THE FINANCIAL IMPLICATIONS OF BUILDING DESIGN

A developer and consumer preference based residential design system

P2 report	**Final Research Proposal**
Student:	Charlotte in't Hout
Student number:	1502808
Address:	Spui 314
	2511 BZ
	The Hague
Phone number:	06 18 37 23 90
Email address:	charlotteinthout@gmail.com
Date of evaluation:	14 January 2016
Graduation lab:	5. Smart campus tools
1st supervisor:	Ruud Binnekamp
	Field of expertise: Operations Research Modelling
2nd supervisor:	Gerard van Bortel
	Field of expertise: Housing
External examiner:	Nico Nieboer

Summary

Within any private company, the main organisational goal is to generate monetary profit for its stakeholders. Real estate developers do so through obtaining sale or lease returns on developed properties. In this context consumers' preferences and their perception of 'quality' are essential, because these factors determine actual market demand, which contributes to higher (rental) value, which in turn affects capital value and investor behaviour (Bell, 2005). The importance of a real estate supply that is well adapted to the prevailing demand is also being emphasized by the NVM (the Dutch real estate brokers' association) (NVM, 2009) as well as the Dutch government (Blom et al., 2012).

Thus, developers increasingly need more consumer preference focussed buildings - which puts even more importance on a project's physical design. With regard to preference based design as a technique to determine the optimal product characteristics to maximize a project's financial feasibility, so far none examples have been featured in leading literature. This study aims to deliver the first applicable proof of concept of such a preference based design system. It will assist project developing stakeholders in determining which design requirements should theoretically lead to the maximum financial return possible. Designers on the other hand will be able to apply the model to broaden their scope of feasible design alternatives, for instance when solving a complex design problem, or to further accommodate a profit-focussed client.

The assumed current situation, in which developers deliver a programme of requirements based on their feasibility studies, is visualised in figure 1. Based on this programme of requirements an architect is commissioned to deliver a design which takes user preferences into consideration.

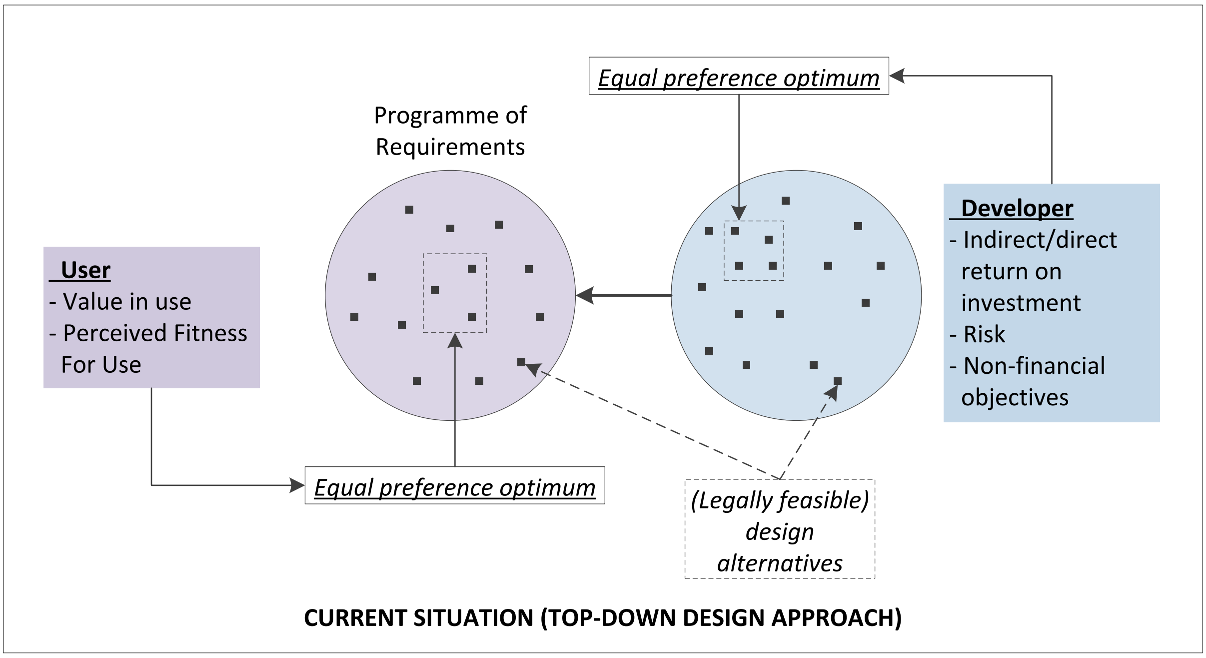


Figure 1. A standard top-down design approach (own ill.)

Hypothesis and research questions

This study aims to test the following hypothesis:

The application of a preference-based design system leads to residential design alternatives that are more in line with consumer preferences, while simultaneously maximising financial profitability over design processes without application of a preference-based design system.

To be able to create an appropriate model with which the hypothesis can be validated or rejected, the following main research question needs to be answered:

How can developers generate residential design alternatives that are more in line with consumer preferences, while simultaneously maximising financial profitability?

In order to answer the stated main question, the following sub-questions will be answered first:

1) How are financial implications of a dwelling design measured by investors/project developers?
2) Which costs, income, risk and profit related requirements and constraints do developers apply, both directly and indirectly, when commissioning building designs?
3) What residential design aspects are relevant in relation to the developer's financial profit?
4) Which of those aspects (see question 3) are also relevant in relation to consumer preference measurement, and which design constraints result from this?

Research design

Throughout the research process there will be two different approaches towards answering the stated research questions. These approaches are expected to complement each other and will ensure proper validation of the eventual findings. The first approach is *empirical research*. The second approach is that of *formal research*, more specifically the field of *operations research*.

The empirical research approach will be applied to collect generalized data from previous studies. This knowledge can then be used to generate theoretically valid assumptions on which the prototype of the model will be based (i.e. the prototype's initial input, criteria, variables and constraints).

The operations research approach allows for an analytical and exploratory attitude towards a problem or situation in which not all variables are defined yet. It will be used to determine the most appropriate mathematical solution for the stated research problem in a specific case study context.

Figure 2 illustrates the proposed combined research approach. It shows how empirical theory is used to substantiate the operations research problem statement. Both processes will be followed roughly simultaneously. While the iteration in both approaches is separated, a reflection moment is incorporated after the model prototype has been designed to ensure an empirically validated definitive model. Also, after final calibration, the definitive model will be used to validate the original hypothesis.

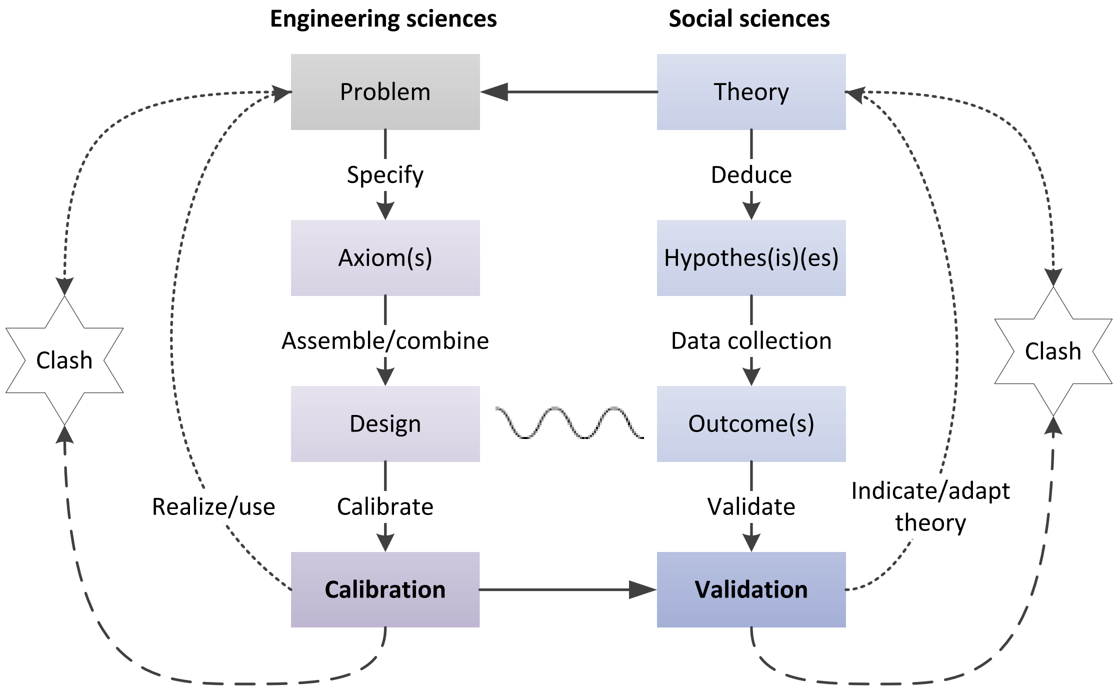


Figure 2. Proposed combined research approach (own ill. based on Barendse et al., 2012)

Proposed model

It is expected that a model which incorporates multi-actor and multi-criteria preference function modelling can be applied in order to relate found measured variables, requirements and constraints to each other mathematically. The mathematical concept of Preference Function Modelling (PFM), as described by Barzilai (2010), is shown in figure 3.

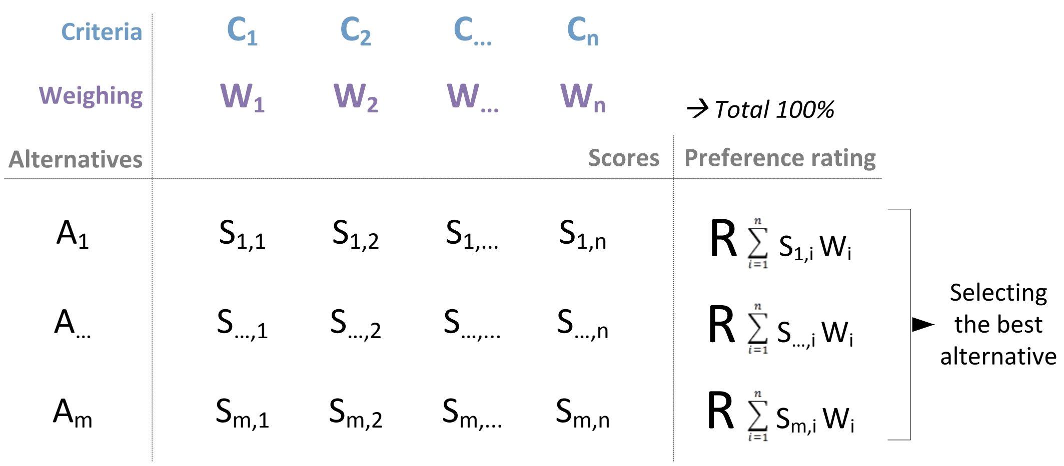


Figure 3. The mathematical concept of Preference Function Modelling (PFM) (own ill. based on Borst, 2014)

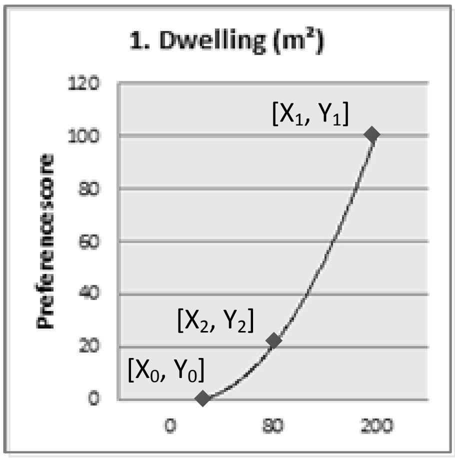


Figure 4. Example of a Lagrange curve (own ill.)

The exact score for each criteria is determined by the Lagrange curve for that specific criteria. For an example of a drawn Lagrange curve, see figure 4.

Microsoft Excel will be the software programme in which the prototype will be created. This software is relatively easy to use and allows for plenty mathematical functions to achieve the model's objectives.

The fundamental method to select the most preferred design alternative is visualized in figure 5.

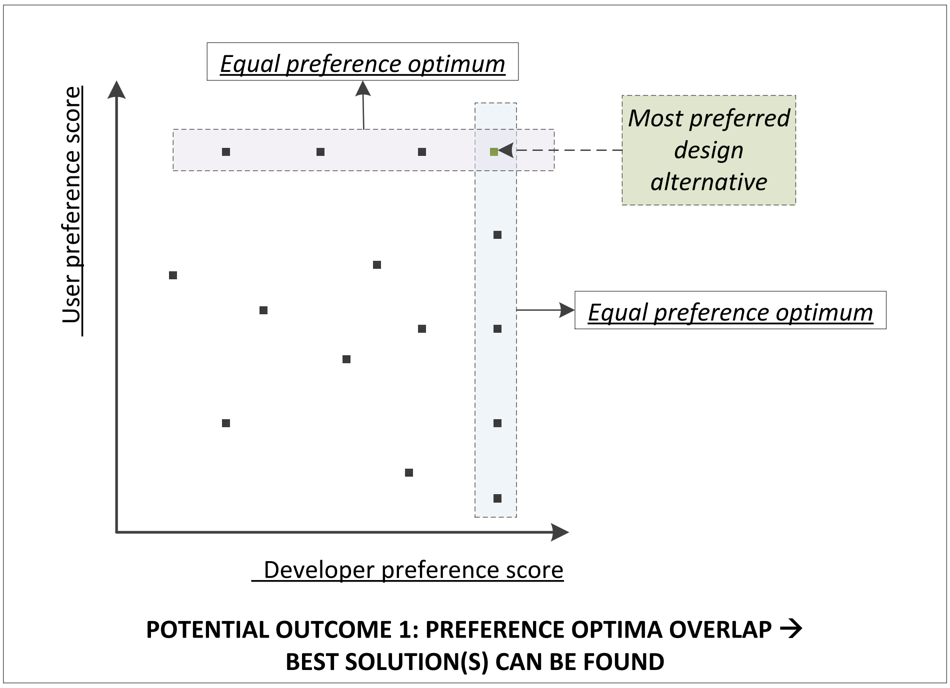


Figure 5. Visualisation of method to select the most preferred design alternative (own ill.)

Variables/criteria

In order to answer the knowledge part of the described research questions, the outcomes are related to potential variables that may together construct the model. As the proposed model aims to optimize the potential development profit, as well as exposing the relationship between financial requirements and design characteristics, the variables are divided into financial and design variables.

Financial variable	Input type	Explanation
Construction costs	Automated input	Results from input design variables; t = 0
Additional costs (permit fees, consultants, etc.)	Input from developer	Expected additional costs; t = 0
Land acquisition costs	Input from developer	Land acquisition costs at t = 0
Expected sale price	Input from developer	Expected sale price per m^2 GFA based on targeted market segment; t = (0 + construction period)
Construction period	Input from developer	Expected construction period
Discount rate	Input from developer	Annual discount percentage based on expected risk free rate, real estate risk premium and object specific risk premium
Net present value (NPV)	Automated output	Resulting developer's profit

Table 1. Financial variables

<table>
<tr><th>Structural attribute</th><th>Design variable</th><th>Financial implication</th></tr>
<tr><td>Number of bedrooms</td><td rowspan="4">Number of rooms
(including outdoor areas)</td><td rowspan="6">Sum of size and number of rooms → m^2 GFA → construction costs per dwelling</td></tr>
<tr><td>Number of bathrooms</td></tr>
<tr><td>Presence of basement/garage</td></tr>
<tr><td>Presence of patio</td></tr>
<tr><td>Floor area</td><td rowspan="2">Size of rooms
(including outdoor areas)</td></tr>
<tr><td>Lot size</td></tr>
<tr><td>Presence of fireplace</td><td rowspan="2">Completion level
(based on typical cost levels)</td><td rowspan="2">Completion level →
construction costs per dwelling</td></tr>
<tr><td>Housing quality</td></tr>
<tr><td>-</td><td>Composition of rooms
(including outdoor areas)</td><td rowspan="2">Composition of rooms and ceiling height → m^2 façade → construction costs per dwelling</td></tr>
<tr><td>-</td><td>Ceiling height</td></tr>
</table>

Table 2. Structural attributes, subsequently defined design variables and (in)direct financial implication for developers

The relations between all selected variables is visualised in figure 6. In this figure it is shown how design variables together form design alternatives, which delivers the input for the financial variable 'construction costs'. All other financial variables need to be specified by the developer. If no specific set of design alternatives exists, the model can generate design alternatives based on optimisation of financial profitability. The design alternatives which are classified 'most profitable' will then be selected in order to calculate their overall consumer preference score.

