

Designing and Testing a Strategy Game



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Abstract

A persistent problem in Corporate Real Estate Management (CREM) is the issue of aligning an organization's real estate to its organizational objectives. In this thesis a decision-making model has been designed for the Delft UT in order to provide the organization with a solution as to how they can renew their portfolio of lecture halls. In order to achieve alignment, the Delft UT requires the solution that maximally supports their primary process: education. This solution is argued to be the solution that best fulfills the preferences of the stakeholders.

Aside from designing solutions to the problem, the stakeholders involved are allowed to repeatedly adjust and refine their preferences and design criteria. In this thesis it is argued that this process of gaming is necessary in order to gain an understanding of the problem and acceptance of the eventual results. The tests done with the decision-making model largely affirm this hypothesis. The process also shows that the model environment is so complex that users need a certain amount of time to familiarize themselves with it.

Keywords:

Corporate Real Estate Management, alignment, operations research, preference measurement, strategy design, gaming, decision-making

Preface

”
We are searching for some kind of harmony between two intangibles:
a form which we have not yet designed, and
”
a context which we cannot properly describe.

Those are the words of Christopher Alexander in his 1964 work, ‘Notes on the Synthesis of Form.’ Alexander believed that the architect’s solution to a design problem had to be derived from a full understanding of the problem and its specific context, instead of him imposing a formal style onto the problem (modernists) or relying on artistic intuition (postmodernists). Good design is defined as finding a fit between form and context: the objective is to reduce the amount of misfits between form and context to zero.

The translation of this notion can be found at the University of Oregon’s campus. In the planning process, development decisions are made on an ongoing basis rather than a fixed image. According to the university, this concept “acknowledges the fact that although change will occur, the exact nature and magnitude of that change cannot be predicted with any degree of certainty, and that object-oriented plans based on explicit assumptions about the future become outdated as that future becomes known.”

(University of Oregon, Pattern Language)¹

In this design/planning process, constant adaptation and development serve to identify misfits and reduce the amount of misfits to zero. In order to do so, decisions are made through meaningful consultation with user-groups on campus.

The subject of this thesis has close ties to the notions of Alexander. In real estate, aligning real estate to organizational objectives is a long-standing issue. How can we use our real estate to add value to the organization? At the Delft University of Technology we contend that alignment is achieved by designing an accommodation strategy. This strategy must be designed, it must be continuously adapted in light of the ever-changing world around us.

What is especially important is that although we can think that our real estate is ‘aligned’ to the organization, we do not truly know if that is the case until we make alignment measurable. This is done by incorporating stakeholders as equals into the decision-making process and allowing them to repeatedly determine what they find important. This will lead to a set of criteria or decision variables that will reflect the preferences of the stakeholders. The resulting ‘overall preference score’ can be used to measure their satisfaction in the present and future – helping us to measure alignment.

If we view each criterion as a potential ‘misfit,’ then continuously searching for a future where the preference score on each criterion is as high as possible is to reduce the amount of misfits between form and context to zero.

¹ <http://uplan.uoregon.edu/faq/FAQPatternLanguage.html>

Summary

The very start of this research lies within the organization of the Delft University of Technology. Recently, the university's department of Facility Management and Real Estate (FMRE, Dutch: FMVG) has expressed the desire to manage its real estate portfolio more efficiently. At the same time, the department of Real Estate and Housing (RE&H) at the faculty of Architecture has been doing research on the management of real estate for many years.

In Real Estate Management, aligning real estate to the objectives of an organization is a long-standing issue (C. Heywood, 2011). The answer of the department of RE&H to this problem was the DAS-Frame, a framework that helps to match organizational objectives and real estate (H. De Jonge et al., 2009) in order to design an accommodation strategy. Four tasks are completed iteratively to achieve alignment.

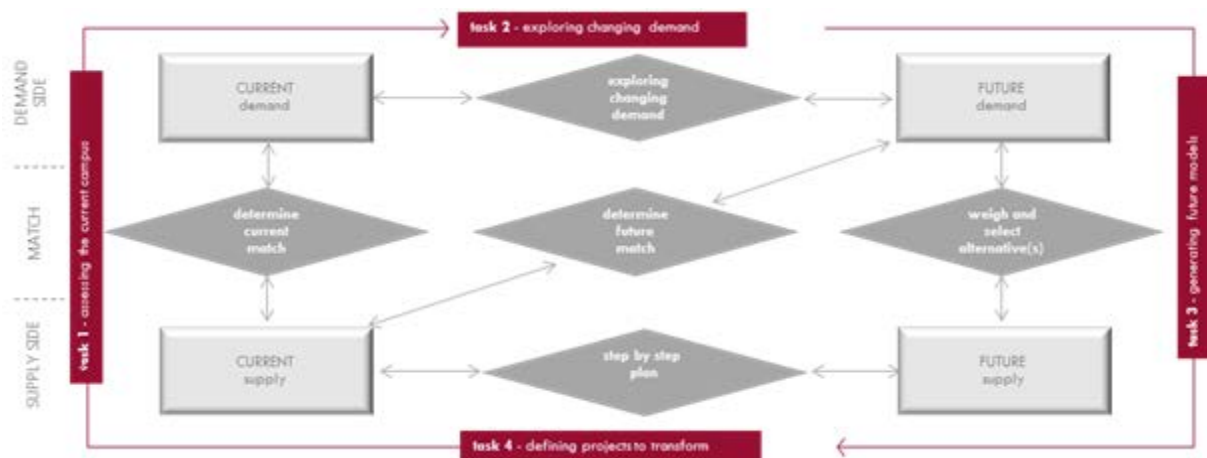


Figure 1 - DAS Frame (Den Heijer, 2011), adapted from De Jonge et al. (2009)

More recently, PAS has been invented by Arkesteyn (expected 2014) in order to make the DAS Frame operational. PAS, short for Preference-based Accommodation Strategy, is applicable to organizations that want to use real estate to add value to the organization. The best way to do this is to satisfy the demands of all the relevant stakeholders within the organization. If a design meets the demands set by the organization's stakeholders, it is an optimal design.

In PAS the decision-making process takes place as displayed below. First the stakeholder completes step 1 and 2 in the DAS Frame in an interview. Then step 3 is completed in workshops by designing solutions in a decision-making model. These interviews and workshops are done repeatedly to give stakeholders the opportunity to adjust and refine their criteria.

- 1, 2 Assessing current demand and exploring changing demand.
 - A. Specify the decision variable;
 - B. Assign the stakeholder's preference to each variable;
 - C. Assign the stakeholder's relative weight to each variable;
 - D. Determine the design constraints.
- 3 Generating future models.
 - E. Generate design alternatives.
 - F. Use the PFM algorithm to yield an overall preference scale)

Steps A-F are derived from Binnekamp's preference-based design (Binnekamp, 2010), which has been converted so that it can be used on a portfolio scale rather than on the scale of an individual building (Arkesteijn & Binnekamp, 2012). Each stakeholder defines their criteria and assigns preference scores to each variable; thereby creating a curve such as is displayed in figure 2. In this particular case, the stakeholder has determined that he is fully unsatisfied if less than 75 percent of the lecture halls is equipped with a beamer, and fully satisfied if 100 percent is equipped with a beamer. By assigning weights to each criterion an overall preference score can be determined.

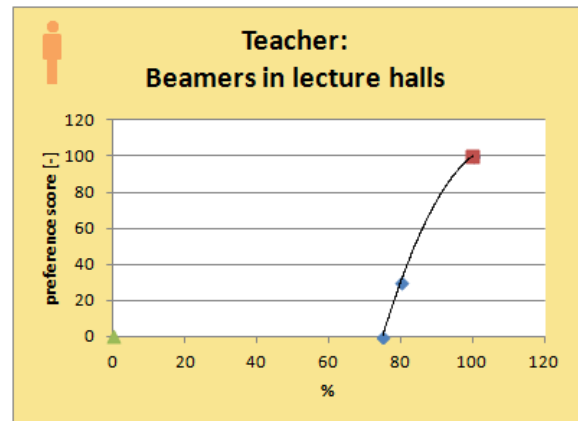


Figure II – Preference curve of a decision variable.

This particular research will be occupied with the design of a PAS decision-making model. Previous experiences reveal that decision-making models are complex, they are often not understood completely, and it requires time to get acquainted to them (Van de Schootbrugge, 2010; P. P. J. Van Loon, Heurkens, & Bronkhorst, 2008; Van Ussel, 2010). The author's hypothesis is that gaming can be used to help overcome these difficulties.

The decision-making model designed in this thesis is preoccupied with finding a solution to the Delft UT's management of their lecture halls. The problem is as follows:

- The current supply of lecture halls does not meet present-day requirements with regard to facilities and capacity;
- The university is starting a new curriculum next year, which will lead to a changing demand for lecture halls;
- There are too little types of educational facilities to accommodate this changing demand;
- The current supply is being used ineffectively.

In order to solve these problems in one decision-making model, a model is made that is able to make a timetable allocation for the university based on the demands set by its stakeholders and the characteristics of the supply. By modifying demand and supply the stakeholders can design a solution to the problem. The timetable allocation is represented in the model as a linear programming (LP) problem. In order to find out whether the designed solution is also an optimal solution, the decision variables of each stakeholder are integrated into the model.

The results of the interviews and workshops show that the hypothesis can be largely affirmed. Most stakeholders have indicated that the model helps them to gain insight into the consequences of their actions, which suggests that they understand the relationships between variables in the model. The role of gaming in this process is that stakeholders are allowed to readjust and refine their decision variables. This iterative process has two advantages. Firstly, readjusting and refining criteria helps the stakeholders to understand what they really want and thereby creating a more accurate representation of their preferences. Secondly, it gives them a safe environment to experiment in and gain insight into the consequences of their actions in the model on their preferences without being held to the results.

Reader's Guide

The main body of this thesis is split up into four parts: the research basis, the theoretical framework, the model design, and the results.

In the 'Research Basis' section the research project is introduced and put into its scientific context. The research questions, hypotheses, objectives and relevance are laid out as well as the research methodology.

In the 'Theoretical Framework' section the theoretical fundament of this research is discussed. Four scientific fields are discussed: real estate management, decision systems, timetabling, and gaming. Each of these fields is split up into theories, methods and applications.

In the 'Model Design' section the issues relating to the design of the decision-making model are discussed. This includes the representation of the problem in the form of a mathematical model and the design of a solution to the problem in the model.

In the 'Results' section the results of the rounds of interviews and workshops are discussed. Then, these results are evaluated in light of the observations made in the theoretical framework. Finally, conclusions are drawn up and recommendations for further research are provided.

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List of Acronyms/Definitions

CREM	Corporate Real Estate Management. The goal of CREM is to optimally attune corporate accommodation to organizational performance.
DAS Frame	Framework for the Design of an Accommodation Strategy. A strategic framework which can be used to iteratively match supply and demand in time.
FMRE	Facility Management and Real Estate. The department within the TU Delft that is responsible for the management of campus real estate.
LP	Linear Programming. An operations research technique that provides the user with an optimal solution given an objective function, and a set of goals, constraints, and objectives.
PAS	Preference-based Accommodation Strategy. Combination of the DAS Frame with PBPD developed by Arkesteijn, which provides users of the DAS Frame with the means to measure the match between supply and demand.
PBD	Preference-based Design. A design methodology developed by Binnekamp, based on the principles of PFM.
PBPD	Preference-based Portfolio Design. A design methodology developed by Arkesteijn and Binnekamp, converting PBD from the scale of one building to that of multiple buildings.
PFM	Preference Function Modeling. An evaluation methodology developed by Barzilai which enables preference measurement in a mathematically correct way.
PREM	Public Real Estate Management. The goal of PREM is similar to CREM, given that organizational goals in public organizations are not mainly economical, but rather societal and/or political.
PRE System	Public Real Estate System. Decision-making model developed by Arkesteijn, van Loon, and van de Schootbrugge to achieve the public goals of the municipality of Rotterdam by using minimal means.
REM	Real Estate Management (by investors). In REM, performance is measured by the amount of income generated from real estate.
UDR	Urban Decision Room. Decision-making model developed by van Loon et al. to support decision-making in an urban management context.

Part One Research Basis

In this research project I have set out to design a solution that will contribute to the alignment of an organization's real estate to its organizational strategy. As a reader, part one will provide you with all the necessary information with regard to the 'setup' of this thesis. The structure of this chapter resembles the way in which I have structured my own thoughts during this research.

In the following order these questions are answered:

- What is the broader context in which this research has taken place?
 - What is the exact problem that this research aims to solve?
 - What are the author's research questions/hypotheses?
 - What is the relevance of this research?
-
- How does the author intend to answer his research questions/affirm his hypotheses?
 - Which research techniques are used to accomplish this?



Chapter 1 - Introduction

The very start of this research lies within the organization of the Delft University of Technology. Recently, the university's department of Facility Management and Real Estate (FMRE, Dutch: FMVG) has expressed the desire to manage its real estate portfolio more efficiently. The underlying motive can be found in Sprong (2011):



Figure 1-A – TU Delft

In the immediate future the TU Delft will have to deal with a reduction in public funding, which puts pressure on their allocation of resources. This puts an increasing pressure on FMVG, because it has also had a deficit on its maintenance budget for the past few years. However, at the same time the TU Delft wants to invest in the campus, recently having set out a plan envisioning the university campus in 2030. (Sprong, 2011)

At the same time, the department of Real Estate and Housing (RE&H) at the faculty of Architecture has been doing research on the management of real estate for many years. Its researchers have invented the DAS-Frame, a framework that helps to match organizational objectives and real estate (De Jonge et al., 2009) in order to design an accommodation strategy. Recently, De Vries (2007) and Den Heijer (2011) have applied this theory to campuses of institutes of higher education and universities in order to find out how real estate can add value to the performance of these organizations.

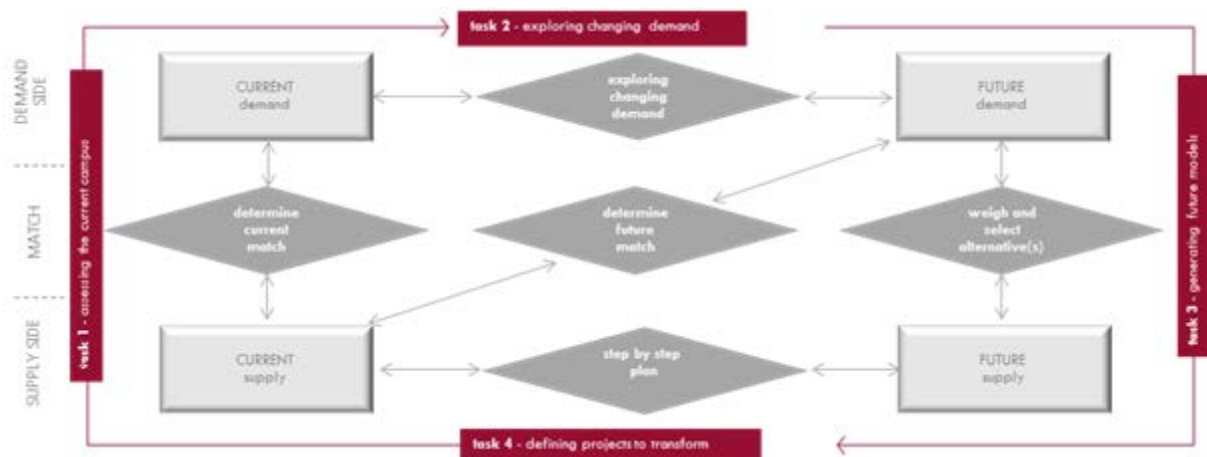


Figure 1-B - DAS Frame, (Den Heijer, 2011), adapted from De Jonge et al. (2009)

What the research by De Vries and Den Heijer has given us is all the information that is necessary in order to make informed decisions with regard to the real estate portfolio. The next step is to structure the information in a way that helps decision makers to actually make decisions *better*. Currently, Arkesteijn is writing her postdoctoral dissertation on this subject. In her dissertation she makes the DAS-Frame operational by linking it to tools and methodologies of decision analysis.

The result of this research is PAS (short for Preference-based Accommodation Strategy). PAS is a decision system that is based on the assumption that organizations primarily wish to support their primary processes. The best way to do this is to satisfy the demands of all the relevant stakeholders within the organization. If a decision meets the demands set by the organization's stakeholders, it is an optimal decision.

Based on this research, the department of FMRE has requested Arkesteijn to develop solutions that help them to manage their real estate more efficiently. The result, which will also be a part of her dissertation, consists of two PAS systems. One of these systems will be applied to the university's portfolio of restaurants; the other to the portfolio of lecture halls.

1.1 Problem Statement

This research has been conducted within the postdoctoral research of Arkesteijn (to appear 2014), and is occupied with the design and testing of FMRE's decision system for lecture halls. Due to this focus on the decision system this thesis will be more concerned with the operational side of real estate management than the theoretical side.

Both literature on decision systems and real estate management reveal the actuality of the subject. With regard to real estate management, Heywood writes that *alignment* (i.e. bringing into harmony organizational objectives and real estate) is one of the long-standing issues (Heywood, Kenley, & Waddell, 2009) in the scientific field of Corporate Real Estate Management. A number of causes are put forward for this:

- Current approaches to alignment do not fully capture the alignment phenomenon (Heywood, 2011); each method covers a part of the truth and is therefore useful (De Jonge et al., 2009);
- Decision variables are becoming more complex (Englert, 2001, p. 1), and in the decision-making process more stakeholders are involved and more information is required (Den Heijer, 2011);
- None of the existing methods provide an unambiguous procedure on how to take the leap from analyzing the situation to strategy design (De Jonge et al., 2009, pp. 87-88).

In order to overcome these problems De Jonge et al. (2009) propose the use of the DAS Frame – iteratively matching supply and demand in order to include multiple perspectives on strategy design. Heywood (2011) suggests that other approaches be considered, i.e. heuristics, wicked problems, and game theory.

Furthermore, literature on decision systems reveals that in systems for management of the built environment similar to PAS, users have difficulty comprehending certain aspects of the computer models.

- Van Loon et al. (2008, pp. 64, 66) conclude that in the UDR users do not understand certain steps in the model precisely. They also have difficulty understanding the computer language used in the UDR, and they require a better explanation of the objectives and the purpose of the UDR.
- Van de Schootbrugge (2010, p. 62) states that initially, users of the PRE System found the model to be quite complex and that they felt that the system took over control of the process, which eliminated room for creativity. After becoming acquainted with the model, the users rated it more positively.
- Van Ussel (2010, p. 139) writes that initially, users of ORES have difficulty to navigate in the model. Also, the relation between input and output is unclear. This can be resolved by becoming more acquainted to the model.

Each of these evaluations shows that the users of the models have difficulty understanding certain aspects of the model. If, according to Englert (2001) and Den Heijer (2011), the amount of information required for decision-making is increasing and becoming more complex,

this will also have its effects on these model approaches. This is supported by van Loon et al. (2008, p. 72), who have put forward that “new instruments need to be developed [for urban planners] to support planning issues that are becoming more and more complex.”

Based on the previous content the following problem statement has been formulated:

In CREM theory and practice alignment is a long-standing issue. An example of this in practice is experienced by the TU Delft itself; therefore FMRE has requested the department of Real Estate and Housing to develop a solution that enables them to manage their real estate more efficiently. Within this context a solution based on PAS has been developed.

The PAS is an alignment approach based on the simulation of real estate strategy design in a multi-actor environment. In the past various models have been developed to solve similar design or decision-making problems. Some of these models encounter problems relating to user-friendliness and complexity. If the decision-making process in real estate is becoming more complex over time, then the importance of the aforementioned problems will only increase. Therefore, this is a significant hurdle which has to be eliminated in order for these approaches to be usable in practice.

1.1.1 Hypothesis

The author’s hypothesis given the aforementioned problem statement is:

Decision-making models (such as those identified in the previous sections) are becoming increasingly complex and therefore more difficult to understand. If users do not understand such models, they are not likely to take decisions based on their outcome. Gaming is a valid technique that can help users to comprehend the complexity in these models. Therefore the use of gaming in these kinds of models increases their potential.

1.1.2 Research Questions

The main research question that is answered by this thesis is:

How can the use of gaming in real estate decision-making models help users to better understand the increasing complexity in real estate management?

The following subquestions are designed in order to help answer the main question.

“Why exactly is alignment a long-standing issue?”

“Which solutions are provided by literature?”

“How are they applied in practice?”

“Which circumstances have made the use of these decision systems necessary?”

“Which methods are used to solve decision-making problems?”

“How are these methods applied in practice?”

“What is the exact definition of the timetabling problem?”

“What are the solutions proposed in theory to overcome the problem?”

“What types of programs are often applied in practice?”

“What exactly constitutes gaming?”

“What are the benefits and drawbacks of gaming?”

“What is the difference between gaming and decision support systems?”

“How is gaming represented in PAS?”

1.1.3 Objective

Through this research I would like to contribute to the improvement of FMRE's real estate management by further development of the PAS model. I hope to achieve a number of goals by doing this:

1. Designing a PAS model for the educational facilities of the TU that can deal with the complexity of the problem.
2. Gaining knowledge about the purpose and role of gaming in these models.
3. Making progress in solving the problem of alignment in Corporate/Public Real Estate Management.

The end product of this research will thus consist of a computer model that, based on real estate strategy design, can facilitate FMRE's real estate decision-making for their portfolio of educational facilities. A theoretical framework will be built up, consisting of CREM literature on alignment, literature discussing previous decision-making models, and literature about the use of gaming in decision-making. This framework should serve as a basis for the design of the model. It gives insight into the theoretical and practical problems of alignment, the approaches used in previous models and their advantages and drawbacks, and the use of gaming. Put together, the theoretical framework should provide enough information upon which the computer model can be built.

1.2 Relevance

1.2.1 Scientific Relevance

The research topic described in the previous pages can be placed best into the research theme of 'Successful real estate strategies.' Within this theme this particular research is focused on further developing a strategy design tool for decision making on a portfolio level.

If the objectives described in section 1.1.3 are met in this research, then it will contribute to the validity of using preference-based accommodation strategy as tool that can be used for strategy design and real estate decision making. In doing so it might also prove to be another step towards solving 'the long-standing issue of the alignment of corporate real estate (CRE) to organizational strategies' (Heywood et al., 2009).

1.2.2 Societal Relevance

The development of a decision making tool that can be used in practice has far wider implications than merely scientific ones. If such a tool can effectively align the CRE to an organization's strategies then it will promote aspects such as innovation, growth, wealth creation and thereby enhance its competitive advantage (Roulac, 2001). Organizations will be enabled to utilize real estate in a better and more efficient manner, thus also making more efficient use of the resources on Earth.

Aside from these reasons there might also be benefits for employees and other stakeholders. In more recent years organizations are measuring their own performance by factors such as growth, market share, employee satisfaction, whilst in the past they were focused much more on profit (De Vries, De Jonge, & Van der Voordt, 2008). Within this context the use of a decision making tool that can incorporate preferences of employees and consumers seems a very logical and sensible step for organizations.

Chapter 2 - Research Methodology

In this chapter the methodology of this research will be discussed in its entirety. Firstly, the research design will be presented by deducing from the research question the types of research that are necessary to answer the research question adequately. This will be done in subchapter 2.1. Then, in subchapter 2.2 and 2.3 operations research will be discussed as well as its relationship to empirical research. Subchapter 2.4 moves to the practical side of this chapter, where the research design is made operational by explaining each step in the process precisely.

2.1 Research Design

The main research question presented previously was:

“How can the use of gaming in real estate decision-making models help users to better understand the increasing complexity in real estate management?”

Based on this research question operations research fits the question best, as the question can only be answered properly by creating an artifact or changing situations (Barendse et al., 2012). However, there are a number of subquestions that are aimed at better understanding the current situation: these are empirical questions. These questions will serve as a background for the model design. Therefore, the research becomes a hybrid between operations research and empirical research, with a heavier emphasis on operations research.

