder has specified the values of ratios $r_{j,l}$ and $r_{l,k}$ the value of ratio $r_{j,k}$ can simply be derived by multiplying the former ones:

$$r_{j,k} = r_{j,l} r_{l,k} = \frac{w_j}{w_l} \frac{w_l}{w_k} = \frac{w_j}{w_k} \tag{5.5}$$

If the stakeholder is consistent when specifying the ratios, then:

$$\forall_{j,k,l} r_{j,k} = r_{j,l} r_{l,k} \tag{5.6}$$

A ratio-matrix R satisfying this rule is called *consistent*, if not *inconsistent*. In case of an inconsistent R the final ratios can differ from the specified ones due to least squares averaging.

Note that the weight ratios $r_{j,k}$ are calculated without any manipulation of the stakeholder's input. If we use these weight ratios to reduce the multi-criteria problem to a single-criterion one by optimising the weighted sum, we

---

*∀ means: for all

Table 5.1 Part of the enquiry in use on the criterion Reliability

Subcriterion Reliability					Grade					
Skill of office workers	1	2	3	4	5	6	7	8	9	10

are still respecting the Open Design principle that no preference of the modeller should be allowed. In this way, the *preference method* of using the weight factors arbitrarily chosen by the modeller is replaced by a *nonpreference method* which exclusively reflects the preferences of the stakeholder concerned. For a more detailed discussion on preference and non-preference methods, see Chapter 6.

If the problem is 'over-defined' in the sense that a stakeholder specifies more equivalent alternatives than necessary to compute the weight ratios, that means the number of trade-offs is larger than $(n-1)$, least squares fitting is in order as long as the preferences are related to one stakeholder only. Averaging preferences belonging to different stakeholders using least squares curve fitting would be against the basic philosophy of Open Design.

5.3 Single criterion preference measurement of a group

As mentioned before in Section 5.1, a reputable construction company used to address their customers with a yearly inquiry to measure their perception of the quality of the firm. Respondents were requested to give a grade for the performance of the company in regard to various criteria that were considered to be relevant. On all criteria the company scored well above seven, so everything seemed to be in order. In this section we will show that this is misleading and how proper use of preference measurement and statistical analysis can improve the probability that the construction firm will be selected in future bidding procedures.

To this end, first a (correct) *single criterion preference measurement of a group* of customers is conducted to grade the company's performance. Next a *criteria ranking on relevance* using the enquiry results of the same group of customers is peformed to assess the relative relevance of the various criteria as perceived by the customers. The procedure generates feedback from customers which is essential for a learning organisation.

An example of the old and improved scaling is given in Table 5.1 and 5.2 respectively.

In short, to measure preference correctly, you need at least three scores per criterion. Measuring with only one score, on an arbitrary scale, is meaningless. The simple change in the enquiry as indicated in Table 5.2 made it possible to measure how the firm scored in comparison to the competition.

Table 5.2 Part of the improved enquiry on the criterion Reliability

Subcriterion Reliability		Grade									
Skill of office workers	Firm	1	2	3	4	5	6	7	8	9	10
	Best competitor	1	2	3	4	5	6	7	8	9	10
	Worst competitor	1	2	3	4	5	6	7	8	9	10

Table 5.3 Results new enquiry

Criterion	Best score	Firm's score	Worst score	% higher	% lower
Communication	8.55	7.19	4.45	25.99%	74.01%
Reliability	8.27	7.30	4.35	15.78%	84.22%
Delivery times	8.29	7.24	7.34	18.08%	81.92%
Eye for customer's interests	8.48	7.03	4.13	27.47%	72.53%
Quality control	8.06	6.88	4.06	21.99%	78.01%
Image	8.17	7.41	4.30	12.12%	87.88%

Statistical analysis

By having three scores from the group of customers on every (sub)criterion, it becomes possible to establish if the company achieves its objective score in all criteria at least in the top quartile. With the assumption that performances of competitors follow a normal distribution, the relative position of the firm on each criterion can be assessed (Fig. 5.1). A confidence level (meaning that the probability that the conclusion from the statistical analysis is true) of 97.5% was chosen. Figure 5.2 shows how the construction firm scores in relation to the competition on the criterion 'Communication'.

Table 5.3 shows the results of the analysis. It shows that on two criteria the firm scores just below the top quartile, namely 'Communication' and 'Eye for customer's interests', which could warrant managerial measures in those areas.

5.4 Criteria ranking on relevance by a group

Knowing on which criteria the firm scores below the top quarter is not enough. To justify managerial measures, one also needs to know how much importance customers attach to these criteria. To this end, the enquiry was extended to enable ranking of the criteria according to their importance to the customer. The customer is asked to rank all criteria on relevance and to scale them on relevance on a scale of one to ten. Figure 5.3 is an example of how one customer might scale relevance for all six criteria.

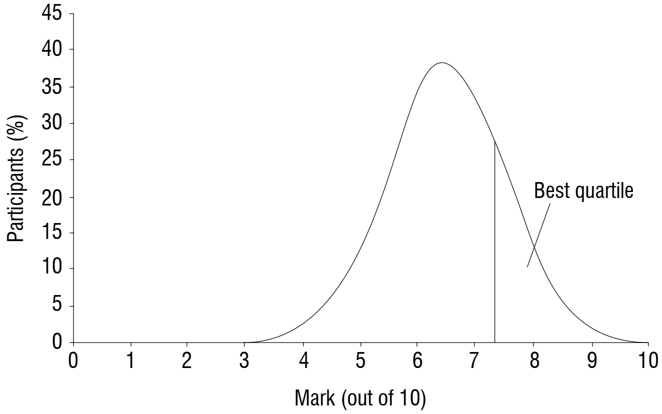


Figure 5.1 Normal distribution: Number of competitors and scores

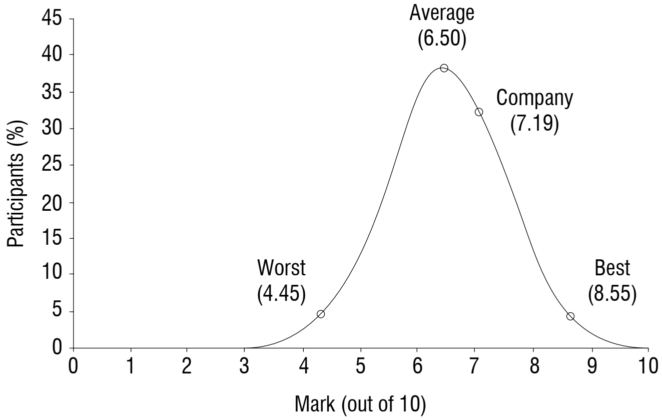


Figure 5.2 Normal distribution: Number of competitors and scores

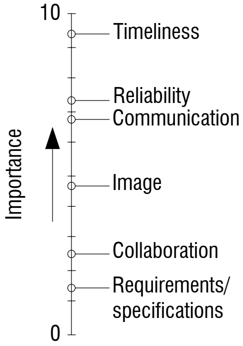


Figure 5.3 Example of relevance scaling

Table 5.4 Criteria ranking (averages)

Criterion	Relevance
Communication	8.25
Reliability	8.13
Delivery times	8.13
Eye for customer's interests	7.88
Quality control	7.25
Image	4.88

Statistical analysis

The results of all enquiries are analysed to show the ranking of all six criteria by the group of customers. This is done by averaging all rankings. The average ranking is shown in Table 5.4

Based on this outcome, the firm might discard the criterion *image* in future enquiries.

5.5 Conclusions

1. Preference measurement enables to incorporate soft variables in computer models, which is essential in both architecture and urban planning.
2. Great care is required in the correct scaling of the stakeholders' preferences.

6 Integrating LP Multi Criteria Optimisation and Preference Modelling

In optimisation models for multiple objective problems, we can distinguish non-preference and preference methods, as was discussed in *Open Design, a Collaborative Approach to Architecture*. With the non-preference approach, we limit the model to the production of information on non-dominated (Pareto) performances. A non-dominated (Pareto optimal) solution is one for which no other solution exists that is capable of providing a better performance in one criterion and no worse performance in all other criteria. Given criteria that completely express the goals of a decision problem and a complete Pareto set of solutions for those criteria, the best solution must lie within the Pareto set. In the preference approach, the model designer's trade-off preferences are incorporated in the model. For instance, he can reduce the multi criteria problem to a single-criterion problem by assigning weight factors to the criteria and optimise the weighted sum. The choice of the weight factors remains rather arbitrary however. Even if there were a rationale for a certain choice, it would be extremely difficult for the designer to explain why the interests of some crucial stakeholders are given less weight than those of others.

The non-preference Pareto optimisation generally used in Open Design is the Constraint method. This method retains one objective as primary, that means as variable to be optimised, while treating the remaining objectives as constraints. By doing this in turn for the various objectives, the relevant part of the Pareto set is found. Which member of that set is finally chosen, is determined in an iterative procedure in which crucial stakeholders in turn make concessions until a solution is found or the conclusion is drawn that their interests are irreconcilable.

An advantage of this procedure is that stakeholder's negotiations are limited to feasible solutions. A disadvantage is that stakeholders cannot express their preferences a priori, because their willingness to make concessions depends on how much their concessions influence the feasibility of the project in combination with concessions from other stakeholders. Preference modelling does allow stakeholders to express their preferences a priori, but does not take into account feasibility due to constraints imposed by other stakeholders.

This limitation is removed by integrating the preference and non-preference methods. In its simplest form, this can be done by incorporating the preferences and their associated weights as decision variables into the LP model. Since the weight factors are not manipulated by the modeller this procedure is still a non-preference method. This procedure is explained in the next section with the Project Developer's problem from Section 1.2

	A	B	C	D	E	F
1	Endogenous variables	N_A	N_B			
2	Outcome	0	0			
3						
4	Objective function	30000	100000	0		
5				required		available
6	Max. type A	1		0	<=	60
7	Max. type B		1	0	<=	50
8	Max. parking-places	1	2	0	<=	150

Figure 6.1 Model structure after adding restrictions

6.1 Integrating LP Multi Criteria optimisation with Preference Modelling using fixed weight factors

The LP model that was used for the project developer's problem of Section 1.2 maximised the profit of the project developer. The municipality, however, is interested in maximising the number of parking places. This means that we want to maximise both the profit and the number of parking places. An objective function should not contain variables with different units. To overcome this problem weight factors can be used to express the relative importance of both decision criteria 'profit' and 'number of parking places'.

Suppose we assume that both stakeholders agree that the criteria 'number of parking places' has a weight factor of 1 and the criteria 'profit' has a weight factor of 2. The original objective function was:

$$\text{Maximise} \quad Z = 300x_1 + 500x_2, \tag{6.1}$$

We can then change the objective function to reflect these weight factors:

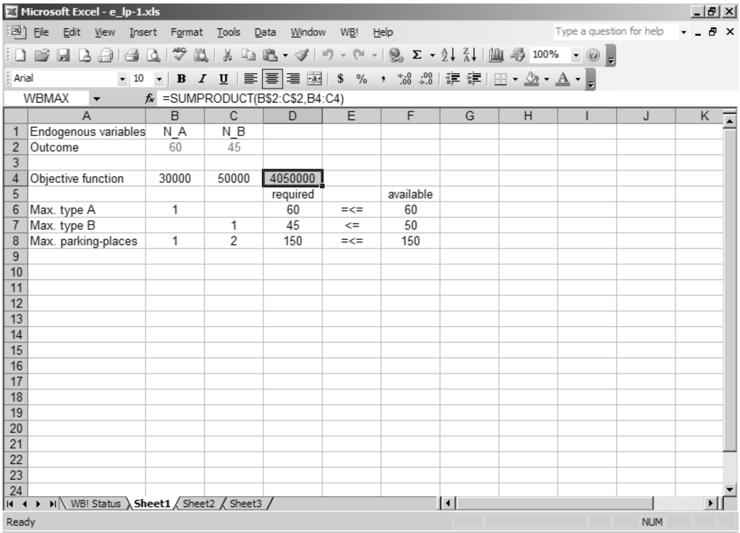
$$\text{Maximise} \quad Z = 1 \times 300x_1 + 2 \times 500x_2, \tag{6.2}$$

The modified model structure can be seen in Figure 6.1. Figure 6.2 shows a screenshot of the actual solved model. [○ e_pm-1.xls]

As can be seen, developing 20 houses of type A and 50 houses of type B will yield the highest preference.

So far, the assumption was made that the scaling of preferences is not affected by any variations in the decision variables. This assumption has to be removed whenever a preference is dependent on the value of a decision variable.

A difficulty is, however, that more often than not stakeholder's preferences depend on other decision variables. How to allow for this, is explained in the next example.



WBMAX =SUMPRODUCT(B$2:C$2,B4:C4)

	A	B	C	D	E	F
1	Endogenous variables	N_A	N_B			
2	Outcome	60	45			
3						
4	Objective function	30000	50000	4050000		
5				required		available
6	Max. type A	1		60	=<=	60
7	Max. type B		1	45	<=	50
8	Max. parking-places	1	2	150	=<=	150

Figure 6.2 Screenshot solved model (project developer's problem using stakeholder's weight factors)

Alternative	A_1	A_2	A_3
Profit	2.6	3.1	3.2
Number of affordable houses	60	20	40

Table 6.1 Numerical output of each alternative

6.2 Accounting for decision variable dependent preferences

When we maximise the number of affordable houses we basically end up on a corner point of the solution space. This is labeled Alternative 1. Maximising the profit, in essence, changing the objective function, we end up on a completely different corner point. This outcome is labeled Alternative 2. In order to choose between both we can use preference function modelling. Because we need at least three alternatives to measure we also add a third point on the boundary of the solution space. This point lies between both before mentioned corner points and is labeled Alternative 3.

The numerical output from running the LP model for each alternative is illustrated in Table 6.1

We can then measure the overall preference of each of these alternatives using the preference measurement software. Both stakeholders have to state their preference for each alternative regarding the criteria 'amount of profit' (project developer) and 'number of affordable houses' (municipality). The in-

Alternative	A_1	A_2	A_3
Profit	0	100	83
Number of affordable houses	100	0	50

Table 6.2 Numerical input for PFM software

put is given in Table 6.2.

The output yields the following ranking:

1. Alternative 3 (midpoint) with an overall preference of 68;
2. Alternative 1 and 2 both with an overall preference of 50;

As this example illustrates, it can be very useful to explore the edges of the solution space to establish a group optimum. In this example adding more alternatives on the boundary of the solution space between both corner points may yield an alternative with a better overall preference than the corner point solutions.

6.3 Conclusions

1. Preference measurement can be incorporated in LP multi-criteria optimisation with negotiable constraints.
2. The preferences can be allowed to be dependent on decision variables.

7 Non-linear optimisation

In Open Design methodology the preferences of stakeholders are assumed to be of a linear nature. For instance, the price per square meter for a parking lot is kept the same for a relatively small parking lot as for a large one. The stakeholder may be prepared, however, to pay more per square meter for a small parking lot to be used by VIPs only. This Chapter describes a method to take such non-linear preference behaviour into account, under the assumption that the non-linear preference behaviour follows an exponential pattern (De Graaf and Van Gunsteren, 2002). The relevant stakeholder has to specify three equivalent alternatives, instead of two as required in the linear case. A numerical example shows that the non-linearity of stakeholder's preferences can significantly affect the outcome. The validity of the assumption of exponential preference behaviour can be tested by asking stakeholders more than three equivalent alternatives.

7.1 Non-linear optimisation for exponential preference behaviour

In both the Open Design methodology of Chapter 1 and the preference measurement as described in Chapter 5, linearity is implied. For instance, a finance-oriented stakeholder can specify the price per square meter he or she is prepared to pay for a parking lot. The realistic case mentioned before, that the stakeholder is prepared to pay more per square meter for a small parking lot for VIPs only, cannot be taken into account. Non-linear stakeholder preference behaviour is quite common. For instance:

- Price to be paid for a location related to the distance from a noisy factory;
- Price to be paid for percentage green in an urban area;
- Price to be paid for safety;
- Price to be paid for energy savings;
- Price to be paid for an airport island related to the distance to the shore;
- Unsupported length of buildings over the railways of a station related to the number of railway tracks;
- Price to be paid for shape, volume and area to enable the architect to create interesting architecture.