Case study

Based on the research problem description and demarcation, a case from practice was selected to test and validate the model prototype. This operations research validation phase will finally lead to a definitive design.

The case selected is the "Zusterflat case". In 2014 this former office building was transformed to student housing by SHS Delft (Stichting Herontwikkeling tot Studentenhuisvesting Delft). Due to long term vacancy and obsolescence of the property, the owner was willing to cooperate with SHS Delft and accepted them as a tenant for the upcoming ten years. After that period the building will be demolished.

During the project planning phase there were two major decisions that had to be made in order to determine the financial feasibility of the project. One was related to the target groups that would be included in the programme. The other decision was related to the type of accommodation that would be realized. Figure 7 illustrates how these two important decision variables would together influence the consumer preferences and financial feasibility of the project.

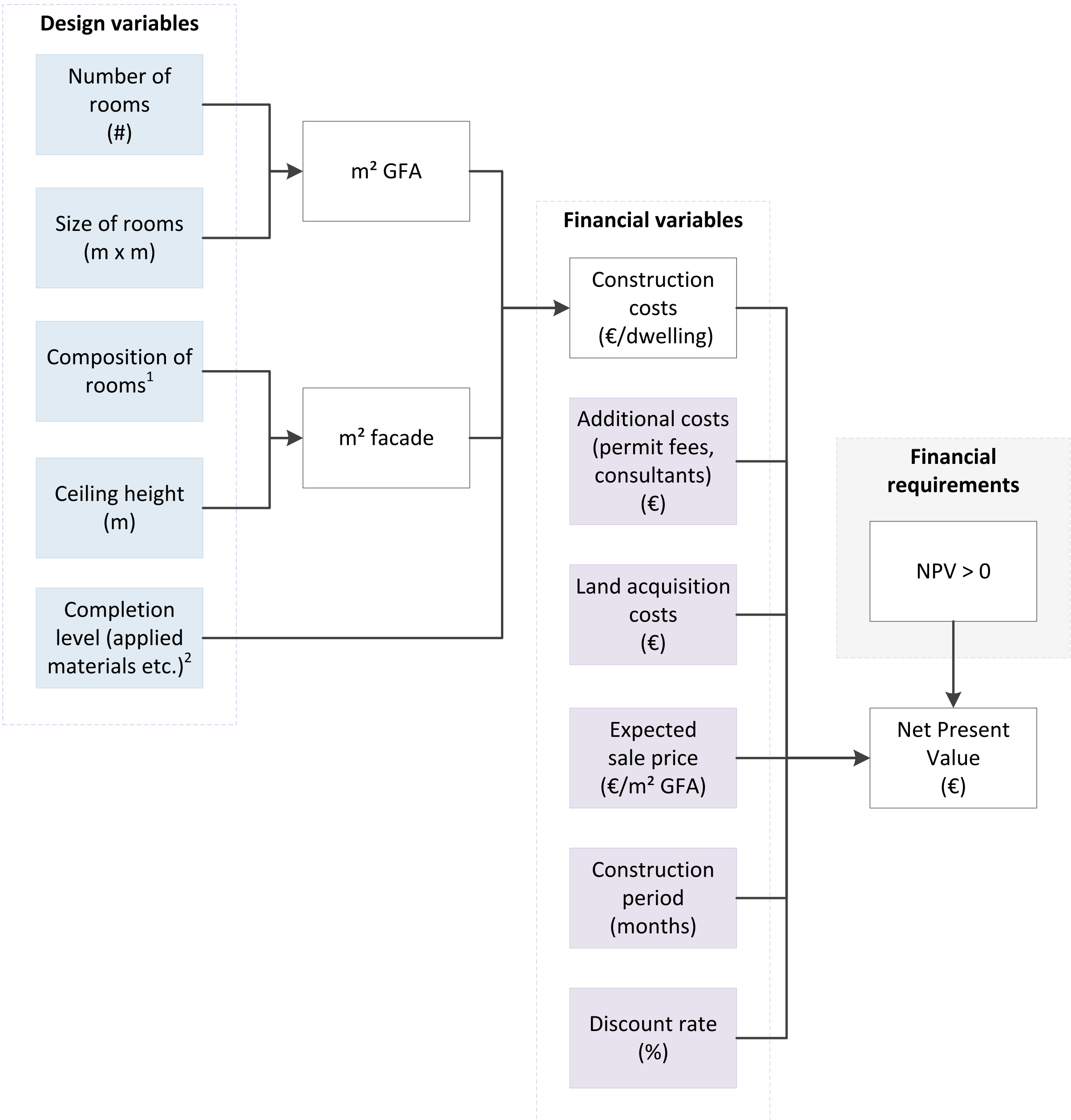


Figure 6. Conceptualisation of the proposed method to measure the financial performance of dwelling designs (own ill.)

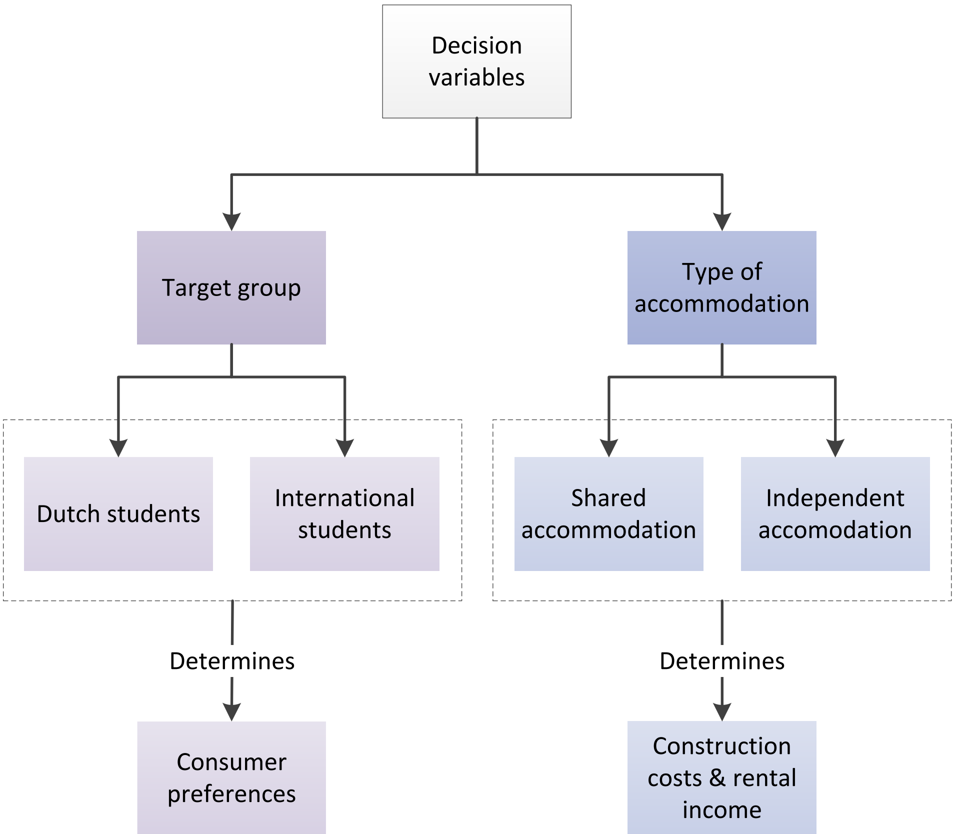


Figure 7. Initial decision variables the developer was faced with in the Zusterflat case (own ill.)

In order to test the model prototype, and to generate valid outcomes for the posed research questions, the existing model needs to be adjusted to reflect the Zusterflat's context. Aside from configuring the consumer preferences to correspond with those of the relevant end-users, financial variables need to be processed into the model. Also, the model needs to be adjusted to incorporate the technical and functional limitations of the Zusterflat building. This means the constraints that are included in the model prototype will be adjusted.

Additional empirical research regarding consumer preferences will be needed to assure the model reflects the preferences of the Zusterflat's potential end-users. This will be done by a brief literature study, which focusses specifically on student preferences. The results from this literature study will be then compared with stated consumer preferences from the actual target groups. A representative will be selected for both potential target groups (Dutch and international students) and they will be asked to draw Lagrange curves that represent the prevailing preferences within their group.

Expected results

After initial examination of the Zusterflat case, the following results are expected to be found at the end of this research process:

1. Adjustment of the 'current situation' (see figure 1), likely to reflect a more bottom-up design approach (see figure 8).

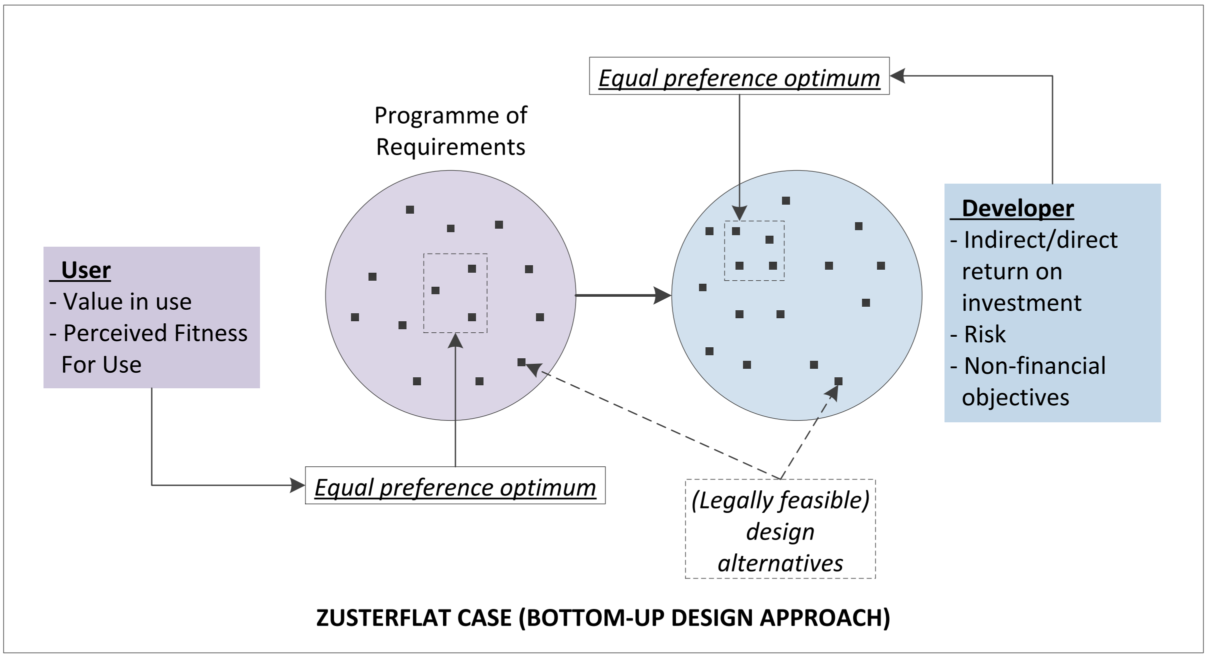


Figure 8. Proposed bottom-up design approach (own ill.)

2. Evaluation of the model prototype and analysis of the related decisions made in the Zusterflat case. Possible adjustment of the variables found in the literature research to reflect this specific residential development process.

3. Delivery of a detailed model and generated alternative design configurations, specified to the Zusterflat case.

4. Evaluation of the detailed model and produced results, reflecting on both the general problem statement and the Zusterflat case specifically.

5. Answers to the proposed research questions, founded on both the literature research and case study outcomes.

6. Recommendations on the model's applicability and potential added value to future decision making processes (related to residential property design).

Content

I | Introduction

This final research proposal is the second document to be handed in for the graduation process for the master track Management in the Built Environment at Delft University of Technology. Its aim is to provide information on the chosen research topic, including the selected research method, as well as to monitor academic progression so far. This report and the presentation thereof, which will take place on January 14th 2016, will be formally assessed by the student's 1st and 2nd mentor plus an external examiner.

1. Personal motivation

Throughout my bachelor and master studies I have gained experience with both architectural and property development practice. Increasingly I have become aware of the paradox that surrounds these separate professions: shared interests are often directly related to conflicting ones. These conflicting interests continuously result into costs versus value negotiations between the architect, who represents the future users, and the developer who needs to generate financial profits. But quite frequently users praise architectural designs that seem to defy the 'more quality costs more' principle. From these observations I have become interested in the interaction between 'design quality' and financial profit. From the profit focussed developer's perspective, user appreciation can be considered much more relevant than architectural peer acknowledgement. After all it is the user for whom the developer constructs property, and who generates income, not other architects. I want to find out whether developers actually must compromise on financial profit in order to better accommodate user preferences. Therefore I decided to perform my graduation research on the optimisation of financial profitability through design, with incorporation of user preference scoring regarding the generated design alternatives.

Study targets

Aside from satisfying my curiosity, I want to be able to position myself within the frequent industry debate regarding costs and design quality. I consider my current knowledge level insufficient to participate in this discussion in a well substantiated manner. Furthermore I want to learn to properly present research findings in an academic setting, to deduct theory and induct hypothesis correctly, and to accurately model a situation observed in practice, as I do not have much experience with these areas as of yet. Lastly, I of course want to successfully pass the assessment criteria that are set for this course (see RE&H Graduation Guide) so I can officially graduate from TU Delft.

2. Research relevance

Societal relevance

"*...the formation of an economically feasible project is what motivates the private sector to undertake development*" (Adair et al. quoted in Bell, 2005, p. 92).

Within any private company, the main organisational goal is to generate monetary profit for its stakeholders. Real estate developers do so through obtaining sale or lease returns on developed properties. With a national overall (commercial) real estate investment sum of €9 billion in 2014 (ABN AMRO, 2015), it is important to better understand the financial targets and mechanisms that determine a specific project's profitability - and thus feasibility, not only for private developing organisations themselves but also for other stakeholders within the real estate supply chain.

In this context consumers' preferences and their perception of 'quality' are essential, because these factors determine actual market demand, which contributes to higher (rental) value, which in turn affects capital value and investor behaviour (Bell, 2005).

Figure 1a. General effect of consumer preferences on project feasibility, as described by Bell (2005)

The importance of a real estate supply that is well adapted to the prevailing demand is also being emphasized by the NVM (the Dutch real estate brokers' association) (NVM, 2009) as well as the Dutch government (Blom et al., 2012). In addition to this, Bole & Reed (2011) state that the general public "is increasingly having its say in the shape and design of the buildings in which they live and work – as clients, inhabitants, users, and as citizens concerned with the long-term environmental sustainability of the planet". Marsh (quoted by Bell, 2005, p. 97) substantiates this assertion:

> "*One beneficial result of the recession in the property market in the early 1990s, the worst for over 20 years, has been that occupiers have had much greater choice of buildings at far lower rents. Functional and aesthetic qualities have thus become more important determinants of tenant choice, and as a result, developers and investors have become discriminating and increasingly acknowledge good design*."

While the market recession this statement referred to mainly existed in the United Kingdom, France, Spain and Finland (Van Dalen & De Vries, 2015), it is indicated by both NVM (2009) and Blom et al. (2012) that a similar trend currently exists in the Netherlands.