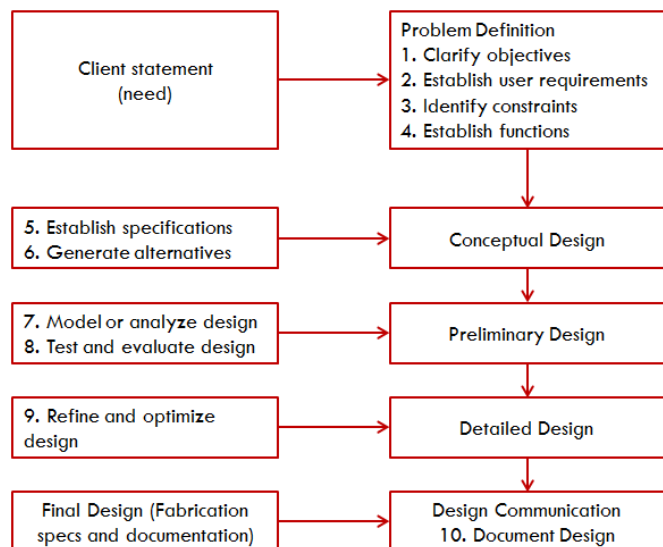


Figure 2-A - Steps of a design process (Dym and Little, (2004, p. 24)

The research design presented in this subchapter is based on the generic design process used in operations research as is provided by Dym and Little (2004, p. 24). The use of empirical research is implied in this figure; literature studies are used for e.g. identifying constraints, establishing specifications, etc. Also, testing and evaluating the design is done empirically.

Figure 2-B represents the proposed research design. The exploration of the field and the first part of the design cycle can be seen as the ‘problem definition’ phase. Then, a theoretical framework has been drawn up and simultaneously the design cycle moves onward. As the design is adapted and improved by testing, the theoretical framework is also continuously used as input for the design. Additionally, lessons learned in the testing of the design can also call for amendments to the theoretical framework.

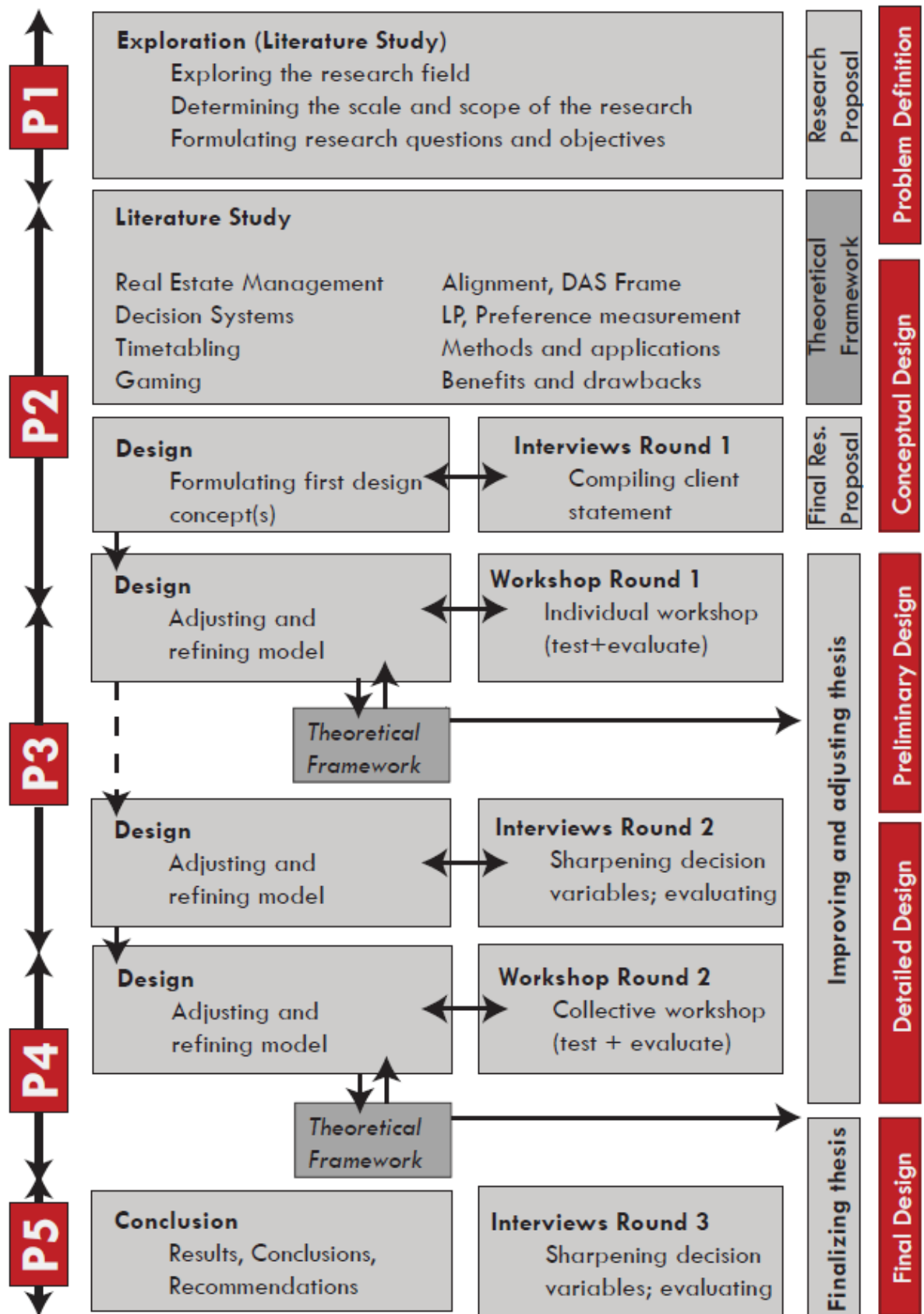


Figure 2-B - Research Design

2.2 Operations Research

In the previous subchapter we have determined that the prevalent research method in this research is operations research. Operations research is used to help people to make better decisions by application of advanced analytical methods. These analytical methods are used to understand and structure complex problems, after which they can be applied to improve the performance of a system.

The basis of operations research can be found in a formulaic notation used by Ackoff and Sasieni (1968). This notation displays the structure of a generic decision-making problem.

$$U = f (X_i, Y_i)$$

U = the utility or value of the system's performance
X_i = the variables that can be controlled: the 'decision' or 'choice' variables
Y_i = the aspects of the situation over which we have no control (the environment of the problem)

The engineer has the task of selecting the set of values X_i that, given the function *f* and the set of values Y_i, produces the best value of U (Barendse et al., 2012). According to Ackoff and Sasieni (1968, p. 11), this is done by completing the following five steps:

1. Formulating the problem;
2. Constructing the model;
3. Deriving a solution;
4. Testing the model and evaluating the solution;
5. Implementing and maintaining the solution.

Operations research assumes that an engineer designs a solution for a certain problem that arises in practice. A 'problem' in this case is defined as a situation where the current solution for a problem does not correspond to the normative image that the engineer has of the problem. For example, a building has a façade with a certain type of isolation. The architectural engineer assumes that higher isolation standards can be achieved by using different types of materials; therefore he designs a solution that optimizes the isolation of the façade.

Similarly, in this research a situation has been described in which the decision-making process is becoming more complex. Users already experience difficulties with decision-making models: in order to understand it, they require a certain amount of time to become acquainted with such models. From an operations research approach, the hypothesis then is that gaming can help overcome these difficulties by reducing the time it takes to become acquainted with the model.

2.3 Operational-Empirical

In this research, operations research and empirical research are combined in order to reach the desired end result. On the one hand, operations research is used to design and improve the decision-making model. On the other hand, empirical research is used to test and evaluate the model, compose the theoretical framework, and to research the value of using gaming in the decision-making model.

This relationship between operations research and empirical research is implicitly described by Dym and Little in their model for a design process. For each of the five stages in the design process Dym and Little (2004, p. 24) define inputs and sources of information. These are displayed in Table 2-A.

Design Stage	Sources of Information	Inputs
Problem Definition	Literature on state-of-the-art, experts, codes, and regulations	Client statement
Conceptual Design	Competitive products	Revised problem statement, refined objectives, functions, constraints, requirements
Preliminary Design	Rules of thumb, simple models, known physical relationships	Conceptual design schemes, specifications
Detailed Design	Design codes, handbooks, regulations	Test and evaluation results
Design Communication (Final Design)	Feedback from clients	Fabrication specifications

Table 2-A - Design Stages and Required Input (Adapted from Dym and Little (2004, p.24))

Essentially, this table implies that each phase of the design process requires a lot of empirical research. The designer requires a lot of information that he needs to deduce from the available literature. He also needs to compile a problem statement and establish user requirements, constraints and objectives. This can be done by using interviews. Also, he needs to test and evaluate his design in one way or another.

Barendse et al. (2012) have described this relationship between operational and empirical research more in detail by means of a diagram, displayed in figure 2-C. The cyclical process that it displays can be applied to this research. The research process then describes itself as follows:

Step 1: Theory/Problem

Step 1 can be viewed as the problem definition phase of the research. At the outset of this research the priority was to find a research subject – therefore literature was studied on real estate management theory and decision system theory. These theories showed that alignment is a long-standing issue in REM and that decision systems often have difficulties relating to user-friendliness. At the same time the problem statement for the PAS for lecture halls was specified. The interplay between formal and empirical research here is that on the one hand, sharpening the problem statement helps to understand theory better, whilst on the other hand reading more theory and trying to find a possible solution space helps to specify the problem statement. This process also formed the basis of the theoretical framework.

Step 2: Hypothesis/Axioms

At a certain point in time the problem statement and knowledge of the existing theory are such that a definition of a possible solution can be put forward. In the empirical reality, this possible solution leads to a hypothesis: that gaming can provide a solution to the problem. In formal research, the choice of this hypothesis helps to define the basic rules and assumptions of the decision-making model, together with the context of the assignment provided by FMVG. Furthermore, axioms are also provided in this model through interviews with stakeholders, as they determine the decision variables.

Step 3: Outcome/Design

After assembling the axioms and setting a hypothesis one can move forward to the design of the decision-making model. This design is then tested in a workshop, which gives the engineer an outcome that he can hold against his hypothesis.

Step 4: Validated Outcome/Calibrated Design

Based on the workshop the engineer can adapt the model according to his own insights, as well as those of the stakeholders that participated in the workshop. Also, the comparison of the results from the workshop with his hypothesis gives him a validated outcome depending on whether the hypothesis is affirmed or disproved.

Step 5: Clash

In formal research, the engineer compares his design to the problem statement in order to decide whether he has sufficiently solved the problem. If not, he can choose to redo the cycle. In empirical research the validated outcome can lead to the engineer adding his results to the existing theory, or he can redo the cycle to see if an adapted design yields different results.

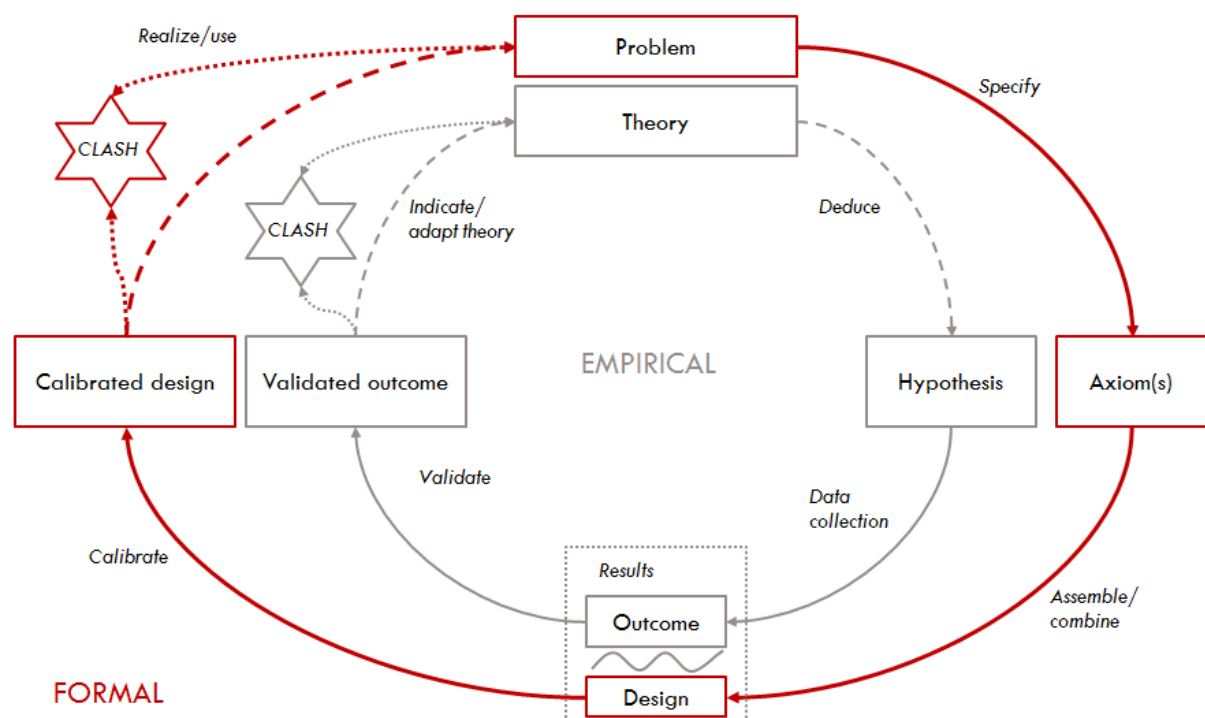


Figure 2-C - Engineering and social sciences (Barendse et al., 2012).

2.4 Research Instruments

The main research instruments used in this research are interviews and workshops. Interviews and workshops are used in order to improve the model design and to answer the research question. This method, which is discussed in this subchapter, has been designed by Arkesteijn (to appear 2014). She has related these instruments to the PAS methodology, where they are used for the following steps:

Interviews

1. Specify the decision variable(s);
2. Assign the decision maker's preference to each variable;
3. Assign the decision maker's relative weight to each variable;
4. Determine the design constraints;

Workshops

5. Generate (all) the design alternatives;
6. (Use the PFM algorithm to yield an overall preference scale.)

Interviews are conducted separately with each decision maker. They are free to determine whichever decision variables they wish to incorporate, and they are allowed to modify their decision variables, preferences, and weights in later stages.

Workshops are conducted either individually or with all the decision makers together. In the workshops, the decision makers are requested to perform certain tasks, of which the most important is to design alternatives. As of yet the PFM algorithm does not yet exist; this algorithm would enable the user to calculate the best design alternative rather than design it by himself.

As is displayed in the research design discussed previously, a repetitive process of interviews and workshops will be carried out. This process will be as follows:

- Interview 1;
- Workshop 1;
- Interview 2;
- Workshop 2;
- Interview 3.

The cyclical process of interviews and workshops allows the engineers to continuously adapt and improve the computer model, thereby providing a better reflection of the stakeholders' preferences as well as a better representation of reality. It also gives stakeholders the opportunity to adapt their decision variables and design new alternatives based on the insights that they gain during the process.

2.4.1 Interview 1

A number of representatives are chosen that represent each stakeholder perspective: they will be the decision makers. Prior to the interview, the interviewee is introduced to PAS. Firstly, the interviewee needs to understand what the purpose of the project is and what is required of him during the process. After that the introduction the interview starts.

The objective of the interviews is twofold. Firstly, the interviews are necessary for the progress of the model design; this is termed as the formal objective. Secondly, in the interviews the use of gaming needs to be evaluated in order to answer the research question; this is termed as the empirical objective.

Formal Objective	Empirical Objective
Specify decision variable(s)	Goal
Assign preference scores	First reaction
Determine weights	Expectations
Determine design constraints	

Table 2-B - Objectives and necessary information

Theoretical variable	Raw variable	Sets of values
1 Specify Decision Variable(s)	1.1 Current problems with the supply of educational facilities 1.2 Goals that one wishes to achieve by participating 1.3 Conversion of goals into criteria	e.g. lack of capacity, insufficient acoustic quality e.g. solving the current problem(s) e.g. total occupancy of lecture halls
2 Assign preference scores	2.1 Assign a preference score of 100 to your most desired outcome 2.2 Assign a preference score of 0 to your least desired outcome 2.3 Assign a preference score between 0 and 100 to an acceptable outcome	e.g. 70% total occupancy of lecture halls e.g. 80% total occupancy of lecture halls e.g. 72% total occupancy of lecture halls
3 Determine weights	3.1 Determine relative weights between each decision variable	e.g. 50% for 'total occupancy of lecture halls' and 50% for 'acoustic quality'
4 Determine design constraints	4.1 Determine which decision variables must be met	e.g. Each lecture hall must have a working beamer
5 Reaction	5.1 First reaction to the completed working method	e.g. Easy to complete
6 Expectations	6.1 Expectations of participation in this project	e.g. A desirable end result, a say in the process

Table 2-C - Interview variables and values (Derived from (Emans, 2007))

Table 2-C displays a conversion of the empirical and formal objectives to interview variables. The interviewee is helped along in the first stage of the interview to determine decision variables by asking him what problems he experiences with the current facilities and what goals he hopes to achieve by participating in this process. Then, the formal objective is completed by collecting the required information. Finally, the empirical objective is addressed by asking the interviewee what his first impression of the working method was and what his expectations are.

2.4.2 Workshop 1

In this round of workshops the decision makers each have separate workshops. This is done in order for them to become familiar with the computer model before trying to reach an optimal result as a collective. Initially, this round would be a collective workshop similar to the second round, but in the testing of the PAS for catering facilities this was found to be unsatisfactory by Arkesteijn (to appear 2014).

Similarly to the interviews, the workshop has a formal and an empirical objective.

Formal Objective	Empirical Objective
Generate design alternatives (Use the PFM algorithm)	Test gaming

Table 2-D – Objectives and tasks

In the workshops the decision makers are asked to perform a number of assignments. On the one hand, they need to design alternatives in order to gain insights on a macro level. This is needed to make progress on the model design (i.e. the formal objective). On the other hand, they first need to understand how the model works in order to gain these insights. This is where gaming is used, and relates to the empirical objective. Therefore, the following sequence of assignments is proposed:

- Become familiar with the depiction of the problem in the computer model by looking at the relationship between current demand and current supply.
- Explore the effects of the changing demand on the supply of lecture halls by using scenarios to alter the demand.
- Design alternatives based on the selected scenarios and attempt to reach the highest preference score.

In each of these assignments the decision maker focuses on a different aspect of the problem. By doing this, the decision maker and moderator can discuss the effects and increase the understanding that the decision maker has of the problem and how certain decisions affect the problem. This discussion will reflect the understanding that the decision maker has of the problem. Then, in the third assignment he proceeds to reach an optimal preference score by applying the insights that he has gained from the first two assignments.

2.4.3 Interview 2

In this round of interviews each decision maker is allowed to adjust his or her variables, preferences, and weights and add new decision variables. Also, the method is evaluated with each stakeholder. Again, this marks a division between formal and empirical objectives.

Formal Objective	Empirical Objective
Specify additional decision variable(s)	Attractiveness of the method
Assign/adjust preference scores	Perception of effectiveness of the method
Adjust weights	Experiences with the method
Determine/adjust design constraints	

Table 2-E - Objectives and necessary information

The information required for the empirical objective is also used by Arkesteijn (to appear 2014) to evaluate the use of the PBPD method. This way of evaluating computer models is provided by Joldersma & Roelofs (2004), who have found that the impact of similar ‘soft operations research’ methods on problem structuring is measured in four different ways: (1) experiences with the method; (2) attractiveness of the method; (3) participants’ observations on effectiveness of the method; and (4) observers’ perceptions of the effectiveness of the method.

Attractiveness		Perception of effectiveness	
<ul style="list-style-type: none"> • Like • Feel comfortable • Confidence performing task • Quality problem solving • Willingness to use again • Impact of intervention (is method) • Satisfaction • Acceptance results • Components <ul style="list-style-type: none"> ○ Like visible results ○ Like facilitation ○ Less to technical procedures ○ Like less to tools ○ Like less to forums 		<ul style="list-style-type: none"> • Outcome • # ideas • Effectiveness • Attractiveness • Objectives: intervention realised • Declared purpose • Contribution to generation <ul style="list-style-type: none"> ○ More to rich interaction ○ More relevant information ○ Less to learning ○ Less to involvement 	
Observation of effectiveness		Experiences	
<ul style="list-style-type: none"> • Ownership • Quality of ideas in certain time • Likelihood of acceptance • Quantity of ideas • Attitude participants 		<ul style="list-style-type: none"> • Ownership • Speed up • Acceptability of the model • Structure for managing interventions • Understanding each other • Support steering of thinking process • Communication 	

Table 2-F – Interview variables Joldersma & Roelofs (2004)

This method can also be used to evaluate with each decision maker the contribution of assignments in the workshop to his understanding of the problem. The interview variables of the first interview will remain unchanged, aside from the final part of the interview:

Theoretical variable	Raw variable	Sets of values
5 Attractiveness	5.1 User-friendliness of the model 5.2 Attractiveness of assignments	See Table 6, ‘Attractiveness’
6 Effectiveness	6.1 Suitability of the model to solve the problem 6.2 Suitability of gaming in order to gain better understanding	See Table 6, ‘Effectiveness’
7 Experiences	7.1 Contribution of the model to the problem-solving process 7.2 Contribution of the first two assignments	See Table 6, ‘Experiences’

Table 2-G – Adjustment Table 2-C, Interview variables and values

2.4.4 Workshop 2

In this round of workshops, all the decision makers come together to participate in one collective workshop. In this workshop decision makers are asked to reach an optimal result together as a group. Again, the engineer can improve the computer model based on insights gained from this round of workshops and, if necessary, adjust the theoretical framework. If necessary, the cycle can be extended by repeating the second round of interviews and workshops until a satisfactory result is reached.

Formal Objective	Empirical Objective
Generate design alternatives	Test gaming
(Use the PFM algorithm)	

Table 2-H – Objectives and tasks

The difference compared to the first workshop is that in this workshop, users are already acquainted with the decision-making model. Also, they have to work together rather than individually. In this workshop it will be more interesting to find out how gaming influences the acceptance of results generated by the model.

In workshop 2 the sequence of assignments is the following:

1. The participants are split up into two groups. The first group focuses mainly on reaching the highest preference score by doing process interventions (i.e. relating to the timetable) whilst the second group focuses mainly on optimization by object interventions.
2. The groups come together and discuss their findings, after which a combination is sought between the two types of interventions in order to reach the highest preference score.

The difference between the two types of interventions is that the consequences of object interventions for the overall preference score can often be fed back directly, whilst the consequences of process interventions can only be determined after an allocation of the timetable, which takes some time. The group that focuses on object interventions can thus make good use of the game: finding an optimal solution by trial-and-error in order to gain an understanding of the relationship between variables. Conversely, the group that focuses on process interventions delivers input into the model and then has to wait for approximately a minute, after which the results are presented. Here it is much more difficult to see how one variable affects the other.

2.4.5 Interview 3

In the third series of interviews, which concludes this research, the exact same procedure will be carried out as in the second series of interviews. Users are allowed to change their decision variables according to latest insights from the workshop and the method is evaluated together with them.

Part Two Theoretical Framework

This second part of my thesis provides the theoretical framework for conducting research on the design and testing of a strategy game. Based on the research proposal and assignment by FMRE described in chapter 1, a literature review has been conducted in order to collect all the information relevant to the subject. This literature review has been divided into four parts.

1. Real Estate Management

The first chapter introduces Real Estate Management and the concept of alignment. In a sense, the conclusion of this chapter is a client statement for an alignment approach, prescribing what it should or should not contain.

Research question(s) to be answered:

“Why exactly is alignment a long-standing issue?”

“Which solutions are provided by literature?”

“How are they applied in practice?”

2. Decision Systems

The second chapter discusses the use of decision systems in the field of real estate management at the TU Delft. When designing a decision-making model it is necessary to understand the theory behind these models and the used optimization methods.

Research question(s) to be answered:

“Which circumstances have made the use of these decision systems necessary?”

“Which methods are used to solve decision-making problems?”

“How are these methods applied in practice?”

3. Timetabling

The third chapter discusses the operations research problem of timetabling. Optimizing the use of lecture halls for FMRE is closely linked to timetabling, therefore the model must contain some sort of timetabling method.

Research question(s) to be answered:

“What is the exact definition of the timetabling problem?”

“What are the solutions proposed in theory to overcome the problem?”

“What types of programs are often applied in practice?”

4. Gaming

In the fourth and final chapter gaming is addressed. This chapter should provide insight into what the purpose of gaming is in decision-making and how it can be represented in a model design.

Research question(s) to be answered:

“What exactly constitutes gaming?”

“What are the benefits and drawbacks of gaming?”

“What is the difference between gaming and decision support systems?”

“How is gaming represented in PAS?”

Chapter 3 - Real Estate Management

Real Estate Management constitutes the overarching subject of this thesis, as the designing and testing of a strategy game is an application within this field. Therefore a comprehensive understanding of the theories and concepts, methods and possible applications is necessary.

The structure of this chapter is based on providing answers to a number of questions. Firstly, there is a 'Theory' subchapter that introduces the issues in Real Estate Management that need to be resolved. Secondly, the 'Methods' subchapter displays a range of tools that have been developed in order to overcome these issues. Finally, the 'Application' subchapter deals with the application of theory and methods in practice.