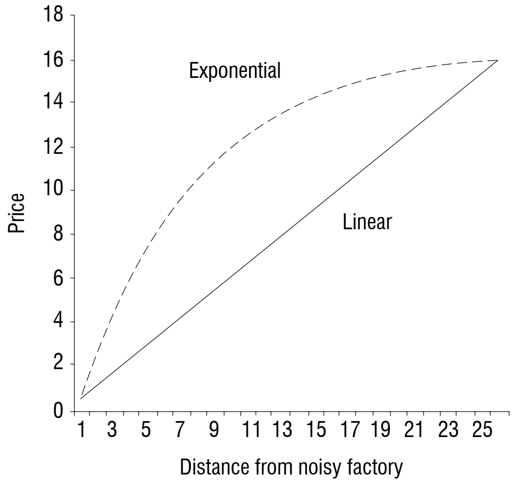


Figure 7.1 The price a decision maker is prepared to pay for a location at some distance from a noisy factory follows an exponential curve

Non-linear preference behaviour tends to follow an exponential pattern (see Lootsma, 1999). For instance, the extra price the decision maker is prepared to pay for having a location at some distance from a noisy factory will be as indicated by the exponential curve in Figure 7.1 and not the linear one. The exponential curve can be expressed in the equation:

$$y = a \cdot g^x + b \tag{7.1}$$

The unknown coefficients a, g and b can be determined if three points on the curve are given. The decision maker must, therefore, specify three instead of two equivalent alternatives. For the linear case, we could write:

$$w_1 \cdot p_{1,1} + w_2 \cdot p_{1,2} = w_1 \cdot p_{2,1} + w_2 \cdot p_{2,2} \tag{7.2}$$

from which the ratio w_1/w_2 could be obtained. For the non-linear case, this becomes:

$$w_1 \cdot p_{1,1} + w_2 \cdot p_{1,2} = w_1 \cdot p_{2,1} + w_2 \cdot p_{2,2} = w_1 \cdot p_{3,1} + w_2 \cdot p_{3,2} \tag{7.3}$$

from which the coefficients a, g and b can be obtained.

To incorporate the result in the LP procedure of Open Design, we introduce the substitution variable $z = \ln(y - b)$, as a linear variable into the LP model.

7.2 Numerical example of an airport island in the North Sea

A computer program has been written to solve Equations 7.3 through an iterative procedure. It turns out that both $g > 1$ and $g < 1$ can be processed without any difficulty. As an example, let us consider the case of an airport island in the North Sea as discussed in Chapter 15. The distance d from the shore is divided into two parts:

$d_{minimal}$	distance the island should be from the shoreline anyway;
d_{extra}	extra distance from the shore to reduce hindrance.

For d_{extra} we assume an exponential curve for the prices to be paid for it. For the first few kilometres we are prepared to pay more than for the more remote kilometres. We then can conduct both linear and non-linear simulations of this example.

The LP model can be formulated as:

$$\text{Maximise} \quad D \tag{7.4}$$

subject to the restrictions:

$$\begin{gathered} I = I_0 + C_{If}(F-6); \quad T \leq t_c; \quad D \geq d_c; \\ F \geq f_c; \quad v \cdot T = d_0 + D; \quad D - D_x = d_{min}. \end{gathered}$$

Linear:

$$I_{id} = C_{Id} \cdot D; I_{id} < I_{Idc}$$

Exponential:

$$\begin{aligned} I_{id} = a \cdot b^D + p &\Rightarrow \ln(|I_{Id} - p|) = \ln(|a|) + \ln(|b|) \cdot D \\ I_{id} < I_{Idc} &\Rightarrow \ln(|I_{Id} - p|) \leq \ln(|I_{Idc} - p|) \end{aligned}$$

where:

I_0 = investment to build an island for 600 k flight movements per year at a distance of 10 km from the shore line

I_{Id} = investment to build a tunnel longer then 10 km from the shore line

I_{Idc} = maximum investment for a tunnel longer then 10 km from the shore line

C_{If} = increase of required investment per 100 k flight movements over 600 k

C_{Id} = increase of required investment per km more distance from the shore than 10 km

F = number of flight movements (×100 k)

d_{min} = minimum distance shuttle train travels from the shore line

d_0 = distance shuttle train travels over land

v = average speed of shuttle train

D = total distance shuttle train

D_x = extra distance shuttle train travels from the shore line above d_{min}
t_c = maximum travelling time in the shuttle
f_c = minimum number of flight movements ($\times$100 k)
d_c = minimum length of tunnel
a = scale factor
b = base of the exponent
p = intercept of the logarithmic function

The parameters used in our simulation are:

I_0 = € 30 billion
I_{Idc} = € 4 billion
C_{If} = € 1 billion per 100 k flight movements
C_{Id} = € 0.1 billion per km
d_{min} = 10 km
d_0 = 30 km
v = 100 km per hr
t_c = 0.58 hr (35 minutes)
f_c = 8 100 k flight movements
d_c = 30 km

The values of a, b and p differ per example.

Linear

Investment for tunnel depends on its length: $I_{Id} = C_{Id} \cdot D$ (distance d from shore); maximum investment for extra € 4 billion: $I_{Id} \leq 4$. The maximum extra length of the tunnel is 38 km, constrained by the maximum travelling time of 35 minutes.

Exponential

Example 1:

- From 0 to 10 extra km is € 2.5 billion available;
- From 10 to 50 extra km is € 5 billion available.

So:

$$a \cdot b^0 + p = 0 \qquad a \cdot b^{10} + p = 2.5 \qquad a \cdot b^{50} + p = 5 \tag{7.5}$$

Then:

$$a = -5.1954 \qquad b = 0.9365 \qquad p = 5.1954 \tag{7.6}$$

Table 7.1 Results of simulations for an airport island in the North Sea

Variable	Linear	Exponential	Exponential
Costs extra tunnel 1 10 km [bil.]	1.0	2.0	2.5
Costs extra tunnel 10 50 km [bil.]	5.0	5.0	5.0
Flight movements [100k per yr]	8	8	8
Time [hr]	0.58	0.48	0.42
Length extra tunnel [km]	38	28.25	22.40
Costs extra tunnel [bil.]	3.8	4	4

The maximum length of the tunnel is 22.40 km, constrained by the maximum budget for the 'extra' tunnel.

Example 2:

- From 0 to 10 extra km is € 2 billion available;
- From 10 to 50 extra km is € 5 billion available.

So:

$$a \cdot b^{0} + p = 0 \qquad a \cdot b^{10} + p = 2 \qquad a \cdot b^{50} + p = 5 \tag{7.7}$$

Then:

$$a = -5.6247 \qquad b = 0.9570 \qquad p = 5.6247 \tag{7.8}$$

The maximum length of the tunnel is 28.25 km, constrained by the maximum budget for the 'extra' tunnel.

Table 7.1 summarises the results of the different simulations for an airport island in the North Sea. The conclusion is that the non-linearity of the cost/distance ratio has a significant effect on the outcome, i.e. the optimum distance from the shore. The example shows how to deal with the difficulty that an exponential variable cannot be mixed with a linear one. We simply introduce two variables: a price per distance as a constraint in the LP model and an extra price per extra distance, which is assumed to vary exponentially.

7.3 Conclusions

1. Preference behaviour which is non-linear, but which is however exponential, can be accounted for in multi-criteria optimisation.
2. The validity of the assumption of exponential preference behaviour has to be verified with the stakeholder concerned.

8 Geometric modelling

In Open Design problems, as in nearly all architectural and urban design problems, not only the quantities of and the preferences for the resources to be allocated play a role, but also the location of the resources in the architectural and urban space. A lot has been studied and written in the domain of architectural design methods about this spatial dimension of architectural and urban resources. In this chapter we will explain mathematical techniques and tools for negotiations on the spatial dimension of resources. We will do this within, and as an extension of, the mathematical framework for Open Design negotiations on quantities and preferences. Since the techniques and tools of this chapter are an extension of the basic Open Design tool, the linear programming model with negotiable constraints, we will start with the general LP model from Chapter 1 and extend this numerical tool step by step with a geometrical component.

8.1 Allocation of activities to spaces

In architectural design and urban planning, a dominant spatial dimension of resources is the position of resources in two- and three-dimensional space. This position is commonly expressed in floor plans, land use plans, and three dimensional models of buildings and their urban environments. In terms of allocation of resources, a floor plan is a proposal for allocation of architectural spaces to accommodate human activities such as living, shopping, eating, and office work. In terms of Open Design: Which spatial layout of the resources fits the activities to be accommodated best, in accordance with stakeholders' wishes, goals, and constraints, and with the architectural style chosen?

Starting from the standard LP model:

$$\text{Maximise} \quad Z = \sum_{j=1}^{n} c_j x_j \tag{8.1}$$

subject to:

$$\sum_{j=1}^{n} a_{ij} x_j \leq b_i \quad \text{for } i = 1, 2, \ldots, m$$

and

$$x_j \geq 0 \quad \text{for } j = 1, 2, \ldots, n$$

If we define the activities as demand (d) and the resources as supply (s) we can represent this problem (which is called in Operations Research literature the transportation problem, or the distribution problem) in an LP model as follows:

$$\text{Minimise} \quad Z = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij} \quad \text{for } i = 1, 2, \ldots, m, \quad j = 1, 2, \ldots, n \tag{8.2}$$

	1	2	3	4	$\ldots$	n
1	c_{11}	c_{12}	c_{13}	c_{14}	$\ldots$	c_{1n}
2	c_{21}	c_{22}	c_{23}	c_{24}	$\ldots$	c_{2n}
3	c_{31}	c_{32}	c_{33}	c_{34}	$\ldots$	c_{3n}
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$		$\vdots$
m	c_{m1}	c_{m2}	c_{m3}	c_{m4}	$\ldots$	c_{mn}

subject to:

$$\sum_{j=1}^{n} x_{ij} \geq d_i \quad \text{for } i = 1, 2, \ldots, m$$

$$\sum_{i=1}^{m} x_{ij} \leq s_j \quad \text{for } j = 1, 2, \ldots, n$$

	1	2	3	4	$\ldots$	n		
1	x_{11}	x_{12}	x_{13}	x_{14}	$\ldots$	x_{1n}	$\geq$	d_1
2	x_{21}	x_{22}	x_{23}	x_{24}	$\ldots$	x_{2n}	$\geq$	d_2
3	x_{31}	x_{32}	x_{33}	x_{34}	$\ldots$	x_{3n}	$\geq$	d_3
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$		$\vdots$		$\vdots$
m	x_{m1}	x_{m2}	x_{m3}	x_{m4}	$\ldots$	x_{mn}	$\geq$	d_m
	$\leq$	$\leq$	$\leq$	$\leq$		$\leq$		
	s_1	s_2	s_3	s_4	$\ldots$	s_n		

and

$$x_{ij} \geq 0 \quad \text{for } i = 1, 2, \ldots, m, \quad j = 1, 2, \ldots, n$$

In this model x_{ij} is the representation of an activity i in space j. c_{ij} is the representation of the cost (expressed in money, energy, appreciation, and the like) of the realisation of activity i in space j. This representation can be explained with two aspects of the relationship between activities and spaces as follows: Since in buildings and urban areas human activities are not fixed to one unique space – or in other words activities are spread out over more spaces, like rooms, auditoria, corridors, zones, areas – a design expresses, among a lot of other things, a spatial pattern of different architectural and urban spaces to fit a set of different activities allocated to the designed spaces.

The second aspect concerns the fact that most of the architectural spaces are suited for more than one activity, but of course not all. This means that the designer can propose alternative arrangements of the activities required, for a given spatial arrangement of spaces. Also the other way around: for a given spatial arrangement of activities, alternative layouts of architectural spaces may be proposed. By changing the input values of c_{ij}, a representation of the design process on both aspects becomes available. With this mechanism, a designer can represent his pattern of possible activities in such a way that he can see how well this pattern fits the activities required.

While architectural spaces may be suited for more than one activity, they are not necessarily suited for all activities due to technical constraints such as daylight, noise hindrance, permitted location in the building, or conceptual constraints such as structure of spaces and patterns of connections.

The model for this design problem (the limited distribution problem) can be formulated as follows:

$$\text{Minimise} \quad Z = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij} \quad \text{for } i = 1, 2, \ldots, m, \quad j = 1, 2, \ldots, n \tag{8.3}$$

subject to:

$$\sum_{j=1}^{n} a_{ij} x_{ij} \geq d_i \quad \text{for } i = 1, 2, \ldots, m$$

$$\sum_{i=1}^{m} a_{ij} x_{ij} \leq s_j \quad \text{for } j = 1, 2, \ldots, n$$

and

$$x_{ij} \geq 0 \quad \text{for } i = 1, 2, \ldots, m, \quad j = 1, 2, \ldots, n$$

$$a_{ij} = \{0, 1\} \quad \text{for } i = 1, 2, \ldots, m, \quad j = 1, 2, \ldots, n$$

Due to the LP problem solving algorithm, x_{ij} will be zero (non Basic) if $a_{ij} = 0$, and x_{ij} will get a value if $a_{ij} = 1$. This means that if the designer decides that space s_j is not suited or otherwise not appropriate for activity i, he sets $a_{ij} = 0$ and automatically x_{ij} becomes 0. In other words, using the zero and one value of a_{ij}, the designer uses the model to calculate the best allocation of activities to the designed pattern of spaces.

The function of the variable a_{ij} is explained with an example (Table 8.1): A floor plan F for building B consists of four spaces, s_1, s_2, s_3, s_4. The floor plan should accommodate three different activities, d_1, d_2, d_3. The designer of the

Table 8.1 Example allocation

Activity type 1				Activity type 2				Activity type 3					
x_{11}	x_{12}	x_{13}	x_{14}	x_{21}	x_{22}	x_{23}	x_{24}	x_{31}	x_{32}	x_{33}	x_{34}		
1	0	1	1									$\geq$	d_1
				1	1	1	0					$\geq$	d_2
								0	1	1	1	$\geq$	d_3
1				1				0				$\leq$	s_1
	0				1				1			$\leq$	s_2
		1				1				1		$\leq$	s_3
			1				0				1	$\leq$	s_4

floor plan decides that s_1 is suited for d_1 and d_2, s_2 is suited for d_2 and d_3, s_3 is suited for d_1, d_2, and d_3, and s_4 is suited for d_1 and d_3. The optimal allocation then follows from equation (8.3).