Figure 1b. Effect of recession in property markets on tenant choice,
based on Marsh (quoted by Bell, 2005)

Scientific relevance

Thus, to a certain extent developers need consumer preference focussed buildings - which puts importance on a project's physical design. While many studies have aimed to determine the implicit monetary value of specific residential design characteristics (e.g. Fung & Lee, 2014; Otegbulu et al. 2009; CABE, 2003; Chin & Chau, 2003) or have thoroughly analysed stated consumer preferences (e.g. WoON 2012, Naderi, 2012; Otegbulu et al. 2009), only few studies exist that apply stakeholder preferences in order to establish a preference based product design (e.g. Arkesteijn et al., 2015). Real estate researchers and managers appear to consistently overlook this method. Possibly the industry is not yet very familiar with - or convinced of - its full scientific potential. With regard to preference based design as a technique to determine the optimal product characteristics to maximize a project's financial feasibility, so far none examples have been featured in leading literature. Therefore no applicable proof of concept appears to be available as of yet.

Research demarcation

As time for this graduation research is limited, a clear scope is needed to ensure results with enough academic depth. Both residential and utility markets currently lack research findings (on the topic of consumer preference modelling and financial feasibility) to gain knowledge from and apply in practice. This makes both segments equally relevant scientifically. However, the amount of new projects and transactions that take place annually is much larger in the residential segment than in the utility property market. Therefore this study will focus specifically on the residential property market, as this makes the outcomes somewhat more societally relevant.

Utilization potential

Research focused on the relation between financial profitability and consumer preferences can be put into a commercial perspective quite easily. As stated before, research on consumer preferences can be used by project developers to better align their portfolio with market demand, which should theoretically result in an increase in capital value/(rental) yield. As this graduation research will focus on making that theoretical financial increase more explicit through mathematical modelling, commercial developers could gain direct insight into new methods of maximizing project profitability while simultaneously aligning their end products with market demand. The same concept could be applied by non-profit project developers, such as housing corporations. While their profit margins are usually quite low, or can even be below 0% at times, this research could help them to make better use of their financial resources while concurrently creating an end product that is more valued by their clients.

Another potential group that might benefit from these scientific outcomes are architects; the design professionals involved with property development. Their knowledge on the functionality and aesthetics of buildings builds a bridge between developers' demands and end users' wishes. Tangible knowledge on how specific design characteristics influence a project's feasibility, both positively and negatively, can help them in creating designs that are appreciated by the consumer as well as valued by the developer.

3. Research objectives

The objective of this graduation research will be to establish a mathematical computer model for real estate professionals (both investor/developer and other) that determines potential (feasible) residential design alternatives and calculates which of these alternatives is the most profitable one, based on predetermined financial requirements and multiple relevant consumer preferences. Aside from generating feasible design outcomes, such a model also provides insight into the financial implications of project requirements (e.g. construction budget, discount rate, etc.) and their relationship with design characteristics (e.g. applied materials, GFA, etc.). This will help project developing as well as designing stakeholders to put design characteristics into a financial perspective more objectively. It will assist project developing stakeholders in determining which design requirements should theoretically lead to the maximum financial return possible. Designers on the other hand will be able to apply the model to broaden their scope of feasible design alternatives, for instance when solving a complex design problem, or to further accommodate a profit-focussed client.

The assumed current situation, in which developers deliver a programme of requirements based on their feasibility studies, is visualised in figure 2. Based on this programme of requirements an architect is commissioned to deliver a design which takes user preferences into consideration.

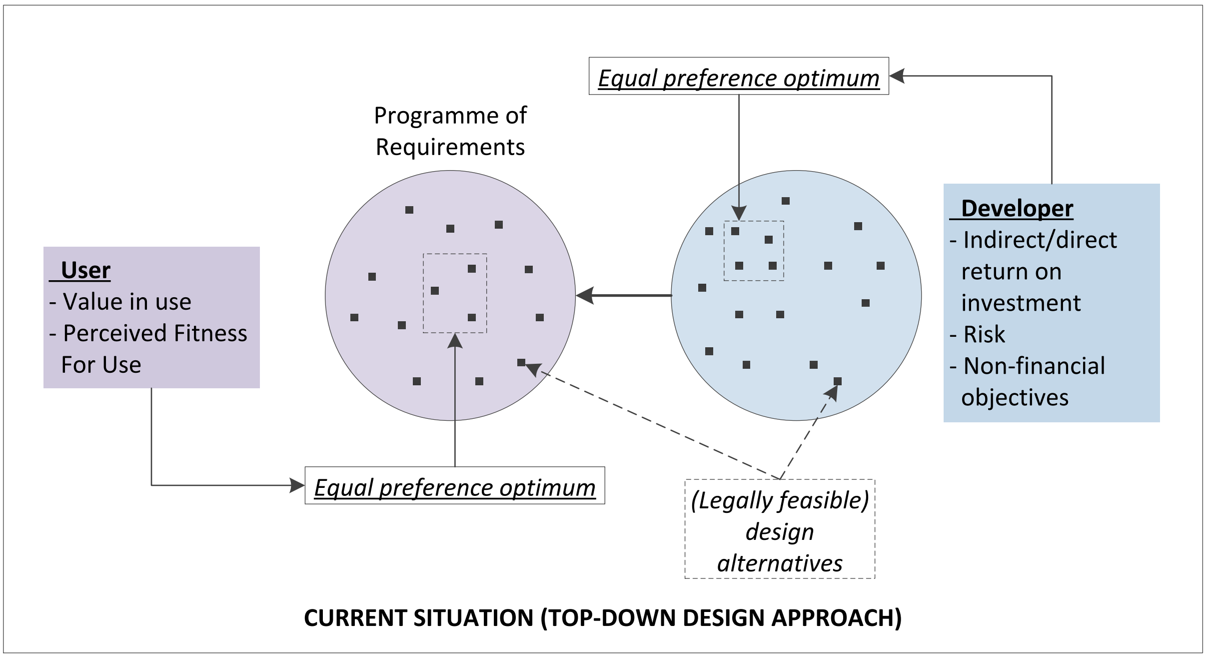


Figure 2. A standard top-down design approach (own ill.)

Figures 3a and 3b show how the proposed model could potentially incorporate user preferences in the design process, simultaneously to the incorporation of developer preferences. Theoretically, this would generate design alternatives with higher aggregated preference scores than the standard situation from figure 2. Figure 3a shows a potential outcome in the situation where the most preferred design alternative of the consumer is coincidentally also the most preferred design alternative of the developer. Figure 3b shows the effect of the developer having more bargaining power than the consumer if the most preferred design alternative differs for both parties.

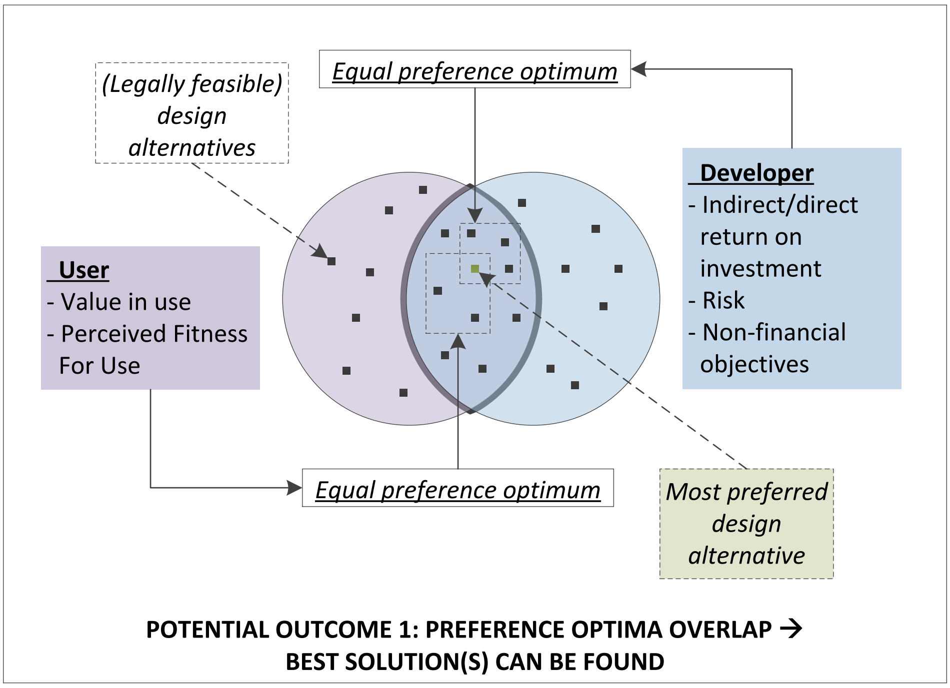


Figure 3a. Potential outcome of proposed mathematical modelling design approach (own ill.)

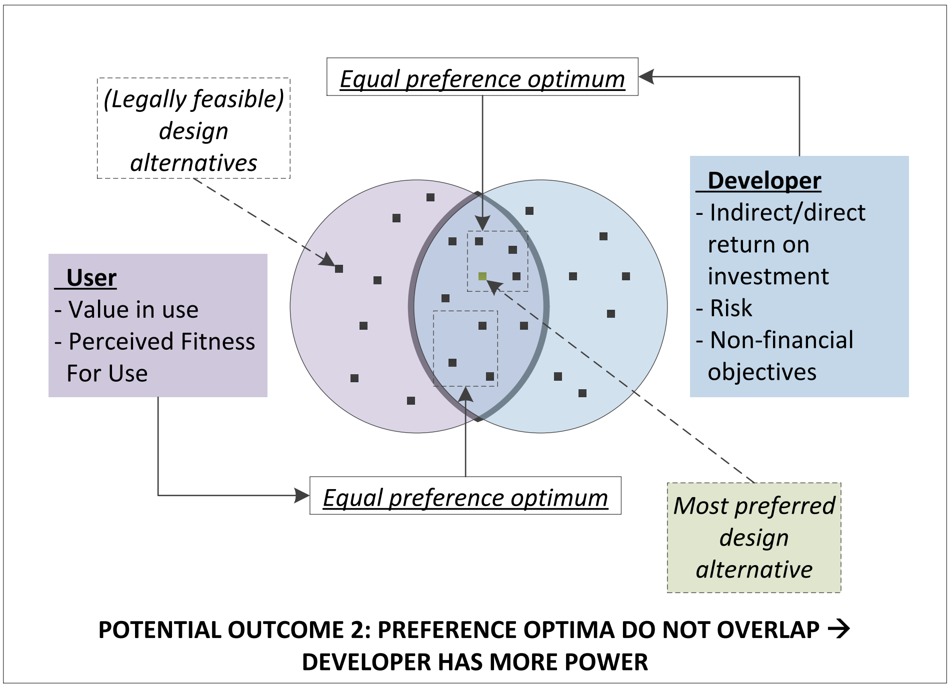


Figure 3b. Alternative outcome of proposed mathematical modelling design approach (own ill.)

4. Research questions

This study aims to test the following hypothesis:

The application of a preference-based design system leads to residential design alternatives that are more in line with consumer preferences, while simultaneously maximising financial profitability over design processes without application of a preference-based design system.

The following assumptions are made (in order to provide a scope for the variables to be included in this research):

1. Developer preference is limited to the financial profitability of the residential design.
2. Consumer preference is limited to design variables that influence the financial profitability of the residential design.

The second assumption is deemed relevant as, given assumption 1, a developer would have no reason to decide against design variables that do not influence the financial profitability of the residential design. Therefore, these would always be included in every possible design alternative and thus incorporating them in the proposed model would not provide additional relevant output.

To be able to create an appropriate model with which the hypothesis can be validated or rejected, the following main research question needs to be answered:

How can developers generate residential design alternatives that are more in line with consumer preferences, while simultaneously maximising financial profitability?

In order to answer the stated main question, the following sub-questions will be answered first:

5) How are financial implications of a dwelling design measured by investors/project developers?

It is expected that the financial implications of a dwelling design are measured through the influence of specific building design characteristics and their overall combination on project costs, income, risk and profit.

6) Which costs, income, risk and profit related requirements and constraints do developers apply, both directly and indirectly, when commissioning building designs?

It is expected that investors/project developers apply at least one direct financial requirement regarding the total construction costs, and multiple indirect financial requirements regarding cost limitations and income projections through e.g. maximum construction period/date of completion, minimum amount of GFA/LFA per function and minimum construction quality level. It is expected that these direct and indirect requirements contain certain margins which will reduce the project's financial risks to a level that is considered acceptable by the investor/developer, and thus properly secure certain hidden profit requirements.

7) What residential design aspects are relevant in relation to the developer's financial profit?

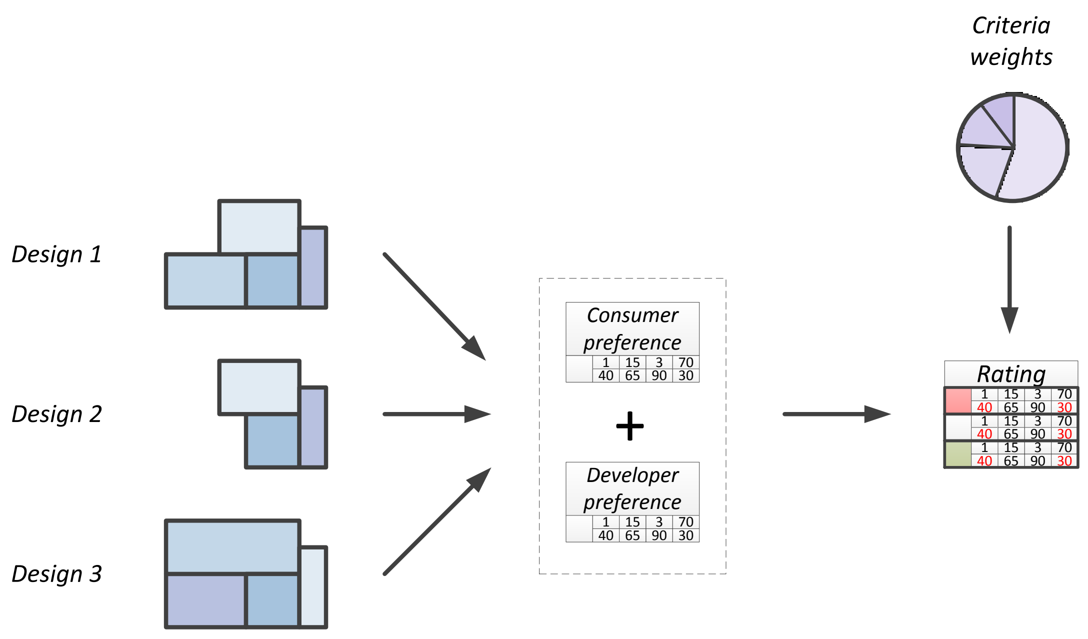
While some design aspects are directly related to e.g. construction costs, others will possibly not have any measurable financial implications.

8) Which of those aspects (see question 3) are also relevant in relation to consumer preference measurement, and which design constraints result from this?

If consumers' preferences show, for instance, that they require a minimum amount of bedrooms in order to consider the purchase of a dwelling, this constraint will need to be included in the model. Design aspects that consumers have no preference over are not relevant for the model, since each design alternative will score equally on that criteria.