3.1 Theory

The theory discussed in this subchapter can be divided into two parts. There is the basic theory of Real Estate Management, which entails the relationship between real estate and the organization. Out of this body of theory a number of issues have developed that will be discussed in separate sections.

3.1.1 Real Estate Management theory

The basis of Real Estate Management (REM) is the assumption that real estate has an added value to the performance of an organization, society, or individual (Den Heijer, 2011, p. 91). The objective in any type of REM is to maximize the relationship between the added value of real estate and performance. However, how this relationship is maximized depends on the definition that the organization, society, or individual has of performance. This is displayed in figure 3-A.

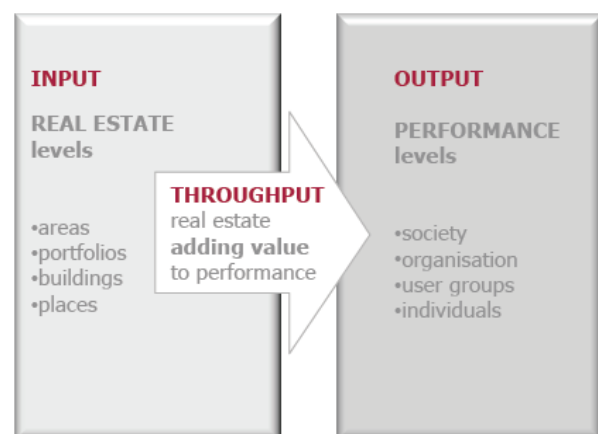


Figure 3-A - Relationship between real estate and performance (Den Heijer, 2011)

De Jonge has categorized the definitions of performance per type of real estate management by positioning these types in terms of a match between business, i.e. the demand side, and real estate, i.e. the supply side (De Jonge, 1994, p. 15 in De Jonge, et al. (2009)). In these definitions it becomes clear how the type of REM affects the definition of performance through real estate.

- In REM (also referred to as real estate management by investors) the objective is to achieve a return on investment in real estate, thus directly generating income from real estate (De Jonge et al., 2009). This means that performance is defined by the amount of income generated.

- In Corporate Real Estate Management (CREM), the objective is to optimally attune corporate accommodation to organizational performance, thus indirectly generating income by facilitating the primary processes of the organization. This is done by using real estate as a corporate resource (Joroff et al., 1993). Performance in CREM is therefore defined by the added value of real estate to the primary processes of the organization.

- In Public Real Estate Management (PREM) the objective is the same as in CREM. The difference is that organizational goals in public organizations are not mainly economical, but rather societal and/or political. This means that performance in PREM is focused on the added value of real estate in achieving the organization's economic, social, and political goals.

The difference between REM and C/PREM is displayed in figure 3-B. Because the focus of REM is on direct revenues from real estate, the institutional and strategic focus lies on asset management. C/PREM, on the other hand, focuses on facilitating primary processes: therefore the strategic and institutional focus in C/PREM becomes general management. In C/PREM, real estate is used as a resource to achieve organizational objectives (De Jonge et al., 2009).

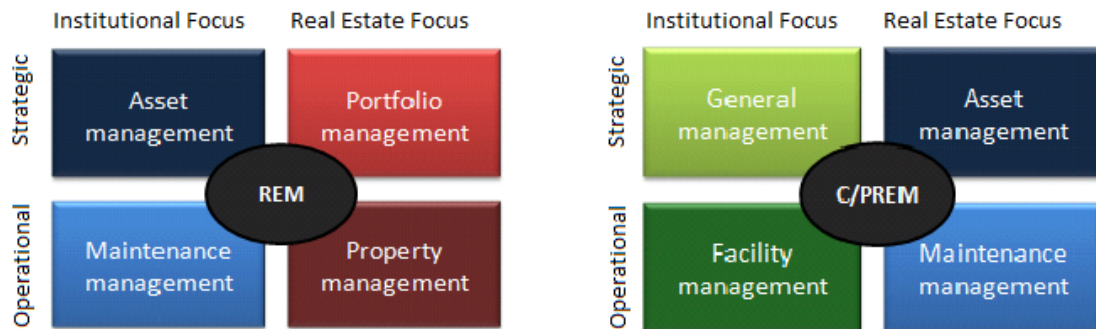


Figure 3-B – REM domains versus C/PREM domains (Struthman, 2012), adapted from (De Jonge et al., 2009)

Over the past few decades the significance of corporate real estate and the awareness that real estate can provide added value to the organization's performance have greatly increased. Figure 3-C and 3-D show that over the years the role of corporate real estate has evolved from facilities administration and monitoring technical conditions of buildings to effectively supporting primary processes and adding value (Den Heijer, 2011; Joroff et al., 1993; Roulac, 2001).

Corporate Real Estate Era	Years	Management Awareness / Concern	Management Orientation	Corporate Real Estate Role
Custodial	Pre-1970	Limited	Benign neglect	Facilities administration
Entrepreneurial	1970–1985	Growing	Growth, expansion, conglomerates, diversification	Active in real estate business: development subsidiary; create space, joint venture
Administrative	1985–1995	Efficiency / cost	Cost reduction, performance enhancement, downsizing, reengineering	Outsource, benchmark, financial assessment
Managerial	1995–2002	Effectiveness	Growth, change, differentiation	Develop systems for process and service
Strategic	2002	Efficacy: Crucial resource	Competitive advantage	Creating compelling places to work and shop

Figure 3-C - Evolution of Corporate Real Estate emphases(Roulac, 2001)

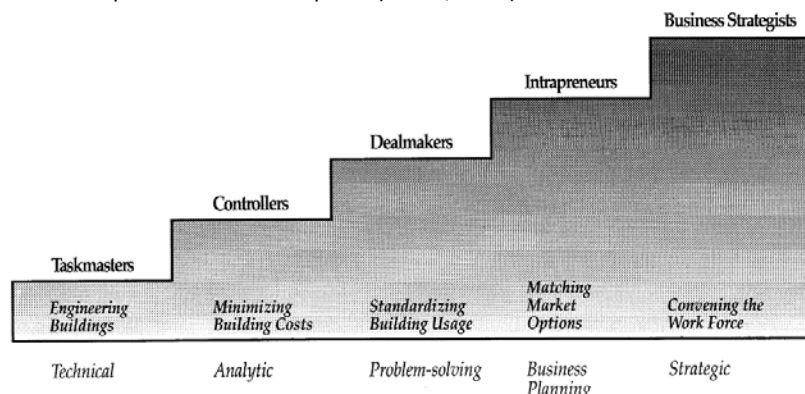


Figure 3-D - Corporate Real Estate competency shifts (Joroff et al., 1993)

3.1.2 Alignment

In order to maximize the added value of real estate to an organization's performance, real estate and organizational objectives are continuously matched to each other. In this thesis, this match is termed *alignment*. One can foresee that creating this match is by no means easy: real estate is a static resource whilst organizational objectives are very dynamic.

Based on a definition also used by Heywood (2011, p. 2), alignment is:

“the bringing into harmony things that differ or could differ (for instance corporate strategy and real estate strategy) by making them consistent or in agreement with each other.”

This definition of alignment is consistent with the objectives defined in Corporate Real Estate Management (CREM) and Public Real Estate Management (PREM):

- In CREM, de Jonge (1994) defined the objective of CREM as: “to optimally attune corporate accommodation to organisational performance, adding value to corporate objectives and indirectly generating income.” In: Arkesteijn and Binnekamp (2012)
- In PREM, van der Schaaf (2002) defined the objective of PREM within a government as: aligning the portfolio and services to (1) the needs of the users, (2) the financial policy set by the Treasury and (3) the political goals that governments want to achieve.

According to Heywood (2011), the alignment in CREM is a long-standing issue for practitioners and theoreticians, despite the multitude of approaches developed for alignment. This statement also applies to PREM, as PREM can be defined as a specific form of CREM (Den Heijer, 2011, p. 104). Heywood identifies two reasons that indicate why alignment is still a long-standing issue:

1. There is not a dominant alignment method in CREM theory (no ‘core technology.’).
2. Theoretical approaches to alignment do not seem to have had much uptake in practice.

Heywood also provides answers to these statements by analyzing current alignment approaches. Two types of approaches are dominant: single-factor determinism and algorithmic (model) (Heywood, 2011). Single-factor determinism focuses on one aspect to align on, e.g. location or workplace, whilst the algorithmic approach is a series of steps that the user should complete.

Heywood argues that single-factor determinism is inadequate to achieve alignment in a multi-dimensional environment (Heywood, 2011, p. 6), which is why we will focus on algorithmic approaches. According to Heywood, most of the algorithmic approaches that he analyzed lacked completeness according to the presence of fifteen components. This is similar to an observation by De Jonge et al. (2009). They analyzed six algorithmic approaches, of which they remarked: “each method covers a part of the truth and is therefore useful” (2009, p. 50).

Both Heywood and De Jonge et al. seem to agree that despite the multitude of approaches that have been developed to achieve alignment, there is still something that should be added in order to make these approaches effective in practice. The solutions that they propose will be discussed further along in this chapter.

3.2 Methods

This subchapter is concerned with delivering methods that can help overcome the issues of alignment in CREM. Each of these methods is concerned with a different part of the problem – the DAS Frame, for instance, concerns itself predominantly with strategy design challenges. Conversely, the CREM Model focuses on managing information effectively. Furthermore, three other possible approaches suggested by Heywood (2011) to achieve alignment are put forward: heuristics, wicked problems, and game theory.

3.2.1 DAS Frame

The DAS Frame is a method developed by De Jonge et al. (2009), designed to better match real estate to organizational objectives. They argue that in order for an organization to achieve alignment and make real estate decisions, a strategy is necessary. However, because alignment is a continuous process, the process of creating and adjusting a strategy also needs to be continuous. Therefore they argue the necessity of real estate strategy design. (De Jonge et al., 2009)

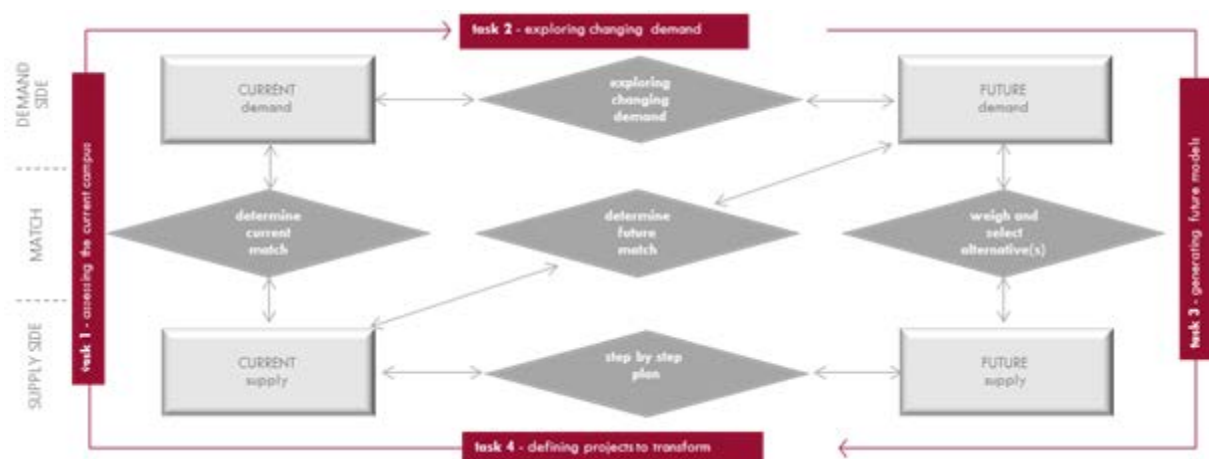


Figure 3-E – DAS Frame (Den Heijer, 2011), adapted from De Jonge et al. (2009)

However, utilizing a strategy is easier said than done. When designing a strategy the user often encounters numerous challenges (De Jonge et al., 2009, p. 34): such as where to start the strategy design process, data blindness, using different perspectives, and implementation. The DAS Frame offers its users a framework to cope with these problems.

The DAS Frame is a framework which can be used to match supply and demand in time. In the DAS Frame the four 'coordination moments' are of great importance (Den Heijer, 2011):

- Between current demand and current supply;
In this step the user compares the current demand, defined by the objectives/scope of the organization and stakeholder demands, to the current supply, its real estate. In doing so the user determines the current match or mismatch between the two.
- Current demand and future demand
In this step the user compares the current demand to the future demand by considering future changes to the organization's goals or objectives, projected growth/shrinkage of the organization, etc. An example of a method used to do this is scenario planning. Simultaneously the user can determine the future match or mismatch between the perceived future demand and the current supply.

- Future demand and future supply
In this step the future demand and future supply are coordinated. This is done by considering how adaptations to the current supply can help improve the match between future demand and future supply. This will result in a weighing and selecting process of alternatives.
- Future supply and current supply – determining a step-by-step plan
Finally, after an alternative is selected a step-by-step plan can be set out to determine how the supply will be adapted (how to get from A to B).

An example of how the DAS-frame can be used in practice can be found in Meijer (2011).

3.2.2 CREM Model

The evolution of corporate real estate management discussed previously also has its effects on decision-making. Englert (2001) states that in today's world, decision variables are more complex and require input from a larger range of people. Without this broad input, decisions (and decision-making) might not be optimal. Alignment approaches can help to incorporate this broad input, but as the input is increasing over time, achieving alignment is becoming more and more difficult.

In CREM theory, this is addressed by an elaboration on the stakeholders that should be connected to CREM and decision-making in CREM. Joroff et al. (1993) already add perspectives and variables that can be integrated in the decision-making process; this has been elaborated and has eventually evolved into the framework in figure 3-F.

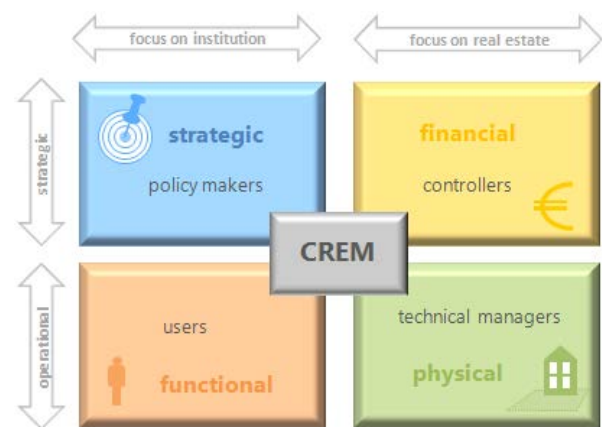


Figure 3-F - Stakeholder perspectives in CREM (Den Heijer, 2011); adapted from Den Heijer and De Vries (2005)

Den Heijer writes about this framework: “involving the stakeholders displayed in this framework can be done either passively, by informing them about the consequences of various alternatives, or actively, by making them participants in defining the brief and selecting solutions” (Den Heijer, 2011, p. 108). Den Heijer also links the required information for management decisions to each stakeholder perspective, thus using the CREM model to effectively organize information and decision variables.

3.2.3 Heuristics

Heuristics is the branch of study concerned with the methods and rules of discovery and intervention (Allinson, 1997, p. 55). Allinson describes the heuristic approach as follows:

“The synoptic planning method of the rational deductive ideal is a search for the sharpest needle in the haystack. The heuristic approach is the search for a needle sharp enough to sew with – it accepts that information, time and resources are limited and looks for a solution that appears to work rather as an alternative to a prolonged search for the optimal solution that is logically available.” (Allinson, 1997, p. 55)

The question with heuristics is, as Heywood (2011) notes, whether the use of intuitive judgement will reflect actual alignment. However, the use of rules of thumb that have been developed

through trial-and-error in practice can still be valid as an overlay or elaboration on existing theories (Heywood, 2011).

The problem with heuristics is that they are generally considered to be useful, but occasionally they lead to severe and systematic errors in prediction and estimation (Tversky and Kahneman (1982), in: Winch (2010, p. 355)). These errors are divided into three main categories:

- Representativeness: The tendency to assess the probability that an object of class A belongs to class B based on their resemblance. For example, assuming that users will rate lecture hall A higher than lecture hall B because lecture hall A corresponds better with the image that one has of the ideal lecture hall (1982, pp. 4-11).
- Availability: the tendency to base our assessment of a probability on high-profile or recent experiences without considering the whole range of experiences. For example, basing the budget of a real estate intervention on that of a previous intervention without considering the differences between the two (1982, pp. 11-14).
- Anchoring: the tendency to anchor subsequent estimates towards the first estimate. For example, anchoring towards early budget estimates whilst information has arrived that invalidates these figures (1982, pp. 14-18).

With regard to alignment this would imply that although the use of rules-of-thumb may lead to alignment of organization and real estate, occasionally the user would make erratic assumptions or decisions based on the systematic errors in his prediction and estimation of those rules.

3.2.4 Wicked Problems

Wicked problems are famously defined by Rittel and Webber in contrast to tame problems: “The problems that scientists and engineers have usually focused upon are mostly ‘tame’ or ‘benign’ ones. As an example, consider a problem of mathematics, such as solving an equation; [...] Wicked problems, in contrast, have neither of these clarifying traits; and they include nearly all public policy issues – whether the question concerns the location of a freeway, adjustment of a tax rate, ..” (Rittel & Webber, 1973, p. 160)

Based on this definition alignment can be viewed as a wicked problem. If we view alignment as a wicked problem, then it becomes a problem that is solvable, but not by using rational means to achieve definitive answers (Heywood, 2011, p. 7). Conversely, the field of Operations Research does exactly the opposite: it uses advanced mathematical methods to solve complex problems and help people to make better decisions.

Roberts (2000) writes about wicked problems that they are termed wicked because (1) there is no definitive problem statement, (2) without this statement the search for solutions is open ended, and (3) the problem-solving process is complex because constraints are constantly changing. In order to tackle wicked problems, there are three possible strategies:

- The authoritative strategy lays the problem in the hands of a few, which reduces the complexity of the problem but increases the information that is excluded from the decision-making process.
- The competitive strategy entails that opposing views are held by two parties that are challenged to come up with their preferred solution. Advantage is that the solutions can be weighed up to each other, but on the other hand the sharing of knowledge is discouraged.
- The collaborative strategy engages all stakeholders in the process, aiming to find a collective solution between them. However, achieving a shared understanding of the problem and solving it is a time-consuming process.

3.2.5 Game Theory

Heywood (2011, p.7) writes that according to recent research, the strategic process at the CREM level involves trade-offs: these trade-offs between stakeholders in decision-making are studied by game theorists. The definition of game theory is that it studies the “*mathematical models of conflict and cooperation between intelligent rational decision-makers*” (Myerson, 1991, p. 1). Therefore game theory could be useful in understanding alignment.

The assumption in game theory is that each decision-maker has the objective of maximizing his or her own payoff, which is measured by using a *utility* scale. In essence the user’s utility scale represents his preference. Therefore it has a potential added value in alignment, because decisions are frequently based on subjective variables such as quality or location. By measuring each user’s utility or preference, game theory can help to predict what decisions would maximize their preference, as individuals and as a group.

However, game theory also has disadvantages. By definition game theory assumes that decision-makers are intelligent and rational. According to Myerson (1991), they are rational if they consistently make decisions in pursuit of their own objectives, and they are intelligent insofar as they have as much knowledge about the game as game theorists do. In practice especially the assumption of rationality is flawed: people often make decisions differently due to irrationality, deliberation or motives such as altruism. This is most notably demonstrated by the Prisoner’s dilemma: in practice, individuals tend to behave more cooperatively than in theory (Fehr & Fischbacher, 2003). As for intelligence, if decision makers do not fully understand the game or its underlying theory, then they might behave differently in the game than they would in practice.

The assumption that decision-makers are intelligent and rational means that the mathematical models used in game theory to *describe* or *predict* human behavior can only do so if humans act intelligently and rationally.

Another important aspect of game theory to consider is the construction of utility scales mentioned previously. Barzilai (Barzilai, 2007, 2010a) has identified errors at the foundations of game theory, which lie in the book “Theory of Games and Economic Behavior” by von Neumann and Morgenstern (1944). On these foundations, Barzilai writes:

“... addition and multiplication cannot be applied without a foundation. These conditions have only been identified recently and are not satisfied by any scales constructed in the classical literature, including von Neumann and Morgenstern’s utility scales.” (Barzilai, 2010a, p. 3)

In order to measure preference correctly, Barzilai defines proper scales to which mathematical operations can be applied (Barzilai, 2007). These conditions must be satisfied in order to properly apply game theory. Barzilai’s solution as to how proper mathematical scales should be devised can be found in Chapter 4.

3.3 Application

In this subchapter the application of theory on real estate management and the proposed methods in order to achieve alignment is given.

3.3.1 Managing the university campus

In her postdoctoral dissertation Den Heijer (2011) links CREM theory, the DAS Frame and CREM model to the management of the university campus. Firstly, CREM theory is chosen over PREM theory as Den Heijer observes that universities are becoming more focused on economic goals and have a growing dependency on private funding (Den Heijer, 2011, p. 105).

Subsequently the DAS-Frame and the CREM model are connected to campus management. Den Heijer states that both of them answer a question from CREM theory: the DAS frame provides an answer to which tasks can be distinguished in the management process whilst the CREM model provides an answer to who decides if the match between supply and demand is satisfactory. The stakeholder perspectives in the CREM model are then projected on to the four management tasks in the DAS-Frame in figure 3-G.

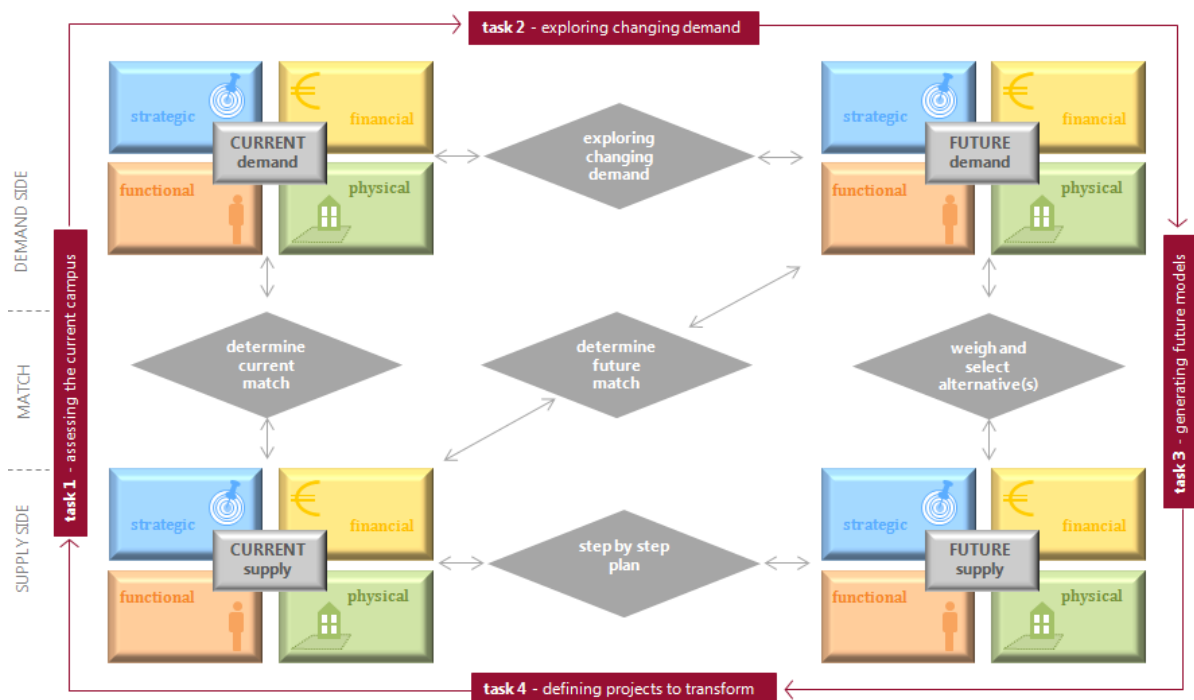


Figure 3-G - Stakeholder perspectives within the DAS-frame (Den Heijer, 2011).

By connecting these two frameworks Den Heijer provides universities with the means to deal with the increasing complexity in real estate decision-making and it supports the incorporation of multiple stakeholders in the process. Her conclusion is that campus management is more successful when all stakeholder perspectives are considered in the management process. This should be done by supplying information in an accessible way – “any tool that brings structure to the management information or supports the process to operationalize and integrate different stakeholder perspectives can be beneficial” (Den Heijer, 2011, p. 239). Furthermore, confronting stakeholders with the consequences of campus management decisions will lead to more conscious and transparent decision-making (Den Heijer, 2011, p. 240).