8.2 Fit of activities into spaces

In the representation of the space allocation described above, it is assumed that the total demanded space for activities equals the total supplied space for the activities. In the beginning of a design process this is often not the case. In architectural design and urban planning, demand and supply are independent of each other. They are not fixed at the start of a design process. Designers propose spatial arrangements of spaces based on their ideas, style, and concepts. Of course, these proposals are not that far from the required spaces, but they are not equal. So, a design can give ideas for activities one was not thinking of. Similarly, a designer can discover that he does not yet have space for an activity which certainly should be in the building. The designers have to find the best fit. With two extensions to the above model, it is possible to cope with this design question.

$$\text{Minimise} \quad Z = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij} \quad \text{for } i = 1, 2, \ldots, m, \quad j = 1, 2, \ldots, n \tag{8.4}$$

subject to:

$$\sum_{j=1}^{n} a_{ij} x_{ij} - D_i = 0 \quad \text{for } i = 1, 2, \ldots, m$$

$$\sum_{i=1}^{m} a_{ij} x_{ij} - S_j = 0 \quad \text{for } j = 1, 2, \ldots, n$$

$$D_i \leq d\_max_i \quad \text{for } i = 1, 2, \ldots, m$$

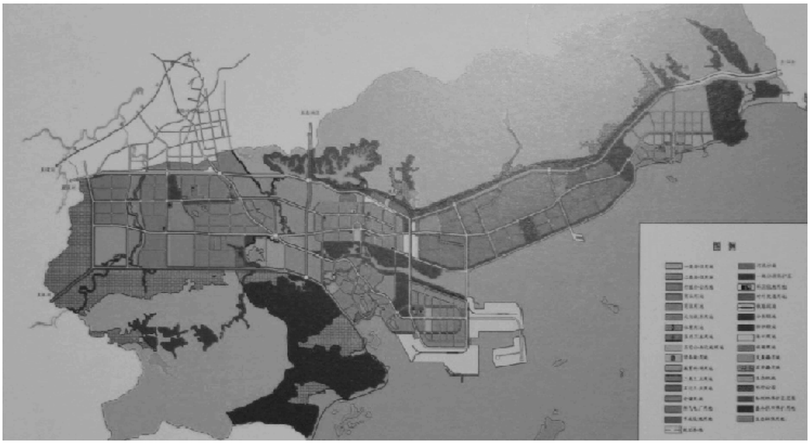


Figure 8.1 Urban area

$$D_i \geq d\_min_i \quad \text{for } i = 1, 2, \ldots, m$$

$$S_j \leq d\_max_j \quad \text{for } j = 1, 2, \ldots, n$$

$$S_j \geq d\_min_j \quad \text{for } j = 1, 2, \ldots, n$$

and

$$x_{ij} \geq 0 \quad \text{for } i = 1, 2, \ldots, m, \quad j = 1, 2, \ldots, n$$

$$D_i \geq 0 \quad \text{for } i = 1, 2, \ldots, m$$

$$S_j \geq 0 \quad \text{for } j = 1, 2, \ldots, n$$

$$a_{ij} = \{0, 1\} \quad \text{for } i = 1, 2, \ldots, m, \quad j = 1, 2, \ldots, n$$

8.3 Old city preservation example

In this example* we show how geometric modelling can be used in trading-off preservation of an old city against other, more general, objectives. Consider the plan shown in Figure 8.1. The plan shows that the old city is near petrochemical industries. The regional planning department has formulated different general objectives for the allocation of new urban functions:

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*This case, concerning the Daya Bay region in China, was prepared by the authors for their workshop at Tsinghua University, Beijing, in February 2005.

- There should be enough urban area for new industrial development (ID);
- The new residential area should be in balance with the new industrial area (RA);
- There has to be enough space for leisure for the new residents like sporting, outdoor meetings and cultural events (LE);
- Nature protection is necessary as a compensation for the new urban developments (NA).

These objectives are quantified as follows:

- Industrial Development: $ID > 20$ square kilometres;
- Residential Area: $RA = 0.90ID$;
- Leisure: $LE = 0.10RA$;
- Nature: $NA = 0.20ID + 0.20RA$;

Rearranging these equations to fit into the standard LP structure yields:

- $X_{id} > 20$;
- $X_{ra} - 0.90X_{id} = 0$;
- $X_{le} - 0.10X_{ra} = 0$;
- $X_{na} - 0.20X_{id} - 0.20X_{ra} = 0$.

The plan is then divided into zones as shown in Figure 8.2. This results in the capacity per zone. Because of the spatial arrangement of the zones and their capacities not all zones are suited for all functions. This is why the planners decided that:

- Zone 2 and 8 are not suitable as a residential area;
- Zone 2, 3, 7 and 8 are not suitable as an industrial area;
- Zone 1 is not suitable as a leisure area;
- Zone 1, 3, 4 and 7 are not suitable as a a nature area.

Table 8.2 shows how this is fed into the model.

The model is then run to maximise the total industrial area. Table 8.3 shows the results of this run. It shows how much of a certain function is allocated to a certain zone. As can be seen from the results, both the general and geometrical objectives are met. One can easily explore different allocations by simply

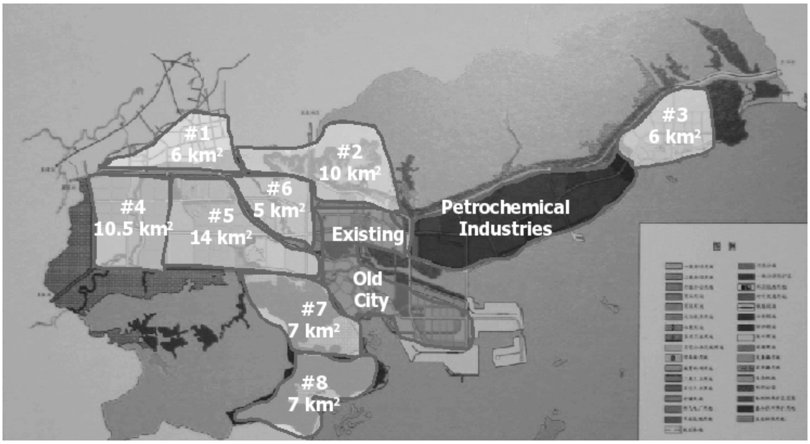


Figure 8.2 Division into zones

Table 8.2 Allowed allocations

	Zones							
	1	2	3	4	5	6	7	8
Residential	1	0	1	1	1	1	1	0
Industries	1	0	0	1	1	1	0	0
Leisure	0	1	1	1	1	1	1	1
Nature	0	1	0	0	1	1	0	1

Table 8.3 Model output (initial allocations)

	Zones							
	1	2	3	4	5	6	7	8
Residential	6.0	0.0	6.0	0.0	0.0	4.0	7.0	0.0
Industries	0.0	0.0	0.0	10.5	14.0	1.0	0.0	0.0
Leisure	0.0	5.0	0.0	0.0	0.0	0.0	0.0	2.3
Nature	0.0	5.0	0.0	0.0	0.0	0.0	0.0	4.7

Table 8.4 Allowed allocations (after negotiations)

	Zones							
	1	2	3	4	5	6	7	8
Residential	1	0	1	1	1	1	1	0
Industries	1	0	0	1	1	1	0	0
Leisure	0	0	1	0	0	0	1	1
Nature	0	1	0	0	0	0	0	1

Table 8.5 Model output (altered allocations)

	Zones							
	1	2	3	4	5	6	7	8
Residential	5.0	0.0	6.0	0.0	0.0	5.0	7.0	0.0
Industries	1.0	0.0	0.0	10.5	14.0	0.0	0.0	0.0
Leisure	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3
Nature	0.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0

altering the allowed spatial allocations. For instance, suppose a second optimisation is conducted after negotiation has taken place about allowed allocations of the different functions. This is represented in Table 8.4 (input) and Table 8.5 (output).

8.4 Reflection in action: the urban decision room

The above way of modelling assumes that the designer has an overview of the spatial arrangements of possible activities. To add detail to this overview, the designer can use expert knowledge, from specialists on acoustics, daylight, construction, and so forth, as well as from the prospective users, who have expert knowledge on such issues as the exploitation and maintenance.

It is common in architecture and urban design to optimise on architectural criteria. The style, the concept, the fashion, are dominant issues. However, the user, the owner, the investor, and the politician wish to have more and more influence on the design. The design tool explained in this chapter enables optimisation from both the architect's point of view and the user's point of view. The procedure supports what Schön (1982, 1987) calls *reflection in action*.

The latest development is to have preference input from stakeholders online. Stakeholders convene in a room with interconnected computers in which the mathematical model of this chapter has been programmed: *The urban decision room* (Figure 8.3).

Figure 8.3 The Urban Decision Room

8.5 Conclusions

1. Integration of geometrical and numerical modelling can be achieved with a mathematical model for the allocation of activities to spaces.
2. Having stakeholders′ preferences online – the urban decision room – enables them to adjust their preferences when seeing their impact on the model as a whole (reflection in action).

Part II

Cases

9 Linear Programming with negotiable constraints

The railway station and the old city centre of Utrecht, the Netherlands, are connected by a multi-functional building complex: Hoog Catherijne. Passengers are almost compelled to go through this complex to get from the station to the city centre and vice versa. Hoog Catherijne has been considered a frustrating heritage from the sixties, because the complex functions poorly, especially at night. The complex contains shops, offices, houses and parking garages. The shops of Hoog Catherijne cover about 30% of the total sales surface area in the city centre of Utrecht. The number of shops as well as the turnovers have grown (10% since 1997) in Hoog Catherijne, just like in the rest of the city centre. The functioning of the shopping centre cannot be considered the core problem. Difficulties in functioning are caused by unclear routes in the complex, differences in levels, and a separation of functions inside the complex. For instance, there are apartments on top of the complex, but they can hardly be noticed at ground floor level, because the entrances to the apartments are not very obvious and they have direct access to the parking garages underground. The result is that Hoog Catherijne is a very unpleasant area for passengers going to and from the city centre, especially after closing time of the shops. The current transportation hub located right beside Hoog Catherijne, which includes the railway station, also functions poorly. Passengers who want to change to different ways of transportation are compelled to use unsafe routes. In addition, the current capacity of these transition areas is not large enough to deal with the growing number of passengers. The annual number of passengers is currently at 57 million and is expected to grow to 100 million by 2015.

In order to improve the current situation of the railway station and its surroundings, an urban design for the whole area was approved by the city council in December 1997. This urban design is the framework for all the new developments in the area now and in the future. The possibilities for the transportation interchange are determined by this urban design. The new design was not received with applause. On the contrary, the plans for the railway station area in Utrecht were so much disputed among citizens of the city, that a political party came into being to fight against the plans. This party, 'Liveable' Utrecht, even got a seat in the city council. Liveable Utrecht believes that the municipality takes too much financial risk, and that the plans are too bombastic for the city of Utrecht. The heated political debate on the issue is still not concluded at the time of writing.

To provide insight into the possibilities and impossibilities of various solutions, Open Design simulations were conducted by Merema (2000).

9.1 Parties concerned, their targets and means

To realise a multi-functional public transportation hub, many parties have to cooperate. For Open Design theory to be applied, it is very important to get an overview of the goals and resources of each party. A resource is what one employs to achieve a goal. Usually parties like to talk about solutions straight away. While negotiating about the solutions, parties will all keep their goals in mind. If necessary, they will try to manipulate the solutions in such a direction that their goals will be pursued.

The Open Design approach is different in the sense that it requires to have an overview of all the common and individual goals, and of the resources parties have at their disposal to pursue these goals. The common solution space that we are looking for is determined by constraints. A constraint consists of two dimensions: goals and resources. A constraint indicates what resources may be employed to achieve the goal.

The following stakeholders were identified:

- Municipality;
- Public transportation licensee;
- Financiers (of real-estate part);
- Experts;
- Future users.

9.2 Model usage

The working of the model will now be explained by applying it to four topical questions in the decision making process. These questions are taken from current political, economic, and urban design issues:

- Is it possible to add dwellings in an inexpensive price category to the plan?
- What effect do disappointing rental and selling prices have on the plan?
- What is the effect of changing the ratio between rental and owner occupied dwellings?
- Is it possible to make the building more flexible so that it can fit more than one bill of requirements?

The basic model, numerical and geometrical, represents the current proposal for the transportation junction. The basic model and its input enable to generate a solution space. The outcomes of each alternative will be compared with the outcomes of the basic model, to show what the new optimum solution is under different circumstances. All the outcomes meet the demands of the parties, as they were expressed in the exogenous variables.

Adding dwellings in an inexpensive price category to the plan

There are several arguments in favour of including more dwellings in the plan. In the current proposal, dwellings are only situated in those parts of the building complex (the two towers on top of the office block) where they do not have a direct view on the public areas. By situating dwellings high up in the air, they do not contribute to the safety of the area. Arguments to realise more dwellings in the building complex will especially be brought in by the parties Dutch railways and the municipality in the negotiations, because they are mostly concerned with the quality of the public areas. It could be worthwhile for the safety of the area to situate dwellings in the lower part of the complex, where they are nearer to the flow of passengers.

The municipality will probably introduce another argument to realise more dwellings of a different type, because they want to attract other target groups to this area of the city, for example students. This argument can be motivated by the fact that there is a large demand for student housing in Utrecht, especially in a luxury segment. Young people are generally attracted to urban living and like to be easily accessible by public transportation. Students are not such a burden to the parking capacity of the locations as office employees or residents of more expensive types of dwellings are.

The geometrical model will be changed to include small studios situated right above the passenger terminal (Fig. 9.1). The floor plan of the dwellings is such that they are oriented towards the roof above the railway tracks. This roof is meant to function as a park, a public area. The access to the dwellings is through a gallery that can be seen from the passenger terminal.

Not only the geometrical model will be changed, also the input of the numerical model will be changed, in accordance with the geometrical model. The minimum values of the exogenous variables that say something about the number of dwellings of the studio type, will be changed from zero to sixty. The minimum amount of sixty studio apartments has been chosen because a certain critical mass is necessary of each dwelling type.

The most relevant outcomes of this new solution are shown in Table 9.1. The new outcomes show that it is possible to add seventy dwellings of the studio type to the plan, as long as more offices are also realised. A shift of the number of dwellings of the two types of apartments should also take place. The proposed spatial changes in the new outcomes can take place because of

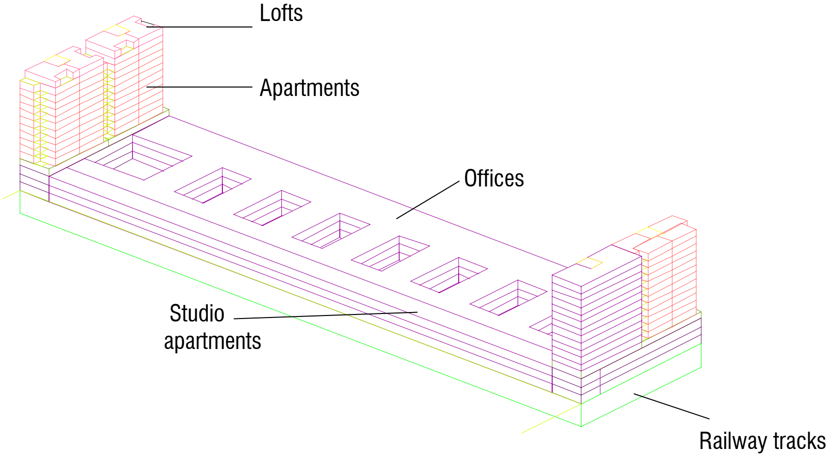


Figure 9.1 The position of the dwellings in the building complex

a reduction of the size of the skylights above the passenger terminal (4 200 m2 instead of 6 300 m2). It could also be realised by an enlargement of the total gross surface area of the real estate, or by a combination of both. The addition of offices and dwellings demands for more parking spaces.

The combination of adding offices and dwellings makes it possible to get a higher gross return than in the basic model. The net present value of the revenues is much higher in this solution, because not only the amount of square metres of offices that can be rented out has increased, but some of the rental prices have been raised as well. Namely for offices (€ 178/m2 instead of € 153/m2), and for apartments and lofts (€ 864 and € 1 182 instead of € 773 and € 1 091). The enlargement of office space and the increase of the number of dwellings cause a rise in investment costs. As the investment costs will not rise as much as the expected revenues, however, the financial results of the project will increase considerably. The higher expected revenues are mainly under influence of the increase of rental prices in this solution. The increase of rental prices in combination with an increase of offices and dwellings explains the new gross return of 7.5%. The gross return is determined by the rental incomes in the first year divided by the investment costs minus the investment costs of the dwellings that will be sold.

To summarise, the comment that initially was made, ‘to include more dwellings in the functional programme demands a financial sacrifice’, is proved to be incorrect in this case.

Table 9.1 Outcomes of adding inexpensive dwellings

	Requirements	Basic outcomes	New outcomes	Change
Total surface area dwellings (m2)		21 000	24 000	3 000
Number of standard apartments	9 - 53	53	46	-7
Number of studio apartments	60 - 70	-	70	70
Number of large apartments	41 - 165	153	161	8
Number of lofts	2 - 21	7	7	-
Total surface offices (m2)	> 30 000	46 600	48 200	1 600
Number of parking places	-	517	547	30
Investment costs (€ million)	-	146.6	154.8	8.2
Revenues (net present value, € million)		155.9	182.6	26.7
Gross return (%)	5.5 - 7.5	6.5	7.5	1

Disappointing rental and selling prices

The second alternative to be researched is the case that rental and selling prices will be disappointing. It is essential to research this possibility because in Dutch politics a discussion has started about the height of mortgages. There are two scenarios to be taken into account concerning mortgages. The first economic scenario will be an increase of the interest on mortgage. The second, political, one is that top mortgages, i.e. more than three or four times the yearly income, will not be granted anymore. These two scenarios may have their effects on the selling prices for which the dwellings can be put on the market.