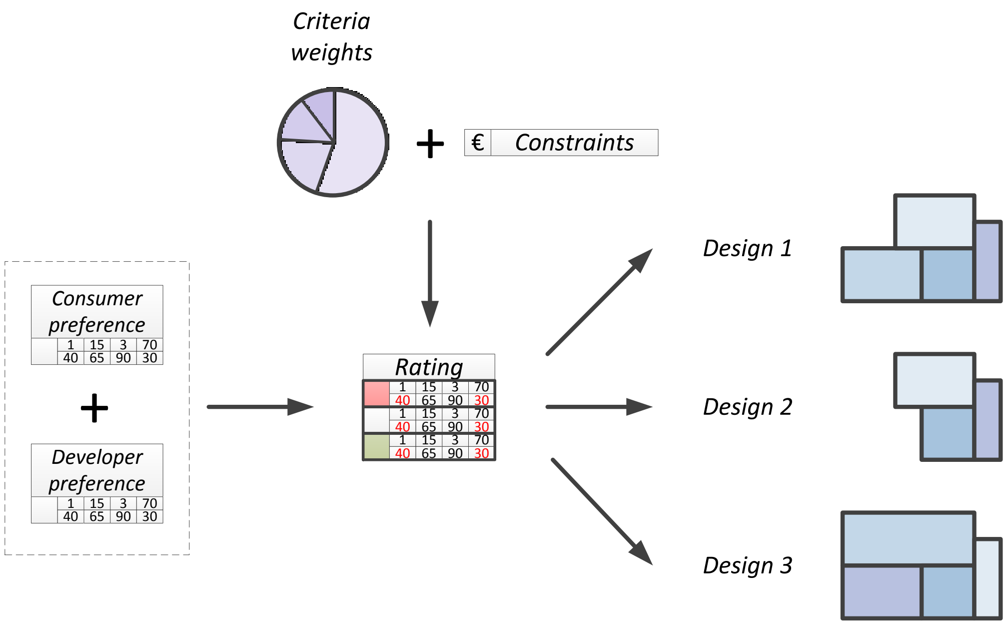
Application possibilities

When the described research questions have been answered, and a sufficiently realistic computer model has been constructed based on the outcomes, there will be three main applications for which this research may serve. These concepts behind these applications have been visualised in figure 4a, b and c.



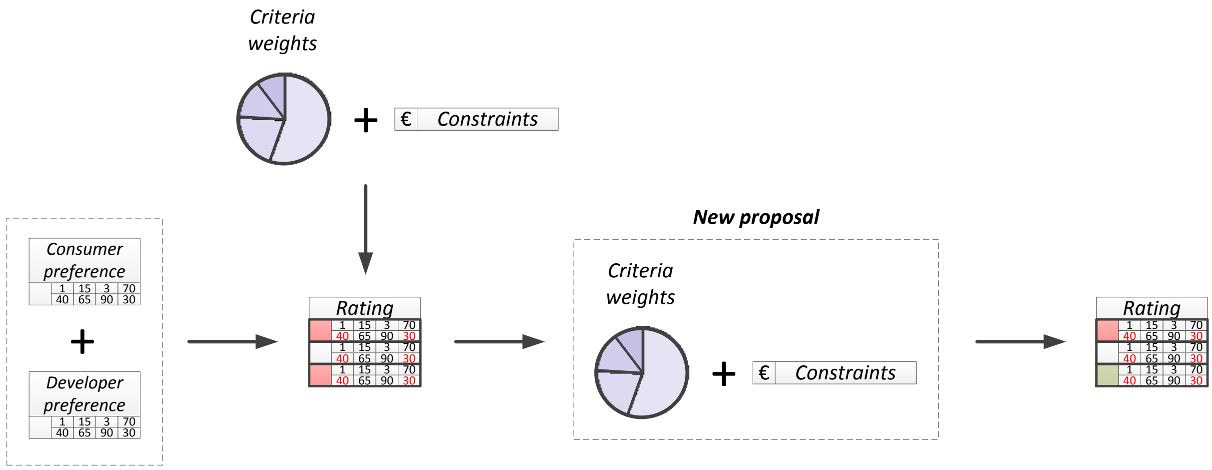
Option 1 | Comparing design alternatives

Figure 4a. First potential application of research results (own ill.)



Option 2 | Generating design alternatives

Figure 4b. Second potential application of research results (own ill.)



Option 3 | Determining conflicting interests

Figure 4c. Third potential application of research results (own ill.)

The first option (figure 4a) shows how practitioners could use the model to compare multiple design alternatives more transparently. While stakeholder preferences remain subjective, the model makes these preferences more explicit and it ensures that each alternative is rated on the exact same criteria. This reduces any personal bias towards a specific alternative.

The second option (figure 4b) shows how the model could generate new design alternatives, based on specific criteria and stakeholder preferences. The outcome the model generates will depend on the selected optimization criteria (e.g. highest NPV, IRR, consumer preference score or aggregated preference rating).

The third option (figure 4c) visualizes how the model can be used to determine which conflicting interests exist within a design problem. If none of the compared or generated design alternatives turn out to be feasible or sufficiently satisfies all stakeholders, the model can be used to construct a new proposal with adjusted criteria(/stakeholder) weights and/or new financial constraints.

5. Research design and methodology

Throughout the research process there will be two different approaches towards answering the stated research questions. These approaches are expected to complement each other and will ensure proper validation of the eventual findings. The first approach is *empirical research*. The second approach is that of *formal research*, more specifically the field of *operations research*. In this chapter both methods and their application in this study will be described. Table 1 shows the main distinctions between the two methods, according to Barendse et al. (2012).

	Operations research	Empirical research
Type	Operation-related	Knowledge-related
Aim	Creating an artefact Changing situations	Producing knowledge Formulating explanations
Relevance	Operational	Theoretical
Subject	Future	Past
Goal	Improvement	Understanding
Methodology	Prescriptive	Descriptive
Science	Formal sciences	Empirical sciences

Table 1. Distinctions between operations research and empirical research (Barendse et al., 2012)

The empirical research approach will be applied to collect generalized data from previous studies. This knowledge can then be used to generate theoretically valid assumptions on which the prototype of the model will be based (i.e. the prototype's initial input, criteria, variables and constraints).

The operations research approach allows for an analytical and exploratory attitude towards a problem or situation in which not all variables are defined yet. It will be used to determine the most appropriate mathematical solution for the stated research problem in a specific case study context.

Figure 5 illustrates the differences (and similarities) between performing research following a formal or empirical method. Both processes can be perceived as iterative and have somewhat similar phases to reach the desired end result.

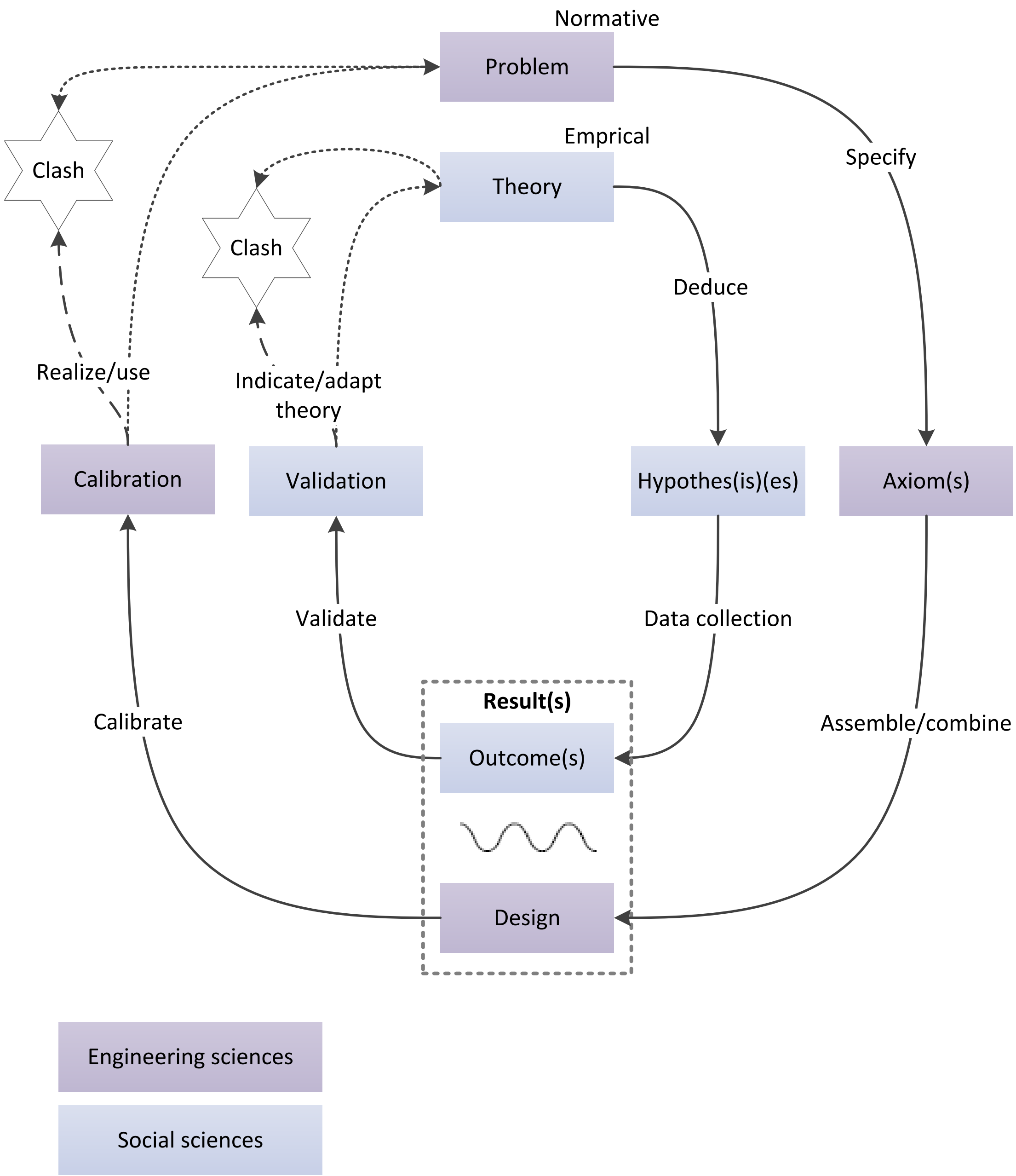


Figure 5. Formal and emperical sciences (own ill. based on Barendse et al., 2012)

5.1 Empirical research

Figure 6 shows the main steps of an empirical research process, as described by Kumar (2011).

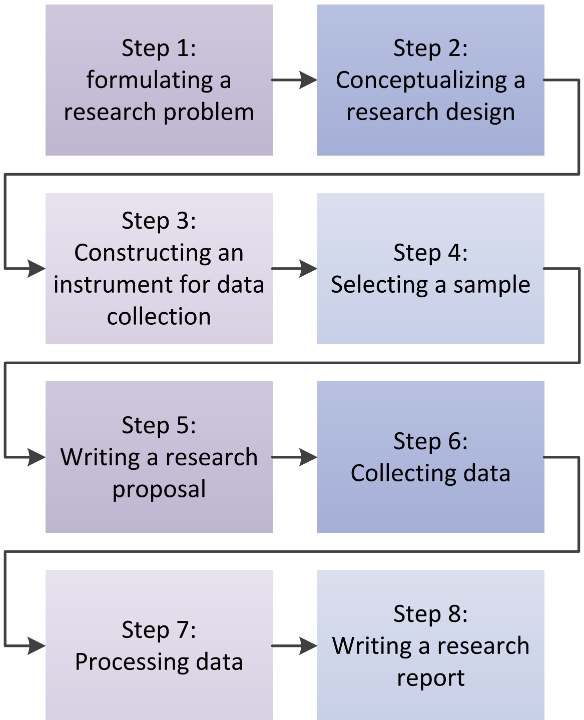


Figure 6. Steps of an empirical research process (own ill. based on Kumar, 2011, p. 22)

Through thorough data collection and interpretation a clear theoretical framework has been established on which the proposed model can be build. This empirical exploration also offers initial validation for the criteria and variables used in the model.

The main method of data collection so far has been literature research - a 'secondary source' method (Kumar, 2011, p. 139). When performing the case study this approach will be become more 'primary source' focussed to ensure the validity of the research results. *In-depth interviewing* involves the collection of data regarding informants' perspectives on their experiences or situations as expressed in their own words (Kumar, 2011, p. 160). As decision making processes are subjective to the personal perceptions of decision makers, this approach should result into more relevant data regarding the observed context of the studied case. The studied *sample* will consist of decision makers that were involved with the problem/situation of the selected case. As the goal is to design a model which is representative for the selected case, it is important to determine all similarities and differences in perception of the decision makers. Therefore the sample will be questioned through a series of *structured interviews*. This way their individual perception of relevant concepts and variables can be compared more objectively than through the application of unstructured interviews (Kumar, 2011, p. 145). For a detailed interview schedule with coding concepts, specified to the selected case (as described in chapter 9 'Case study'), see appendix 3. Steps 6, 7 and 8 of figure 6 will result from this phase.

5.2 Operations research

This approach will offer a more practical framework that assures validation of the mathematical concept behind the model itself.

Largely in line with the iterative research process as visualized by Barendse et al. (see figure 5), the following five stages can be identified for an operations research project (Ackoff & Sasieni, 1968):

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

While these stages will be incorporated into the proposed research design, the visualisation of Barendse et al. will be applied for the elaboration of each stage.

In order to design a model which is able to perform as required, the following steps for Preference Function Modelling (PFM) will be followed throughout this graduation research (Arkesteijn & Binnekamp, 2013):

Step 1: Specify the decision variable(s) the decision-maker is interested in.

Step 2: Rate the decision-maker's preferences for each decision variable by fitting a curve (the so-called *Lagrange curve*) through three decision variable value/preference rating coordinates as follows:

• Establish (synthetic) reference alternatives which define two points of the curve.

• Define a "bottom" reference alternative, the alternative associated with the value for the decision variable that is least preferred, rated at 0. This defines the first point of the curve (x0, y0).

• Define a "top" reference alternative, the alternative associated with the value for the decision variable that is most preferred, rated at 100. This defines the second point of the curve (x1, y1).

• Rate the preference for an alternative associated with an intermediate decision variable value relative to the reference alternatives. This defines the third point of the curve (x2, y2).

Step 3: To each decision variable, assign decision-maker's weight.

Step 4: Determine the design constraints.

Step 5: Generate all design alternatives (using the number of buildings and allowed interventions). Then use the design constraints to test their feasibility.

Step 6: Use the PFM algorithm to yield an overall preference scale of all feasible alternatives.

As these steps make clear, the method for determining developer and consumer preferences will not be normative (i.e. similar to e.g. discrete choice analysis). Instead, a logistical method will be applied. To correctly measure preference, a stakeholder is asked to rate their preference for each criterion as follows: the (design/financial) variable value for the criterion that is most preferred is rated at 100. The value that is least preferred is rated at 0. A third intermediate value needs to be rated to define the slope of the Lagrance curve as a reflection of the decision maker's preference for values between the most and least preferred value. The Lagrange curve described in step 2 is then constructed through those three points as individually defined by the stakeholder. Then for each value of x, the corresponding value of y can be found by the following formula:

$$P(x) = \frac{(x-x1)(x-x2)}{(x0-x1)(x0-x2)} * y0 + \frac{(x-x0)(x-x2)}{(x1-x0)(x1-x2)} * y1 + \frac{(x-x0)(x-x1)}{(x2-x0)(x2-x1)} * y2 \quad (1)$$

5.3 Proposing a combined approach

Figure 7 illustrates the proposed combined research approach. It shows how empirical theory is used to substantiate the operations research problem statement. Both processes will be followed roughly simultaneously. While the iteration in both approaches is separated, a reflection moment is incorporated after the model prototype has been designed to ensure an empirically validated definitive model. Also, after final calibration, the definitive model will be used to validate the original hypothesis.