3.4 Conclusion

Theory:

- CREM/PREM differs from REM in the sense that it utilizes real estate to add value to the performance of the organization instead of merely generating income;
- CREM has evolved over the past few decades, resulting in a more comprehensive role but also more complexity;
- Alignment in CREM is a long-standing issue, and theory and practice have not yet succeeded in developing a method that offers a complete solution to the problem.

Methods:

- The DAS-Frame offers a solution to alignment by means of a framework for strategy design. Supply and demand are matched by four coordination points.
- The CREM model provides a tool to involve a multitude of stakeholders in decision-making and to manage the increasing amount of information;
- Methods using heuristics have some potential to solve the problem of alignment, but occasionally they lead to systematic errors in prediction and estimation;
- Alignment can be viewed as a wicked problem. The search for a solution to wicked problems is open ended because of the unclear problem statement and changing constraints. There are multiple strategies on how to tackle wicked problems, and Operations Research can provide useful tools for analysis.
- Game theory can be useful to understand alignment as it allows users to apply mathematical operations to subjective variables. However, the foundations of game theory contain errors that must be overcome before game theory can be used properly. Furthermore, one must pay attention to the assumptions that decision makers are rational and intelligent.

Applications:

- The application of CREM theory, the DAS frame and CREM model to campus management shows that the methods derived from theory can be applied to practice and provide decision makers with the means to take real estate decisions.

Chapter 4 - Decision Systems

This chapter extensively covers the use of decision systems. As we have concluded in the previous chapter, how to align real estate to the organization and how to design a strategy are essentially decision-making problems. The field of Design and Decision Systems is preoccupied with the development of tools and instruments that facilitate decision making in architecture and urban planning, and can thus provide us with the means to overcome alignment and strategy design problems.

In order to be able to make use of these decision systems and conclude this chapter, a few things must become clear. Firstly, why exactly are these decision systems useful and why does our current way of making decisions not suffice? Secondly, given this explanation, how are problems structured in decision systems? These two questions will be answered in the 'Theory' subchapter. Subsequently it must become clear what methods are used to solve these problems. These methods are discussed in the 'Methods' subchapter. Finally, theories and methods come together in the application of these models in practice: this will be discussed in the 'Application' subchapter.

4.1 Theory

The decision systems that are discussed in this chapter are based on two theoretical concepts. Firstly, the authors of these systems support the claims that classical decision theory is not good enough and that improvements must be made. Secondly, the authors recognize a shift in the decision-making process that has taken place over the last few decades, which has implications on the way that problems are structured.

4.1.1 Decision Theory

As mentioned in the introduction of this chapter, the field of Design and Decision Systems is preoccupied with the development of tools that facilitate decision-making in architecture and urban planning. In these fields, decisions have two key characteristics: a multitude of decision-makers are involved and a multitude of solutions (i.e. designs) can offer a suitable answer to a design problem (Binnekamp, 2010).

Decision theory concerns itself with the question of how to select the best solution. Finding the means to actually answer this question is provided by preference measurement. However, Binnekamp (2010) finds that existing methods using preference measurement yield contradictory results. Logically speaking, only one of these methods can yield the correct result. Strikingly, even though these methods yield contradictory results, their use in their respective fields is commonplace.

The reason that preference measurement yields contradictory results is because it does not satisfy the mathematical operations of addition and multiplication. If, as is true in this case, preference measurement is used as the mathematical foundation of a scientific discipline (e.g. decision theory, economics), these operations must be applicable (Barzilai, 2010b).

In order to be able to use preference measurement as the mathematical foundation of decision theory it must be mathematically modeled in a correct way. The following passage is based on the work of Barzilai (2010b) and Binnekamp (2010). See figure 4-A.

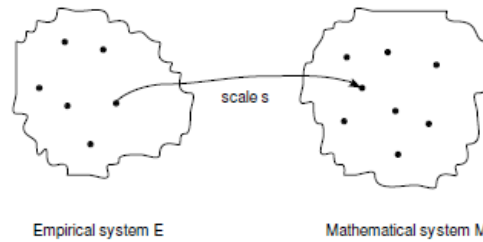


Figure 4-A - Empirical and mathematical systems (Binnekamp, 2010)

The empirical system E is the set of empirical objects together with operations (i.e. functions) and possibly the relation of order which characterize the property under measurement. The mathematical system M is a set of operations that reflect the empirical operations in E as well as the order in E . In order to map the objects of E into the objects of M a scale s is required that reflects the structure of E into M . In order for the operations of addition and multiplication to be applicable, the mathematical system M must be:

- (i) a field if it is a model of a system with an absolute zero and an absolute one
- (ii) a one-dimensional vector space when the empirical system has an absolute zero but not an absolute one
- (iii) a one-dimensional affine space, which is the case for all non-physical properties with neither an absolute zero nor absolute one.

In the case of preference measurement, the mathematical system M must thus be a one-dimensional affine space. A scale for this type of space is modeled similar to the Celsius scale: See figure 4-B. This scale is constructed by connecting the boiling point of water to the value of 100°C and the freezing point of water to 0°C . Then, other temperature values can be measured relative to these two reference points. In the social sciences this connection in a scale between mathematical objects and empirical objects is absent. One is often asked to rate his/her preference on a scale of 1 to 5, 1 being 'very bad' and 5 being 'excellent.'

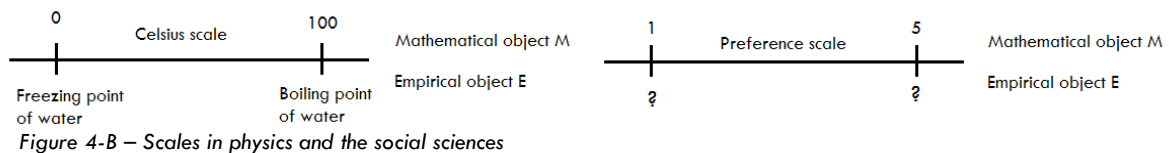


Figure 4-B – Scales in physics and the social sciences

However, the terms 'very bad' and 'excellent' have no link to an empirical object. Therefore the necessary conditions in order for mathematical operations to be applicable are not satisfied. This is the problem with the utility scales that lie at the foundations of decision theory, devised by von Neumann and Morgenstern (1944). Barzilai (1997) has developed a methodology that does satisfy these conditions and thereby enables the operations of addition and multiplication, called 'Preference Function Modeling' (PFM).

For each criterion establish a 'bottom' reference alternative rated at 0;
 For each criterion establish a 'top' reference alternative rated at 100;
 Rate all other alternatives relative to these references;
 Attach a relative weight to each criterion;
 Use the PFM algorithm to yield an overall preference scale.

4.1.2 Open Design

The underlying premise of each of the decision systems described in this chapter is the Open Design concept. The Open Design concept applies the ‘poldermodel’ of Dutch politics to decision-making in the field of architecture and urban planning. The ‘poldermodel’ refers to the way in which political issues in the Netherlands are typically resolved, which is characterized by dialogue, exchange and openness. This contrasts traditional decision-making in architecture and urban planning, which often takes place in a black box. (Binnekamp, Van Gunsteren, & Van Loon, 2006, p. 1)

This contrast means that in Open Design concepts, any stakeholder is allowed to influence the design, and the optimal design from a professional’s point of view is thought to be the same as the optimal design from the stakeholders’ point of view. This means that each stakeholder involved in the process is treated equally. In the field of architecture and urban planning, this means that a number of shifts in decision-making take place – these are displayed in figure 4-C. (Binnekamp et al., 2006)

Because of these shifts and the increase of stakeholders involved in the decision-making process, the amount of information that is relevant to decision-making greatly increases.

This has also been addressed by Den Heijer (2011) and Englert (2001) in the previous chapter. In Open Design, the use of decision-making models gives the stakeholders a means to deal with the overabundance of information: incorporating ‘information paid attention to’ in the decision-making model can increase the use of relevant information and decrease the use of confusion information (Binnekamp et al., 2006, pp. 55-56).

For the decision-making models that adhere to Open Design, it is important that they are ‘glass box’ models. The decision-making models used currently for design problems are more often ‘black box’ models: in this type of model the control unit (i.e. where the decision variables are represented) is closed and often fixed. Conversely, in ‘glass box’ models the decision variables are open and transparent. An open control unit allows users to change their decisions during the decision making process. (Binnekamp et al., 2006, p. 15)

The advantage of choosing a glass box model over a black box model is that the solution space becomes negotiable, as it is not fixed. This means that the modeling process for the solution space also changes. For black box models, standard behavior of the actor is assumed when the model is being designed. Then, the model is fixed and it is evaluated based on the outcomes it generates. For glass box models, the modeling of the solution space becomes part of the design process, because modeling and model application run parallel to each other. (Binnekamp et al., 2006, pp. 15-16)

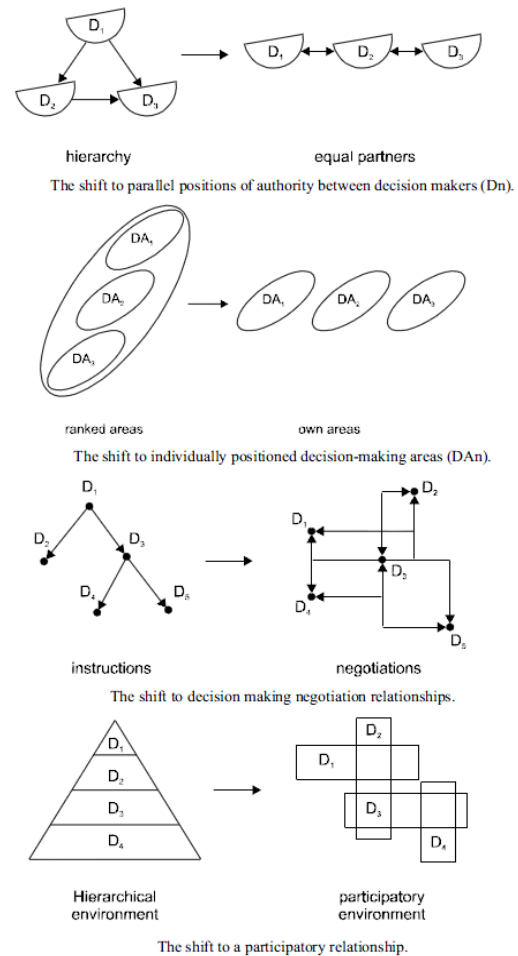


Figure 4-C – Open Design concept (Binnekamp, et al., 2006)

4.2 Methods

In this subchapter the methods that are applied in decision making models based on Open Design are introduced. Both methods are used to achieve the same goal: to find the one solution within a complex design problem that provides the best result. The best result, as can be deduced from Open Design, is the result that is most satisfactory to all decision makers. However, as we will see, both methods have very different ways of finding that solution.

4.2.1 Linear Programming

The use of linear programming (LP) in the field of architecture has arisen from the basic design problem, being that multiple design alternatives offer a solution to the problem. Ideally, one would desire to find the alternative that offers the best solution to the problem. However, this does imply that the design alternatives need to be known a priori, which is not the case in architecture.

Linear programming offers a technique where this is not necessary. The design alternative is represented as a set of all the relevant design variables (i.e. attributes such as a building's gross floor area and number of floors). Each decision maker expresses his interests in these design variables by using constraints, goals, and objectives. LP then helps us to find the optimal solution given these constraints, goals, and objectives: it maximizes an objective function that is subject to a number of constraints. (Barendse et al., 2012, pp. 9-10)

The standard form of the LP problem is formulated as follows (Barendse et al., 2012):

$$\begin{aligned} \text{Maximize} \quad & Z = \sum_{j=1}^n c_j x_j && \text{(Objective function)} \\ \text{Subject to:} \quad & \sum_{j=1}^n a_{ij} x_j \leq b_i \quad \text{for } i = 1, 2, \dots, m && \text{(Constraints)} \\ & \text{and } x_j \geq 0 \text{ for } j = 1, 2, \dots, n && \text{(Non-negativity constraints)} \end{aligned}$$

Linear programming allows the computer to control the decision variables (x_j) in order to optimize the outcome, whilst the user inputs the parameters of the model (a_{ij} , b_i , c_j). 'Optimizing the outcome' refers to maximizing the objective function Z . Given the set of constraints the LP model will yield a globally optimal solution on one criterion within a feasible set of solutions (i.e. the solution space) given the set of constraints, or an infeasible result when the feasible set is empty.

4.2.2 Preference-based Design

The application of preference measurement to decision-making in the field of architecture and urban planning emerged out of experiments with linear programming that revealed a number of limitations to the methodology. These limitations have been addressed by Binnekamp (2010) in his doctoral dissertation (Binnekamp, 2010, p. 2):

- 1 The constraints [in LP] divide all possible solutions into either feasible or infeasible ones. There is no range of solutions that is 'acceptable' to the decision makers;
- 2 The overall preference of a solution is determined as the weighted sum of the preference rating of that solution on all criteria, which is merely an approximation;
- 3 The results produced are still single-criterion design solutions, thereby not extending to group decision-making.

The consequences of these limitations are far-reaching. If one wishes to use LP to find a solution to a design problem that involves multiple stakeholders, it requires multiple optimization models for each stakeholder or criterion. The consequence is that LP cannot select the best solution for all the stakeholders out of these models, but requires the decision makers to find it themselves by means of negotiation (Barendse et al., 2012).

Binnekamp set out to develop an alternative to LP that could arrive at an optimal solution mathematically, without requiring negotiations. Binnekamp found a suitable methodology in Preference Function Modeling (PFM) by Barzilai (2005). However, PFM is an evaluation tool, and not a design tool. PFM helps decision makers to choose from a set of already existing alternatives, whilst Binnekamp wished to develop a methodology that would help decision makers to select a design when the alternatives are not known beforehand. This methodology would become Preference-based Design (PBD).

The adaptation of the previously mentioned PFM procedure leads to the following PBD procedure (Binnekamp, 2010, p. 91):

1. Specify the decision variable(s) the decision maker is interested in.
2. Rate the decision maker's preferences for at least three values for each decision variable as follows:
 - a) For each decision variable establish (synthetic) reference alternatives.
 - b) Rate the preference for alternatives associated with the other decision variable values relative to these reference alternatives on the scale established.
3. To each decision variable assign decision maker's weight.
4. Determine the design constraints.
5. Combine decision variable values to generate design alternatives and use the design constraints to test their feasibility.
6. Use the PFM algorithm to yield an overall preference scale of all feasible alternatives.

PBD removes each of the limitations from LP identified previously by Binnekamp. It enables optimization on multiple objectives by selecting the best design alternative based on the decision variables. For each decision variable, measurement scales (such as in figure 4-D) are devised that display the decision maker's preference. Design alternatives can be rated according to these scales.

PBD also removes the weighted sum limitation by including the PFM algorithm to yield an overall preference scale. Furthermore, it removes the harsh distinction between feasible or infeasible solutions. A solution is only infeasible if it does not meet the design constraints. For the decision variables, each score on the Bézier curve is considered to be feasible.

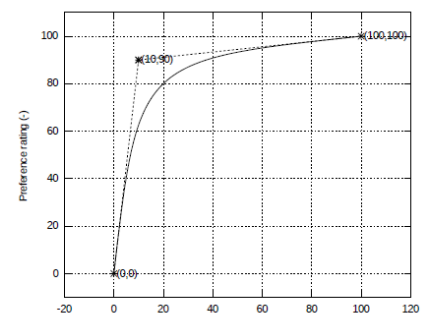


Figure 4-D - Bézier curve (Binnekamp, 2010, p. 151). A preference rating 100 reflects the decision variable value at which the decision maker is fully satisfied; a preference rating 0 when the decision maker is fully unsatisfied. The definition of the *third point* determines the curve.

Binnekamp (Binnekamp, 2010, p. 145) concluded that PBD reflects the decision makers' preferences more accurately than was done by LP, based on applications in architecture and urban planning. The quality of the design decision is therefore higher and the outcome more acceptable. Furthermore, the methodology yields results that are found to be plausible and satisfactory to the decision makers. However, he does state that the Bézier curves are a limitation because they are predetermined, which means that they do not purely reflect the decision maker's preference.

4.3 Application

This subchapter discusses a number of applications that are based on the use of Linear Programming (LP) and Preference Measurement/Preference-based Design (PBD). Two applications using LP and one application using PBD will be discussed. These applications display the development in the use of decision-making models to find solutions to group decision-making problems.

4.3.1 Urban Decision Room

The 'Urban Decision Room' (UDR) is a decision-making model used in an urban planning context that helps various stakeholders with different interests to reach a collective solution. Van Loon and Wilms (2006) write that the UDR is intended to be a methodological answer to the shifts recognized in Open Design.

This methodological answer is the use of LP with negotiable constraints, introduced by Van Loon (1998). Traditionally, constraints are fixed by definition:

"A constraint is a fixed requirement which cannot be violated in a given problem formulation. Constraints divide all possible solutions (combinations of variables) into two groups: feasible and infeasible" Zeleny ((1982, pp. 225-226) in Barendse et al. (2012)).

Van Loon (1998) created a distinction between 'hard constraints' and 'soft constraints': hard constraints are still fixed, whereas soft constraints are negotiable and can thus be used to broaden the solution space (Van Loon, 1998). In LP this means that the mathematical outcome 'infeasible' can be changed to 'feasible' by altering the constraints.

The use of negotiable constraints is necessary order to make LP suitable for group decision-making. Due to the limitations of LP the goal of the UDR is to create a solution space in which the ultimate (joint) goal can be found (Van Loon et al., 2008, p.2.). In the case of the UDR Heijsehaven, this is done by first letting each stakeholder enter their proposals for solutions into the UDR, after which a central computer is used to calculate the common solution space (figure 4-E). Then the stakeholders negotiate the outcome (figure 4-F), after which the round can be repeated. This way of using LP is in accordance with the way described by Barendse et al. (2012) on the previous page.

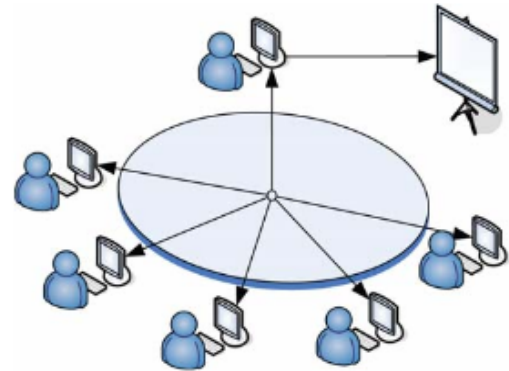


Figure 4-E - Urban Decision Room (van Loon et al., 2008)

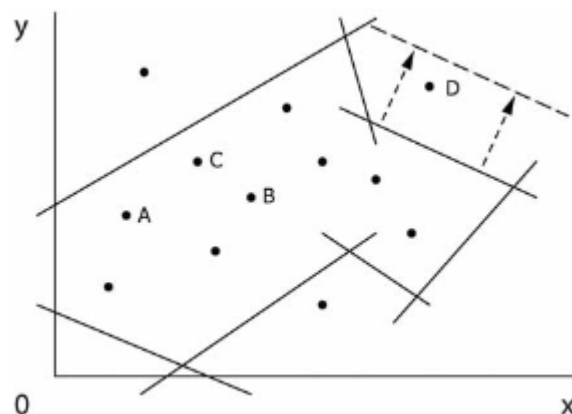


Figure 4-F – Common solution space (van Loon et al, 2008, p.2)

In addition the UDR removes the distinction between 'goal design,' a conceptual model of the desired new solution, and 'resources design,' a concrete proposal for a situation which can be achieved in reality Van Loon and Wilms (2006, p. 373). This is because the UDR can link the decision-making area to all of the components (goals and constraints) of the users.

In the evaluation of the tool, van Loon et al. (2008, pp. 64-66) concluded that users do not understand certain steps in the model precisely. They also have difficulty understanding the computer language used in the UDR, and they require a better explanation of the objectives and the purpose of the UDR.

For future research the authors recommend that new instruments should be tested in terms of content, process, and communication. With regard to content, new instruments should be tested on the relevance of the decision variables they incorporate. Process-related questions are also important, relating to the role of the UDR leader (i.e. the person that moderates the decision room) and the introduction of the tool. Finally, communication aspects of these models are also important: the use of the UDR as a means of communication has not been tested (Van Loon et al., 2008, pp. 72-73). Over the years the UDR has been applied to a range of complex urban development cases: an inner city area, central station area, and an old city port area (Van Loon, Barendse, & Duerink, 2012).

4.3.2 Public Real Estate System

The Public Real Estate (PRE) System is a decision-making model that has been developed specifically for portfolio management by Arkesteijn, Van de Schootbrugge, and Van Loon (2011). The development of the PRE System was one of the steps leading up to the development of PAS. The PRE System has been developed for the municipal development company of Rotterdam, OBR. OBR influences the public realm by ownership and management of real estate in order to achieve the municipality's goals. Their desire was to steer more explicitly on these goals through their real estate management – in other words, to *align* their real estate to their organizational goals.

Van de Schootbrugge (2010, p. 6) formulates the goal of the PRE System as follows:

- The development of a digital (computerized) public real estate decision support system to steer on the [municipality of Rotterdam's] complex real estate portfolio;
- Steering will focus on the relation between public goals and the portfolio, which is influenced by complex selling, user, technical and costs relations;
- Steering is essential in order to create strategic real estate interventions;
- Which will ultimately lead to a strategic portfolio.

Van de Schootbrugge connects LP techniques to the DAS Frame and stakeholder perspectives mentioned in Chapter 3. The real estate portfolio consists of the municipality's residential buildings. Each stakeholder perspective has its own objective (e.g. user perspective has 75% user satisfaction as objective, technical manager perspective a condition score of 5). Also, a database of all the buildings in the portfolio exists that contains the scores on each objective for each building (e.g. 25% user satisfaction and a condition score of 2). Then, a number of steps derived from the DAS Frame are completed to match these objectives (demand) and object characteristics (supply) (Van de Schootbrugge, 2010, pp. 53-60).

The goal of the PRE System leads to a different use of LP compared to the UDR. The UDR creates a common solution space in order to negotiate a common solution, resulting in LP with negotiable constraints as the main feature of the decision-making model. The PRE System is used to give decision makers the means to make strategic decisions. The DAS Frame as a main structure helps them to gain insight into their real estate objects and the portfolio. After identifying problems per portfolio object, LP is used to prioritize on those objects that have multiple problems. By addressing these objects first the user can achieve public goals by minimal means. (Van de Schootbrugge, 2010)

In the evaluation of the PRE System, Van de Schootbrugge states that users initially found the model to be quite complex and that they felt that the system took over control of the process, which eliminated room for creativity. In later stages these concerns were not reiterated.

4.3.3 Preference-based Accommodation Strategy

In this section, Preference-based Accommodation Strategy (PAS) will be discussed. PAS is a strategy design tool that is currently being developed as a part of the postdoctoral dissertation by Arkesteijn (to appear 2014) to which this research will contribute. The PAS model that is discussed here includes no contributions by the author.

In the first place, the development of the PAS has resulted from the desire to incorporate proper preference measurement into the process of real estate portfolio decision-making. Therefore the methodology used in the PAS is based on a conversion of the preference-based design (PBD) methodology by Binnekamp (2010). This methodology is called 'Preference-based portfolio design (PBDP) (Arkesteijn & Binnekamp, 2012).

The difference between the two methodologies is the scale level to which they are applicable: the PBD is applicable on an object level whilst the PBDP is applicable on a real estate portfolio level. This has some practical implications for the methodology.

Firstly, in PBD the combination of decision variables only needs to be applied to one object whilst in PBDP it needs to be applied to a range of objects (i.e. a portfolio). In order to resolve this problem, all the design alternatives for the portfolio must be generated first. In PBD, design alternatives were generated based on the values of decision variables.

This leads to the second implication. In PBD, the decision maker establishes his preference by rating reference design alternatives on a preference scale *a priori*. In PBDP, the decision maker's preference needs to be a function of the decision variable value if he wishes to evaluate a design alternative *a posteriori*. Therefore it is not possible to use a Bézier curve as it is a parametric equation. Instead, Lagrange curves are used in order to relate preference ratings to decision variable values. Thereby previously mentioned limitations regarding the Bézier curves are removed, although the Lagrange curves have their own limitations as they accept negative values under certain circumstances. (Arkesteijn and Binnekamp, 2012)

The PBDP methodology consists of the following series of steps, as defined by Arkesteijn and Binnekamp (2012):

1. Specify the decision variable(s);
2. Assign the decision maker's preference to each variable;
3. Assign the decision maker's relative weight to each variable;
4. Determine the design constraints;
5. Generate all the design alternatives;
6. Use the PFM algorithm to yield an overall preference scale.