The exogenous variables that give expression to the selling prices of the dwellings, will be lowered by twenty percent compared to the basic numerical model. This will also be done for the rental prices, in case those will fall short of expectations as well. In the basic numerical model the rental prices for apartments was set between € 773 and € 864. In this alternative this will be shifted to € 618 and € 691 for a standard apartment.

The new optimum solution can be found with the following changes of the spatial endogenous variables. The housing programme will have to change in such a way that less standard apartments are going to be realised and more large apartments. In addition to this more offices will have to be realised, namely 4 900 m2. The decrease of parking places is, in this solution, not caused by the functions housing or offices, but by a decrease of the surface area of shops in the passenger terminal (3 200 m2 instead of 4 300 m2). The most relevant outcomes of this new solution are shown in Table 9.2.

In the new solution the likely financial negative effects of lower selling and rental prices is compensated with the revenues of the offices. In such a way that although the investment costs of the project will be higher, caused by an

Table 9.2 Outcomes of disappointing rental and selling prices

	Requirements	Basic outcomes	New outcomes	Change
Total surface area dwellings (m2)		21 000	21 500	500
Number of standard apartments	9 - 53	53	46	-7
Number of studio apartments	0	-	0	0
Number of large apartments	41 - 165	153	161	8
Number of lofts	2 - 21	7	7	-
Total surface area offices (m2)	> 30 000	46 600	51 500	4 900
Number of parking places		517	504	-13
Investment costs (€ million)		146.6	155.7	9.1
Revenues (net present value, € million)		155.9	182.7	26.8
Gross return (%)	5.5 - 7.5	6.5	7.46	0.96

enlargement of offices, the net present value revenues will be much higher as well. The rental price for offices should be € 182 for this solution, instead of € 153 in the basic model. The new proposed rental price for offices is the maximum allowed, but still within the common solution space.

The conclusion is that the same amount of dwellings can still be realised within the building complex, even if selling and rental prices on the housing market drop.

More rental than owner occupied dwellings

The real estate developer of the project believes that the current market situation demands for 25% of the dwellings in the rental sector and 75% in the owner occupied sector. This ratio may have to be changed if the demand for rental dwellings increases, for instance if the interest on mortgages cannot be fully deducted from income tax anymore. The growing popularity of new rental constructions, such as renting the casco and buying the interior, also have to be taken into account. In this alternative we will study the case that 75% of the dwellings will be in the rental sector and that after 15 years 75% of these rental dwellings will be sold. It is important to incorporate the sale of dwellings in fifteen years time in this study, because that may happen in case interest rates are currently high and will be much lower in fifteen years time. Another reason to let the dwellings and sell them at a later stage, is that during the construction period of the area it is unattractive to invest in a dwelling in such an area. Finally, the investor may not want to have a large cashflow at once, but wish to spread it over a longer period.

The ratio of 75% to 25% for owner occupied to rental will be changed in the exogenous variables to 25% to 75% and we assume that 75% of the rental dwellings will be sold after 15 years of exploitation.

Table 9.3 Outcomes of changing the ratio between rental and owner occupied dwellings

	Requirements	Basic outcomes	New outcomes	Change
Total surface area dwellings (m2)		21 000	21 400	300
Number of standard apartments	9 - 53	53	53	0
Number of studio apartments	0	-	-	-
Number of large apartments	41 - 165	153	153	0
Number of lofts	2 - 21	7	7	0
Total surface area offices (m2)	>30 000	46 600	42 000	- 4600
Number of parking places		517	475	-42
Investment costs (€ million)		146.6	137.4	-9.2
Revenues (net present value, € million)		155.9	137.4	-18.5
Gross return (%)	5.5 - 7.5	6.5	6.49	-0.01

Table 9.4 Outcomes prices alternative 3 (€)

		Basic	Alternative 3
Offices	- rental	336	325
Apartment standard	- rental	636	591
Apartment large	- rental	773	727
	- sale	200 000	181 818
Loft	- rental	1 091	1 045
	- sale	263 636	254 545

The consequences for the optimum solution are marginal for the housing programme, as shown in Table 9.3.

The amount of square metres of office space will decrease and the financial results of the project will drop to zero. This outcome can be explained by the fact that changes in rental and selling prices will take place in this solution, namely a fall of the prices of the dwellings as shown in Table 9.4.

The housing programme remains the same in this alternative solution, but the net present value revenues of housing will change, due to the fact that 75% of the rental dwellings will be sold after 15 years. This will be compared to the outcomes of the basic model in the Table 9.5.

The comparison shows us that with the same housing programme, but more rental dwellings than owner-occupied dwellings during the first fifteen years of exploitation and lower prices, the total net present value revenues of housing can be approximately the same.

Flexible building

In the discussion about the planning of railway station areas the demand was raised by investors as well as by architects for the realisation of flexible build-

Table 9.5 Outcomes housing revenues alternative 3 (€ million)

	Basic	Alternative 3
Rental revenues 1st half exploitation	9.2	17.0
Rental revenues 2nd half exploitation	5.6	2.6
Revenues dwellings sold immediately	24.4	7.4
Revenues dwellings sold after 15 yrs	0.0	11.5
Total	39.2	38.5

Table 9.6 Outcomes of making the building more flexible

	Requirements	Basic outcomes	New outcomes	Change
Total surface area dwellings (m2)		21 000	21 000	0
Number of standard apartments	9 - 53	53	53	0
Number of studios		-	-	0
Number of large apartments	41 - 165	153	153	0
Number of lofts	2 - 21	7	7	0
Total surface area offices (m2)		46 600	51 500	4 900
Number of parking places	>30 000	517	539	22
Investment costs (€ million)		146.6	168.4	21.8
Revenues (net present value, € million)		155.9	174.4	18.5
Gross return (%)	5.5 - 7.5	6.5	6.37	- 0.13

ings. A flexible building will also have user value in the future. But to realise the possibility of flexible use, the building requires special qualities, concerning the materials used, the access and the floorplan. A flexible building demands that the structure is such that the building can contain functions for both living and working. Generally speaking it is more expensive to build a flexible building, because the height of the floors of the dwellings should be larger than usual. This is necessary to make it possible that the same floors will be used as offices later on.

A larger height of the floors results in higher building costs per square metre for the dwellings. So a change will be made in the exogenous variables giving expression to the building costs for dwellings. These costs will be increased with € 682/m2 for dwellings.

The LP program calculated that an optimum solution within the solution space can be found, provided the numerical outcomes change as shown in Table 9.6.

Changes in the housing programme will not be necessary for this solution. But three major changes should be made and accepted for this solution. First of all an enlargement of the surface area of offices with about 4 900 m2. Secondly the acceptance of a lower gross return: 6.37%. Finally, a raise of the rental prices of the various functions.

The comment that these changes should be accepted is in fact a bit deceptive. They have been accepted already, since the stakeholders allowed them in the solution space by setting the minimum and the maximum values of the exogenous variables. The three changes result in a drop of the financial result by about € 3.3 million, compared to the outcomes of the basic model. This new solution has been found with the building costs of dwellings at € 1 136/m2 instead of € 909/m2. This solution shows that it is justified to invest in the enlargement of the height of the floors of dwellings.

9.3 Conclusions

1. The outcomes of the Open Design simulations show that a lot of the arguments used in the heated political debate were actually incorrect prejudices.

2. Many more wishes from various stakeholder groups turned out to be feasible than was initially considered to be possible.

3. This case shows that a political debate about the constraints which are determinant for the solution space makes a lot more sense than a discussion on various specific designs (representing no more than a few solution points).

10 Monte Carlo simulation

Let us consider the portfolio of real estate objects described in Chapter 12, and address the question of whether it would be advisable to install a lift in existing multiple family units of the portfolio (new multiple family units will nowadays already have a lift).

10.1 Multiple regression analysis including the effect of a lift

A multiple regression analysis as described in Chapter 12 yielded the following regression equation for multiple family units:

$$EXPL = 4\,295.26 + 1\,480.04 \times VRIJ + 887.10 \times LFT \tag{10.1}$$

where:

$EXPL$ = exploitation result (in NLG anno 1980) per year per family unit

$VRIJ$ = fraction in the free (non-subsidised) sector (= 1.0 in this case)

LFT = (1 or 0) indicator for presence of a lift

The model has an R^2_{adj} of 15.7%.

The median and the standard errors of this model provide the input values for the yearly exploitation result (€) with and without lift as given in Table 10.1.

10.2 Monte Carlo simulation

To determine how much the investor can invest in a lift, to get at least the same return at the same risk level as without a lift, we have to search for input variables which generate the same return-risk profile for both cases. This can be done, in a trial and error manner, with the following assumptions (Table 10.1):

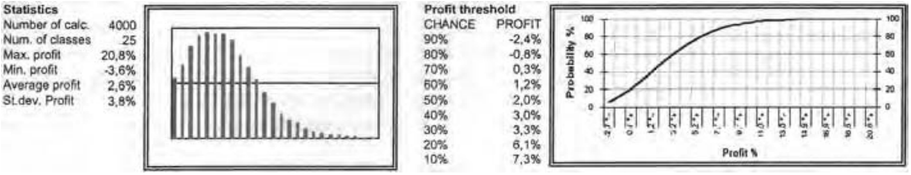
- Investment for a multiple family unit without lift:
  - Best guess: € 70 500;
  - Pessimistic/optimistic estimates: ±10% from best guess.
- Rest value: 80% of initial investment.
- Exploitation results from regression equation (10.1).

- Lifetime: 15 years.
- Inflation: see Table 10.1.
- Equal number of units.

The Monte Carlo simulations with the software package MIS give the same return-risk profile for both cases for a value $x = €\,15\,500$ (Figs. 10.1, 10.2). This means that € 15 500 per multiple family unit can be spent on installing a lift. A simple lift for four floors costs about € 44 500. The investment in a lift is, therefore, justified if three or more multiple family units can make use of it.

Table 10.1 Input values for Monte Carlo simulation

	Object without lift	Object with lift
Investment (€):		
best guess	70 500	*x*
optimistic (-10%)	64 000	*x*
pessimistic (+10%)	77 000	*x*
Inflation:		
best guess	2.0%	2.0%
optimistic	0.5%	0.5%
pessimistic	4.0%	4.0%
Exploitation result (€):		
best guess	2 500	3 000
optimistic	3 600	4 500
pessimistic	140	1 600
Rest value (€) (80% of investment))		
best guess	56 000	0.8 × *x*
optimistic (+10%)	62 000	0.8 × *x*
pessimistic (-10%)	51 000	0.8 × *x*
Exploitation	15 years (start 2001)	15 years (start 2001)



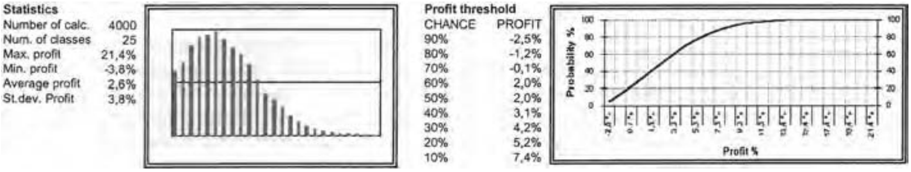
Statistics

Number of calc.	4000
Num. of classes	25
Max. profit	20,8%
Min. profit	-3,6%
Average profit	2,6%
St.dev. Profit	3,8%

Profit threshold

CHANCE	PROFIT
90%	-2,4%
80%	-0,8%
70%	0,3%
60%	1,2%
50%	2,0%
40%	3,0%
30%	3,3%
20%	6,1%
10%	7,3%

Figure 10.1 Return-risk profile without lift



Statistics

Number of calc.	4000
Num. of classes	25
Max. profit	21,4%
Min. profit	-3,8%
Average profit	2,6%
St.dev. Profit	3,8%

Profit threshold

CHANCE	PROFIT
90%	-2,5%
80%	-1,2%
70%	-0,1%
60%	2,0%
50%	2,0%
40%	3,1%
30%	4,2%
20%	5,2%
10%	7,4%

Figure 10.2 Return-risk profile with lift

11 Network planning & risk assessment

There is no such thing as 'The Critical Path'

When reporting progress to the Board, the manager of a multi-billion-dollar construction project invariably was asked what his Critical Path was and how activities on that path were progressing. Invariably, his answer was: 'There is no such thing as *The Critical Path*.' Why? Because a path which is not critical today may be critical tomorrow. This Chapter shows that in a large, several billion dollar, complex construction project, there is not just one Critical Path, but several paths that require particular attention from the project management. The concepts of path ranking on slack and on risk, as described in Chapter 3, were applied in a software package developed for this purpose. This package provided the project manager with information on what paths it would be worthwhile to pay attention to. It also provided information on how critical the Critical Path established beforehand really is. We will show that the project manager is proved right and that there is indeed no such thing as 'The Critical Path'.

11.1 Project network of activities

The (condensed) network planning consists of about 190 activities. Most of the activities have a Finish to Start relation. Some have a Finish to Finish relation. Some activities are partly completed as the project is assumed to be still in progress.

The deterministic approach is used to identify the critical path which has no slack. Then the other paths are ranked based on the total slack each has.

The probabilistic approach is used to rank paths on risk. This approach uses not only estimates on the expected duration of each activity, but also pessimistic and optimistic estimates. A Monte Carlo simulation can then be carried out using these estimates to rank paths on risk.

11.2 Path ranking on slack (deterministic)

At first, the paths are ranked based on the total slack of each path. In this ranking the expected activity durations are used. This results in the ranking as shown in Table 11.1. It should be noted that the lists of activities, as shown in this table, do not reflect the order in which they are related to each other.

The paths are labelled as path A, B, C, D, E, and F in order to identify them when we compare the outcomes of this ranking with the outcomes of the ranking based on risk. Traditionally, the path with no slack (path A) is identified as The Critical Path.

11.3 Path ranking on risk (probabilistic)

In addition to the expected duration, estimates on pessimistic and optimistic durations are added to each activity. These estimates are based on the experience of the project managers involved. With this extra information a Monte Carlo simulation is carried out. A counter keeps track of how many times a particular path through the network is critical. This results in the ranking shown in Table 11.2. It shows four relevant paths that did not show in the ranking based on slack (G, H, I, and J). These new paths clearly are of significance, especially because one of the new paths is ranked first (path G).

11.4 Conclusions

When we compare the outcomes as shown in both tables, we can conclude the following.

The ranking based on slack is totally different from the ranking based on risk. Out of the six paths ranked highest based on risk, only two were identified using the ranking based on slack. This means that the information the project manager would get from path ranking based on slack alone would not provide him with all the information he needs.

Path A, identified as The Critical Path based on the deterministic approach, is not the path that was most critical based on the probabilistic approach. Even more surprising: Path A was never critical according to the Monte Carlo simulation.

Path G, ranked as the most critical in the risk ranking, is not ranked high when based on slack. Should the project manager use the ranking on slack to identify which paths to pay particular attention to, path G would not get appropriate attention.

It turns out that six different paths (not including 'The Critical Path' A!) have substantial associated risk (frequency of being the critical path in the Monte Carlo simulation), indicating that they should get particular attention from the project management.

Simulations including mitigations on-the-run and allowance for limited human resources are left to the reader.

Table 11.1 Path ranking on slack

Ranking	1st	2nd	3rd	4th	5th	6th
Path ID	A	B	C	D	E	F

Table 11.2 Path ranking on risk

Ranking	1st	2nd	3rd	4th	5th	6th
Path ID	G	C	H	B	I	J
Percentage	22.35	15.81	12.16	9.71	9.28	7.88

12 Regression analysis: residential real estate

Dutch investors (participating in the ROZ-real estate index) have invested a total sum of € 37.6 billion in real estate. Investments in houses make up 44% of this sum. Despite the size of the investments in this sector, decision-making is based on the experience and gut feeling of the investor, and his notion of how the properties of real estate objects influence the return on investment and the associated risk. There is no objective way of measuring the influence that the properties of real estate objects have on the return on investment. This state of affairs induced one of our students (Bomer, 2002) to write her graduation thesis on this subject.