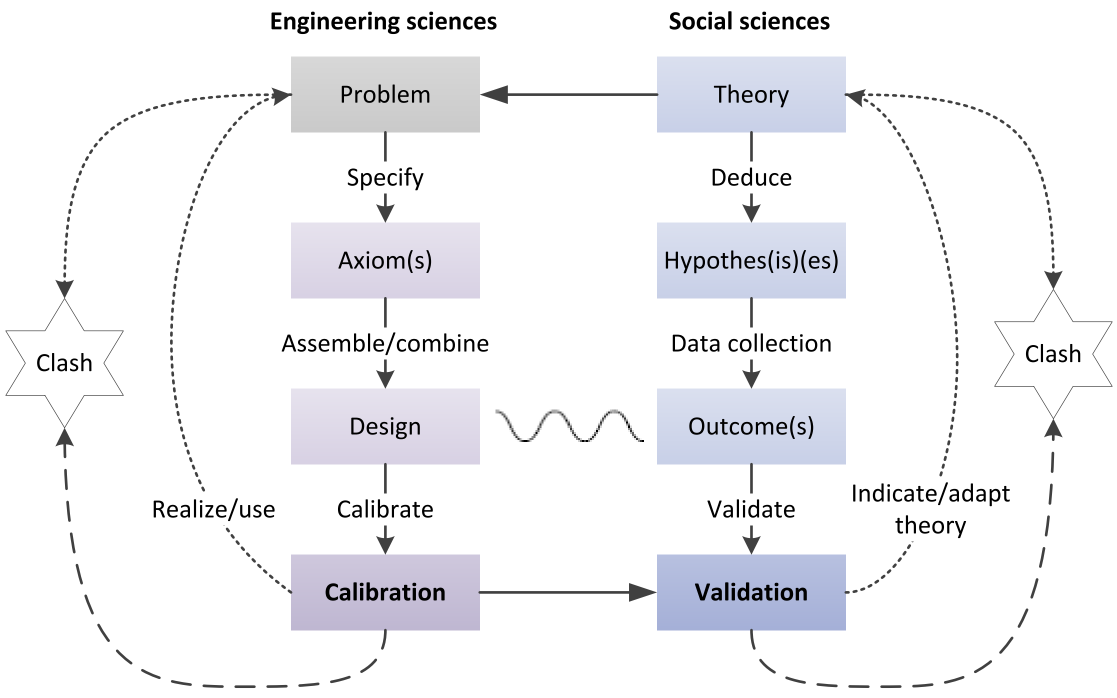


Figure 7. Proposed combined research approach (own ill. based on Barendse et al., 2012)

Chapter 2 ‘Research relevance’ gives a brief description of the relevant theories regarding the research subject. An more extensive theoretical background is provided in chapter 7 ‘Defining the variables’. A specification of the problem itself has been described in chapter 3 ‘Research objectives’. This has led to the formulation of the hypothesis and several knowledge questions, as described in chapter 4 ‘Research questions’. That chapter also covers some initial expected outcomes. This chapter, ‘Research design and methodology’, describes the selected research approach (resulting in the implicit axiom). The following chapter ‘Model specification’ will provide an introduction to the proposed design framework. Finally chapter 8 ‘Model prototype’ will discuss the calibrated design (prototype). A definitive design, along with the final outcomes to the knowledge questions will be constructed throughout the upcoming months. A large portion of this research will be related to the testing of the model prototype and the preliminary empirical outcomes by putting them in the context of a specific practical case. This case is described in chapter 9 ‘Case study’ and a brief summary of the expected results is provided in chapter 10 ‘Expected results’. The six operations research steps mentioned earlier, based on Arkesteijn & Binnekamp (2013), are continuously taken and checked during construction of the conceptual and detailed design. For a summary of the different research phases and related chapters, see table 2.

Research fragment	Chapter
Theory	2. Research relevance; 7. Defining the variables
Problem	3. Research objectives
Hypothesis	4. Research questions
Axiom	5. Research design and methodology
Design	6. Model specification
Calibration	8. Model prototype; *To be added in the upcoming months*
Outcome(s)	9. Case study; 10. Expected results; *To be added in the upcoming months*
Validation	*To be added in the upcoming months*
Reflection on (adapted) theory	*To be added in the upcoming months*

Table 2. Division of research phases and related chapters

6. Model specification

It is expected that a model which incorporates multi-actor and multi-criteria preference function modelling can be applied in order to relate found measured variables, requirements and constraints to each other mathematically. The mathematical concept of Preference Function Modelling (PFM), as described by Barzilai (2010), is shown in figure 8. Each stakeholder will be given a decision power weight percentage. Each individual criteria will also receive a certain weight from the relevant stakeholder. An algorithm will need to be incorporated in the model to determine the preference ratings. For the model prototype, a weighted sum calculation will be sufficient. This means each preference score is multiplied with the weight assigned to its criteria. For the definitive model it might prove more realistic to adjust this algorithm to reflect the specific case studied.

Criteria	C_1	C_2	$C_{...}$	C_n		
Weighing	W_1	W_2	$W_{...}$	W_n	→ *Total 100%*	
Alternatives				Scores	Preference rating	
A_1	$S_{1,1}$	$S_{1,2}$	$S_{1,...}$	$S_{1,n}$	$R \sum_{i=1}^{n} S_{1,i} W_i$	
$A_{...}$	$S_{...,1}$	$S_{...,2}$	$S_{...,...}$	$S_{...,n}$	$R \sum_{i=1}^{n} S_{...,i} W_i$	► Selecting the best alternative
A_m	$S_{m,1}$	$S_{m,2}$	$S_{m,...}$	$S_{m,n}$	$R \sum_{i=1}^{n} S_{m,i} W_i$	

Figure 8. The mathematical concept of Preference Function Modelling (PFM) (own ill. based on Borst, 2014)

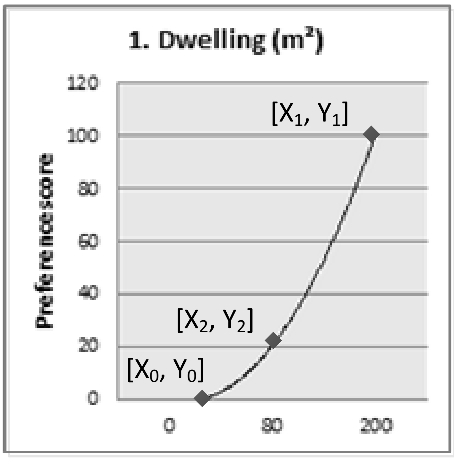


Figure 9. Example of a Lagrange curve (own ill.)

The exact score for each criteria is determined by the Lagrange curve for that specific criteria. The process of constructing a Lagrange curve has been described in the Preference Function Modelling steps discussed in chapter 5 ('Research design and methodology'). For an example of a drawn Lagrange curve, see figure 9.

Figures 10a and 10b illustrate how the most preferred design alternative will be determined in the prototype. The developer will receive a larger stakeholder decision power weight than the consumer as to reflect the ability of the developer to 'overrule' the consumer in the design process.

The variables/criteria included in the model prototype will be determined based on the established theoretical framework (see chapter 7 and onwards). Microsoft Excel will be the software programme in which the prototype will be created. This software is relatively easy to use and allows for plenty mathematical functions to achieve the model's objectives.

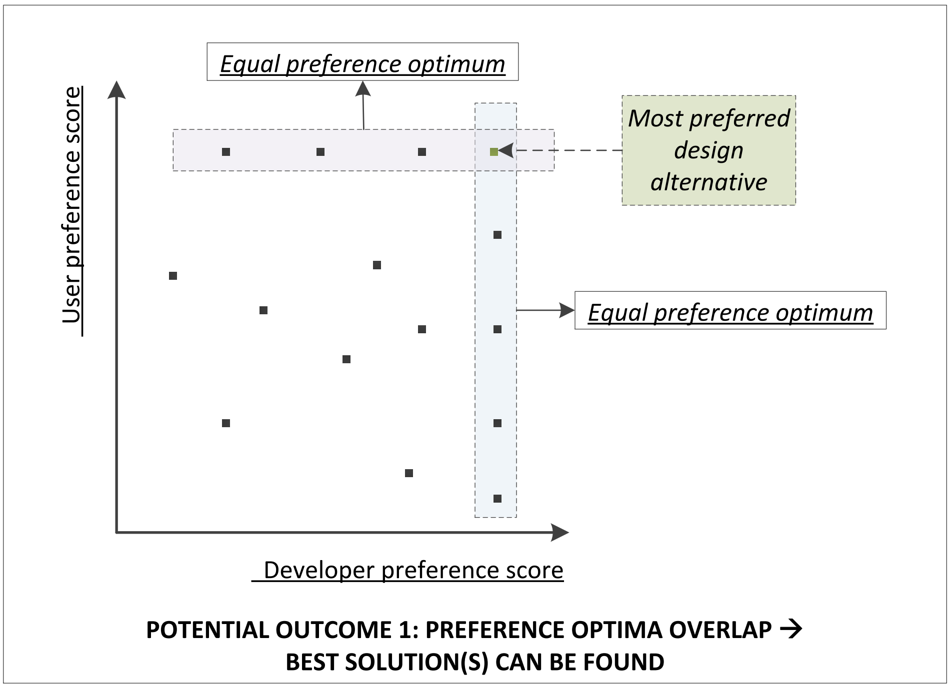


Figure 10a. Visualisation of method to select the most preferred design alternative (own ill.)

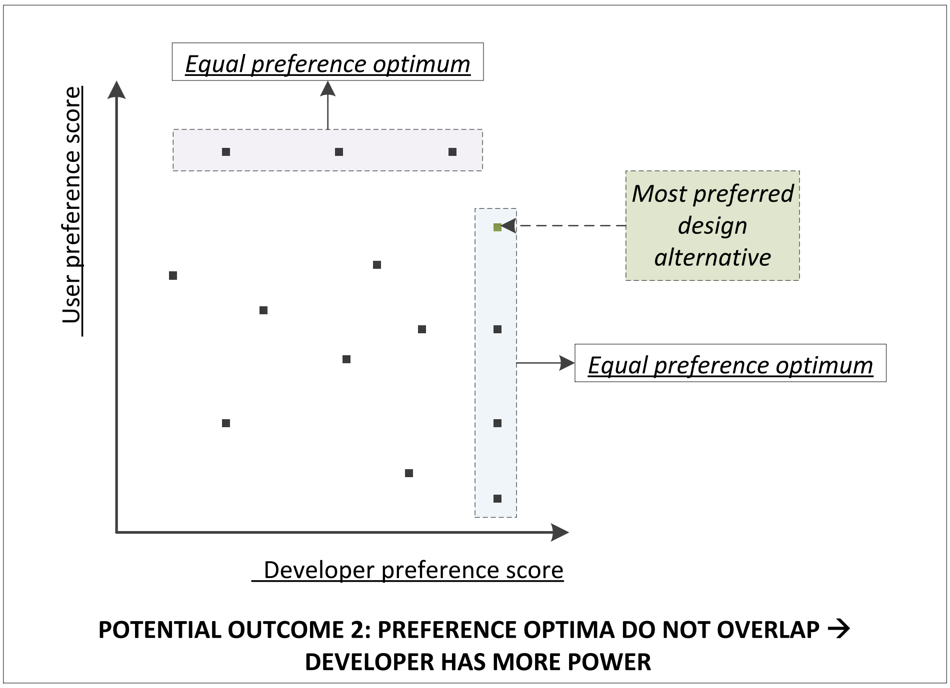


Figure 10b. Visualisation of alternative method to select the most preferred design alternative (own ill.)

7. Defining the variables

This chapter will discuss the preliminary outcomes of the empirical (literature) research performed so far. In order to answer the knowledge part of the described research questions, the outcomes are related to potential variables that may together construct the model. As the proposed model aims to optimize the potential development profit, as well as exposing the relationship between financial requirements and design characteristics, the variables are divided into financial and design variables.

7.1 Financial variables

Real estate developers often construe the prospected costs and revenues and relevant risk premiums of potential projects through discounted cash flow (DCF) calculations. The DCF method is extensive and widely used in practice. In order to generate accurate results that are easy to interpret, the developers' preference scores will be based on the outcome (the net present value, or NPV) of automated DCF calculations. The financial variables applied by the model are thus input for these DCF calculations.

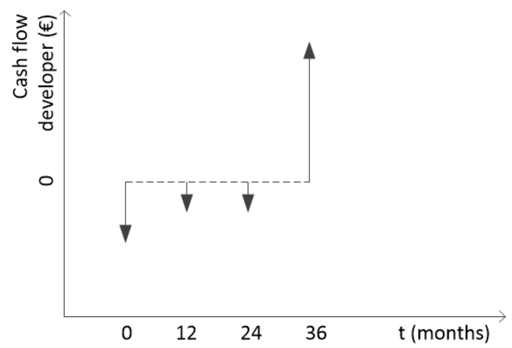


Figure 11. Example of develop-and-sell cash flow diagram (own ill.)

Figure 11 illustrates how cash flow models set out different costs and revenues against time. The DCF method applies an annual discount rate in order to compensate for inflation and cost and revenue postponement.

Table 3 shows all the financial variables that are considered relevant for DCF implementation within the proposed model.

Financial variable	Input type	Explanation
Construction costs	Automated input	Results from input design variables; t = 0
Additional costs (permit fees, consultants, etc.)	Input from developer	Expected additional costs; t = 0
Land acquisition costs	Input from developer	Land acquisition costs at t = 0
Expected sale price	Input from developer	Expected sale price per m^2 GFA based on targeted market segment; t = (0 + construction period)
Construction period	Input from developer	Expected construction period
Discount rate	Input from developer	Annual discount percentage based on expected risk free rate, real estate risk premium and object specific risk premium
Net present value (NPV)	Automated output	Resulting developer's profit

Table 3. Financial variables

7.2 Design variables

Existing literature has been examined in search of relevant design variables. Since the objective of this research is to determine whether developers are (theoretically) able build properties according to consumer preferences without compromising on financial profit, the selected design variables should only include aspects that have some sort of financial implications for the developer. Also, all design variables should be mathematically measurable in order to determine and compare design alternatives' consumer preference scores.

Chin and Chau (2003) have thoroughly described which hedonic pricing studies had been performed until then in regard to residential property. They make a clear distinction between locational, structural and neighbourhood attributes. For the purpose of identifying design characteristics that consumers are likely to show a preference in, all relevant structural attributes are listed in table 4.

Structural attribute	Relation to property value	Source of Chin and Chau (2003)
Number of bedrooms	Positive correlation	(Fletcher, et al. 2000; Li & Brown 1980)
Number of bathrooms	Positive correlation	(Garrod & Willis 1992; Linneman 1980)
Floor area	Positive correlation	(Carroll, Clauretie, & Jensen 1996; Rodriguez & Sirmans 1994)
Lot size	Positive correlation	(Li & Brown 1980)
Presence of basement/garage	Positive correlation	(Forrest, Glen & Ward 1996; Garrod & Willis 1992; Li & Brown 1980)
Presence of patio	Positive correlation	(Li & Brown 1980)
Presence of fireplace	Positive correlation	(Li & Brown 1980)
Housing quality (condition of drives and walks, exterior structure, floors, windows, walls, and levels of housekeeping)	Positive correlation	(Kain and Quigley 1970)

Table 4. Structural attributes described by Chin & Chau (2003)

While correlation results give an indication on whether or not a certain characteristic is preferred by consumers, preferences regarding structural attributes are not always identical. Kohlhase (1991) found that the significance of structural attributes is dependent on time and location. Attributes relating to the number of rooms and floor area are relatively important universally, however other attributes change with e.g. the tradition of building style or local climate. Therefore, the preference curve for all proposed variables will be based on stated preferences of Dutch residential property consumers. Initially, WoON (2012) will be consulted for development of the model prototype. After this phase the prototype and its input will be validated through interviews with practitioners. More detailed data, regarding the preferences of specific target groups, will be collected and processed during the phase after that, which will focus on applying the model to real-life cases.

In addition to the structural attributes described by Chin and Chau, the total composition of the rooms and ceiling height will be applied as design variables. This will help determine construction costs more accurately and also allows for further expansion of the model, as to include consumer preferences regarding floorplan layout.