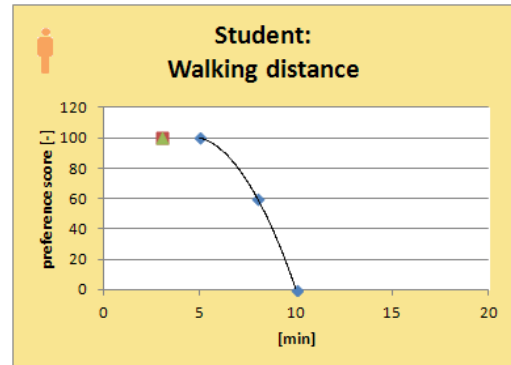


Figure 4-G - Lagrange curve (Arkesteijn & Binnekamp, 2012)

1. If user can reach a restaurant within 5 minutes, he/she is fully satisfied (pref. score 100)
2. If user cannot reach a restaurant within 10 minutes, he/she is unsatisfied (pref. score 0)
3. If user can reach a restaurant within 8 minutes, he is still quite satisfied (pref. score 60). This value determines the curve.

In PAS Arkesteijn combines (to appear 2014) this methodology with the DAS-frame and stakeholder-perspective frameworks by De Jonge et al. (2009) and Den Heijer (2011). The combination of the DAS-frame, stakeholder perspectives framework and the PBDP methodology by Arkesteijn (to appear 2014) leads to the following procedure in the PAS:

- 1, 2 Assessing current demand and exploring changing demand.
 - A. Specify the decision variable;
 - B. Assign the stakeholder's preference to each variable;
 - C. Assign the stakeholder's relative weight to each variable;
 - D. Determine the design constraints.
- 3 Generating future models.
 - E. Generate design alternatives.
 - F. Use the PFM algorithm to yield an overall preference scale)
- (4 Defining projects to transform; omitted in PAS)

The first two steps in PAS are completed separately with each stakeholder group. By using interviews they are enabled to specify their decision variables, assign preferences, and assign weights. The third step is completed in workshops: all the decision variables defined and weighted by the stakeholders are put together in one table and related to the objects in the current portfolio. The objective of the workshop is to design an alternative with the highest overall preference score, i.e. the optimal design. This is done manually in the screen displayed in figure 4-H, but can be done alternatively by using the PFM algorithm. However, as of yet this algorithm does not exist.

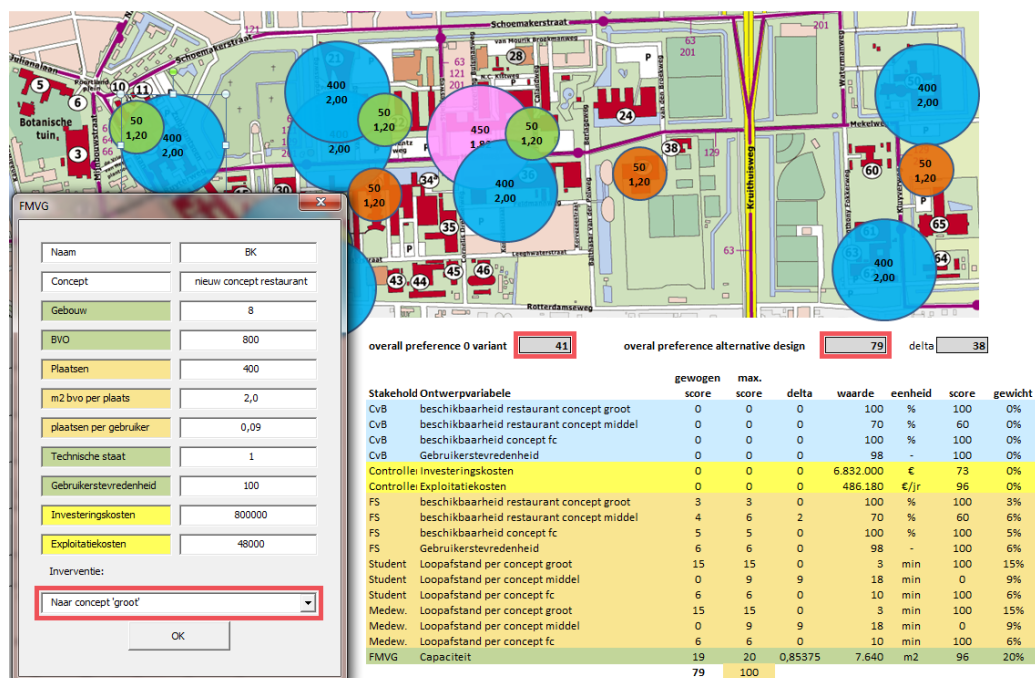


Figure 4-H – PAS Design Screen (Arkesteijn, to appear 2014)

During the workshop, results are directly fed back: users can see the results of their actions by looking at the difference between the overall preference score of the current situation and the overall preference score of their design. The interviews and workshops are repeated, as the use of the model is part of the strategy design process in the DAS Frame. This iterative process helps to perfect both the model's depiction of reality as well as the depiction of the stakeholders' preferences.

4.4 Conclusion

Theory:

- In decision theory, the use of preference measurement yields contradictory results due to mathematical errors at its foundations. Barzilai (2010b) has developed a methodology which yields mathematically correct results.
- Open design intends to offer solutions in decision-making problems between stakeholders in participatory decision-making environments. This leads to decision models that are 'glass box' models. In these models the solution space can be discussed and negotiated;

Methods:

- Linear programming aims to find the best solution to a design problem by making variables explicit as goals, objectives, and constraints. It can only maximize on a single objective. If used to solve group decision-making problems, decision-makers must negotiate the solution themselves.
- Preference-based design removes each of the limitations from LP in group decision-making. It enables optimization on multiple objectives by selecting the best design alternative based on the decision variables.

Applications:

- The Urban Decision Room is a decision-making model developed to solve decision-making problems in an urban area context. The UDR demonstrates that using LP to solve group decision-making problems has limitations: it can at best be used to identify a common solution space, negotiate that solution space and the eventual solution.
- The PRE System is a decision-making model developed to solve decision-making problems in a real estate management context. In the PRE System, the DAS-Frame is used to identify the mismatch between supply and demand. LP is used as a technique to prioritize on the objects with multiple problems in order to 'achieve public goals by using minimal means.'
- Preference-based Accommodation Strategy is a decision-making model developed to solve decision-making problems in a real estate management context. PAS uses PBPD to establish decision variables. Given this set of decision variables, users search for a set of real estate interventions (i.e. a design alternative) that will lead to the highest overall preference score. This process is repeated a number of times.

Chapter 5 - Timetabling

This chapter forms the body of knowledge in this thesis regarding the timetabling problem. Because timetabling will form a significant part of the decision-making model, it is important to understand the benefits and shortcomings of the timetabling method that is used compared to the solutions developed in theory and practice. Therefore, this chapter provides an answer to the following research questions:

“What is the exact definition of the timetabling problem?”

“What are the solutions proposed in theory to overcome the problem?”

“What types of programs are often applied in practice?”

5.1 Theory: The timetabling problem

The timetabling problem is a problem that is found across many sectors: in nursing, sports, transportation, etc. In their survey of search methodologies in timetabling, Qu et al. state that the timetabling problem has found increasing attention in operations research in the recent past (Qu et al., 2009).

A definition given for the timetabling problem is as follows:

“A timetabling problem is a problem with four parameters: T , a finite set of times; R , a finite set of resources; M , a finite set of meetings; and C , a finite set of constraints. The problem is to assign times and resources to the meetings so as to satisfy the constraints as far as possible.”

(Burke, Kingston, & De Werra, 2004) in (Qu et al., 2009, p. 3)

Within this definition, the objectives of the solution proposed are as follows:

- 1) To assign times and resources to all the meetings, i.e. to allocate all the meetings to a time and space.
- 2) In fulfilling objective 1, as much constraints as possible must be satisfied.

In order to be able to fulfill objective 2, a distinction is usually made between hard and soft constraints. Hard constraints cannot be violated under any circumstance, whilst soft constraints “are desirable but not absolutely critical” (Qu et al., 2009, p. 4). In practice it is often found that it is impossible to satisfy all the soft constraints. The quality of a timetabling solution is measured by the degree to which it has incorporated these soft constraints: the more, the better. (Qu et al., 2009)

In addition to this definition of quality, timetabling solutions need to be able to fulfill the required needs from practice. The timetabling process at universities is aimed at the satisfaction of three goals (McCollum, 2007, p. 10). First, students must be offered maximum flexibility of choice. Then, the timetable should provide flexibility to the staff, and finally, the effective use of teaching space becomes an objective.

The result of these priorities is that any solution that satisfies all of the hard constraints is seen as a good solution, and that optimization of this solution is not a main objective in the process. Often, the creation of a timetable requires significant staff work instead of relying solely on the software program. That is why McCollum emphasizes the gap between theory and practice that needs to be overcome. (McCollum, 2007, pp. 10-11)

5.2 Methods

This subchapter discusses a set of methods developed to tackle the timetabling problem. The reason why optimization is not a priority in timetabling and why the process is still not automated can be found in Qu et al. (2009): automation of timetabling is simply a relatively new field. Many of the timetabling systems that have appeared have been tailor-made for specific institutions (2009, p. 8); standards for timetabling have not yet been adopted by the community (2009, p. 9); and there are no universally accepted complete models for the timetabling problem (2009, p. 10). In general, seven types of timetabling techniques are put forward in scientific literature. (Qu et al., 2009, pp. 11-28).

5.2.1 Graph-based sequential techniques

Graph-based sequential techniques for timetabling are a relatively old branch of timetabling techniques, already introduced in 1967 (Welsh & Powell, 1967).

The basics of graph-based sequential techniques lie in graph coloring, which can be made insightful by the example in figure 5-A. In the graph, each vertex corresponds with a job or class and each line corresponds with a conflict or constraint. Each quadrant (set 1-4, 5-8, 9-12, 13-16) represents a time slot, to which a class can only be allocated once. Each colored vertex represents a class, which must be placed in the graph without resulting in any conflicts with vertices of the same color. These techniques, although relatively simple, are still widely applied in scheduling in addition to other scheduling methods.

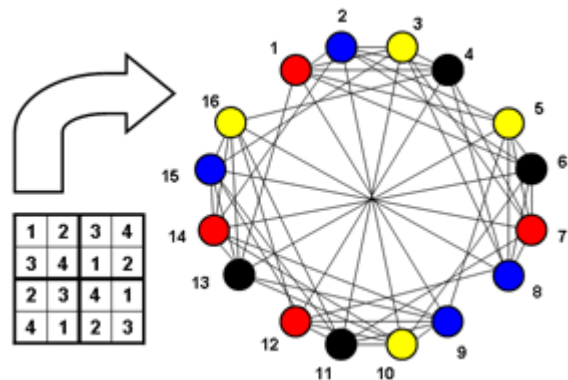


Figure 5-A - Graph coloring (Lewis, 2013)

5.2.2 Constraint-based techniques

An alternative to the use of graph coloring techniques is the use of constraint-based techniques. These techniques model the timetabling problem as a set of constraints to be satisfied, similar to linear programming as described previously. The constraint program often searches for a solution that satisfies all the hard constraints. Within timetabling, however, the use of constraint-based techniques becomes harder as the scale of the problem grows: the number of possible assignments increases exponentially with the number of variables. Therefore, in recent research on timetabling the use of constraint-based techniques has been combined with the use of other timetabling techniques. However, Qu et al. (2009, p. 15) note that a constraint-based method does produce the best results on some of their benchmark timetabling problems.

5.2.3 Local Search based techniques

Local search based techniques are a set of methods such as algorithms that move from a proposed solution to a problem to find a better solution in its neighborhood. The search for a better solution is guided by an objective function. Within a set of parameters and search boundaries, the algorithm searches for a better solution based on its objective function, thereby arriving at a local optimum. According to Qu et al. (2009) the effectiveness of these techniques are largely determined by the parameters and search boundaries that are used to find a better solution. Unfortunately the amount of effort required to find the best set of parameters and search boundaries is very high, but the amount of success acquired by using these techniques has been quite high (Qu et al., 2009).

5.2.4 Population-based algorithms

Population-based algorithms are a set of algorithms that assume that better solutions can be achieved by manipulation and evolution of those solutions. These types of algorithms are called evolutionary algorithms and are often used in biology. Essentially, population-based algorithms are used in a similar way to local search based techniques, but they differ in the sense that they search for a better solution at once by manipulation and evaluation instead of reaching a better solution iteratively by adjusting parameters and search boundaries. The disadvantage of this is that in comparison to local search based techniques, the time required to compute results increases greatly and setting parameters and search boundaries becomes more difficult.

5.2.5 Multi-criteria techniques

Multi-criteria techniques differ from the aforementioned approaches in their evaluation of a solution. As mentioned previously, timetabling is often evaluated by the amount of soft constraints violated by a certain method. Multi-criteria optimization strives to search for a solution that satisfies the criteria of the stakeholders involved towards the constraints. Multi-criteria techniques thereby assign weights to the constraints in order to make a distinction in the importance of each constraint. Multi-criteria approaches often provide timetablers with the flexibility to find desired solutions by managing the weights of the constraints (Qu et al., 2009, p. 24).

5.2.6 Hyper-heuristics

Hyper-heuristics is a name given by the author to a range of more generic solutions provided for the timetabling problem. In timetabling, the methods developed are often tailor-made to suit certain organizations and are not transferable. Hyper heuristics can be seen as “a search space of heuristics [that] is the focus of attention rather than a search space of solutions” (Qu et al., 2009, p. 25). To summarize, hyper-heuristics focus on the more abstract level of what types of strategies or methods should be chosen to achieve the best result, rather than developing a low-level approach.

5.2.7 Decomposition techniques

Decomposition techniques are a range of techniques that propose the breaking-down of a large problem into smaller sub-problems in order to search for optimal solutions. In terms of computing time and complexity, these types of techniques offer significant advantages. Unfortunately, later reconstruction of the large problem can lead to infeasibility, or optimal solutions might be missed in the reconstruction because not all the constraints could be incorporated into the sub-problems.

5.3 Application

In this subchapter two applications will be discussed that are especially relevant to this research. The first application is a range of tools named EventMAP discussed by McCollum (2007) that aims to bridge the gap between theory and practice in timetabling. The second application is the scheduling program that the Delft UT currently uses.

5.3.1 EventMAP

EventMAP is a company dedicated to the development of software that “acts as an enterprise resource planning tool as well as a management information service, informing on strategic ways forward for the need for, use of and allocation of resources within an institution” (McCollum, 2007, pp. 3-4). With regard to course scheduling, McCollum recognizes the potential of a model that relates timetabling to the campus:

“The Company [EventMAP] aims to model how increases in course delivery, through effective timetabling, can affect the overall nature and structure of the campus. Ultimately, this would allow for strategic decisions to be taken in relation to room types, sizes and quantities across all space types within the Institution. The course timetabling system is therefore a fundamental part of the strategic computing systems within the institution.” (McCollum, 2007, p. 13)

All the products offered by EventMAP are based on an ‘algorithmic engine’ named Optime. This description implies the use of local search based techniques and population-based algorithms. One of the products using Optime is named ‘Resource,’ which is a space planning tool that can help users to manage their space more effectively. On the website, the description of the product is as follows:

“Resource allows for investigations to take place in terms of resource usage scenarios relating to how ‘good’ the current timetable solutions are, how they might be made ‘better’ and how ‘change’ could be introduced to allow the institution to position itself for the future in terms of resource requirement. This involves a computer assisted approach in terms of overall institutional modeling i.e. overall current and projected resource.” (EventMAP, 2013)

This implies that Resource can evaluate current timetable solutions based on the usage of space. Propositions as to how the usage of space can be made more effective are modeled alongside performance drivers, such as space type mix, average contact hours, length of timetabled week, frequency of use, projected occupancy, curriculum need, staff preferences etc. The program can thus evaluate the effects of different types of education programs on the space resources of a university.

5.3.2 Scheduling at the Delft University of Technology

The scheduling process used at the Delft University of Technology is especially relevant to this thesis, especially in relation to the problems identified in the introduction. In 2009 the university implemented a new scheduling system called Syllabus Plus (ICTO TU Delft, 2010).

Syllabus Plus is a constraint-based method that alerts the user when an activity compromises certain constraints. The user can then manually move an activity to a time slot where the activity violates fewer constraints, which is a form of graph coloring. (McCollum et al., 2002) identify Syllabus Plus as one of the marketing leaders in scheduling. The problem with each of these market leaders is that it is not clear how the user should reschedule conflicting activities. Moving another activity to accommodate a conflicting activity can result in more constraints being violated, making the scheduling task all but impossible. (McCollum et al., 2002, p. 2)

5.4 Conclusion

Theory:

The objective of scheduling is firstly to offer students maximum flexibility, secondly to offer staff maximum flexibility, and thirdly to efficiently manage resources. The result of this setting of priorities is that schedulers often look for a workable solution and that optimization is often not an objective.

Methods:

Qu et al. (2009) identify seven different types of methods that have been discussed and developed in literature.

- Graph-based sequential techniques form the basis of research in timetabling, but are still used frequently complementary to other methods;
- Constraint-based techniques provide good solutions, but limitations occur in scaling of the models;
- Local search based techniques and population algorithms look for a local optimum given a previously calculated optimal solution, but their results depend for a great deal on the parameters and search boundaries set by the user;
- Multi-criteria techniques offers flexibility in finding good solutions by managing the importance of the constraints;
- Hyper-heuristics focuses on what types of strategies should be employed to find the best timetable solution;
- Decomposition techniques are used to find a solution by breaking down a problem to a number of smaller sub-problems. Although this leads to some practical advantages, it can also lead to infeasibility of the solution if the problem is brought back to its original size.

Applications:

- EventMAP has developed a range of tools supposedly based on local search based algorithms and/or population algorithms. One of these tools, Resource, links the timetabling problem to efficient management of university resources.
- Timetabling at the Delft University of Technology is done by using a program named Syllabus Plus. This program combines constraint-based techniques with a form of graph coloring, but the process of optimization is very difficult.

Chapter 6 - Gaming

In the previous chapter the use of decision-making models in real estate management has been discussed. In this chapter gaming will be introduced and its relationship to decision-making models will be discussed. This chapter will answer the following questions:

“What exactly constitutes gaming?”

“What are the benefits and drawbacks of gaming?”

“What is the difference between gaming and decision support systems?”

“How is gaming represented in PAS?”

6.1 Theory: Gaming, Game Theory and Simulation

In subchapter 3.1 the concept of alignment has been introduced. It has been explained that alignment is a long-standing issue and possible solutions found in literature have been put forward. One of the proposed solutions was game theory. Before proceeding, the difference between game theory and gaming must first be clarified.

The confusion between gaming and game theory is quite logical. Shubik (1971) states that although the two disciplines are very different, they are very intertwined. Shubik (1971, pp. 2-4) uses the following definitions to distinguish gaming and game theory. To prevent further confusion, his definition for simulation is also added.

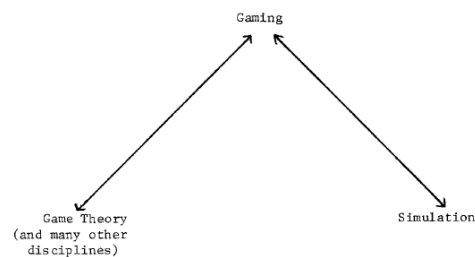


Figure 6-A - Relationship between gaming, game theory, and simulation. (Shubik, 1971)

Gaming

“A gaming exercise employs human beings acting as themselves or playing simulated roles in an environment which is either actual or simulated. The players may be experimental subjects whose behavior is being studied or they may be participants in an exercise being run for teaching, training or operational purposes. The discipline of gaming deals with the construction, organization, running, and analysis of games for this purpose.” (Shubik, 1971, p. 2)

Game theory

“Game theory is part of a large body of theory concerning decision-making. It provides a language for the description of conscious, goal oriented decision-making processes involving more than one individual. [...] It is a branch of mathematics which can be studied as such with no need to relate it to behavioral problems, to applications, or to games.” (Shubik, 1971, p. 3)

Simulation

“Simulation involves the representation of a system or organization by another system or model that is deemed to have a relevant behavioral similarity to the original system. The simulation or model is usually far simpler than the system or organism it represents. It should be far more amenable to analysis and manipulation. Games utilize a simulated environment or simulated roles for players, or both. In general, all games are simulations. [...] However, not all simulations can be considered as games.” (Shubik, 1971, p. 3)

Based on these definitions, it is clear that the concepts of gaming and simulation are very similar. In this chapter, theory on simulation is thought to be applicable to gaming if the simulation allows freedom of human decision-making.

Game theory studies *why* people make certain decisions in certain situations by providing explanations for them. These explanations can be clarified by the use of games (e.g. the prisoner's dilemma), although this is by no means required. Similarly, game theory can provide someone who wishes to utilize gaming with guidelines how to construct these games (Shubik, 1971, p. 30).

6.2 Method: Benefits and Drawbacks of Gaming

Now that the relationship between game theory, gaming, and simulation has been delineated, gaming itself can be addressed. By definition it has become clear that all games are simulations, but not all simulations are games. Then we must know what a simulation must contain in order to be an effective game. Also, if gaming is to be used as a technique, we must be aware of its benefits and drawbacks.

Erisman et al. (2002) write that in a game, players should have a clear goal and that they need to have access to a (limited) set of actions that they can take. It must also provide quick responses to the actions of player actions, thereby giving adequate insight into the consequences of the player's choices.

Bekebrede (2010, pp. 12-14) describes gaming as the use of multi-dimensional models that deal with social systems as well as technical systems. Gaming combines simulation and role-playing in order to deal with these two systems. This is in accordance with Shubik's definition, as we have established that simulation does not necessarily include the freedom of human decision-making. This freedom is represented in gaming by role-playing.

These statements imply that gaming must be a simplification of reality, it must give players freedom of decision-making, and players require direct feedback in order to gain an understanding of the problem. Also, gaming must include realism of both the social systems and the technical systems that apply to the problem. The games for which this holds true are called 'serious games.'

Before proceeding, it must be noted that serious games can also imply entertainment games such as SimCity or Civilization that are used for educational purposes, but have no direct relation to the actual decision-making problem that a group is facing. Conversely, this chapter concentrates on serious games as a type of game that represents the social and technical systems of actual decision-making problem, albeit in simplified form.

According to Erisman et al. (2002, p. 194), games are useful for a number of reasons:

- Gaming allows decision makers to experiment in a safe and cost-effective way;
- Games can be used for awareness building;
- Games can facilitate the transfer of knowledge and can help novices understand complex theories and problems;
- Games can provide insight into complex problems.

This statement is supported by other authors. Mayer and De Jong (2004, p. 228) write that the proclaimed benefits of gaming are to show how a variety of mechanisms work together and how it helps in 'getting the big picture.' Bekebrede (2010, p. 14) writes that gaming has been

used to understand complex problems: the use of multiplayer games starts discussions about the topic, relations and outcome of the game. It also enhances social interplay and creates a better understanding of the work process and the organization.

Unfortunately, gaming also has a number of drawbacks. Bekebrede (2010, pp. 13-14) draws up the following limitations:

- It is impossible to reproduce the game, because they are dependent on the availability and characteristics of the players;
- A game can be played less often than a simulation in the same time, because it takes more time for players to play a game than it takes for a computer to run a simulation;
- A game cannot be repeated from the same starting position: each time it is played, there are players with different roles and interpretations, as well as players that have played the game previously and thus have more experience and knowledge about the game.

Mayer and De Jong (2004, p.228) write that despite the advantages of gaming, games are not very well equipped for in-depth focus on the effects of a single mechanism, instrumental recommendations, or solutions to problems. These effects can be mitigated in decision-making models.

6.3 Application: Gaming and Decision-making Models

Before discussing the use of gaming in group decision-making and policy support it must first become clear what constitutes gaming in this context and what does not. This distinction is made by Mayer and De Jong (2004): they define the concepts of gaming and 'group decision support systems' (GDSS).

GDSS "A GDSS is a system consisting of computer software, computer hardware, meetings procedures, and facilitation that supports groups engaged in intellectual collaborative work" (Mayer & De Jong, 2004, p. 225).