Bomer uses multiple regression analysis to find out what properties of real estate objects directly influence the return on investment. She bases her research on a database of some three hundred objects, containing data gathered over several decades. The objects are exclusively residential real estate projects. The analysis includes the following steps:

1. Determine object properties that might be relevant;
2. Analyse the database using correlation analysis;
3. Perform single regression analysis;
4. Perform multiple regression analysis.

12.1 Determine object properties that might be relevant

The Return on Investment (ROI) or exploitation result is chosen as the dependent variable. The independent variables are assumed to be the object's properties. The exploitation result is governed by the cashflows that take place during the exploitation period of an object, including the cashflow as a result of selling the object at the end of the exploitation period. A distinction is made between the properties that govern the yearly cashflows and the properties that govern the selling price of the object at the end of the exploitation period. This distinction is made because of the time-aspect of the cashflows (during the exploitation period or at the end of it) and because the magnitude in which these properties influence the ROI might differ significantly. The following object properties were taken into consideration based on the assumption that they might be related to the exploitation result:

Type of house states whether or not the object consists of apartments. Database representation: Boolean value.

Number of houses states the number of houses the object consists of. Database representation: exact number of houses.

Percentage of houses without rent restriction states the object's percentage of houses for which the government does not have a say in setting the rent. Database representation: Percentage of houses.

Houses with different number of dwelling units states whether or not the object consists of houses with a different number of dwelling units (mixed). Database representation: Boolean value.

Subsidised states whether or not the object was subsidised by the government. Database representation: Boolean value.

Floorspace states the average usable floorspace per unit.

Number of dwelling units states the objects percentage of units with a given number of dwelling units. Database representation: Percentage of units having 2/3/4/5 dwelling units.

Reserved parking states the objects percentage of units that have a reserved parking place. Database representation: Percentage of units having a reserved parking place.

Year of construction states in what decennium the object was built. Database representation: Dummy value representing the decennium.

Number of addresses per square kilometre states how densely populated the object's neighbourhood is.

Number of houses per hectare states how densely populated the object's neighbourhood is.

Income per resident states how much residents earn on average in the objects's neighbourhood.

Average household size states the average household size in the objects neighbourhood.

Number of companies per hectare states how much non residential real estate is mixed with residential real estate.

Number of schools states how many schools are located in the postcode area.

In densely populated western province states whether the object is built in one of the most densely populated provinces also called 'Randstad'.

12.2 Analyse database using correlation analysis

The properties 'Number of addresses per square kilometre' and 'Number of houses per hectare' are very similar, which means that, possibly, only one should be used in the regression analysis. For this purpose correlation analysis is carried out prior to the regression analysis.

To determine whether a coefficient is meaningful to include in the regression, the following relationship holds (for derivation, see standard text books on statistics):

$$|r| > \frac{Z}{\sqrt{n}} \tag{12.1}$$

where:

r = correlation coefficient
n = sample size
Z = coefficient depending on the chosen confidence level; for confidence level 95%, $Z = 1.96$

Table 12.1 shows the results of analysing the database to see which properties correlate to the return on investment. It shows that the property 'Number of addresses per square kilometre', correlates to the exploitation result much better than the property 'Number of houses per hectare' which is, therefore, not included in the regression analysis.

Before performing the regression analysis, the correlation between independent and dependent variables was analysed on multi-collinearity. This means two variables being so strongly related to each other, that only one should be included in the regression model. Part of the results of this analysis is shown in Table 12.2.

This correlation analysis is interesting because it shows that virtually every property relates to the type of house (apartment or non-apartment). This is called multi-collinearity. This means that regression analysis would not be useful because the influence of a particular property (i.e. floorspace) might be different for an apartment than it would be for a non-apartment. This is why the regression analysis is done per type of house.

Table 12.1 Location vs return on investment

Property	Coefficient
Number of addresses per square kilometre	*0.217*
Number of houses per hectare	-0.007
Sample size: 293	

Numbers in italics represent meaningful coefficients ($|r| > 0.1145 = \frac{1.96}{\sqrt{293}}$)

Table 12.2 Correlation analysis whole database

Property	ROI	MFU	SFU
Average Return on Investment		*0,392*	*-0,392*
Single family units (SFU)	*0,392*		*-1,000*
Multiple family units (MFU)	*-0,392*	*-1,000*	
No. of houses the object consists of	*-0,285*	-0,067	0,067
Perc. of houses without rent restriction	0,085	*0,230*	*-0,230*
Houses with different no. of dwelling units	-0,156	*-0,587*	*0,587*
Subsidised	*0,445*	0,089	-0,089
Floorspace	0,083	*0,573*	*-0,573*
Houses with 2 dwelling units	-0,073	*-0,350*	*0,350*
Houses with 3 dwelling units	-0,082	*-0,622*	*0,622*
Houses with 4 dwelling units	0,043	*0,229*	*-0,229*
Houses with 5 dwelling units	0,098	*0,487*	*-0,487*
Reserved parking	-0,124	0,054	-0,054
Year of construction 1950-1959	*-0,213*	*-0,271*	*0,271*
Year of construction 1960-1969	*-0,292*	-0,154	0,154
Year of construction 1970-1979	-0,021	*0,303*	*-0,303*
Year of construction 1980-1989	*0,523*	*0,185*	*-0,185*
First five years of exploitation	*0,216*	-0,047	0,047
First ten years of exploitation	*0,176*	0,052	-0,052
First fifteen years of exploitation	*-0,342*	-0,001	0,001
Number of addresses per square kilometre	*0,171*	*0,529*	*-0,529*
Average family size	*0,257*	*0,553*	*-0,553*
Income per household	*-0,237*	*-0,446*	*0,446*
No. of primary schools in postcode area	0,048	*0,235*	*-0,235*
No. of supermarkets in postcode area	-0,162	*-0,288*	*0,288*
Built in densely populated provinces	-0,001	*-0,193*	*0,193*
Sample size: 130			

Numbers in italics represent meaningful coefficients $(|r| > 0.17 = \frac{1.96}{\sqrt{130}})$ for the correlation of the variable concerned to the exploitation result

Table 12.3 Results of single variable regression analysis

Property	t-statistic	R^2_{adj}
No. of houses the object consists of	*-3.41*	*0,10*
Perc. of houses without rent restriction	*2.51*	*0.05*
Subsidised	*13.18*	*0.63*
Year of construction 1960-1969	*-2.07*	*0.03*
Year of construction 1970-1979	*-8.33*	*0.41*
Year of construction 1980-1989	*14.65*	*0.68*
Floorspace	-0.07	-0.01
Houses with 4 dwelling units	*4.15*	*-0,15*
Houses with 5 dwelling units	*-3.73*	*-0,12*
Reserved parking	*2.32*	*-0,04*
Number of addresses per square kilometre	1.46	0.01
Average family size	*2.93*	*-0,07*
Income per household	0.18	-0.01
No. of primary schools in postcode area	-1.57	0.01
No. of supermarkets in postcode area	*-2.22*	*0.04*
Built in densely populated provinces	*2.41*	*0,05*

Numbers in italics are significant on a 5% level

12.3 Single variable regression analysis

Table 12.3 shows the results of the single variable regression analysis.

These results show that the following properties significantly influence the exploitation result ($R > 0.17 = \frac{1.96}{\sqrt{130}}$):

- No. of houses the object consists of;
- Perc. of houses without rent restriction;
- Subsidised;
- Year of construction 1960-1969;
- Year of construction 1970-1979;
- Year of construction 1980-1989;
- Houses with 4 dwelling units;
- Houses with 5 dwelling units;
- Reserved parking;
- Average family size;
- No. of supermarkets in postcode area.

12.4 Multiple regression analysis

Using multiple regression analysis, three equations are found linking object properties to the Return on Investment.

First equation

This equation takes the percentage of houses without rent restriction and the year of construction into account.

$$y = 4450.00 + 1097.59 \cdot x_1 + 5316.77 \cdot x_2 \tag{12.2}$$

where:

y = Exploitation result in guilders
x_1 = Percentage of houses without rent restriction
x_2 = Year of construction 1980-1989

In this case the R^2_{adj} was 70.9% which means that over 71% of the exploitation result can be explained with these object properties.

Second equation

This equation takes the year of construction into account.

$$y = 10119.25 - 5323.77 \cdot x_1 - 5085.98 \cdot x_2 \tag{12.3}$$

where:

y = Exploitation result in guilders
x_1 = Year of construction in period 1960-1969
x_2 = Year of construction in period 1970-1979

In this case the R^2_{adj} was 61.2% which means that over 61% of the exploitation result can be explained with these object properties.

Third equation

This equation takes the number of houses the object consists of and the location into account.

$$y = 7272.88 - 16.02 \cdot x_1 + 1873.87 \cdot x_2 \tag{12.4}$$

where:

y = Exploitation result in guilders
x_1 = Number of houses the object consists of
x_2 = Built in densely populated provinces

In this case the R^2_{adj} was 17.6% which means that over 18% of the exploitation result can be explained with these object properties.

12.5 Conclusions

1. From the regression analysis can be concluded that the following object properties influence the Return on Investment and their effect on the ROI can be quantified in three linear equations.
    - Number of houses the object consists of
    - Year of construction
    - Percentage of houses without rent restriction
    - Built in densely populated western province
2. All other considered object properties turn out to be (statistically) irrelevant for the ROI.

13 Preference Measurement: The key to incorporating soft variables

The preference measurement described in Chapter 5 can be used for a great variety of choices or decisions:

- Choice of a holiday destination on criteria such as price, travel distance, sports facilities, and cultural events;
- Choice of a consumer product on criteria such as price, score in consumer tests, user friendliness, and expected service from a nearby dealer;
- Choice of a supplier on criteria such as price, expected service, reputation, and personal relation with the managing director.

Experience with those applications shows that this method not only helps to make the decision, but that it also increases awareness of the relative weight the decision maker attaches to the various criteria. The method is particularly useful for extremely complex cases involving many alternatives and many criteria.

13.1 The case of military airport Valkenburg

An example of such a complex case is the decision making on the future of the military airbase 'Valkenburg' (De Graaf et al., 2003), which will be described in this section.

History

Military airbase 'Valkenburg' has a rich history. Its location (Fig. 13.1) close to The Hague (Den Haag), where the Dutch Government resides, is of strategic importance. During the Second World War, the capture of the airbase was the first priority of German parachute troops in May 1940. After the war the airbase was returned to the Royal Navy to accommodate their aeroplanes and associated operations. The size of these operations has been steadily reduced over the last half century as a result of changes in the mission and tasks of the Navy. The Navy's aircraft carrier was sold and the helicopters to support frigates in their anti-submarine operations were moved to Den Helder, the harbour hosting the Navy's fleet. Only a few functions remained for the airbase 'Valkenburg':

- NATO airport and home base for thirteen long-distance four propeller Lockheed Orion aeroplanes of the Royal Navy;

Figure 13.1 Location of military airbase 'Valkenburg'

- Airport for governmental flights, performed by the Royal Air Force;
- Airport for sport flights.

In total, this constitutes less than 10 000 flight movements yearly. This low occupancy of the airbase, although convenient to its users and attractive to the surrounding villages, makes it relatively costly. The poor economics provided a plausible argument to Leiden, the nearest city in the environment, in its political lobby to get the destination of the airbase changed to a residential area. After decades of political debate, Leiden's lobby culminated in the acceptance, on November 28, 2001, by the Dutch Parliament of the fifth memorandum urban planning ('Vijfde Nota over de Ruimtelijke Ordening', PKB deel 3), which includes moving the Navy's aeroplanes to Den Helder and allowing a residential development on 'Valkenburg' by the year 2010. The fate of the airbase seemed to be inescapable: its days were counted.

Mayor Van der Reijden of the village 'Valkenburg' (having only 3760 inhabitants) then took the remarkable initiative to ask our research group to support him in the crusade of his municipality against the closure of the airbase. Remarkable, because he accepted the condition that the group would be authorised to publish and present to the press any conclusions from their research, whatever these might be. On January 31, 2002, we presented our first preliminary observations:

- Some crucial stakeholders, including the municipalities of the surrounding villages, are excluded from the decision process;

- The discussions tend to be conducted within a too limited perspective, namely that Leiden's housing demand can only be resolved by a large-scale urban development;
- The security aspect is not taken into account in any report, as if the events of September 11, 2001, had never happened;
- The location 'Grote Polder' at the east side of Leiden is a priori excluded as a building location for Leiden without any argumentation that makes sense to an independent outsider.

On February 2, 2002, the wedding of crown prince Willem-Alexander and Máxima took place in Amsterdam. The fact that more than fifty VIP flights of guests took place via 'Valkenburg' received extensive attention on television, radio and in the press. The political debate in the media then really took off. Members of parliament raised questions. Petitions with 5 760 signatures of inhabitants of surrounding villages were offered to the relevant authorities. On April 16, 2002, the government stumbled over the issue Sebrenica and resigned. On April 17, 2002, parliament decided to leave the fifth memorandum urban planning to the next government. On May 6, 2002, the upcoming political leader Pim Fortuyn was murdered. His party achieved a landslide victory in the elections, but its participation in government lasts only 86 days: on October 10, 2002, the prime minister handed in the resignation of his government to the queen because of too much internal quarrelling in the party of Fortuyn, where his leadership was badly missed. At the moment of writing the future of the airbase 'Valkenburg' is still in the dark.

Preference Modelling

At first, the issue was considered from the viewpoint of preferences of stakeholders: what options are preferable in view of various criteria? Three basic options were considered for the destination of the area:

- Airport;
- Protected nature reservation;
- Residential area.

Initially, five criteria were taken into account:

- Security (both defence of the region against terrorist attacks and safety of VIPs);

Table 13.1 Location - function alternatives and preference input values

	VB	GP	DB	DH	WD	RA	AA
A1	MA VA	RA	-	-	-	-	-
A2	MA VA	-	RA	-	-	-	-
A3	RA	-	-	MA	-	VA	-
A4	RA	-	-	MA	-	-	VA
A5	RA	-	-	-	MA	VA	-
A6	RA	-	-	-	MA	-	VA
A7	NA	RA	-	MA	-	VA	-
A8	NA	RA	-	MA	-	-	VA
A9	NA	RA	-	-	MA	VA	-
A10	NA	RA	-	-	MA	-	VA
A11	NA	-	RA	MA	-	VA	-
A12	NA	-	RA	MA	-	-	VA
A13	NA	-	RA	-	MA	VA	-
A14	NA	-	RA	-	MA	-	VA

Legend: A1. . . 14: Alternatives 1–14
VB: Valkenburg; GP: Grote polder; Duin- en bollenstreek; DH: Den Helder; WD: Woensdrecht;
RA: Rotterdam airport; AA: Amsterdam airport; MA: Military Airbase; VA: VIP Airport;
RA: Residential area; NA: Nature area

- Protection of nature;
- Housing demand;
- Infrastructure consequences;
- Economics.

Three different functions have to be fulfilled:

- Military airbase (MA);
- VIP airbase (VA);
- Residential area (RA).

In addition to the location 'Valkenburg', two other location alternatives were considered for each of these three functions, which yields seven location alternatives in total. Combining these seven location alternatives with the three possible functions for the location 'Valkenburg' yields the fourteen location-function combinations as given in Table 13.1.

Preferences are expressed on a scale of 1 (worst imaginable) to 8 (ideal). The fourteen alternatives have to be considered in the light of the five criteria

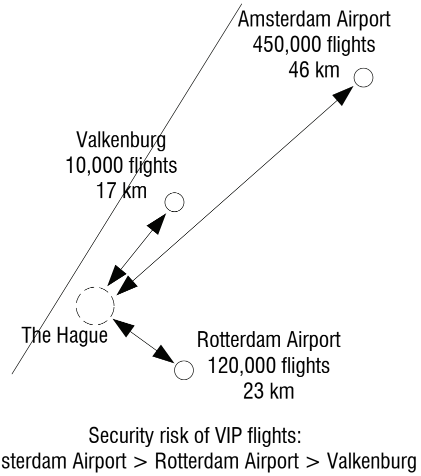


Figure 13.2 Preference scaling according criterion 'Security of VIPs'

mentioned before: security, nature, housing, infrastructure and economics. These criteria have to be further subdivided to relate them to the various geographical possibilities, which yields a total of ten criteria. The location of a 10 000 house urban development seriously affects the water management of the province. For this reason, water management has been added as the eleventh criterion.