Structural attribute	Design variable	Financial implication
Number of bedrooms	**Number of rooms** (including outdoor areas)	Sum of size and number of rooms → m^2 GFA → construction costs per dwelling
Number of bathrooms		
Presence of basement/garage		
Presence of patio		
Floor area	**Size of rooms** (including outdoor areas)	
Lot size		
Presence of fireplace	**Completion level** (based on typical cost levels)	Completion level → construction costs per dwelling
Housing quality		
-	**Composition of rooms** (including outdoor areas)	Composition of rooms and ceiling height → m^2 façade → construction costs per dwelling
-	**Ceiling height**	

Table 5. Structural attributes, subsequently defined design variables and (in)direct financial implication for developers

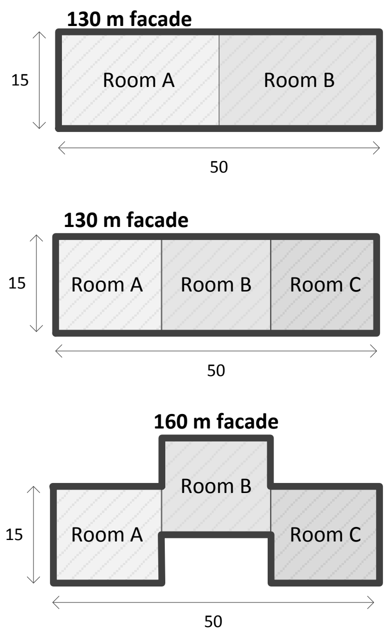


Figure 12. Relation between total façade surface and the composition of rooms (own ill.)

The described relation between room composition and façade surface area, rather than room size or number of rooms, is briefly illustrated in figure 12.

Architectural elements, including specific style and façade materialization are not explicitly taken into consideration in this study. While these factors may influence the construction costs and market value of a project it is not part of the scope of this research to determine the average consumer's willingness-to-pay for certain design elements. Therefore, additional costs or revenues related to these excluded aesthetic variables are considered part of the variables 'completion level' (for additional construction costs) and 'expected sale price' (for additional sales revenues) as seen in figure 13.

7.3 Relations between variables

The relations between all selected variables is visualised in figure 13. In this figure it is shown how design variables together form design alternatives, which delivers the input for the financial variable 'construction costs'. All other financial variables need to be specified by the developer. If no specific set of design alternatives exists, the model can generate design alternatives based on optimisation of financial profitability. The design alternatives which are classified 'most profitable' will then be selected in order to calculate their overall consumer preference score.

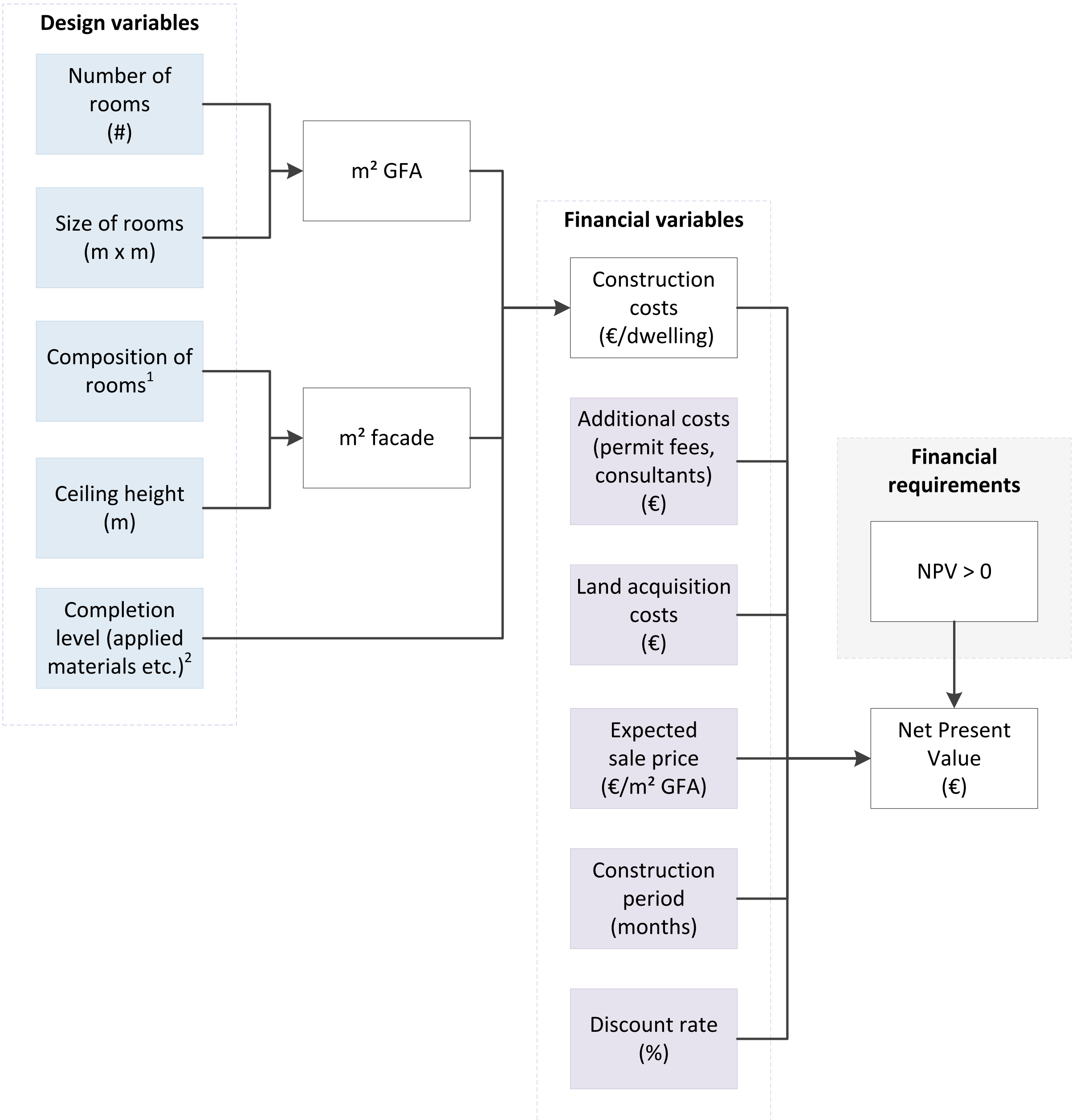


Figure 13. Conceptualisation of the proposed method to measure the financial performance of dwelling designs (own ill.)

8. Model prototype

For screenshots of the prototype in its current condition, see appendix 1 'Model prototype'.

Following the model specification (see chapter 6), a primary prototype has been created using Microsoft Excel. The financial profitability of a residential design is automatically calculated with the discounted cash flow method. The variables incorporated into these calculations are compliant with the financial variables mentioned in figure 13. The developer's preference is incorporated by a Lagrange curve related to the Internal Rate of Return the design is estimated to achieve.

The design variables included in the model are also compliant with figure 13. For each room type the consumer can express their preference regarding number and size of the room.

The rooms types that are included in the prototype are (1) living room, (2) kitchen, (3) primary bedroom, (4) secondary bedrooms, (5) primary bathrooms, (6) secondary bathrooms), (7) primary outdoor spaces (i.e. balconies or gardens), (8) secondary outdoor spaces, (9) indoor storage spaces and (10) outdoor storage spaces. For the bedrooms and bathrooms a differentiation is applied resulting in 'primary' and 'secondary' rooms. This is done so the consumer can express a preference for two different sizes of bedrooms and bathrooms.

The dimensions of all rooms have been limited to the width of a room being no more than three times the length and vice versa. This prevents the model from generating designs that include rooms with unpractical dimensions (e.g. a room of 10 m^2 GFA, shaped as 1 m by 10 m). A different limitation might be applied for the definitive model.

The completion level variable is included in the window that shows the financial variables, as it directly influences the estimated construction costs. However, as this involves a consumer preference related variable, it will be considered a design variable as visualized in figure 13.

All consumer preferences will be entered into the model manually and are automatically processed by the model into Lagrange curves (see appendix 1c). After either (a) a specific design has been manually entered into the model, or (b) the model has been used to generate the most preferred design alternative, the calculated consumer preference scores and the weight of each criteria are shown (see appendix 1e). In another tab the developer preference score is added to the consumer preference scores and an aggregated preference rating is presented (see appendix 1f). Here, the stakeholder decision power weights can be seen (and adjusted).

For a brief overview of all input and output of the model prototype, see tables 6 and 7.

Input	Measurement	Subjects
Consumer preferences	3 points of Lagrange curve; (x0, y0), (x1, y1) and (x2, y2) and criteria weights	1. Total GFA of dwelling
		2. Number of rooms (per room type)
		3. Size of rooms (per room type)
Developer preferences	3 points of Lagrange curve; (x0, y0), (x1, y1) and (x2, y2)	4. Internal Rate of Return
Financial constraints		5. Discount rate 6. Land acquisition costs 7. Construction costs (per m²) 8. Construction period 9. Additional costs 10. Expected sale price (per m²)

Table 6. Model prototype input

Output	Subject	Unit
Design output	1. Total GFA of dwelling	m² GFA
	2. Number of rooms	# (per room type)
	3. Size of rooms	m² GFA (per room type)
Financial output	4. Internal Rate of Return	%
	5. Net Present Value	€
Consumer preference score	Weighted sum of all criteria	Score between 0 - 100
Developer preference score	Score internal rate of return	Score between 0 - 100
Overall preference rating	Weighted sum of all criteria	Score between 0 - 100

Table 7. Model prototype output

9. Case study

Based on the research problem description and demarcation, a case from practice was selected to test and validate the model prototype. This operations research validation phase will finally lead to a definitive design. In order to collect as much relevant data as possible to test the prototype thoroughly, a retrospective case study was selected. Thus the decision making process for which the model could be applied has already taken been completed before collecting the data. This method allows for an objective analysis of the modelled operations in practice.

9.1 The Zusterflat case

The case selected is the "Zusterflat case". In 2014 this former office building was transformed to student housing by SHS Delft (Stichting Herontwikkeling tot Studentenhuisvesting Delft). Due to long term vacancy and obsolescence of the property, the owner was willing to cooperate with SHS Delft and accepted them as a tenant for the upcoming ten years. After that period the building will be demolished. Figure 14 shows the exterior of the property (as seen from the south). Table 8 provides an overview of the building's main characteristics. See appendix 2 for an exemplary floor plan before and after the transformation into student housing.

Figure 14. The Zusterflat in Delft (SHS Delft, 2012)

Building characteristics	
Name	Zusterflat
Address	Aan 't Verlaat 31, 2612 GA Delft
Owner	GGZ Delfland (a semi-public healthcare organization)
Zoning plan	Noordoost Delft
Original function (as stated in zoning plan)	Social purposes
Transformation period	10 years
Accessibility	Direct access to public transport (bus), highway within 2 km, 59 parking spots
Total GFA	5973 m² (of which 737.85 m² unsuitable for residential use)
GFA suitable for residential use	5235.15 m²
GFA low-rise floors (suitable)	1253.43 m²
Ground floor:	*1155.66 m²*
2nd floor:	*417.81 m²*
3rd floor:	*417.81 m²*
GFA high-rise floors (suitable)	3981.72 m²
Ground floor:	*331.81 m²*
2nd floor:	*331.81 m²*
3rd floor:	*331.81 m²*
4th floor:	*331.81 m²*
5th floor:	*331.81 m²*
6th floor:	*331.81 m²*
7th floor:	*331.81 m²*
8th floor:	*331.81 m²*
9th floor:	*331.81 m²*
10th floor:	*331.81 m²*
11th floor:	*331.81 m²*
12th floor:	*331.81 m²*

Table 8. Characteristics of the Zusterflat case (based on SHS Delft, 2012)

From the start of the Zusterflat project it had been clear that SHS Delft's goal was to transform the vacant building into student housing. This foundation had in fact been established by the municipal party of STIP (Studenten Techniek In Politiek) and the local student union VSSD to realize a transformation project as such (Mensink, 2015). After the property owner, GGZ Delfland, had announced interest to let SHS Delft transform the Zusterflat, there were two major decisions that had to be made in order to determine the financial feasibility of the project. One was related to the target groups that would be included in the programme: Dutch students, international students, or both? The other decision was related to the type of accommodation that would be realized: shared accommodation, independent accommodation, or a combination? Figure 15 illustrates how these two important decision variables would together influence the consumer preferences and financial feasibility of the project.

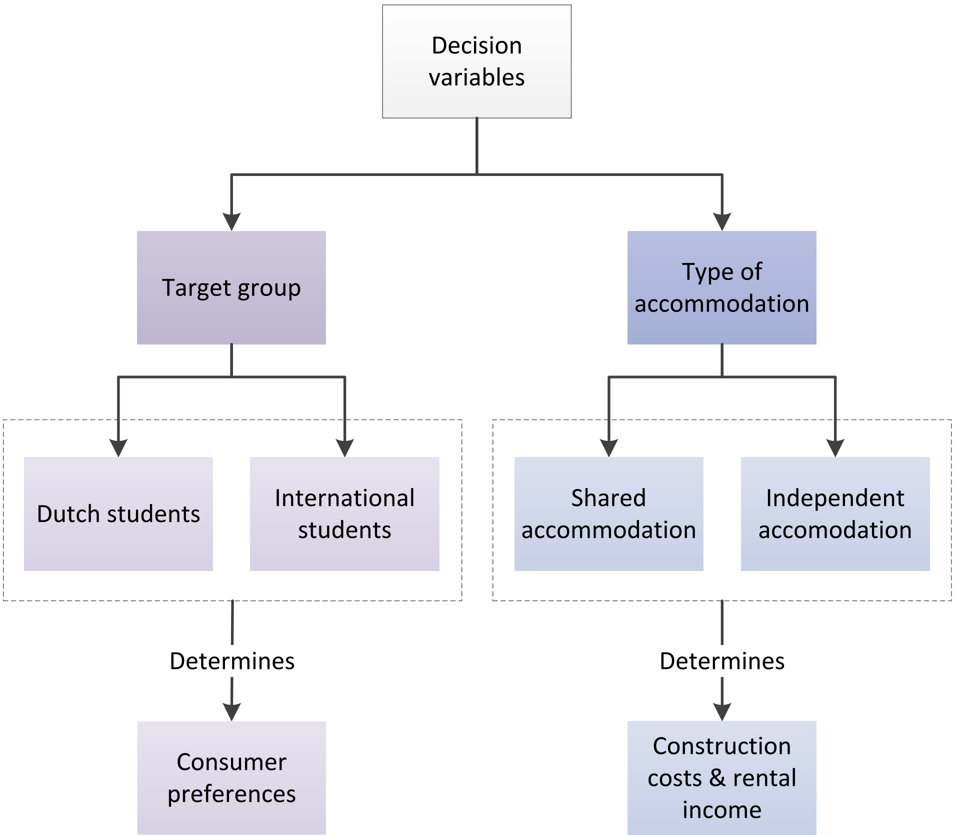


Figure 15. Initial decision variables the developer was faced with in the Zusterflat case (own ill.)

Based on these two variables a decision analysis can be applied by utilizing the proposed model. Because each variable is related to a major component of this research (consumer preferences and financial feasibility), it is expected that evaluating the model prototype using the Zusterflat case will generate applicable feedback and data as to design a detailed model that follows the previously described specifications.

As both decision variables will co-determine the overall preference rating of a design alternative (i.e. the combined developer and consumer preference scores), four different case strategies have been defined. Figure 16 visualizes the differences and similarities between these strategies. The model will be applied in different ways to achieve relevant results with this strategy analysis. First, it will be used to calculate the optimal space configuration (room types, numbers and dimensions) for each strategy. This calculation includes both developer and consumer preferences. These optimal configurations (or: most preferred design alternatives) are then compared with each other as visualized in figure 17. Secondly, if the strategy that has been selected in reality does not come out as the most optimal strategy, the model will be used to explain this discrepancy by adjusting variables such as the stakeholder power percentages or the stakeholder preference curves (depending the type of discrepancy found). If no plausible explanation can be found through these adjustments, further analysis of the model will be necessary to determine the origin of the discrepancy.