Note that Mayer and De Jong use the term GDSS for both systems that support communication and planning in decision-making and systems that facilitate collaborative or interactive group decision-making.

Gaming "Simulation-games are a simplification and condensation of a real system, allowing participants to experiment safely with (future) decisions and institutional designs, and reflect on the outcomes" (Mayer & De Jong, 2004, p. 226).

Note the similarity between this definition and Shubik's definition, as well as the contraction 'simulation-games.' According to Mayer and De Jong, some definitions are so similar that decision support systems can even be considered as games, such as the example of Nitrogenius (Mayer & De Jong, 2004, p. 227).

Furthermore, Mayer and De Jong (2004) analyze the difference between the two methods. They argue that, in order to understand complex multi-actor decision-making problems, both information structuring and experiences of actor and system behavior are important. This analysis is summarized in figure 6-B.

Characteristics	GDSS	Gaming
Problems Method	Complex multi actor problems Interactive facilitated group method for decision and policy support	Complex multi actor problems Interactive facilitated group method for decision and policy support
Way of thinking	Analytical rationality	Strategic and political rationality
Leads to . .	“Texts”; an analysis of substantive aspects of complex multi actor problems	Learning experience: an analysis of social-political context of complex problems
Main advantages	Group memory/fast/ anonymous/information generation and retention/ Instrumental inferences	Group experience/big picture/ holistic view/dynamics of social interaction/Strategic and tactical inferences

Figure 6-B – Overview of the characteristics of GDSS and Gaming. (Mayer & De Jong, 2004)

However, the line drawn by Mayer and de Jong regarding gaming and GDSS focuses on types of GDSS used for planning and communication. In their paper they advocate the benefits of the collective use of these types of GDSS and gaming. By definition the line between GDSS used for interactive group decision-making and gaming is a very thin one. If the main question of this research is how gaming can contribute to group decision-making, then it must become clear where this line is drawn.

Earlier it was mentioned that Nitrogenius (Erisman et al., 2002) is a system that can be used both as an interactive group decision-making tool and a game. The decision support system is introduced first:

“The heart of a decision support system should contain models with simple parameterizations describing all necessary and relevant interactions. These should be accurate enough to produce realistic results for the present time and for the future, and should be influenced by a range of abatement options. These parameterizations are usually based on complex models, which contain process descriptions and are validated with observations.”

(Erisman et al., 2002, p. 191)

Later on, the game is introduced:

“Games and simulations are very closely related. In fact, a game could be thought of as a simulation that determines the consequences of actions taken by one or more actors (players) within the simulated world. In other words, the actors become part of the simulation—the ‘human factor.’ Players will be confronted with the results of their own actions and the actions of others and can act upon them.”

(Erisman et al., 2002, p. 194)

In their distinction between the two, Erisman et al. (2002) refer to the difference between gaming and simulation, also explained in subchapter 5.1. The moment where a decision support system becomes a game is where the players are confronted with the consequences of their actions and those of others in the simulation and can act upon them.

6.4 Application: Gaming and PAS

In the following chapters a game will be designed based on the concepts of Preference-based Accommodation Strategy (PAS). In order to test the game it is necessary to determine what the role of gaming is in PAS. In section 4.3.3 PAS has been introduced. The process that is leading for PAS is as follows:

- 1, 2 Assessing current demand and exploring changing demand.
 - A. Specify the decision variable;
 - B. Assign the stakeholder's preference to each variable;
 - C. Assign the stakeholder's relative weight to each variable;
 - D. Determine the design constraints.
- 3 Generating future models.
 - E. Generate design alternatives.
 - (F. Use the PFM algorithm to yield an overall preference scale)

If the PFM algorithm is used to generate design alternatives then the PAS is not used as a game – users deliver their input and the PFM algorithm calculates the best option. However, the users can also generate design alternatives themselves by choosing out of a limited set of actions and act upon the results that are fed back to them. In this situation PAS is used as a game.

Furthermore, the results that are generated by the model are not held to be final – the users are allowed to redefine their criteria and then play the game again. This iterative process means that users can safely experiment with a limited set of actions and discover how these actions influence their criteria, thereby providing insight into the problem.

6.5 Conclusion

In this subchapter, an answer to the following three questions has been provided:

“What exactly constitutes gaming?”

“What are the benefits and drawbacks of gaming?”

“What is the difference between gaming and decision support systems?”

“How is gaming represented in PAS?”

Gaming is a type of simulation that allows humans the freedom to make their own decisions within the simulation. Game theory can be used to structure problems when designing a game, but it is not necessary to relate games to game theory or otherwise. In comparison with decision systems, gaming focuses predominantly on the learning experience of its users whilst decision systems focus predominantly on providing its users with a solution, i.e. making decisions.

Benefits of gaming:

- Gaming allows decision makers to experiment in a safe and cost-effective way;
- Games can be used for awareness building;
- Games can facilitate the transfer of knowledge and can help novices understand complex theories and problems;
- Games can provide insight into complex problems.

Drawbacks of gaming:

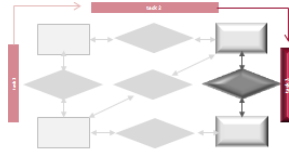
- The impossibility to reproduce the game;
- A reduced number of simulation runs (compared to simulation);
- A game cannot be repeated from the same starting position.
- Less ability to focus on the effects of a single mechanism, recommendations or solutions to problems.

The difference between gaming and decision support systems lies in the possibility that the players are confronted with the consequences of their actions and those of others in the simulation and have the possibility to act upon them. In PAS, this is done by giving users the opportunity to design alternatives themselves and the possibility to adapt their criteria according to insights gained during the game.

Part Three Model Design

This part of my thesis contains a detailed description of the design of the computer model. In chapter 7 the basic functionality of the model will be discussed. The functionality of the model relates mainly to the use of mathematical optimization techniques, which have been described in the theoretical framework as well.

DAS Frame



Stakeholder Perspectives

College van Bestuur		
Gewicht	17%	
Current Match	55	
Future Match	55	

Directeuren Onderwijs		
Gewicht	17%	
Current Match	32	
Future Match	32	

Studenten		
Gewicht	17%	
Current Match	24	
Future Match	24	

Docenten		
Gewicht	17%	
Current Match	60	
Future Match	60	

informatie per zaal

Aula Auditorium

Eigenschappen

Capaciteit

Verbouwingsjaar

Bezetting (%)

Werkelijkheid

Current Match

Future Design

Geschiktheid (% van activiteiten)

Current Match

Future Design

Ingrenen



Beginsituatie

☒ Zaal Aan/Uit

☐ AAN

☐ Smartboard

☐ FALSE



Chapter 7 - Model Design

In this chapter the basis of the model design will be described. The starting point of the model design, just as in any design project, starts with the problem definition: clarifying objectives, establishing user requirements, identifying constraints, and establishing functions (Dym & Little, 2004). With a good problem definition the engineer can proceed to create a design. The basic functionality of the model can be traced back to this design.

7.1 Problem Definition

As mentioned in the chapter on research methodology, the objective of the first round of interviews is to identify each stakeholder's problems, goals, decision variables, and constraints. This is almost exactly the content of the problem definition as defined by Dym and Little (2004).

The first and most important aspect of the problem definition is a solid objective. The following problems relating to the lecture halls were identified in the interviews:

- The current supply of lecture halls does not meet present-day requirements with regard to facilities and capacity;
- The university is starting a new curriculum next year, which will lead to a changing demand for lecture halls;
- There are too little types of educational facilities to accommodate this changing demand;
- The current supply is being used ineffectively.

The subsequent goals, decision variables and constraints defined by the stakeholders relate closely to these problems. In order to overcome these problems, the model must establish a relationship between the demand for educational space and the supply of lecture halls. Only by doing this can its users see how changing the demand for educational space affects the supply and how changing the supply can accommodate the changing demand. Additionally, the model needs to show its users if their goals, decision variables and constraints are met by the proposed solutions. Shortly put, the requirements for the model are the following:

1. The model must be able to make a timetable based on the educational demands for a certain amount of lecture halls;
2. The user must be able to incorporate time constraints per activity in order to make the timetable representative;
3. The user must be able to make changes in the model to the lecture halls and their properties and to the requirements set by activities;
4. The user must be able to see how these changes affect his goals, decision variables and constraints.

7.2 Conceptual Design

The conceptual design forms the first step forward from the problem definition. Two methods are used to address the requirements set in the problem definition: Linear programming (LP) and Preference-based portfolio design (PBPD). As identified in chapter 4, LP is a good optimization technique when selecting multiple design solutions based on a single objective. As soon as there are multiple objectives, LP has limitations which in turn can be overcome by PBPD.

Therefore, LP is used to make a timetable given a set of constraints and a single objective function. The primary objective in LP is to find a feasible timetable solution. PBPD is used to create a design for the portfolio of lecture halls based on the preferences of stakeholders and to evaluate the timetable solution generated by LP. The primary objective in PBPD is to design an alternative with the highest overall preference score.

Finding a feasible timetable solution in LP can be done in two ways: (1) the user can modify a number of constraints that impact the feasible set of solutions, which in turn can lead to a higher preference score of the optimal solution and (2) designing an alternative in PBPD can increase the feasible set of solutions in LP.

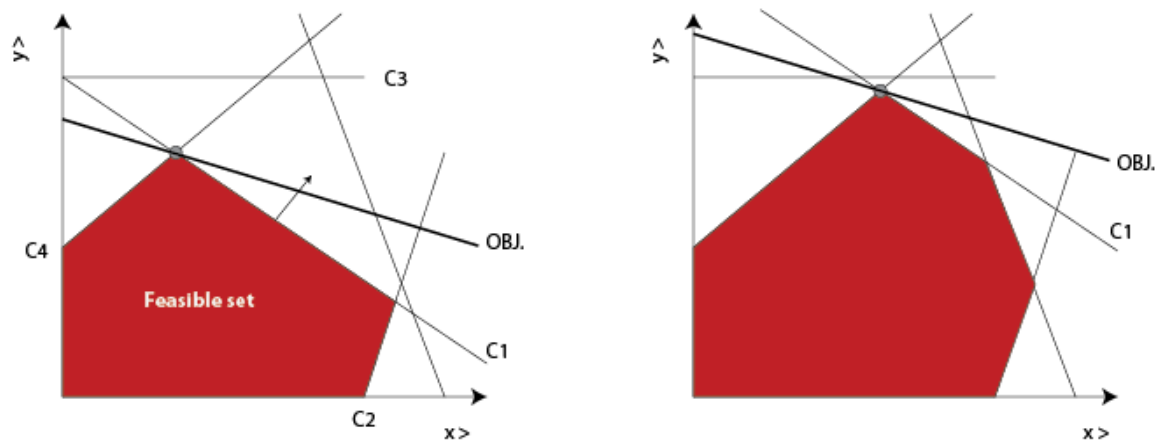


Figure 7-A – Modifying a constraint in LP in order to increase the feasible set of solutions.

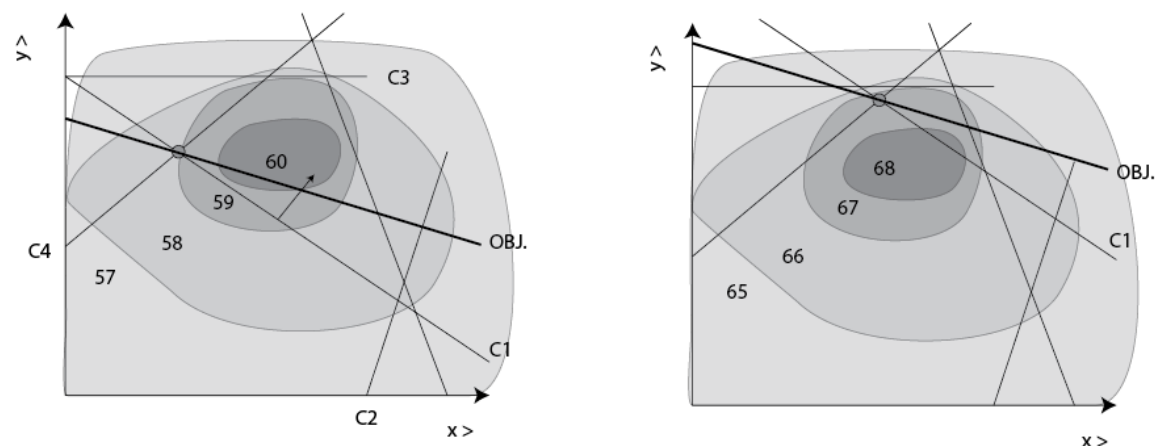


Figure 7-B – Designing an alternative in PBPD that increases the feasible set of solutions in LP and the overall preference score at the same time. For example: by adding a beamer to a lecture hall, the preference score on the criterion 'percentage of beamers in lecture halls' increases. This has immediate effects on the overall preference score irrespective of the timetable allocation. In turn, adding the beamer can lead to the lecture hall being able to host more activities, thereby increasing the feasible set of solutions and possibly the quality of the solution found in LP.

7.2.1 Requirement 1-3: Linear Programming

In order to model a timetable in LP we need to extend the standard definition of LP as mentioned in chapter 4. The standard definition of LP only enables the user to maximize on an objective such as attendance. However, it does not enable the user to incorporate constraints to his demand for space, nor does the model incorporate at which time these activities are hosted. We need a form of LP that enables us to allocate (1) multiple activities with their constraints (2) to multiple lecture halls with their constraints (3) on specific time slots. The LP problem therefore becomes three-dimensional instead of one-dimensional.

The standard form of LP can be reformulated in order to accommodate this as follows (Barendse et al., 2012):

$$\text{Maximize} \quad Z = \sum_{i=1}^m \sum_{j=1}^n c_{ij} X_{ij}$$

$$\text{Subject to:} \quad \sum_{j=1}^n a_{ij} X_{ij} \geq d_i \quad \text{for } i = 1, 2, m$$

$$\sum_{i=1}^m a_{ij} X_{ij} \leq s_j \quad \text{for } j = 1, 2, n$$

$$X_{ij} \geq 0 \quad \text{for } i = 1, 2, m \text{ and } j = 1, 2, n$$

$$a_{ij} = \{0,1\} \quad \text{for } i = 1, 2, m \text{ and } j = 1, 2, n$$

This form of LP is called the limited transportation problem. The limited transportation problem has two types of constraints: demand constraints (d_i) and supply constraints (s_j). The demand constraints mean that the total demand of allocated activities (d_i) must be satisfied by the model. In this specific case, the amount of planned time for every activity must be allocated by the model. The supply constraints state that the total supply (s_j) must not be exceeded by the model. This means that the model cannot allocate more activities than there are available time slots. The variable a_{ij} can be set to 0 if an activity cannot be hosted in a certain lecture hall; X_{ij} will then also be 0.

	Activity 1 2 = 2 (d ₁)	Activity 2 2 = 2 (d ₂)	Activity 3 2 = 2 (d ₃)	
Lecture Hall 1	$a_{11} = 0$	$a_{21} = 1$	$a_{31} = 1$	
Hour 1	0 t ₁ =0	1 t ₁ =1	0 t ₁ =1	≤ 1 (s ₁)
Hour 2	0 t ₂ =0	1 t ₂ =1	0 t ₂ =0	≤ 1 (s ₂)
Hour 3	0 t ₃ =1	0 t ₃ =1	0 t ₃ =0	≤ 1 (s ₃)
Hour 4	0 t ₄ =1	0 t ₄ =0	1 t ₄ =1	≤ 1 (s ₄)
Lecture Hall 2	$a_{12} = 1$	$a_{22} = 0$	$a_{32} = 1$	
Hour 1	0 t ₁ =0	0 t ₁ =1	1 t ₁ =1	≤ 1 (s ₅)
Hour 2	0 t ₂ =0	0 t ₂ =1	0 t ₂ =0	≤ 1 (s ₆)
Hour 3	1 t ₃ =1	0 t ₃ =1	0 t ₃ =0	≤ 1 (s ₇)
Hour 4	1 t ₄ =1	0 t ₄ =0	0 t ₄ =1	≤ 1 (s ₈)

Figure 7-C - Example of a timetable allocation in LP

Figure 7-C shows an example of a timetable made by using LP. Each activity has specified its demand in a number of hours that needs to be scheduled: a total of six hours. LP then maximizes the amount of hours to be scheduled by allocating the demand to a time and place. Each blue colored '1' stands for an allocation. Thus, in figure 7-C six hours have been allocated: the solution proposed here is feasible.

Each blue cell is subject to a number of constraints that predetermine whether or not LP can actually allocate an activity to a time and place. In figure 7-C, LP is only allowed to allocate activities to the bold numbers. These constraints are the following:

1. The group and the teacher must be available at the specified time slot. If they are already occupied with another activity, the time slot cannot be used to allocate activities.

In figure 7-C this constraint is represented by the value of $t=0$ or $t=1$. Note that if a time slot has the value $t=0$, the value of the time slot is always 0 (e.g. activity 1: t₁, t₂).

2. The lecture hall must be suitable to host the activity. If a lecture hall does not meet the activity's demands, for instance because of a lack of capacity or unavailable facilities, the activity cannot be hosted there.

In figure 7-C this constraint is represented by the value of $a=0$ or $a=1$ for each activity. Note that for each value $a=0$, the value of each of the time slots becomes 0 (e.g. a₁₁).

In order to fulfill requirement 2 , the user must be able to incorporate time constraints per activity; in other words, provide the model with $t=0$ or $t=1$. For requirement 3, the user must be able to make changes in the model to the lecture hall properties and requirements set by activities; in other words, change $a=0$ to $a=1$ and vice versa.

In order to be able to make changes to the lecture halls, we need to add user requirements to lecture halls and properties of lecture halls to our model. The model then determines if a_{ij} is 0 or 1 by matching user requirements and properties.

An example of the user requirements to lecture halls:

	Beamer (p_1)	Whiteboard (p_2)	Capacity (p_3)
Activity 1 (d_1)	1	1	250
Activity 2 (d_2)	1	0	300
Activity 3 (d_3)	1	0	200

Figure 7-D - Example of the user requirements of lecture halls defined by each host

An example of the lecture hall properties:

	Beamer (p_1)	Whiteboard (p_2)	Capacity (p_3)
Lecture Hall 1	1	0	300
Lecture Hall 2	1	1	250

Figure 7-E - Example of the properties of lecture halls compiled in a database

Now, if we match these two tables, it will lead to the following result:

	Activity 1 (d_1)	Activity 2 (d_2)	Activity 3 (d_3)
Lecture Hall 1	$a_{11} = 0$	$a_{21} = 1$	$a_{31} = 1$
Lecture Hall 2	$a_{12} = 1$	$a_{22} = 0$	$a_{32} = 1$

Figure 7-F - Example of a matrix that matches Figure 7-C and 7-D.

The values of a_{ij} in this example match the values of a_{ij} in the previous examples. Note that for instance d_1 cannot host its activity in Lecture Hall 1 because it does not contain a whiteboard, therefore $a_{11}=0$. If the user adds a whiteboard to this lecture hall, the lecture hall would meet its demands and a_{11} would become 1, thus enlarging the solution space.

7.2.2 Requirement 4: Preference-based Portfolio Design

The fourth and final requirement is that the user must be able to see how these changes affect his goals, decision variables and constraints. This means that each decision variable or design constraint defined by the stakeholders must be connected to the LP model. In general two types of decision variables can be defined. The first relates to the timetable allocation whilst the second relates to the characteristics of the lecture halls.

An example of the first type of decision variable is displayed in figure 7-G.

In order to link this variable to LP, we need to know which activities and lecture halls are in which faculty. For example:

Faculty X: Activity 1, 2, Lecture Hall 2
Faculty Y: Activity 3, Lecture Hall 1

Ergo, if Activity 1 and 2 are hosted in lecture hall 2 and Activity 3 is hosted in lecture hall 1, the student's preference score will be the highest. In the previous example the following would be the case:

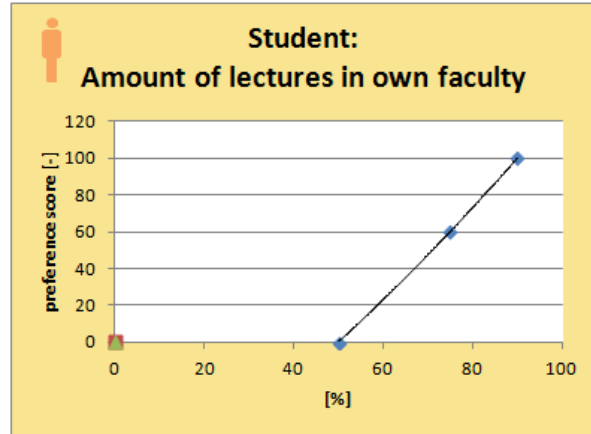


Figure 7-G - Decision variable 1

	Activity 1 2 = 2 (d ₁)	Activity 2 2 = 2 (d ₂)	Activity 3 2 = 2 (d ₃)	
Lecture Hall 1	$a_{11} = 0$	$a_{21} = 1$	$a_{31} = 1$	
Hour 1	0 t ₁ =0	1 t ₁ =1	0 t ₁ =1	≤ 1 (s ₁)
Hour 2	0 t ₂ =0	1 t ₂ =1	0 t ₂ =0	≤ 1 (s ₂)
Hour 3	0 t ₃ =1	0 t ₃ =1	0 t ₃ =0	≤ 1 (s ₃)
Hour 4	0 t ₄ =1	0 t ₄ =0	1 t ₄ =1	≤ 1 (s ₄)
Lecture Hall 2	$a_{12} = 1$	$a_{22} = 0$	$a_{32} = 1$	
Hour 1	0 t ₁ =0	0 t ₁ =1	1 t ₁ =1	≤ 1 (s ₅)
Hour 2	0 t ₂ =0	0 t ₂ =1	0 t ₂ =0	≤ 1 (s ₆)
Hour 3	1 t ₃ =1	0 t ₃ =1	0 t ₃ =0	≤ 1 (s ₇)
Hour 4	1 t ₄ =1	0 t ₄ =0	0 t ₄ =1	≤ 1 (s ₈)

Figure 7-H - Example of a timetable allocation in LP

$$\sum h_{121}:h_{124} = 2 \quad \sum h_{221}:h_{224} = 0 \quad \sum h_{311}:h_{314} = 1$$

Figure 7-I - Sum formulas that calculate the amount of lectures in the own faculty.

The total amount of lectures in the own faculty is thus 3/6 in the current situation, which is 50 percent of all lectures. The preference score of the student would then be 0 out of 100. These values are calculated based on the results of allocation run and do not influence the LP model. However, there is the possibility to steer on some of these variables by adding a constraint to them: for instance, by stating that the amount of lectures in the own faculty must be above 60 percent. In that case the model would now have to search for another solution.

The second type of decision variable relates to lecture hall characteristics and is displayed in Figure 7-J. This type of decision variable can be directly linked to the existing database of lecture hall properties, described earlier in section 7.2.1. These properties are displayed again on this page.

In excel, the COUNTIF-rule can be used to count the amount of times that a lecture hall has a beamer. By making this number a percentage it can be displayed on the Lagrange curve in Figure 7-J. In this example, each lecture hall has a beamer, thus the preference score is 100 percent.

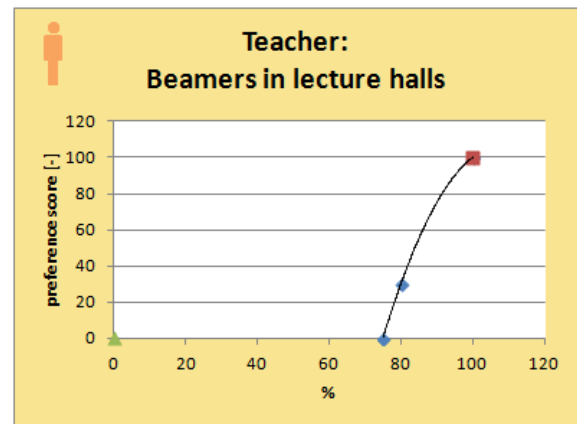


Figure 7-J - Decision variable 2

An example of the lecture hall properties:

	Beamer (p_1)	Whiteboard (p_2)	Capacity (p_3)
Lecture Hall 1	1 (p_{11})	0 (p_{21})	300 (p_{31})
Lecture Hall 2	1 (p_{12})	1 (p_{22})	250 (p_{32})

Figure 7-K - Example of the properties of lecture halls compiled in a database; copy of Figure 7-C

$\text{COUNTIF}(p_{11}, p_{12}) > 0$ = 2	$\text{COUNTIF}(p_{21}, p_{22}) > 0$ = 1
---	---

Figure 7-L - Example of the use of COUNTIF rules.