The first step is to scale each of the fourteen alternatives on the eleven criteria scales. As an example, let us consider the criterion 'Security for VIPs'. Security risk of VIPs is reduced by low airport occupation and short distance to The Hague (Fig. 13.2), hence the preference ratings 2, 5, 7 for, respectively, Amsterdam, Rotterdam and Valkenburg. The complete matrix of the preference input values is given in Table 13.2.

The next step is to trade-off the various criteria. For instance, the trade-off 'Security for VIP flights' versus 'Economics of the VIP airport' is obtained by establishing two equally preferred combinations of the two criteria (Table 13.3). In this example, more weight is assigned to 'Security for VIP flights' than to 'Economics of the VIP airport'. The complete list of trade-off input values is given in Table 13.4.

Scaling the preferences and establishing the trade-offs between the criteria were conducted using, as genuinely as possible, the numerous reports on the subject, which were available from a variety of sources. The PFM software (see Section 5.2) can then establish the overall order of preference for the fourteen alternatives (Table 13.5).

Two alternatives deserve special attention:

Table 13.2 Preference input values

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
	NP	NP	NP	HN	SC	SC	WT	IS	EC	EC	EC
	MA	VA	RA	RA	NL	VIP	RA	RA	MA	VA	RA
Ideal	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
A1	7.2	7.0	7.0	5.0	7.0	7.0	2.0	6.0	7.0	7.0	7.0
A2	7.2	7.0	2.0	5.0	7.0	7.0	5.0	2.0	7.0	7.0	2.0
A3	2.0	4.0	3.0	5.0	2.0	5.0	2.0	2.0	2.0	3.0	4.0
A4	2.0	2.0	3.0	5.0	2.0	2.0	2.0	2.0	2.0	2.0	4.0
A5	3.0	4.0	3.0	5.0	4.0	5.0	2.0	2.0	5.0	3.0	4.0
A6	3.0	2.0	3.0	5.0	4.0	2.0	2.0	2.0	5.0	2.0	4.0
A7	2.0	4.0	7.0	5.0	2.0	5.0	2.0	6.0	2.0	3.0	7.0
A8	2.0	2.0	7.0	5.0	2.0	2.0	2.0	6.0	2.0	2.0	7.0
A9	3.0	4.0	7.0	5.0	4.0	5.0	2.0	6.0	5.0	3.0	7.0
A10	3.0	2.0	7.0	5.0	4.0	2.0	2.0	6.0	5.0	2.0	7.0
A11	2.0	4.0	2.0	5.0	2.0	5.0	5.0	2.0	2.0	3.0	2.0
A12	2.0	2.0	2.0	5.0	2.0	2.0	5.0	2.0	2.0	2.0	2.0
A13	3.0	4.0	2.0	5.0	4.0	5.0	5.0	2.0	5.0	3.0	2.0
A14	3.0	2.0	2.0	5.0	4.0	2.0	5.0	2.0	5.0	2.0	2.0
Worst	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Legend: A1. . . 14: Alternatives 1–14
NP: Nature preservation; HN: Housing need; SC: Security; WT: Water; IS: Infrastructure;
EC: Economics; MA: Military Airbase; VA: VIP Airport; RA: Residential area; NA: Nature area;
NL: National.

Table 13.3 Example of establishing a trade-offs ratio

	I	II
Security of VIP flights	4.0	3.0
Economics of VIP airport	2.0	8.0

Trade-off ratio: (8 - 2) / (4 - 3) = 6.0

Table 13.4 Trade-off input values for computing ratio's

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
	NP	NP	NP	HN	SC	SC	WT	IS	EC	EC	EC
	MA	VA	RA	RA	NL	VIP	RA	RA	MA	VA	RA
C1	-	1.0	1.0	0.8	1.2	1.2	0.4	0.6	0.2	0.2	0.2
C2	1.0	-	1.0	0.8	1.2	1.2	0.4	0.6	0.2	0.2	0.2
C3	1.0	1.0	-	0.8	1.2	1.2	0.4	0.5	0.2	0.2	0.2
C4	1.3	1.3	1.3	-	1.5	1.5	0.5	0.8	0.3	0.3	0.3
C5	0.8	0.8	0.8	0.7	-	1.0	0.3	0.5	0.2	0.2	0.2
C6	0.8	0.8	0.8	0.7	1.0	-	0.3	0.5	0.2	0.2	0.2
C7	2.5	2.5	2.5	2.0	3.0	3.0	-	1.5	0.5	0.5	0.5
C8	1.7	1.7	1.7	1.3	2.0	2.0	0.7	-	0.3	0.3	0.3
C9	5.0	5.0	5.0	4.0	6.0	6.0	2.0	3.0	-	1.0	1.0
C10	5.0	5.0	5.0	4.0	6.0	6.0	2.0	3.0	1.0	-	1.0
C11	5.0	5.0	5.0	4.0	5.0	5.0	2.0	3.0	2.0	2.0	-

Legend:
NP: Nature preservation; HN: Housing need; SC: Security; WT: Water; IS: Infrastructure;
EC: Economics; MA: Military Airbase; VA: VIP Airport; RA: Residential area; NA: Nature area;
NL: National.

Table 13.5 Results of preference modelling

Alternative	Overall Preference
A1	6.49
A2	5.56
A3	4.62
A4	4.13
A5	3.87
A6	3.72
A7	3.69
A8	3.38
A9	3.23
A10	3.21
A11	2.97
A12	2.95
A13	2.49
A14	2.46

- Alternative 2: the option to maintain 'Valkenburg' as a military airbase for both the Navy and VIP flights, combined with a residential area in the (politically taboo) 'Grote Polder' turns out to be the most preferable option.
- Alternative 5: the option to turn the airbase into a residential area, as preferred in the fifth memorandum urban planning and still the official political choice, scores extremely low in the preference ranking.

As a sensitivity analysis with limited deviations, on both the scaling of the preferences and on the trade-offs, did not change this outcome, the question was raised which criteria have to be ignored altogether to get Alternative 5 at the top of the list. It turns out that Alternative 5 only becomes the most preferable option if:

- The criterion 'Security' is completely ignored for both defence and VIPs.
- The nature value of the grass land 'Grote Polder' is valued more highly than the bird breeding area Waddenzee, the dunes, and the flower bulb area.
- The huge infrastructure cost related to locating 10 000 houses on the land and the cost of moving the military activities to Den Helder are ignored.

These conditions demonstrate the absurdity of the original political course. Why this could happen is further elaborated in Chapter 14.

14 Integrating LP Multi Criteria Optimisation and Preference Modelling

How could the authorities come to their erroneous point-of-view on the future of 'Valkenburg'? Are politicians so dumb and ignorant that they cannot follow the reasoning given in Section 13.1? That would be too simple an explanation. More plausible is that an airbase with less than 10 000 flight movements per year is perceived as a luxury by powerful political pressure groups, and in particular by Leiden's municipality. The economics of the airbase, determined by its occupancy, have to be taken into account. Straightforward preference modelling cannot do this. In order to assess the optimum occupancy, expressed in flight movements per year, we have to combine Preference Modelling with LP Multi Criteria Optimisation.

The fixed cost of the airbase is in the order of € 13 million per year. The variable cost per flight movement (each flight entails two flight movements: a take-off and a landing) can be estimated to be € 2 000 for military flights and € 1 000 for (semi-)civil flights. The number of military flights is about 5 000 per year, the remainder being (semi-)civil flights. With these estimates, the average flying cost per flight movement becomes as presented in Figure 14.1. The conclusion is that the economics of the airbase improve dramatically if its occupancy can be increased above the current level of about 10 000 flight movements per year. This level is extremely low compared to the two other airports in the region – Amsterdam airport 'Schiphol' and Rotterdam airport 'Zestienhoven' – which, respectively, process about 450 000 and 120 000 flight movements each year. Clearly, there is still considerable room for improving the economics of the airbase by attracting more civil use of it.

The preference of the surrounding municipalities for maintaining the air-

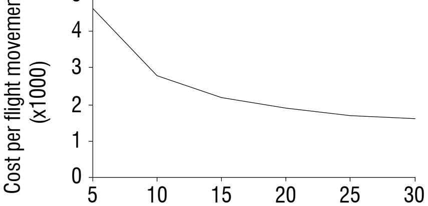


Figure 14.1 Average flying cost per flight movement as a function of occupancy of the airbase

base, however, will decrease with increasing occupancy and this may affect the order of preference of the alternatives of Table 13.5. So the question we have to answer is: To what extent can the occupancy of the airbase be increased without affecting the position of maintaining the airbase as the most preferable option? To this end, an LP optimisation program was written which integrates Open Design Multi Criteria Optimisation and Preference Modelling with the allowance described below for a decision variable (number of flight movements) dependent preference (for nature).

Allowing for decision variable dependent preferences

So far, the assumption was made that the scaling of preferences is not affected by any variations in the decision variables. This assumption has to be removed whenever a preference is dependent on the value of a decision variable. For instance, the preference for maintaining an airbase from the part of the surrounding municipalities will be dependent on the number of flight movements per year. This relationship is non-linear (Fig. 14.2). Beyond a certain threshold of flight movements per year, the preference will drop sharply. This threshold is in the order of three flight movements per hour. Allowing day flights only, this means about 13 400 flight movements per year. When twice this number of flight movements is allowed, the preference for maintaining the airbase will flatten out at a fairly low level. In the LP model, we assume a linear relationship as determined by these two threshold points.

A sensitivity analysis on the scaling of the preference value for nature (associated with Valkenburg as a military airbase) shows that this preference value must be kept above 2.82 (which corresponds to one flight per 11.8 minutes) to ensure that Alternative 2 of Table 13.5 – maintaining the military airbase at Valkenburg – remains the best option. Figure 14.2 was used for the relationship between the occupancy and the average flying cost per flight movement.

The LP program optimises the economics, expressed in the number of flight movements, under a constraint for the preference value for nature. Conversely, it maximises the overall preference value, while setting a constraint for the cost per flight movement. By doing this repeatedly for various constraint values, the average flying cost per flight movement, the preference value for nature and the overall preference are found as a function of the occupancy of the airbase (Fig. 14.3).

The curves represent the Pareto set of solutions of the LP model. They can be used in negotiations among stakeholders. For instance, surrounding villages could agree on a tax charge to them to keep the occupancy of the airbase at a somewhat lower level than according to the economic constraint (average flying cost per flight movement) required by the government. A justifiable value for that constraint is the average cost per flight movement corresponding with an occupancy for which maintaining the airbase just remains the best option.

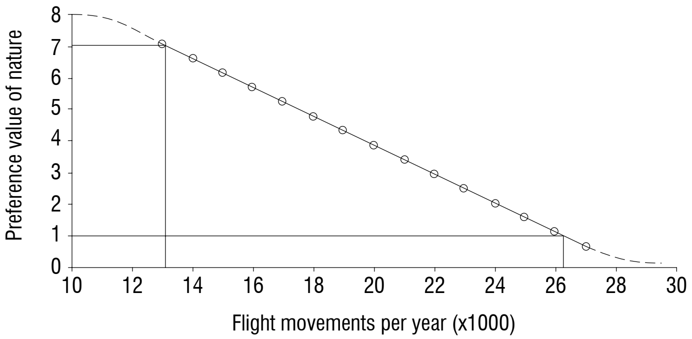


Figure 14.2 Preference for maintaining the airbase depends on its occupancy

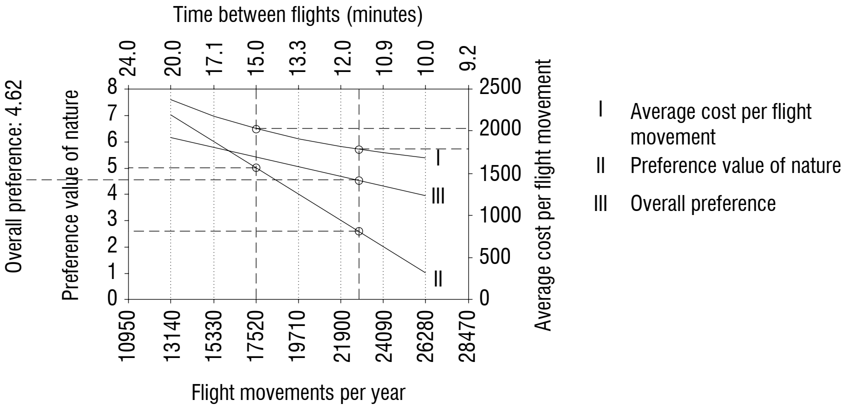


Figure 14.3 Average flying cost per flight movement, preference value for nature and overall preference as a function of airbase occupancy

From Table 13.5, we can derive that this turning point is at an overall preference value of 4.62. The corresponding occupancy and average cost per flight movement are, according to Figure 14.3, 22 300 flight movements per year and an average cost per flight movement of € 1 807. The associated average time between flights is 11.8 minutes.

If the surrounding villages would wish to bring this time between flights to, say, 15 minutes, they would have to pay taxes to cover the difference in average cost per flight movement of € 2 027 and € 1 807 (times the reduced number of flight movements of 17 520 per year). The corresponding tax for the 86 000 inhabitants of the surrounding villages would be around € 40 per inhabitant per year.

Combined preference modelling with LP-optimisation for airbase Valkenburg

The essence of the LP model is an assignment model with additional constraints. Within this assignment model, four functions – military airbase, VIP airport, residential area, and nature area – are assigned to seven locations, according to the preferences for a location in the light of six criteria – security, nature, housing, infrastructure, economics, and water management.

First, the preference measurement model described in Section 5.2 was used as the basis for the LP model, to find the overall order of the preferences of the alternatives from the viewpoint of the stakeholders.

$$\text{Maximise} \quad P = \sum_{i=1}^{m} \sum_{j=1}^{n} w_j p_{i,j} B_i \tag{14.1}$$

subject to:

$$\begin{aligned}
\sum_{i=1}^{m} B_i &= 1 \quad \text{where} \quad \forall_i B_i \in \{0,1\} \\
\forall_i B_i &\in \{0,1\} \\
F_t &= F_{ma} + F_{vip} + F_{com} \\
F_{ma} &\geq 5000 \\
F_{vip} &\geq 1000 \\
F_{com} &\geq 0 \\
F_t &\geq 30000 \\
F_t &= C_{fixed} + c_{ma} F_{ma} + c_{vip} F_{vip} c_{com} F_{com}
\end{aligned}$$

where:

P = overall preference of the alternative yielding the highest preference;
$p_{i,j}$ = preference for alternative i according criterion j;
i = index i refers to the alternatives ($i = 1, 2, 3, \ldots, m$);
j, k = indices j, k refer to the criteria ($j, k = 1, 2, 3, \ldots, n$);
m = total number of alternatives;
n = total number of criteria;
$r_{j,k}$ = ratio of the trade-offs between criteria j and k;
w_j = weight factor w_j of criterion C_j , determined by the ratios $r_{j,k}$ between the trade-offs;
B_i = Binary variable indicating if alternative i is chosen (value = 1) or not chosen (value = 0);
F_t = total number of flight movements per year;
F_{ma} = number of military flight movements per year;
F_{vip} = number of VIP flight movements per year;
F_{com} = number of commercial flight movements per year;
C_t = total costs of flight movements;
C_{fixed} = fixed costs for the military airbase;
c_{ma} = operational cost per military flight movement;
c_{vip} = operational cost per VIPflight movement;
c_{com} = operational cost per commercial flight movement.

Parameters used in all calculations:

m = 14;
n = 11;
$p_{i,j}$ = preference input values according to Table 13.2;
$r_{j,k}$ = trade-off ratio input values according Table 13.4.

With these parameters, the weight factors w_j ($j = 1, 2, \ldots, 11$) were calculated with the method described in Section 5.2. The result is given in Table 14.1.

In the LP optimisations, the following cost parameters were used:

C_{fixed} = € 13 million;
c_{ma} = € 2 000 per flight movement;
c_{vip} = € 1 000 per flight movement;
c_{com} = € 1 000 per flight movement.