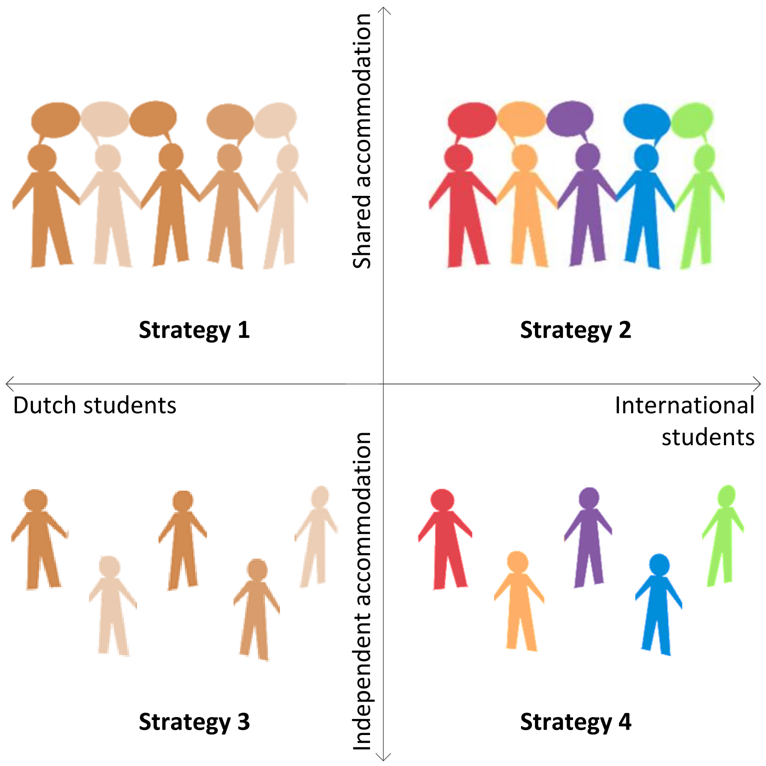


Figure 16. Strategies based on the two main decision variables for the Zusterflat case (own ill.)

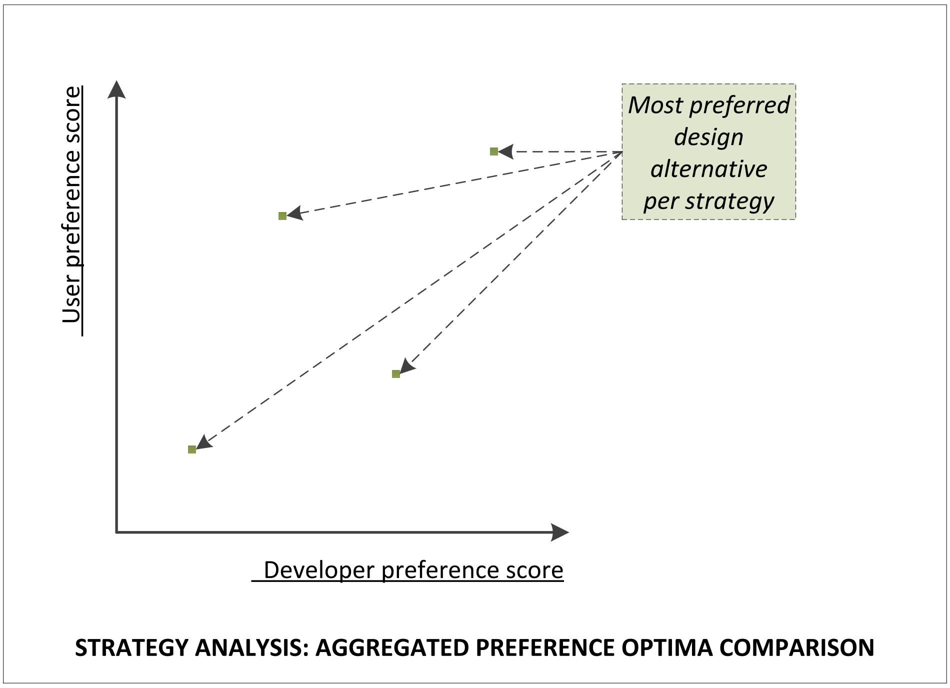


Figure 17. Aggregated preference optima comparison method (own ill.)

9.2 Adjusting the existing model

In order to test the model prototype, and to generate valid outcomes for the posed research questions, the existing model needs to be adjusted to reflect the Zusterflat's context. Aside from configuring the consumer preferences to correspond with those of the relevant end-users, there are financial variables that need to be processed into the model. Figure 18 illustrates how the NPV calculations need to be modelled for the different strategies. The figure shows how no land or property is acquired by SHS Delft, and that there are no sales revenues but instead a monthly rental income is generated. While the discount rate for both strategies may prove similar, this information is not known yet at this stage. Therefore the discount rates are here assumed to be dependent on the cost vs. income structure of each strategy.

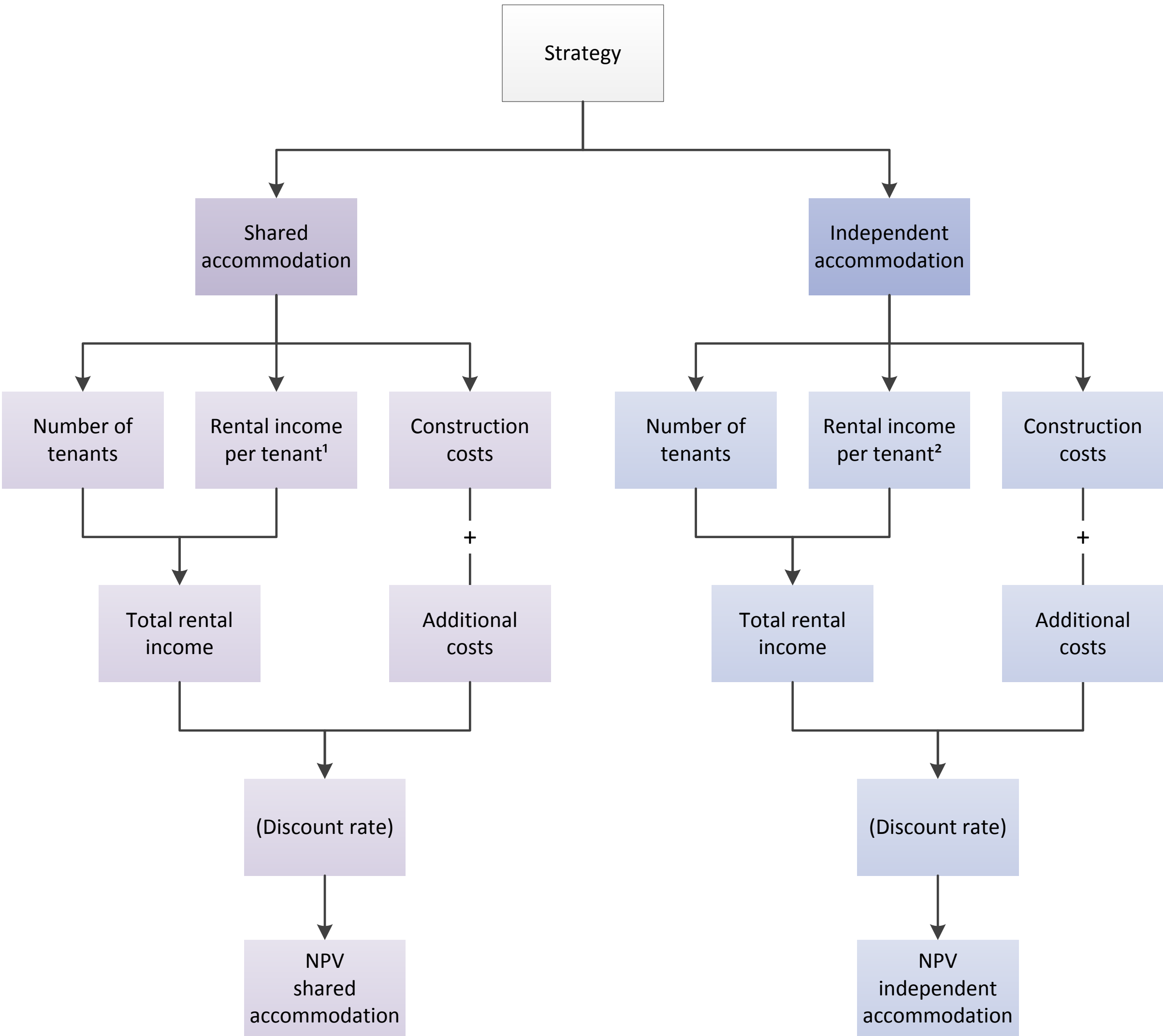


Figure 18. Financial factors related to accommodation type (own ill.)

One of the reasons the Zusterflat case is so interesting for this study is the fact that it is legally considered "social housing" in the Netherlands. This means that the rental income per tenant is maximized by governmental legislation. As this maximization involves a relatively objective method to calculate the permitted rent price with, there is less chance of the NPV calculations being contaminated with subjective valuation perspectives of the researcher. Therefore the maximum rental income associated with each design alternative will be calculated using this standard method. Figures 19a and b show how this standard method works. For both types of accommodation (shared or independent) there is a specific calculation that takes certain building and environmental characteristics into account. The result of both calculations is a definite point score, which determines the legal rent price limit of the accommodation. Because SHS Delft made the decisions regarding the Zusterflat configuration before October 2015, the calculation method that was applied at that time will be used for the model as well. This will allow for a better reflection of reality surrounding the decisions that were made.

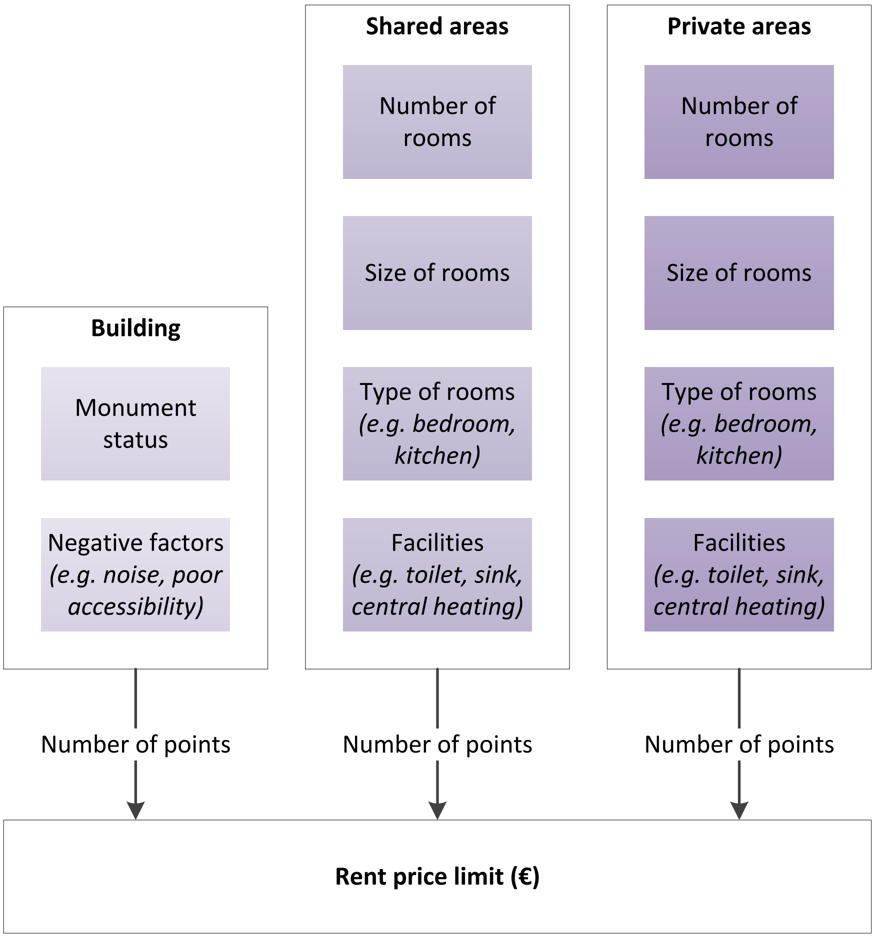


Figure 19a. Rent determinants of shared accommodation (own ill. based on Huurcommissie, 2015)

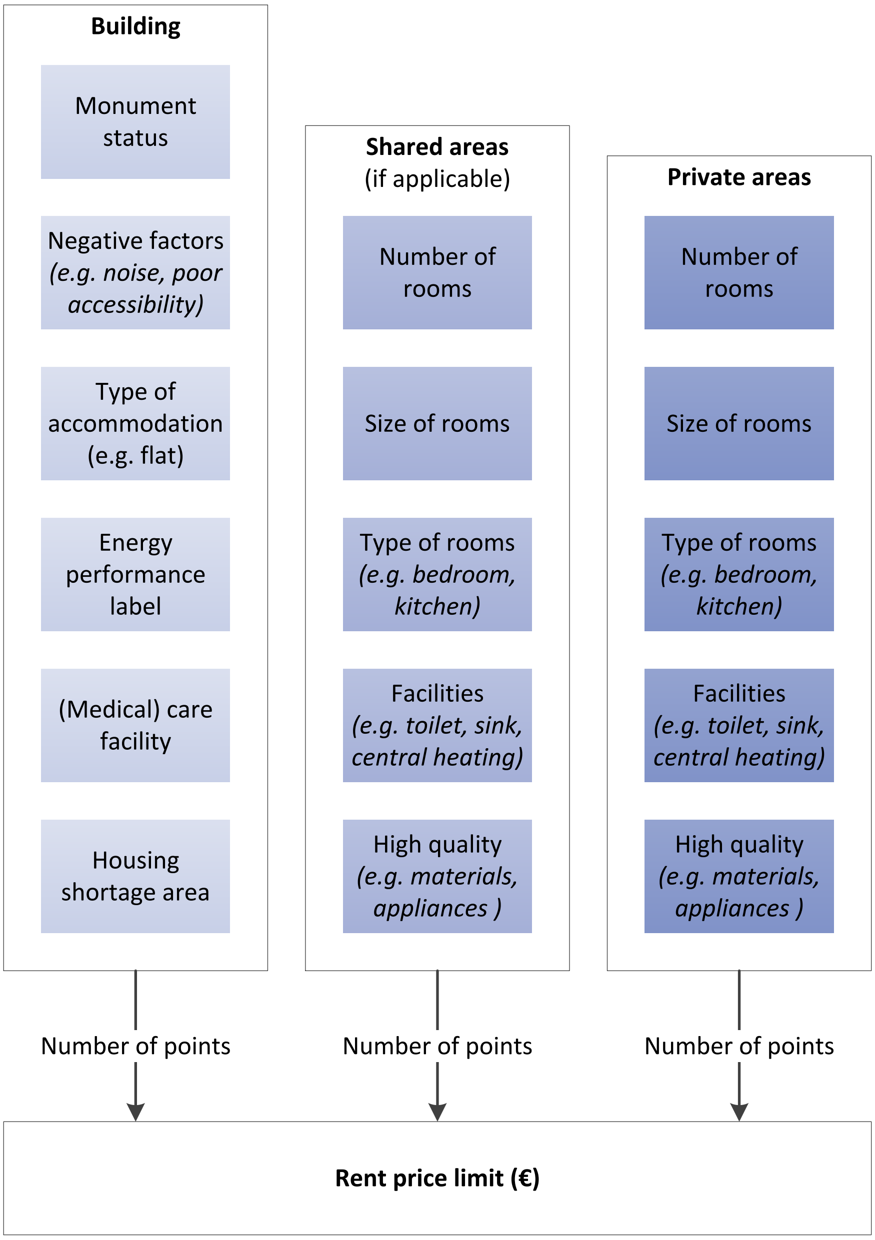


Figure 19b. Rent determinants of independent accommodation (before October 2015) (own ill. based on Huurcommissie, 2015)

Additional empirical research regarding consumer preferences will be needed to assure the model reflects the preferences of the Zusterflat's potential end-users. This will be done by a brief literature study, which focusses specifically on student preferences. The results from this literature study will be then compared with stated consumer preferences from the actual target groups. A representative will be selected for both potential target groups (Dutch and international students) and they will be asked to draw Lagrange curves that represent the prevailing preferences within their group.