Each of these decision variables is put together in a table where the user can find out what the overall preference score of all the stakeholders is. The overall preference score is found by calculating the weighted sum of all the decision variables. Now, the user can implement changes in the lecture halls and timetable to heighten the overall preference score.

Decision variable 1	Lectures in the own faculty	Score	Weight
Decision variable 2	Beamers in lecture halls	100	50%
Overall Preference Score		50	

Figure 7-M - Example of the calculation of the overall preference score.

7.3 Further Design Stages

In addition to the conceptual design described in the previous subchapter information was added to the model in order to make the model's representation of reality as accurate as possible. The model input for both the first workshop and the second workshop is displayed here.

Data Input	Workshop 1	Workshop 2
1. Demand data	50 activities based on own grouping of students; no linked activities	48 activities based on grouping in timetable; linked activities
	Timetable extracted from huidigeroosters.tudelft.nl ; 1 week	Timetable provided by Education and Student Affairs; 3 weeks
	Time constraints specified by engineer	3 time constraint scenarios
	Lecture hall requirements specified by engineer	Lecture hall requirements specified by engineer

Table 7-A – Data relating to demand incorporated in the model in workshop 1 and 2.

In between workshop 1 and 2, one of the most important improvements made was to make the demand input more realistic. Also, the time constraint scenarios enabled us to simulate what would happen to the solution space if the hosts of activities would deliver lenient or strict demands to the schedulers.

Data Input	Workshop 1	Workshop 2
2. Supply Data	14 Lecture Halls	27 Lecture Halls (18 used)
	Lecture hall amenities database provided by FMRE	Elaboration on previous database
	Costs input by engineer	Costs input by engineer

Table 7-B – Data relating to supply incorporated in the model in workshop 1 and 2.

Data Input	Workshop 1	Workshop 2
3. Interventions	5 Lecture Hall interventions	9 Lecture Hall interventions
	5 Timetable interventions	7 Timetable interventions
	5 Scenario variables	5 Scenario variables

Table 7-C – Types of interventions that could be used in the model in workshop 1 and 2.

In the model two types of interventions were used: lecture hall interventions (e.g. add chalk boards) and timetable interventions (e.g. schedule in the evening). The scenario variables were used to simulate how the demand would change in the future, by implementing the new bachelor programs or moving the faculty of TNW to the southern part of the campus. Information regarding the bachelor renewal was provided by Trijntje Kraak (Kraak & Netten, 2013).

Data Input	Workshop 1	Workshop 2
4. PFM Data	35 criteria (26 in model)	38 criteria (28 in model)
	7 design constraints (4 in model)	7 design constraints (4 in model)

Table 7-D – Decision variables and design constraints defined by users and incorporated in the model.

7.4 Feedback Theoretical Framework

The conceptual design as described in subchapter 7.2 has formed the basis of the decision-making model described in this chapter. In the following two sections the basis of the model will be evaluated based on two chapters in the theoretical framework.

7.4.1 Chapter 4 – Decision Systems

The transportation model of LP and the evaluation of its results by using preference measurement have been created in Microsoft Excel with the use of an add-in called Lindo What'sBEST! (Lindo Systems, 2013). What'sBEST! allows the creation of large-scale optimization models, but is bound to numeric constraints.

The most important numeric constraint set by What'sBEST! is the number of adjustable values in an LP model: this number cannot be greater than 32000. Prior to the first set of interviews a sample of lecture halls and activities was chosen to incorporate in the decision-making model. This sample consisted of 15 lecture halls and 50 activities in a one-week timetable. In this model, one week consisted of 55 hours, which makes the maximum number of adjustable values $55 * 15 * 50 = 41250$. Luckily, because of requirements such as time constraints and lecture hall suitability the amount of adjustable values is reduced considerably, as has been demonstrated in subchapter 7.2.

Another important aspect of this model is the relationship between the timetable allocation in LP and the design in PBPD. LP is used to find a feasible timetable solution, whilst PBPD is used to design an alternative with the highest overall preference score. Unfortunately, this design alternative also encompasses decision variables that belong to LP as constraints, e.g. lectures in the own faculty (see figure 7-G). As a consequence, this decision-making model falls short in optimizing on those decision variables.

Consider the following example. When optimizing on the decision variable 'lectures in own faculty,' the user can only influence the solution generated by LP by setting it as a constraint. In figure 7-N this constraint is displayed as C1. By negotiating the constraint, one can increase the feasible set of solutions in LP.

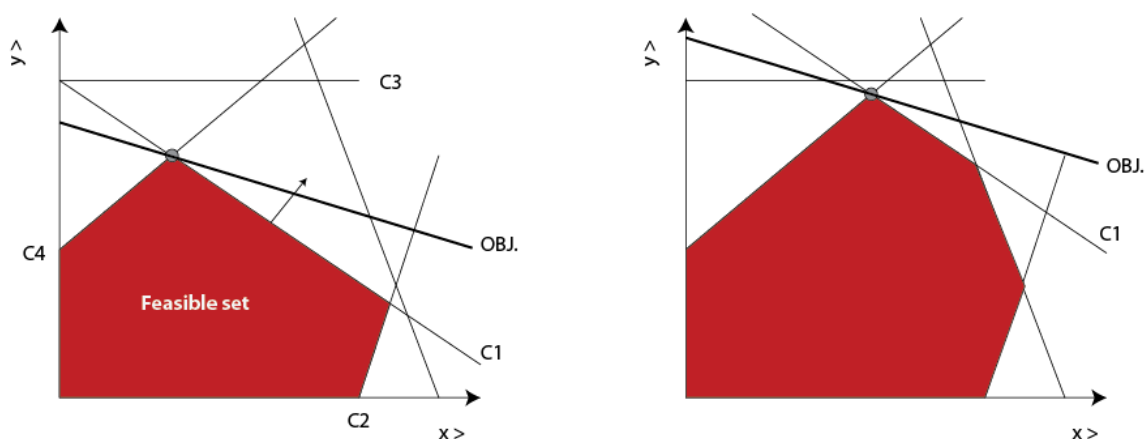


Figure 7-N – Optimizing in LP on decision variable 'Lectures in the own faculty'

However, as figure 7-N displays, LP optimizes on an objective function which does not reflect the overall preference score in any way. It is even possible that by optimizing on this objective function, one is moving away from the timetable solution that would yield the highest overall preference score (figure 7-O).

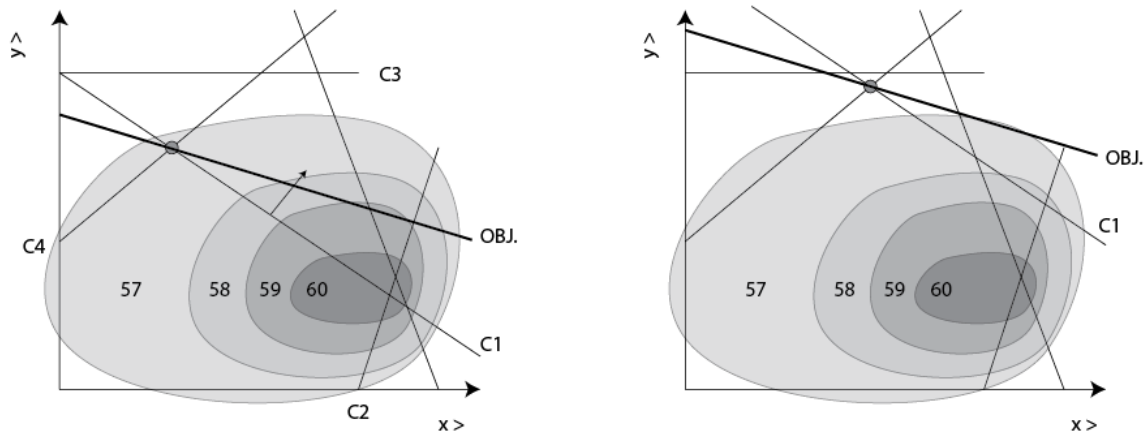


Figure 7-O – The overall preference score projected onto the feasible set of solutions in LP.

This statement can be extended to the previous example in subchapter 7.2, where two decision variables were defined. The overall preference score of that allocation run was a total of 50.

The allocation that yielded this overall preference score can also be modified by moving Activity 3's lecture from the 1st hour in lecture hall 2 to the 1st hour in lecture hall 1 and Activity 2's lecture from the 1st hour to the 3rd hour in lecture hall 1. This solution is just as optimal according to LP: it meets all the constraints set by the model. However, Activity 3's lecture has been moved to the own faculty, thus increasing the preference score of this result on the decision variable 'lectures in the own faculty.'

	Activity 1 2 = 2 (d ₁)	Activity 2 2 = 2 (d ₂)	Activity 3 2 = 2 (d ₃)	
Lecture Hall 1	$a_{11} = 0$	$a_{21} = 1$	$a_{31} = 1$	
Hour 1	0 $t_1=0$	0 $t_1=1$	1 $t_1=1$	≤ 1 (s ₁)
Hour 2	0 $t_2=0$	1 $t_2=1$	0 $t_2=0$	≤ 1 (s ₂)
Hour 3	0 $t_3=1$	1 $t_3=1$	0 $t_3=0$	≤ 1 (s ₃)
Hour 4	0 $t_4=1$	0 $t_4=0$	1 $t_4=1$	≤ 1 (s ₄)
Lecture Hall 2	$a_{12} = 1$	$a_{22} = 0$	$a_{32} = 1$	
Hour 1	0 $t_1=0$	0 $t_1=1$	0 $t_1=1$	≤ 1 (s ₅)
Hour 2	0 $t_2=0$	0 $t_2=1$	0 $t_2=0$	≤ 1 (s ₆)
Hour 3	1 $t_3=1$	0 $t_3=1$	0 $t_3=0$	≤ 1 (s ₇)
Hour 4	1 $t_4=1$	0 $t_4=0$	0 $t_4=1$	≤ 1 (s ₈)

Figure 7-P - Example of a timetable allocation in LP

Now 67% of all the lectures are hosted in the own faculty, increasing the preference score from 0 to 39. The overall preference has thus increased from 50 to 69, whilst according to LP the solution is just as optimal as the previous solution. At best the user can steer on such a variable ex ante by making it a negotiable constraint, but the use of LP means that this model falls short in finding an optimum for group decision-making (Binnekamp, 2010).

7.4.2 Chapter 5 - Timetabling

In the theoretical framework a number of timetabling techniques have been discussed. From this perspective it is interesting to see how LP relates to these techniques and if it has potential to be used as a timetabling technique.

In the theoretical framework, the objective of scheduling was defined as follows: “firstly to offer students maximum flexibility, secondly to offer staff maximum flexibility, and thirdly to efficiently manage resources.” In other words, optimization is not a primary objective. Amongst the range of techniques discussed in chapter 5 is a class of techniques named ‘constraint-based techniques,’ to which LP would belong. The advantage of using constraint based techniques for timetabling over other methods is that they focus on finding an optimal solution: constraint-based techniques yield high scores in comparative benchmark tests (Qu et al., 2009, p. 15).

Unfortunately, the disadvantage is that constraint-based methods encounter problems in scaling, because the amount of constraints increases exponentially with the number of variables. The result is that the computing time increases greatly. Another limitation of constraint-based techniques is that the use of hard constraints will yield either a ‘feasible’ or ‘infeasible’ result, as all these constraints have to be satisfied. In LP this problem can be overcome by using negotiable constraints.

Using LP in combination with other techniques might help to overcome limitations of LP in multi-criteria optimization. Perhaps local search-based techniques can be used to find neighboring solutions to the LP optimum based on functions that optimize stakeholder criteria. In that way the timetable would be better equipped to find an optimum in group decision-making.

7.5 Conclusion

In this chapter all the input for the decision-making model has been described and evaluated. The following conclusions can be drawn:

- Based on the problem statement four requirements were drawn up as to what the model must be able to do. These requirements were as follows:
 - The model must be able to make a timetable based on the educational demands for a certain amount of lecture halls;
 - The user must be able to incorporate time constraints per activity in order to make the timetable representative;
 - The user must be able to make changes in the model to the lecture halls and their properties and to the requirements set by activities;
 - The user must be able to see how these changes affect his goals, decision variables and constraints.
- The first three requirements could be mathematically formulated and represented in a linear programming model. The fourth requirement required linking linear programming to the decision variables and constraints defined by the stakeholders in PAS.
- A number of changes were made in between the preliminary design and detailed design in order to refine and adjust the representation of reality in the decision-making model.
- The combination of LP and PBPD means that the model is subject to the same limitations as LP with negotiable constraints: even though solutions that were previously infeasible can be made feasible, it is still poorly equipped to find an optimum in group decision-making.
- From the perspective of timetabling literature LP has potential; constraint-based techniques yield high scores in benchmark tests compared to other timetabling methods. However, large timetabling problems become increasingly hard to handle for constraint-based techniques.
- Using LP in combination with other techniques might help overcome limitations of LP in multi-criteria optimization.

Part Four Results

This fourth and final part of my thesis contains the results, conclusions and recommendations of my thesis. In chapter 8 the results and evaluation of the rounds of interviews and workshops are displayed. In chapter 9 the conclusions of this research can be found as well as recommendations for further research.



Workshop 1, Education and Student Affairs, March 11th, 2013



Workshop 2, May 2nd, 2013

Chapter 8 - Results

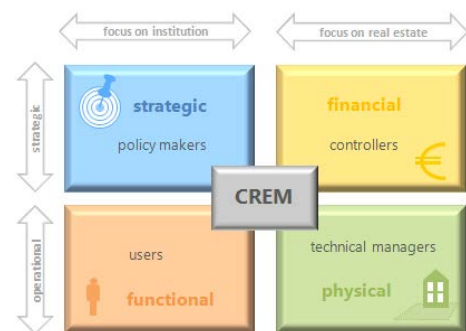
This chapter discusses the results of this study in chronological order, according to the process of interviews and workshops. First the results regarding the test of PAS are discussed: have the stakeholders determined criteria, which criteria have they determined, and which solutions have they designed. Then the evaluation of the method is discussed, and finally the feedback towards the theoretical framework is discussed.

8.1 Testing PAS

For the first round of interviews a number of stakeholders were approached to participate in this project based on their position in the stakeholder perspective framework (figure 9-A). By involving stakeholders from each perspective, the corporate real estate manager should be able to incorporate all the relevant variables into his decision.

The stakeholders involved in the process were as follows:

Executive Board of the TU Delft (Strategic)
Faculty Director of Education (Strategic/Users)
Facility Management and Real Estate (Financial/Physical)
Student Council (Users)
Teacher Feedback Group (Users)
Education and Student Affairs (Physical)



As mentioned in chapter 2, the procedure to be completed in the interviews and workshops is as follows:

Figure 8-A - Stakeholder perspectives (Den Heijer, 2011)

Interviews

1. Specify the decision variable(s);
2. Assign the decision maker's preference to each variable;
3. Assign the decision maker's relative weight to each variable;
4. Determine the design constraints;

Workshops

5. Generate (all) the design alternatives;
6. (Use the PFM algorithm to yield an overall preference scale.)

Figure 8-B displays the results of each interview and workshop. In the first round of interviews, each stakeholder was able to complete the first four steps and define decision variables (C) and design constraints (RV). Not all of these decision variables and design constraints could be addressed in the decision-making model: these are indicated by the red arrows. In the individual workshops, each stakeholder generated design alternatives and with the exception of one workshop a higher overall preference was achieved by each of the stakeholders.

As a result of the first workshop, 4 of the 5 stakeholders that participated chose to adjust and/or refine their criteria. These adjustments were incorporated into the decision-making model, and in the second workshop the stakeholders collectively designed alternatives and achieved an overall preference score of 69. Finally, in the third round of interviews some stakeholders decided to readjust their criteria again.

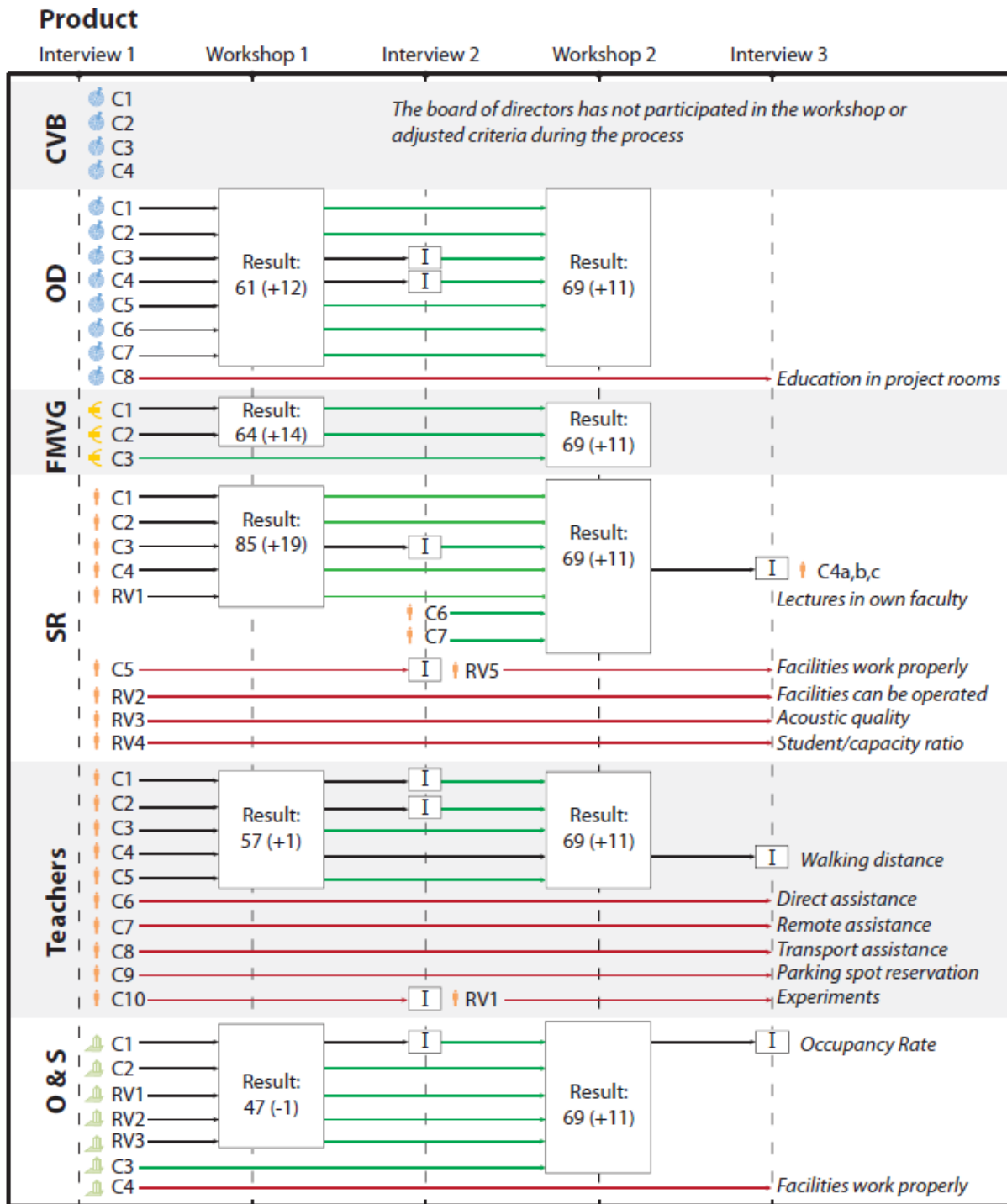


Figure 8-B - Results Interviews and Workshops

8.1.1 Workshop 1

In workshop 1 the starting point of each workshop was different, due to the workshops being held at different times. Therefore the criteria determining the overall preference score were different per workshop. The overall preference score of the current match initially varied between 48 and 50. However, in the student and teacher workshop the starting point did not include scheduling in the evening: this raised the overall preference score of the current match to 56 and 66.

The iterations made after workshop 1 were a result of the following:

- Three criteria were adjusted by the engineer to prevent that the curve exceeded preference score values less than 0 and greater than 100. In interview 2 these changes were confirmed.
- Two criteria were added by the student council as a result of the lecture hall interventions in the model, for which they had not yet established criteria.
- Two criteria were changed by the teachers because the unit of measurement was found to be inconvenient in the workshop.
- One criterion was changed by the directors of education due to insight into the functionality in the model.

8.1.2 Workshop 2

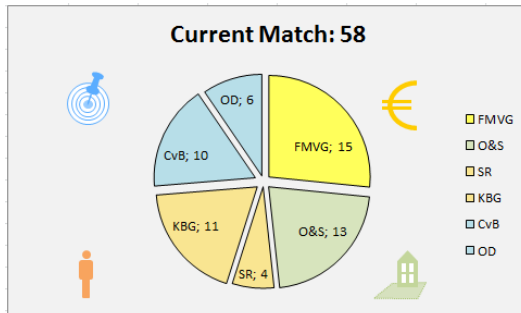


Figure 8-C - Current Match

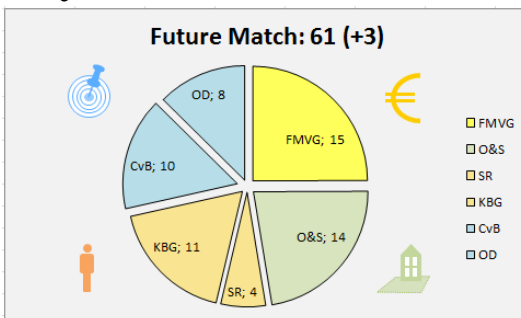


Figure 8-D - Design alternative group 1

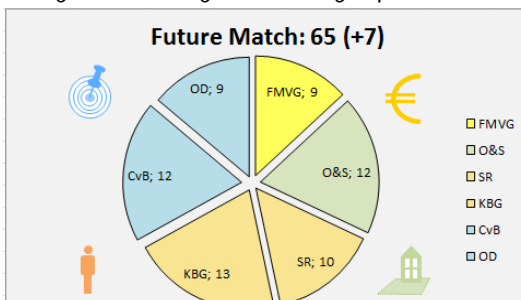


Figure 8-E - Design alternative group 2

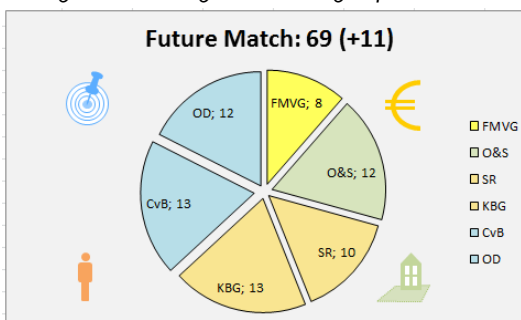


Figure 8-F - Final design alternative

At the start of the second workshop, the current match was determined at 58 after incorporating the new criteria and changes to the model. In this current match the preference scores of Education and Student Affairs and FMRE were especially high.

Group 1 designed an alternative by doing interventions in the timetable. A minor increase in the overall preference score could be reached by these interventions, most notably on the criteria of the directors of education.

Group 2 designed an alternative by doing interventions in the lecture halls. By adding a number of amenities they managed to reach an overall preference score of 65. Especially the teachers and students' preference increased in this alternative, whilst the preference of FMRE decreased due to high intervention costs.

These alternatives were put together and with some minor adjustments the final design alternative was made, with an overall preference score of 69.

The iterations made after workshop 2 were a result of the following:

- The student council split up their 'Lectures in own faculty' criterion due to an insight gained in the workshop, being that the criterion is more important for some groups than for others.
- The teachers adjusted their criterion 'Student walking distance' to include their own walking distance, because they found this to be important as well.
- Education and Student Affairs confirmed the change made to their criterion 'Occupancy rate' in the workshop: there they had the insight that only a high occupancy rate was undesirable for them.

For more details on the iterations the log can be viewed (Appendix).

8.2 Stakeholder Evaluation

During the interviews after the workshops (i.e. interviews 2 and 3) the stakeholders were asked to evaluate the method with regard to: their *experiences* in the workshop and with the model, the *attractiveness* of the method, and their *perception of the effectiveness* of the method. Additionally, they were asked to give a short reaction at the ending of each workshop.