The Pareto-set of optimum solutions is then obtained by systematically:

- Varying the constraint for the average cost per flight movement while optimising the preference value for nature, and

Table 14.1 Weight factors

Constraints	C1	C2	C3	C4	C5	C6
Functions	NP MA	NP VA	NP RA	HN RA	SC NL	SC VIP
Weight factors	0.128	0.128	0.128	0.103	0.154	0.154

Constraints	C7	C8	C9	C10	C11
Functions	WT RA	IS RA	EC MA	EC VA	EC RA
Weight factors	0.051	0.077	0.026	0.026	0.026

Legend:
NP: Nature preservation; HN: Housing need; SC: Security; WT: Water; IS: Infrastructure;
EC: Economics; MA: Military Airbase; VA: VIPs Airport; RA: Residential area; NA: Nature area;
NL: National.

- Varying the constraint for the preference value for nature while optimising the average cost per flight movement.

A linear relationship is assumed for the nature preference value as a function of the airbase occupancy (Fig. 14.3).

This relationship is incorporated in the model by adding the following constraints:

$$p_{2,1} = s_1 \times F_t + b_1 \qquad p_{2,1} \geq p_{min} \tag{14.2}$$

where:

$p_{2,1}$ = preference for nature in alternative 2;
p_{min} = minimum preference for nature in alternative 2;
s_1 = slope of the line defining the relationship between the number of flight movements and the preference value for nature;
b_1 = intercept of the line defining the relationship between the number of flight movements and the preference value for nature.

Parameters used:

p_{min} = 3.0;
s_1 = -0.00050;
b_1 = 11.9.

The results are summarised in Figure 14.3 which provides the necessary information for sound political decision making on the destiny of the airbase.

15 Multi Criteria Optimisation

Open Design methodology, in essence optimisation by means of linear and non-linear programming with negotiable constraints, is a concept that facilitates the resolution of major governmental issues through dialogue and exchange of views (Van Gunsteren and Van Loon, 2000). As it offers concepts and methods that combine technical optimisation and social optimisation into one integrated process, it provides new solutions to the multi-stakeholder problem of urban planning projects.

What Open Design methodology can contribute to complex urban planning projects is illustrated in this chapter with the case of the extension of Schiphol Airport, Amsterdam*. To maintain its position as a European main port (an airport for intercontinental flights), the number of flight movements per year has to increase beyond the current limits that are in force because of noise hindrance. This represents a major political issue that has by no means been resolved yet.

A solution for this dilemma is to move all take-off and landing operations to an artificial island in the North Sea (Van Gunsteren, 2000a). The Ministry of Transportation, however, has recently discarded this option.

In this chapter, the third option is explored with Open Design methodology, namely, using an island also to relieve other European airports from intercontinental air traffic. The conclusion is that such a European airport in the North Sea would have great economic potential. Its realisation, however, requires that decision making on the issue be moved from a national to an international level.

15.1 Rational and irrational decision making

We call a decision rational if this decision yields an economic advantage for the decision maker. The decision is called irrational when the decision entails an economic disadvantage for the decision maker. It should be noted that there is nothing wrong with taking irrational decisions because there may be valid considerations to justify them. Political decisions are sometimes rational, but often they are irrational, as is illustrated in Table 15.1.

Computer aided decision making is generally associated with rational decision making. It should be noted, however, that computer modelling can contribute to both rational and irrational decision making, as we will illustrate with the case of an airport in the North Sea†.

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*Published in (Van Gunsteren, 2005) and reproduced here by courtesy of Elsevier Science Ltd.

†The mathematics of the case have been elaborated further in (Galperin, 2002).

Table 15.1 Some major political decisions in Europe

Decision	Rational/Irrational
Formation of the European Union	Rational. The yearly cost savings of a united Europe were estimated well over $ 300 billion.
Concorde project	Irrational. The UK and France lost billions of dollars in the venture. As a loss was expected, the collaboration contract between the two countries included a clause that no one could stop the project before its completion. The decision was taken for prestige, not profit.
Introduction of the Euro-dollar	Irrational, as far as the northern countries is concerned. These countries used to have a high productivity compared to the southern countries. The central banks could correct for the differences by appropriate devaluation of the southern countries' currencies. This is no longer possible with the Eurodollar. Inflation imported from the Southern countries is unavoidable. The decision for one money unit was nevertheless taken.

15.2 Airport in the North Sea, a rational but probably infeasible option for Schiphol, Amsterdam

The dilemma for Schiphol Airport Amsterdam is the following:

1. To maintain its position as a main port, an airport for intercontinental traffic serving as a 'hub' for further travel and distribution of goods in Europe, the number of flight movements per year should be above certain threshold.

2. To keep the environmental effects, in particular, noise but also air pollution, within acceptable limits the number of flight movements should be kept below certain level.

The minimum number of flight movements as required by market conditions to maintain a position as main port has steadily increased over the past decades. At the same time the maximum number of flight movements in view of noise hindrance and air pollution as demanded by environmentalists remained at more or less the same level. As a result, the 'walk out' values for this constraint as required on one hand by the airport Schiphol (and KLM) and on the other by the environmental pressure groups have moved into a very small range (in the order of 600 000 flight movements per year). In open design terminology: the solution space has become extremely small.

On a longer term, this dilemma could be resolved by the North Sea Island option, i.e. moving the take-off and landing of airplanes to an artificial island in the North Sea which is connected by a train shuttle to the present Schiphol airport. From there, inland transport of passengers and distribution of goods takes place. Transfer passengers remain on the island. Obviously, for the North Sea Island option the number of flight movements per year is no longer the overriding critical constraint, but other factors come into play which may or may not turn out to be critical:

1. Investment, I; the option could simply become too expensive for financing parties, e.g., the government.
2. Time, t, passengers would have to spend in the shuttle; to remain competitive, delay due to travelling to and from the island has to be kept below a market-dictated ceiling;
3. Distance, d, between the island and the shoreline; to avoid hindrance, particularly noise, to coastal residential areas, the island cannot be located too close to the shore;
4. Flight movements, f, per year; this number must be large enough, not only to comply with the minimum required for any main port, but also in view of economic feasibility (economies of scale).

Let us make an open design simulation with only these four constraints. Of course, when it comes to implementation, a model with hundreds constraints would have to be made and also the parameters (coefficients in the inequalities) would have to be established with far greater precision than the extremely rough estimates made here.

The following LP model can be formulated, arbitrarily choosing investment I as the variable to be optimised:

$$\text{Minimise} \quad I = I_0 + C_{If}(f-6) + C_{Id}n(d-10) \tag{15.1}$$

subject to

$$t \leq t_c; \qquad d \leq d_c; \qquad f \leq f_c; \qquad vt = d_0 + d$$

where

I_0 = investment to build an island for 600 k flight movements per year at a distance of 10 km from the shore line
C_{If} = increase of required investment per 100 k flight movements more than 600 k
C_{Id} = increase of required investment per km more distance from the shore than 10 km
d_0 = distance shuttle train travels over land
v = average speed of shuttle train
n = number of tunnels to the shore

(subscript c denotes constraint value used in the LP model).

The values of parameters used in our simulations were:

I_0 = $ 15 billion;
C_{If} = $ 0.15 billion/100 k flight movements;
C_{Id} = $ 0.4 billion/km;
d_0 = 30 km;
v = 100 km/hour;
n = 1 for national airport; 2 for European mega hub.

In multi-criteria optimisation, various variables are chosen in turn as the variable to be optimised. In the case another variable than investment is optimised, the investment has to be added as a constraint: $I \leq I_c$, and the constraint limiting the variable to be optimised has to be removed.

As a measure of economic feasibility, we introduce return on investment, ROI, which is the yearly exploitation revenues E, from a tax per passenger, over the investment I: $ROI = \frac{E}{I}$.

The yearly exploitation revenues E are related to the number of flight movements by the tax per passenger and the average number of passengers per flight. In our simulations, for both the national airport and the European mega hub option, we used for these parameters 100 passengers per flight and a tax of $ 20 per passenger. The constraint ranges that were used are given in Table 15.2, and the results of various pilot runs in Table 15.3.

The return on investment for the final run: $ROI = \frac{2}{20.6} = 0.10$. The conclusion is that the North Sea Island option could significantly increase the solution space for the problem of the extension of Schiphol airport required to maintain its position as main port.

Our open design simulation indicates that a decision to build a national airport in the North Sea can be called rational from a national economic point of view. It would allow Schiphol to grow almost without limits giving the airport a competitive advantage over other main airports like London, Frankfurt and

Table 15.2 Constraints ranges in open design simulation of North Sea Island option for Schiphol (as a national airport)

Stakeholder	Variable	Constraint ranges		
		Walk-out	Acceptable	Ideal
Ministries of Finance and Economics	I [\$ billion]	40	25	15
Airlines (KLM)	t [hours]	0.9	0.7	0.5
Ministry of Environment	d [km]	20	30	40
Airport (Schiphol)	f [100 k]	6	8	10

Table 15.3 Results of the open design simulation of the North Sea Island option for Schiphol (as a national airport)

Pilot run	I	t	D	f
	[\$ billion]	[hours]	[km]	[100 k]
Ideal values	*infeasible*	0.500	40.0	10.00
Acceptable values	*19.3*	0.700(0.600)	30.0	8.00
Walk-out values	*17.0*	0.900(0.500)	20.0	6.00
$P = 0.222$; calculated with ideal values	19.5	0.611	31.1	7.78
Design for maximum capacity	*19.8*	0.611	31.1	10.00
Multi Criteria optimisation: Ministry of Environment relaxes its constraint	19.8(19.6)	*0.600*	30.0	10.00
Multi Criteria optimisation: airlines relax their constraint	19.8	0.700(0.611)	*31.1*	10.00
Final run; I in objective function, d between acceptable and walk-out values	*20.6*	0.700(0.650)	35.0	10.00

Numbers in italic represent optimised values.

When there is a slack, the values in the optimum solution are given between brackets.

P is fraction by which all constraints have to be (equally) relaxed to achieve feasibility.

Paris. But would that option be feasible? Environmentalists will find plenty of arguments against it. Consequently, politicians will be reluctant to approve public funding for it, which is a necessary condition for implementation. The key question, therefore, is: How can sufficient political power be generated to build such an island and overcome the associated political problems? One way would be to make it a European issue instead of a national one, thereby making the previously discussed economic decision also politically viable.

15.3 A European airport in the North Sea, a rational and feasible option for the European main airports

Environmentalists are, in general, not interested in local solutions which only move pollution problems elsewhere. They wish to resolve pollution issues globally. In regard to air transport, they favour substitution of air transport by rail transport.

For the long distances of intercontinental connections, air transport is the only possibility when travel time is of any importance. Intercontinental trains simply do not exist. As a result, environmentalists tend to accept intercontinental flights, but resist short distance flights for which the train offers a good alternative. They would favour any solution which combines intercontinental transport through the air with continental transport, largely by high-speed trains. Such a solution is offered by the option of an European airport in the North Sea, serving as a main port not only to Amsterdam, but also to London, Paris and Frankfurt*. The continental connections from the airport in the North Sea to those cities could be both airplanes and high-speed trains. The latter would allow restrictions of flight movements around the cities mentioned before. To get insight in the consequences of the option of an European airport in the North Sea we have to accommodate it in our open design simulation. Of course, the island should be much larger and should be located at a larger distance from the shore but, in essence, the same mathematical model can be used. The current throughput of the four airports is given in Table 15.4.

The results of the Open Design simulation are given in Tables 15.5 and 15.6. [○ c_mco-1.xls, c_mco-2.xls]

The return on investment for the final run: $ROI = \frac{6}{38.6} = 0.16$. The conclusion is that the feasibility of a European mega hub in the North Sea is definitely better than of an island for a national airport only. It alleviates significantly a serious pollution problem for four major cities in Europe and allows air travel to grow according to market demands. In addition, its economic feasibility is a lot better due to large-scale benefits, which improve the return of investment by some sixty percent.

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*This idea originates from the TUD-MIT Workshop 'Schiphol Airport as a Sustainable City', Delft, 2001 (CD-ROM obtainable through the authors).

Table 15.4 Current yearly throughput of four airports

	No. of passengers [millions]	Amount of freight [million tons]
1. Amsterdam	36.7	1.18
2. London	102.3	1.74
3. Paris	68.9	1.23
4. Frankfurt	45.4	1.40

Table 15.5 Constraints ranges in open design simulation of North Sea Island option for Schiphol (as a European mega hub)

Stakeholder	Variable	Constraints ranges		
		Walk-out	acceptable	ideal
Ministries of Finance and Economics	I [$ billion]	120	75	45
Airlines	t [hours]	1.35	1.05	0.75
Ministries of Environment	d [km]	30	45	60
Airports	f [100 k]	18	24	30

Table 15.6 Results of the open design simulation of the North Sea Island option for Schiphol (as a European mega hub)

Pilot run	I [$ billion]	t [hours]	D [km]	f [100 k]
Ideal values	*infeasible*	0.75	60.0	30.00
Acceptable values	*33.7*	1.05(0.750)	45.0	24.00
Walk-out values	*26.8*	1.35(0.600)	30.0	18.00
$P = 0.267$; calculated with ideal values	37.7	0.833	53.3	28.33
Design for maximum capacity	*37.9*	0.833	53.3	30.00
Multi Criteria optimisation: Ministry of Environment relaxes its constraint	37.9	*0.833*	53.3	30.00
Multi Criteria optimisation: airlines relax their constraint	37.9	1.05(0.833)	*53.3*	30.00
Final run; I in objective function, d between acceptable and walk-out values	*36.6*	1.05(0.850)	55.0	30.00

Numbers in italic represent optimised values.
When there is a slack, the values in the optimum solution are given between brackets.
P is fraction by which all constraints have to be (equally) relaxed to achieve feasibility.

15.4 Conclusions

Open Design methodology (mathematical modelling by means of linear and non-linear programming with negotiable constraints) is proposed to support decision making on major infrastructure investments. The method is applied to the extension on Schiphol airport, Amsterdam. Of the three options for the extension: at the current location, or moving take-off and landing operations to an artificial island in the North Sea, or using the island also to relieve other European airports from intercontinental air traffic, the latter is the best as demonstrated by the Open Design simulations.

16 Non-linear, local, optimisation

Chapter 15 showed that Open Design methodology can contribute to complex urban planning projects like the extension of Schiphol Airport, Amsterdam. Extensions on both a national and a European level were explored and it was shown that both options were feasible. The airport on a European level showed to have a better return on investment, ROI, which is the yearly exploitation revenues E, from a tax per passenger, over the investment I: $ROI = \frac{E}{I}$. The yearly exploitation revenues E are related to the number of flight movements by the tax per passenger and the average number of passengers per flight.

The results of both simulations are given in Table 16.1. [○ c_mco-1.xls, c_mco-2.xls]

For both simulations an LP model was used aimed at minimising the investment. Economy-of-scale is not taken into consideration. To do so the ROI would have to be optimised. The ROI takes the investment and the revenues into account, so it would be better to optimise this variable. Because the ROI is a fraction of endogenous variables ($ROI = \frac{E}{I}$) it turns the linear model into a non-linear model. As a result the outcome of both simulations will be a local optimum, as opposed to a global optimum.

16.1 Optimisation of ROI

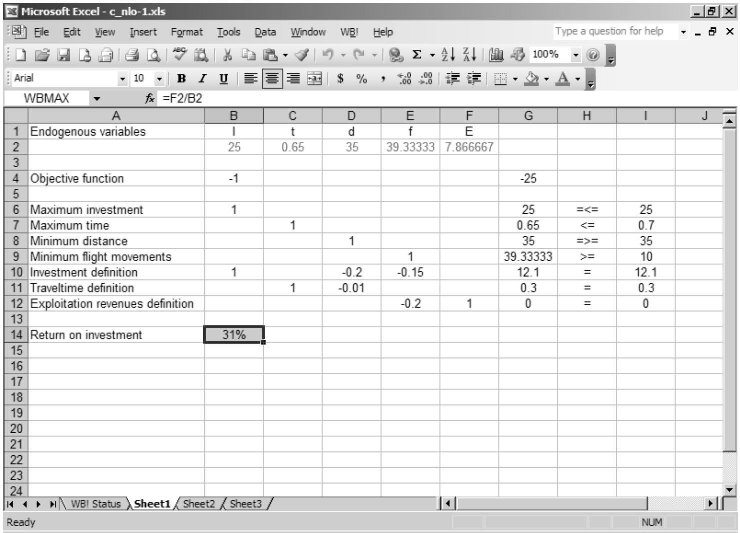
The results of optimising the ROI are shown in Figure 16.1 (national level) and Figure 16.2 (European level) and are summarised in Table 16.2. [○ c_nlo-1.xls, c_nlo-2.xls]

Note that by increasing the number of flight movements, the ROI has increased from 10% to 31% on the national level and from 16% to 38% for the European level. As a result however, the number of flight movements increased beyond a realistic market demand. This means that we have to specify

Table 16.1 Results aimed at minimising the investment

Pilot run	I [$ billion]	t [hours]	D [km]	f [100 k]	ROI [%]
National airport in North Sea	*20.6*	0.700 (0.650)	35.0	10.00	10
European airport in North Sea	*36.6*	1.05 (0.850)	55.0	30.00	16

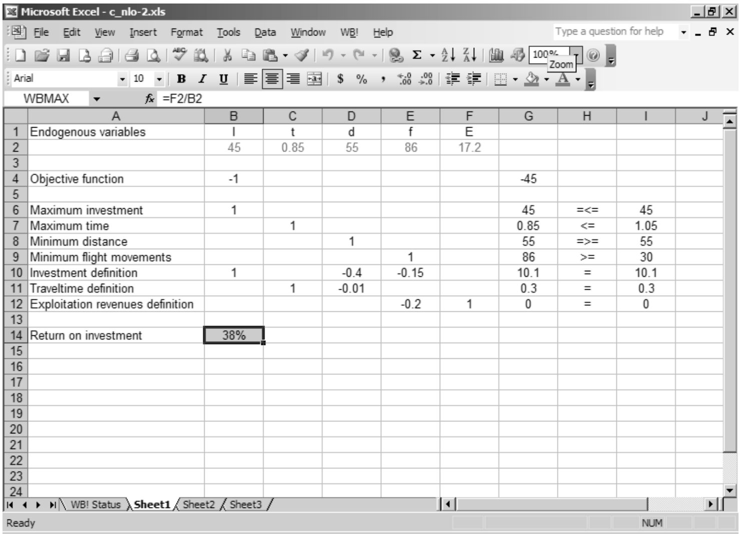
Numbers in italic represent optimised values.
When there is a slack, the values in the optimum solution are given between brackets.



WBMAX =F2/B2

	A	B	C	D	E	F	G	H	I	J
1	Endogenous variables	I	t	d	f	E				
2		25	0.65	35	39.33333	7.866667				
3										
4	Objective function	-1					-25			
5										
6	Maximum investment	1					25	=<=	25	
7	Maximum time		1				0.65	<=	0.7	
8	Minimum distance			1			35	=>=	35	
9	Minimum flight movements				1		39.33333	>=	10	
10	Investment definition	1		-0.2	-0.15		12.1	=	12.1	
11	Traveltime definition		1	-0.01			0.3	=	0.3	
12	Exploitation revenues definition				-0.2	1	0	=	0	
13										
14	Return on investment	31%								

Figure 16.1 Screenshot solved model (national airport)



WBMAX =F2/B2

	A	B	C	D	E	F	G	H	I	J
1	Endogenous variables	I	t	d	f	E				
2		45	0.85	55	86	17.2				
3										
4	Objective function	-1					-45			
5										
6	Maximum investment	1					45	=<=	45	
7	Maximum time		1				0.85	<=	1.05	
8	Minimum distance			1			55	=>=	55	
9	Minimum flight movements				1		86	>=	30	
10	Investment definition	1		-0.4	-0.15		10.1	=	10.1	
11	Traveltime definition		1	-0.01			0.3	=	0.3	
12	Exploitation revenues definition				-0.2	1	0	=	0	
13										
14	Return on investment	38%								

Figure 16.2 Screenshot solved model (European airport)

Table 16.2 Results aimed at maximising the ROI

Pilot run	*I* [$ billion]	*t* [hours]	*D* [km]	*f* [100 k]	ROI [%]
National airport in North Sea	25	0.650	35.0	39.33	*31*
European airport in North Sea	45	0.850	55.0	86.00	*38*

Numbers in italic represent optimised values.
When there is a slack, the values in the optimum solution are given between brackets.

Table 16.3 Results aimed at maximising the ROI

Pilot run	*I* [$ billion]	*t* [hours]	*D* [km]	*f* [100 k]	ROI [%]
National airport in North Sea	21.35	0.650	35.0	15.00	*14*
European airport in North Sea	45	0.985	68.5	50.00	*22*

Numbers in italic represent optimised values.
When there is a slack, the values in the optimum solution are given between brackets.

an upper bound for the number of flight movements. Therefore, on a national level the market demand is restricted to 1 500 000 flight movements and on a European level to 5 000 000 flight movements.

The results of these simulations are summarised in Table 16.3. [○ c_nlo-3.xls, c_nlo-4.xls]

Using a non-linear instead of a linear model results for the return on investment in an increase from 10% to 14% on the national level, and from 16% to 22% for the European level.

The interpretation of this is: the non-linear model takes into account economies of scale and yields an outcome according to the market demand to be expected. The linear model, by contrast, minimises the investment and, as a result, gives the smallest airport as an outcome.

16.2 Optimisation of shuttle speed

Instead of optimising the ROI, the shuttle speed can also be optimised. In this case we still optimise the investment but add the shuttle speed to the endogenous variables for both models.

The results of both simulations are given in Table 16.4. [○ c_mco-5.xls, c_mco-6.xls]

The results show that optimising the shuttle speed does not yield any important new insights. Furthermore running this simulation with different initial values for the endogenous variables yields different shuttle speeds with

Table 16.4 Results aimed at minimising the investment; shuttle speed added to the endogenous variables

Pilot run	I [$ billion]	t [hours]	D [km]	f [100 k]	v [km/h]
National airport in North Sea	*20.6*	0.472 (0.650)	35.0	10.00	204
European airport in North Sea	*36.6*	1.05 (0.850)	55.0	30.00	171

Numbers in italic represent optimised values.
When there is a slack, the values in the optimum solution are given between brackets.

every run because of the fact that it is merely a local optimum.

16.3 Conclusions

When linearity does not apply there are several ways to resolve this:

- See whether an exponential pattern applies, for instance exponential preference behaviour;
- Use routines like the routine built in What's Best! that offer a local optimum;
- Carry out simulations using fixed values for the variables that would contribute to the non-linearity.

The first option is described in Chapter 7. The second option is described in this chapter. The third option is for instance used when not only the length and width of a building are considered endogenous but also the number of floors. By running the simulation several times, with each run having a different (fixed) number of floors, the optimal solution can be found.

17 Geometric modelling

The Stedelijk Museum Amsterdam (SMA), the museum of the city of Amsterdam presenting contemporary art, initiated the renovation of its main building on the Museumplein in 2004 (Fig. 17.1). The building, designed in 1895 by the architect A.W. Weissman, no longer met today's requirements for a museum. Over the last decades a chronic shortage of space had arisen. In the 1950s and '60s annexes and intermediate floors were already added to the main building. The Portuguese architect Alvaro Siza Vieira made the initial plans for the renovation of the old building and an extension. Based on these plans a preliminary bill of requirements was made. This bill of requirements was approved by the municipality along with a budget. The project consulting firm PKB was then asked to refine the bill of requirements to reduce the probability of overruns in time and money. With the aid of both a numerical and a geometrical computer model closely linked to each other, PKB was able to formulate a final bill of requirements that satisfies:

- The budgetary restrictions as imposed by the municipality;
- The geometrical restrictions as imposed by the existing buildings.

The process in which these two models were used to support decision-making and the models themselves are described in this chapter.

Starting point was the proposal of the municipality's so-called Sanders committee. This proposal comprised of a set of spatial restrictions and a budgetary restriction. The spatial restrictions were given in the form of bandwidths per function. In other words, both minimal and maximal floor space requirements were given.

17.1 The first numerical model

The Stedelijk Museum Amsterdam was requested by PKB to give detailed information about its requirements. In accordance with the proposal made by the Sanders committee, the Stedelijk Museum provided minimal and maximal floor space requirements. PKB also made some calculations on the cost of renovating the old building and on the cost per square meter of the extension.

With this information the first LP model was built. This model contained the following restrictions:

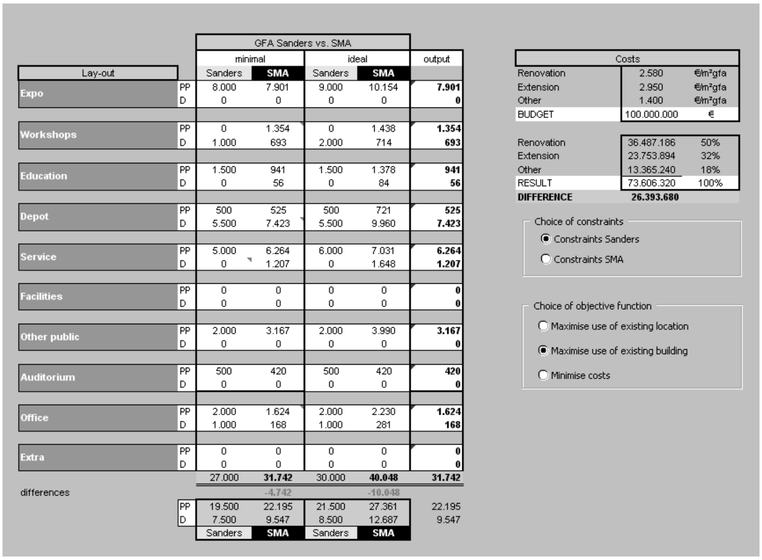
- Spatial restrictions and monetary restrictions as posed by the Sanders committee;

Figure 17.1 Stedelijk Museum, Amsterdam

- Spatial restrictions that were gathered by PKB after consulting the Stedelijk Museum;
- Geometrical restrictions as posed by the existing building and a storage facility elsewhere in the city of Amsterdam;
- Geometrical restrictions limiting the size of the extension.

Note that there were two sets of spatial restrictions, and as a result two solution spaces. Note also that this was a numerical model. The geometry of the existing building was only expressed in floor space restrictions. Figure 17.2 shows a screenshot of the output of the LP-model minimising cost.

The model could switch between the two sets of spatial restrictions and showed that the bill of requirements as gathered from the Stedelijk Museum did not meet the budgetary restriction. By temporarily ignoring the monetary restriction and switching between both sets of restrictions, the Stedelijk Museum could see to what extent their requirements differed from the requirements set by the Sanders committee and the monetary consequences. The Stedelijk Museum became convinced that it had to adjust its requirements. After doing so, the budgetary restriction was met. The spatial requirements were fixed from that moment on, upper and lower boundaries merged into single values.



		GFA Sanders vs. SMA				
		minimal		ideal		output
Lay-out		Sanders	**SMA**	Sanders	**SMA**	
Expo	PP	8.000	7.901	9.000	10.154	**7.901**
	D	0	0	0	0	**0**
Workshops	PP	0	1.354	0	1.438	**1.354**
	D	1.000	693	2.000	714	**693**
Education	PP	1.500	941	1.500	1.378	**941**
	D	0	56	0	84	**56**
Depot	PP	500	525	500	721	**525**
	D	5.500	7.423	5.500	9.960	**7.423**
Service	PP	5.000	6.264	6.000	7.031	**6.264**
	D	0	1.207	0	1.648	**1.207**
Facilities	PP	0	0	0	0	**0**
	D	0	0	0	0	**0**
Other public	PP	2.000	3.167	2.000	3.990	**3.167**
	D	0	0	0	0	**0**
Auditorium	PP	500	420	500	420	**420**
	D	0	0	0	0	**0**
Office	PP	2.000	1.624	2.000	2.230	**1.624**
	D	1.000	168	1.000	281	**168**
Extra	PP	0	0	0	0	**0**
	D	0	0	0	0	**0**
		27.000	**31.742**	30.000	**40.048**	**31.742**
differences			**-4.742**		**-10.048**	
	PP	19.500	22.195	21.500	27.361	22.195
	D	7.500	9.547	8.500	12.687	9.547
		Sanders	**SMA**	Sanders	**SMA**	

Costs		
Renovation	2.580	€/m²gfa
Extension	2.950	€/m²gfa
Other	1.400	€/m²gfa
BUDGET	100.000.000	€
Renovation	36.487.186	50%
Extension	23.753.894	32%
Other	13.365.240	18%
RESULT	73.606.320	100%
DIFFERENCE	**26.393.680**	

Choice of constraints
- ● Constraints Sanders
- ○ Constraints SMA

Choice of objective function
- ○ Maximise use of existing location
- ● Maximise use of existing building
- ○ Minimise costs

Figure 17.2 Screenshot of output of LP-model minimising cost

17.2 The second numerical model linked to a geometrical model

The need then arose to have a model that could allocate functions per room and per floor in the existing building, because the numerical output alone did not provide sufficient information to the Stedelijk Museum. Therefore, a more detailed LP model was linked to a geometrical model.

The numerical model represented all rooms within each floor of the Stedelijk Museum. In this model the Stedelijk Museum could express per room its fitness for use for every function using Boolean values. For instance, not all rooms where fit to be used for exhibitions.

The geometrical model was a drawing in Autocad that also represented all rooms within each floor of the Stedelijk Museum (Fig. 17.3). The extension was represented as a rectangle per floor, because the shape did not matter in this stage of the process.

With the budgetary and spatial restrictions the numerical model could be optimised. The results where handed back to the geometrical model which colour-coded the different rooms according to their function (Fig. 17.4). In other words: the numerical results became graphical. The resulting drawings were presented to the Stedelijk Museum to see whether a proposed layout of functions was acceptable. This iterative process ended when the Stedelijk Museum was satisfied with the proposed layout.

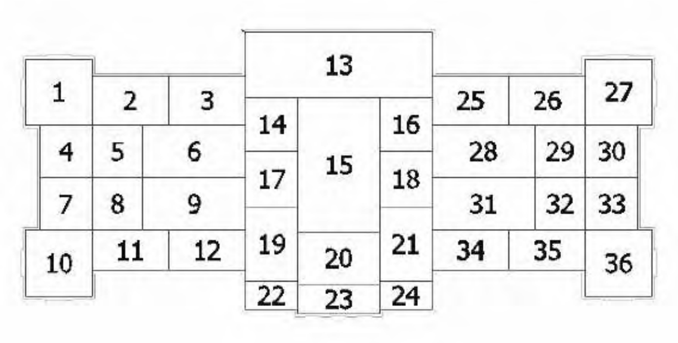


Figure 17.3 Ground floor existing building with roomnumbers

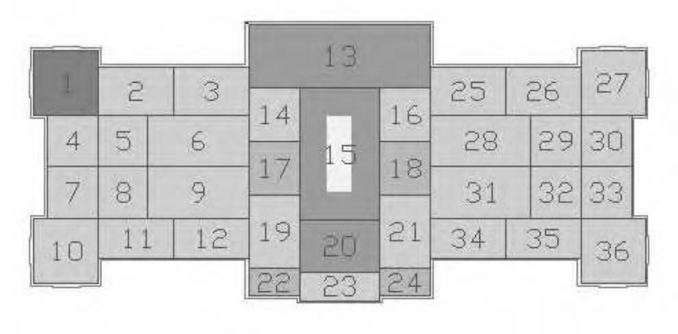


Figure 17.4 Ground floor of existing building showing allocated functions

17.3 Conclusions

The use of both numerical and geometrical models greatly reduced the time it normally takes to develop a bill of requirements for such a complex project. The open process made the people of the Stedelijk Museum feel their wishes were taken seriously and not swept under the carpet. In contrast to traditional approaches, PKB could provide confidence that the bill of requirements would satisfy both budgetary and geometrical restrictions. In the traditional approach some rules of thumb would be used to establish if the bill of requirements would meet both budgetary and geometrical restrictions which often give rise to unpleasant surprises later on in terms of overruns in time and money.

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