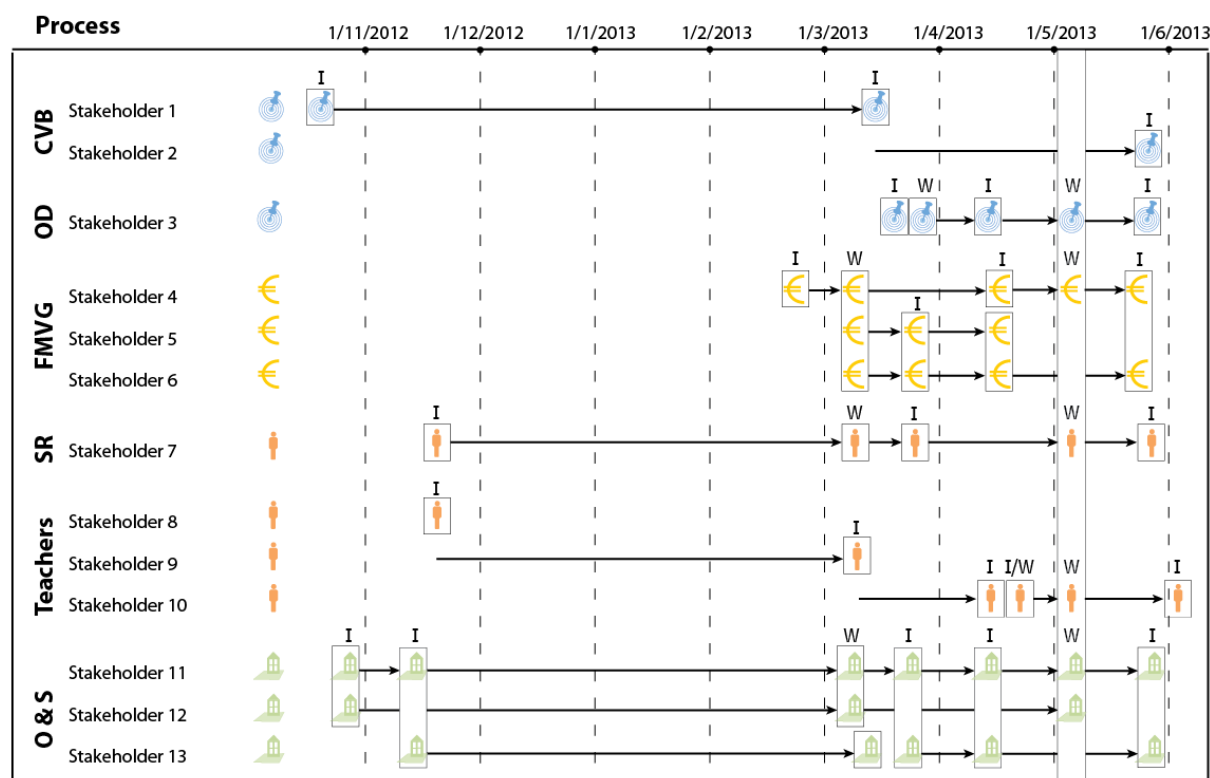


Figure 8-G – Process of interviews and workshops per stakeholder.

8.2.1 Experiences with the workshop and the model

The workshops are generally rated very positively by the stakeholders. All the stakeholders have indicated that the workshop helped them to gain insight into the problem and their own criteria or those of others. Also, during the workshop they saw what the effect of their choices was: how the interventions affected the criteria.

”

*In the workshop you can see what each group wants and
you get insight into the demands of others.*

- Student Council

”

The stakeholders were especially positive about the second workshop: bringing people together, searching together for a good solution, the interaction with each other and the model were all aspects that were rated positively. Some stakeholders also recognized the importance of iteration in the process. The first workshop was rated less positively; some stakeholders recognized that they had more time to focus on their own criteria and understanding the model. However, others did not understand the goal of the workshop or missed the discussion with other stakeholders.

The stakeholders' experiences with the model were mixed. The model helps to make things insightful and it helps people to think about what they need. However, it is also complex and it takes a while to understand what happens in the model.

This model is ideal to have the discussion about what we need.
- Education and Student Affairs

8.2.2 Attractiveness of the method

The attractiveness of the method is rated highly by the stakeholders. They find the process of interviews and workshops helpful – the interviews are a more attractive way to think about what you want than e.g. questionnaires, and the workshops are attractive when multiple stakeholders are brought together to discuss the problem.

Another attractive aspect is the use of curves. The stakeholders describe determining curves as easy, and that the curves result in fewer emotions in the discussion and more thinking in the collective interest. What is generally found difficult is to assign preference scores; one has to estimate his/her satisfaction when a certain value is achieved. That is why the possibility to adjust criteria is so important.

The attractiveness of the model has yielded more mixed responses. Some stakeholders find it to be attractive, whilst others say it is not visual enough or that it is difficult to follow what happens in the model. Nevertheless the use of the model as a means to facilitate a group discussion is found to be attractive by multiple stakeholders.

The methodology is the most important aspect.
- Director of Education

8.2.3 Perception of effectiveness of the method

When asked about their perception of the method's effectiveness, the stakeholders responded very positively. Some of them think that it helps to reach an agreement on an end result and that they will understand quicker why certain choices are made. When looking at the time spent and the results of the process, most stakeholders respond that the process is certainly efficient compared to others. Recommendations include adding more students and teachers to make the results more reliable, adding a stakeholder with a vision on the future of education, and scheduling the events shorter after one another.

The process is faster, more to the point and more transparent.
- Student Council

The question that remains with most stakeholders is: what next? Some measure the effectiveness of the method by its end result, and they wonder what will happen with the results of this process.

It would be a waste if nothing happens with the end result of this process.
- Facility Management and Real Estate

8.3 Feedback Theoretical Framework

8.3.1 Chapter 3 – Real Estate Management

In the theoretical framework it was determined that CREM has evolved over the past few decades, resulting in a more comprehensive role but also more complexity. Furthermore, in order to make decisions and achieve alignment an increasing amount of information is required. This corresponds with the decision-making problems identified by Binnekamp et al. (2006), Den Heijer (2011) and Englert (2001).

Firstly, subchapter 8.1 and 8.2 show that users can determine and adjust their criteria and design alternatives in order to reach a higher overall preference score. Their evaluation of the method suggests that it is possible to (1) make better decisions by using this method by iteration, thus incorporating as much relevant information as possible, and (2) to achieve alignment by designing alternatives with a higher overall preference score than the current situation.

Secondly, subchapter 8.2 shows that stakeholders use estimations when assigning preference scores, which means that heuristics are at play. In chapter 3, the use of heuristics has been found to occasionally lead to severe errors in prediction and estimation (Tversky & Kahneman, 1982, pp. 4-18). These three pitfalls were identified in literature:

- Representativeness: The tendency to assess the probability that an object of class A belongs to class B based on their resemblance.
- Availability: the tendency to base our assessment of a probability on high-profile or recent experiences without considering the whole range of experiences.
- Anchoring: the tendency to anchor subsequent estimates towards the first estimate.

The iterative process of workshops and interviews has the advantage that it largely avoids these pitfalls. Stakeholders are allowed to adjust their variables and criteria after each workshop according to latest insights. Each pitfall is dealt with in the following way:

- Representativeness: Erratic assumptions in object-class relations emerge in the workshops, after which adjustments can be made.
- Availability: By communicating with their backing, stakeholder representatives can eliminate possible overestimates or underestimates in their criteria. The workshops can also confront them in this respect, e.g. if their curve is much too strict or too lenient.
- Anchoring: The tendency to anchor subsequent estimates towards the first estimate is avoided by iterating; subchapter 8.1 shows that stakeholders are willing to adjust their criteria based on new information.

Thirdly, alignment is identified as a wicked problem in chapter 3, and in this process we use rational means (i.e. Operations Research) to solve alignment. According to the strategies of Roberts (2000) we are using a collaborative strategy, engaging all stakeholders in the process, and aiming to find a collective solution between them. As we see, achieving a shared understanding of the problem and solving it is indeed a time-consuming process.

Finally, game theory was mentioned as an approach to better understand alignment. In the decision-making model, a concept familiar to game theory is used: the measurement of preference/utility. However, it is not used in the game-theoretical sense of studying or predicting human behaviour and attempting to understand alignment: it is used to define and establish decision variables and thereby attempting to achieve alignment.

8.3.2 Chapter 6 – Gaming

Based on the definition of gaming established in chapter 6, the process completed by the stakeholders can be described both gaming and decision-making. The users have the freedom to make their own decisions within the simulation (i.e. decision-making model). The process is focused on both a learning experience of its users and providing a solution.

However, as stated by Erisman et al. (2002), a decision system becomes a game when its players are confronted with the consequences of their actions and those of others in the simulation and have the possibility to act upon them. Therefore PAS becomes a game by giving users the opportunity to design alternatives themselves and the possibility to adapt their criteria according to insights gained during the game.

Generally, the responses towards the experiences with the model and the attractiveness suggest that the use of PAS has a positive impact. After both workshops, most stakeholders remark that the model helps them to see the consequences of their actions. Also the use of the model as a means to spark the discussion about the problem is identified as a positive aspect.

However, a number of difficulties remain in the model. Stakeholders consider the model to be complex and especially during the first workshop they raised questions regarding certain issues in the model. These issues were also described by Van Loon (2008, pp. 64, 66), Van de Schootbrugge (2010, p. 62) and Van Ussel (2010, p. 139) in the testing of similar decision-making models. It seems inevitable that users need time to understand relations and parameters in the decision-making model due to its inherent complexity.

The responses by the stakeholders regarding PAS are generally in accordance with the proclaimed benefits and drawbacks of gaming (Bekebrede, 2010; Erisman et al., 2002; Mayer & De Jong, 2004):

Benefits of gaming:

- Gaming allows decision makers to experiment in a safe and cost-effective way;
- Games can be used for awareness building;
- Games can facilitate the transfer of knowledge and can help novices understand complex theories and problems;
- Games can provide insight into complex problems.

Drawbacks of gaming:

- The impossibility to reproduce the game;
- A reduced number of simulation runs (compared to simulation);
- A game cannot be repeated from the same starting position.
- Less ability to focus on the effects of a single mechanism, recommendations or solutions to problems.

Chapter 9 - Conclusion and Recommendations

In this final chapter the main research question will be answered based on the results provided in the previous chapter. Then, recommendations for further research will be given.

9.1 Conclusion

1. Main Research Question

“How can the use of gaming in real estate decision-making models help users to better understand the increasing complexity in real estate management?”

The role of gaming in this process is that stakeholders are allowed to readjust and refine their decision variables. This iterative process has two advantages. Firstly, readjusting and refining criteria helps the stakeholders to understand what they really want and thereby creating a more accurate representation of their preferences. Secondly, it gives them a safe environment to experiment in and gain insight into the consequences of their actions in the model on their preferences without being held to the results.

2. Hypothesis

The author's hypothesis regarding this subject was that the use of gaming helps users to comprehend the complexity in decision-making models, which increases their potential.

The workshop and interview results have shown that this hypothesis can be largely confirmed. After the second workshop most stakeholders have indicated that the model helps them to gain insight into the consequences of their actions, which indicates that they understand the relationships between variables and interventions in the model.

Conversely, in the first workshop some stakeholders indicated that the model was complex and that they did not yet understand the relationship between the variables. An explanation for this is that the problem represented in the model is very complex, and that users require time in order to understand how everything works in the model environment. Nevertheless, each of the stakeholders was already able to design an alternative with a higher overall preference score during this workshop.

3. Objective

The objective of this research was to design a decision-making model in order to affirm or disprove the hypothesis and answer the main research question, and to find out whether this decision-making model could help to solve the issue of alignment.

A decision-making model has been made that combines linear programming with preference measurement. The input for this model was collected during the interviews with the stakeholders and it was tested during the workshops. During the workshops the stakeholders were able to design alternatives with higher overall preference scores. These alternatives can be used to align the organization's real estate to its objectives.

9.2 Recommendations

During the course of this thesis, a number of aspects have emerged that give rise to further research. These aspects are discussed according to the chapter in which they have emerged.

Chapter 1 – Application to FMRE

In this research the methodology of Preference-based Accommodation Strategy is applied within the framework of the campus management of universities by Den Heijer (Den Heijer, 2011). However, in theory Preference-based Accommodation Strategy can be applied in every organization that uses real estate to add value to its organization: for these types of organizations alignment is achieved when the overall preference of all the stakeholders is the highest. Further research could be done in testing the application of PAS to other types of organizations or sectors, such as healthcare, municipalities, corporations, etc.

Chapter 4 – Lagrange curves

The use of Lagrange curves to assign preference scores to decision variables is subject to one important flaw. Because a Lagrange curve is a polynomial equation, it can potentially yield values that are below preference score 0 or above preference score 100. In this research this flaw has been resolved by feeding back the curves to the users, but an interactive curve-fitting tool would enable the user to assign preferences in the best possible way.

Chapter 4 – PFM algorithm

In chapter 4 it was revealed that the search for the design alternative with the highest overall preference score is currently done by letting stakeholders manually design alternatives. However, in the PBPD methodology this would be done automatically by using a PFM algorithm. Once the PFM algorithm has been developed, PAS can thus be used in two different ways. Further research should investigate the added value of the PFM algorithm in the decision-making process.

Chapter 7 – Model design

The model design described in chapter 7 is an attempt to create a model version of the scheduling process as it is done in reality. However, the current model is not able to incorporate numerous aspects that can be incorporated in scheduling programs. Furthermore, it is only scalable to a certain extent due to What'sBEST. In further development of the model these limitations need to be removed.

Chapter 7 – Multi-criteria optimization

The use of both linear programming and PBPD linked together as optimization techniques has not previously been done. Unfortunately, using preference measurement to evaluate the results yielded by LP does not resolve the issues that LP has in multiple criteria optimization. If this model is to be developed further, a method needs to be sought that better equips LP to find a group optimum.

Chapter 8 – Determining preference scores

In chapter 8 it was determined that users use heuristics in order to assign preference scores to criteria. Tversky and Kahneman have revealed that using heuristics can occasionally lead to systematic errors in estimation and prediction (1982). In PAS this is mitigated by giving users the opportunity to adjust their criteria. Further research can be done to study if systematic errors occur in assigning preference scores to criteria and if they are mitigated by giving users the opportunity to adjust them. Other research done by Kahneman and Tversky on decision-making could also prove to be useful in this respect. Their work can be found in Kahneman (2011).

Chapter 8 – First workshop setup

When asked about their experiences with the method, stakeholders responded in mixed ways to the first workshop. The first workshop was held individually per stakeholder rather than in a group in order to give each person more time to become acquainted with the model and focus on their own criteria. Although the first workshop did help in this respect, most users missed the discussion with other stakeholders. Therefore, it is helpful to reconsider this approach in further research: by organizing a workshop with two stakeholder representatives, there would be more time to focus on each stakeholder's own criteria whilst at the same time having the opportunity to discuss with each other.

Chapter 8 – Using stakeholder representatives

When asked about the perceived effectiveness of the method, some stakeholders questioned the amount of stakeholders incorporated in the process. In some cases, the group of a stakeholder representative is so heterogeneous that it is difficult for him to establish criteria and preference scores. In this case, the teachers were the group that had the most difficulties in this respect. In future research, it could be useful to add more stakeholders from the same group if the stakeholder representative has great difficulty in establishing criteria and assigning preference scores.

Reference List

- Ackoff, R. L., & Sasieni, M. W. (1968). *Fundamentals of Operations Research*. Oxford: Wiley.
- Allinson, K. (1997). *Getting there by design. An architect's guide to design and project management*. Oxford: Architectural Press.
- Arkesteijn, M. H. (to appear 2014). *Preference-based accommodation strategy, forthcoming*. (Ph.D.), TU Delft, Delft.
- Arkesteijn, M. H., & Binnekamp, R. (2012). *Real estate portfolio decision making*. Paper presented at the International Engineering Systems Symposium, CESUN 2012, Delft.
- Arkesteijn, M. H., Van de Schootbrugge, S., & Van Loon, P. P. J. (2011). *Municipal real estate decision support system*. Paper presented at the ERES Conference 2011, Eindhoven.
- Barendse, P., Binnekamp, R., De Graaf, R. P., Van Gunsteren, L. A., & Van Loon, P. P. J. (2012). *Operations research methods for managerial multi-actor design and decision analysis*. Amsterdam: IOS Press.
- Barzilai, J. (1997). *A New Methodology for Dealing with Conflicting Engineering Design Criteria*. Paper presented at the The 18th Annual Meeting of the American Society for Engineering Management.
- Barzilai, J. (2005). Measurement and preference function modeling. *International Transactions in Operations Research*, 12, 173-183.
- Barzilai, J. (2007). *On the mathematical foundations of economic theory*. Dalhousie University, Halifax. Retrieved from <http://www.math.mcgill.ca/vetta/CS764.dir/econfound.pdf>
- Barzilai, J. (2010a). *Correcting the mathematical foundations of the social and economic sciences.*, Dalhousie University, Halifax.
- Barzilai, J. (2010b). Preference Function Modeling: The Mathematical Foundations of Decision Theory. In M. Ehrgott, J. R. Figueira & S. Greco (Eds.), *Trends in Multiple Criteria Decision Analysis* (pp. 1-37). New York: Springer.
- Bekebrede, G. (2010). *Experiencing complexity. A gaming approach for understanding infrastructure systems*. (Ph. D.), TU Delft, Delft.
- Binnekamp, R. (2010). *Preference-based design in architecture*. (Ph.D.), TU Delft, Delft.
- Binnekamp, R., Van Gunsteren, L. A., & Van Loon, P. P. J. (2006). *Open Design, a stakeholder-oriented approach in architecture, urban planning and project management*. Amsterdam: IOS Press.
- Burke, E. K., Kingston, J. H., & De Werra, D. (2004). Applications to timetabling. In J. Gross & J. Yellen (Eds.), *The Handbook of Graph Theory* (pp. 445-474). Chapman Hall: CRC Press.
- De Jonge, H. (1994). *The future of corporate real estate management*. Paper presented at the IDRC.

- De Jonge, H., Arkesteijn, M. H., Den Heijer, A. C., Vande Putte, H. J. M., De Vries, J. C., & Van der Zwart, J. (2009). *Designing an accomodation strategy (DAS Frame)*. Delft: TU Delft Faculty of Architecture.
- De Vries, J. C. (2007). *Presteren door vastgoed: onderzoek naar de gevolgen van vastgoedingenrepen voor de prestatie van hogescholen*. (Ph.D.), TU Delft, Delft.
- De Vries, J. C., De Jonge, H., & Van der Voordt, T. J. M. (2008). Impact of real estate interventions on organisational performance. *Journal of Corporate Real Estate*, 10(3), 208-223.
- Den Heijer, A. (2011). *Managing the university campus*. Delft: Eburon Academic Publishers.
- Den Heijer, A., & De Vries, J. C. (2005). *Analyse Universiteitsgebouwen. Resultaten benchmark twaalf recente projecten*. Delft: TU Delft.
- Dym, C. L., & Little, P. (2004). *Engineering Design: a Project-based Introduction*. Oxford: Wiley.
- Emans, B. (2007). *Interviewen: theorie, techniek en training*. Groningen: Noordhoff.
- Englert, J. (2001). *The Strategic alignment handbook*: IDRC.
- Erismann, J. W., Hensen, A., De Vries, W., Kros, H., Van de Wal, T., De Winter, W., . . . Sanders, K. (2002). NitroGenius: a nitrogen decision support system. *AMBIO: A Journal of the Human Environment*, 31(2), 190-196.
- EventMAP. (2013). Expertise. Retrieved 09/04, 2013, from <http://www.eventmap-uk.com>
- Fehr, E., & Fischbacher, U. (2003). The nature of human altruism. *Nature*, 425, 785-791.
- Heywood, C. (2011). *Approaches to aligning corporate real estate and organisational strategy*. Paper presented at the ERES Conference 2011, Eindhoven, The Netherlands.
- Heywood, C., Kenley, R., & Waddell, D. (2009). *The CRE toolbox: Addressing persistent issues in corporate real estate management*. Paper presented at the PREES Conference 2009, Sydney.
- ICTO TU Delft. (2010). Nieuwe interface roostersysteem. Retrieved 09/04, 2013, from www.icto.tudelft.nl
- Joldersma, C., & Roelofs, E. (2004). Impact of soft OR-methods on problem structuring. *European Journal of Operational Research*, 152, 696-708.
- Joroff, M., Louargand, M., Lambert, S., & Becker, F. (1993). *Strategic management of the fifth resource: corporate real estate*. Norcross: IDRC.
- Kahneman, D. (2011). *Thinking, fast and slow*. New York: Farrar, Straus and Giroux.
- Kraak, T., & Netten, M. (2013). *Effecten herziene curricula op ruimtegebruik*. Delft: TU Delft.
- Lewis, R. (2013). Converting Sudoku into Graph Colouring. Retrieved 09/04, 2013, from <http://www.rhydlewis.eu/>
- Lindo Systems. (2013). What'sBest! 11.0 - Excel Add-In for Linear, Nonlinear, and Integer Modeling and Optimization from <http://www.lindo.com>

- Mayer, I., & De Jong, M. (2004). Combining gaming and GDSS for decision support. *Group Decision and Negotiation*, 13, 233-241.
- McCollum, B. (2007). A Perspective on bridging the gap between theory and practice in university timetabling. In E. K. Burke & H. Rudova (Eds.), *Practice and Theory of Automated Timetabling VI* (pp. 3-23). Berlin, Heidelberg: Springer-Verlag.
- McCollum, B., Ahmadi, S., Burke, E. K., Barrone, R., Cheng, P., & Cowling, P. (2002). A Review of existing interfaces of automated examination and lecture scheduling systems. Paper presented at the Fourth International Conference on the Practice and Theory of Automated Timetabling (PATAT).
- Meijer, J. P. (2011). *Organizational performance and real estate*. (M.Sc.), TU Delft, Delft.
- Myerson, R. B. (1991). *Game theory: analysis of conflict*. Cambridge, MA.
- Qu, R., Burke, E. K., McCollum, B., Merlot, L. T. G., & Lee, S. Y. (2009). A Survey of search methodologies and automated system development for examination timetabling. *Journal of Scheduling*, 12(1), 55-89.
- Rittel, H. W. J., & Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy sciences*, 4(2), 155-169.
- Roberts, N. C. (2000). Wicked problems and network approaches to resolution. *The International Public Management Review*, 1(1).
- Roulac, S. E. (2001). Corporate property strategy is integral to corporate business strategy. *Journal of Real Estate Research*, 22(1), 129-152.
- Shubik, M. (1971). *On Gaming and game theory*. Paper presented at the Gaming Conference Rand Corporation, Santa Monica, CA.
- Sprong, G. J. M. (2011). *Wonen, werken, wetenschap*. FMVG Meerjarenplan 2011-2014.
- Struthman, S. (2012). *Koppelen van de gemeentelijke organisatiedoelstellingen aan de vastgoedstrategie*. (M.Sc.), TU Delft, Delft.
- Tversky, A., & Kahneman, D. (1982). Judgment under uncertainty: heuristics and biases. In D. Kahneman, P. Slovic & A. Tversky (Eds.), *Judgment under uncertainty: heuristics and biases*. Cambridge: Cambridge University Press.
- Van de Schootbrugge, S. (2010). *Steering to align a public real estate portfolio*. (M.Sc.), TU Delft, Delft.
- Van der Schaaf, P. (2002). *Public real estate management: challenges for governments*. Delft: DUP Science.
- Van Loon, P. P., Barendse, P., & Duerink, S. (2012). *The Urban Decision Room: a multi-actor design engineering simulation system*. Paper presented at the Third International Engineering Systems Symposium, Delft.
- Van Loon, P. P. J. (1998). *Inter-Organizational Design*. (Ph.D.), TU Delft, Delft.

- Van Loon, P. P. J., Heurkens, E. W. T. M., & Bronkhorst, S. (2008). *The urban decision room, an urban management instrument*. Amsterdam: IOS Press.
- Van Loon, P. P. J., & Wilms, E. (2006). An urban decision room based on mathematical optimisation. In J. P. Van Leeuwen & H. J. P. Timmermans (Eds.), *Innovations in design and decision support systems in architecture and urban planning* (pp. 359-374): Springer.
- Van Ussel, J. F. M. A. (2010). *Optimal real estate strategy. Model voor het optimaliseren van de dynamische organisatie huisvesting*. (Master's degree), TU Delft, Delft.
- Von Neumann, J., & Morgenstern, O. (1944). *Theory of games and economic behavior*. Princeton, NJ: Princeton University Press.
- Welsh, D. J. A., & Powell, M. B. (1967). The upper bound for the chromatic number of a graph and its application to timetabling problems. *The Computer Journal*, 11, 41-47.
- Winch, G. M. (2010). *Managing construction projects*. Chichester: Wiley-Blackwell.
- Zeleny, M. (1982). *Multiple criteria decision making*. New York: McGraw-Hill.

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