Also, the model needs to be adjusted to incorporate the technical and functional limitations of the Zusterflat building. This means the constraints that are included in the model prototype will be adjusted. There will not be any new functions added to the model, as the room types that are currently included remain relevant for this case. Some minor alterations might be required however.

10. Expected results

After initial examination of the Zusterflat case, the following results are expected to be found at the end of this research process:

1. Adjustment of the 'current situation' (see 'Research objectives')., likely to reflect a more bottom-up design approach (see figure 20).

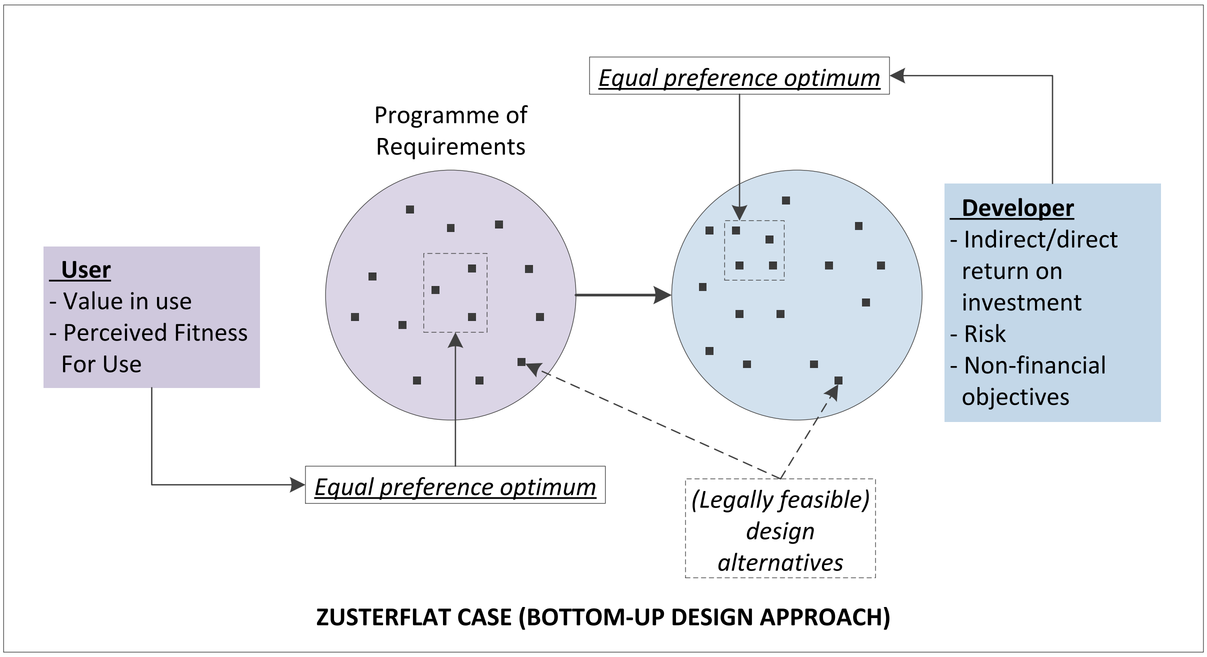


Figure 20. Proposed bottom-up design approach (own ill.)

2. Evaluation of the model prototype and analysis of the related decisions made in the Zusterflat case. Possible adjustment of the variables found in the literature research (see 'Defining the variables') to reflect this specific residential development process.

3. Delivery of a detailed model and generated alternative design configurations, specified to the Zusterflat case.

4. Evaluation of the detailed model and produced results, reflecting on both the general problem statement and the Zusterflat case specifically.

5. Answers to the proposed research questions, founded on both the literature research and case study outcomes.

6. Recommendations on the model's applicability and potential added value to future decision making processes (related to residential property design).

III | Research organisation

Provisional table of contents of the final report

Research fragment	Chapter
Theory	2. Research relevance; 7. Defining the variables
Problem	3. Research objectives
Hypothesis	4. Research questions
Axiom	5. Research design and methodology
Design	6. Model specification
Calibration	8. Model prototype; 11. Definitive model *(to be added in the upcoming months)*
Outcome(s)	9. Case study; 10. Expected results; 12. Findings *(to be added in the upcoming months)*
Validation	13. Conclusions *(to be added in the upcoming months)*
Reflection on (adapted) theory	14. Reflection and recommendations *(to be added in the upcoming months)*

Table 9. Provisional table of contents of the final report

Scientific domains and graduation mentors

The proposed research involves the scientific domains of (1) housing studies and (2) preference based modelling, which is applied and taught within the 'Smart campus tools' graduation lab.

First mentor: Ruud Binnekamp, one of the teachers of the Smart campus tools lab, will act as first mentor throughout the entire graduation process. His knowledge on operations research methods matches the proposed research methodology.

Second mentor: Gerard van Bortel, teacher at the housing studies department, will act as second mentor. His knowledge matches the user preference aspect that the research entails.

Research schedule

In order to achieve the academic and personal objectives that have been set for this graduation course, a summarised and a detailed research schedule have been prepared.

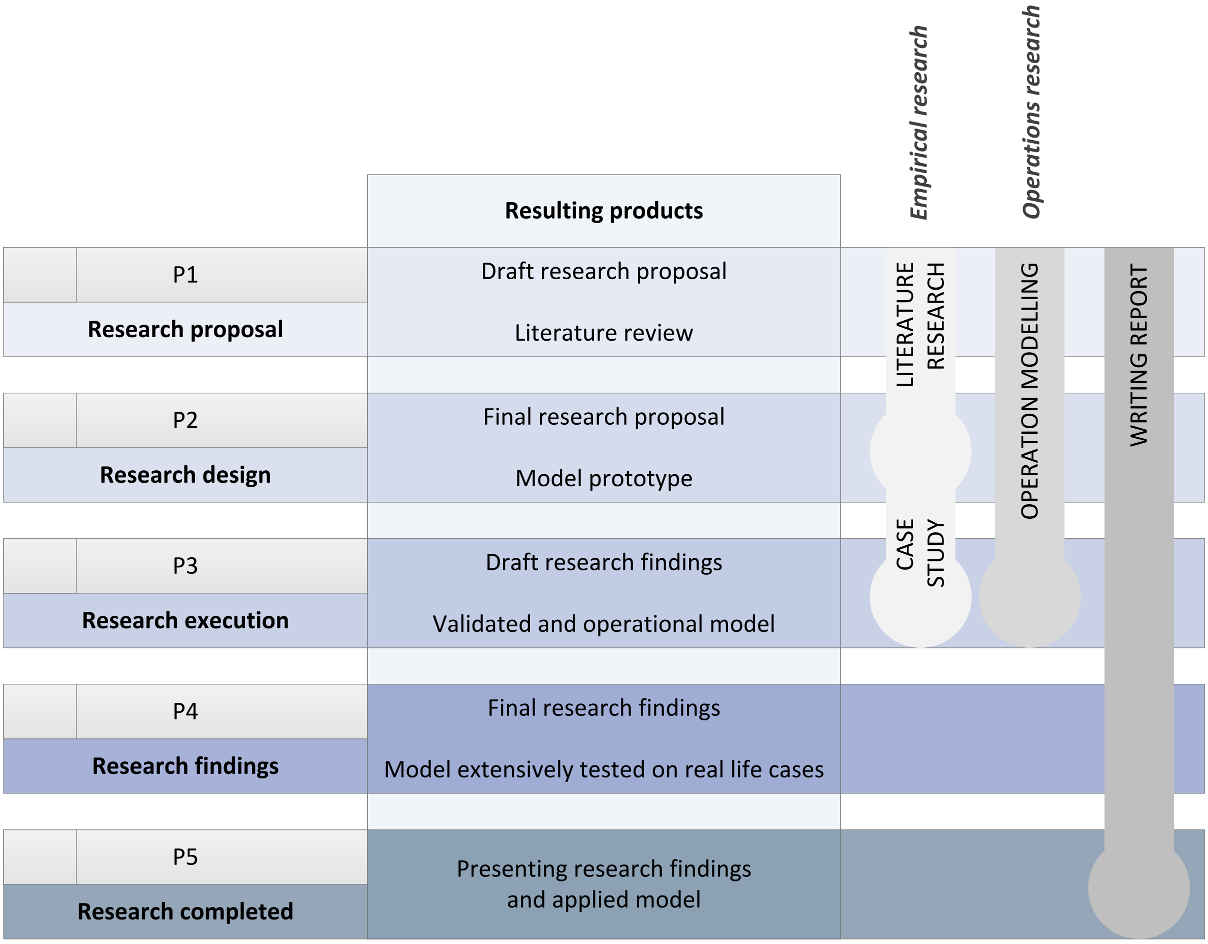


Figure 21. Summarised research schedule (own ill.)

Week	Dates	Activities
WEEK 1.9	Oct. 26 - 30	Thursday Oct. 29 | **P1 presentation**
WEEK 1.10	Nov. 2 - 6	Thursday Nov. 5 | Exam *Real Estate Valuation* Friday Nov. 6 | Deadline QRM2
WEEK 2.1	Nov. 9 - 13	Working on model Collecting data from literature
WEEK 2.2	Nov. 16 - 20	Working on model Collecting data from literature
WEEK 2.3	Nov. 23 - 27	Working on model Collecting data from literature
WEEK 2.4	Nov. 30 - Dec. 4	Working on model Collecting data from literature
WEEK 2.5	Dec. 7 - 11	Writing P2 report
WEEK 2.6	Dec. 14 - 18	Writing P2 report
Christmas break	Dec. 21 - 25	
Christmas break	Dec. 28 - Jan. 1	
WEEK 2.7	Jan. 4 - 8	**Friday Jan. 7 | P2 deadline** Preparing P2 presentation
WEEK 2.8	Jan. 11 - 15	**Friday Jan. 14 | P2 presentation** Studying for exams
WEEK 2.9	Jan. 18 - 22	Studying for exams Jan. 19 & 21 | Exams

LITERATURE RESEARCH

OPERATION MODELLING

WRITING REPORT

Week	Dates	Activities
Spring break	Feb. 1 - 5	*Skiing*
WEEK 3.1	Feb. 8 - 12	**Interviewing practitioners & coding** Adjusting model to case data
WEEK 3.2	Feb. 15 - 19	**Interviewing practitioners & coding** Adjusting model to case data
WEEK 3.3	Feb. 22 - 26	**Interviewing practitioners & coding** Adjusting model to case data
WEEK 3.4	Feb. 29 - Mar. 4	Running model / performing scenario analysis
WEEK 3.5	Mar. 7 - 11	Working on model Additional interviewing (if necessary)
WEEK 3.6	Mar. 14 - 18	Running model / performing scenario analysis
WEEK 3.7	Mar. 21 - 25	Writing P3 report *Good Friday*
WEEK 3.8	Mar. 28 - Apr. 1	*Easter* Writing P3 report *Studying for exam re-sits?*
WEEK 3.9	Apr. 4 - 8	**P3 deadline** Preparing P3 presentation / *Exam re-sits?*
WEEK 3.10	Apr. 11 - 15	P3 presentation *Exam re-sits?*
WEEK 4.1	Apr. 18 - 22	Finalizing research results
WEEK 4.2	Apr. 25 - 29	Finalizing research results

CASE STUDY

OPERATION MODELLING

WRITING REPORT

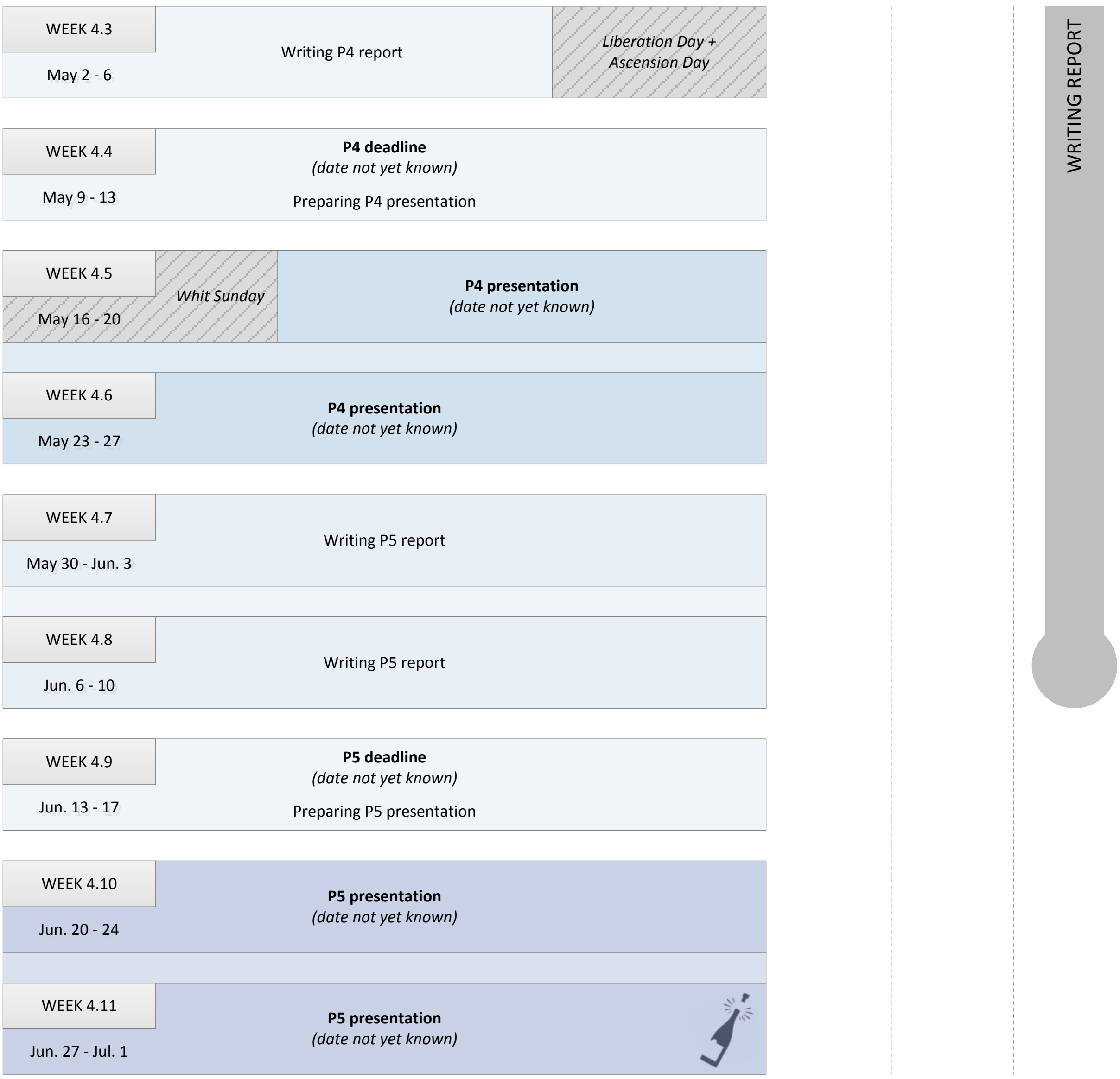


Figure 22. Detailed research schedule (own ill.)

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Appendix 1 | Model prototype

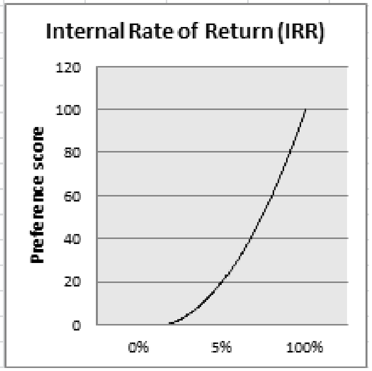
Appendix 1a | Developer preference curve and financial input

Input		Value	Unit	t = (months)
Interest on debt			%	
Discount rate		5,50%	%	
Land acquisition costs		€ 500,00	€	0
Expected sale price per m² GFA		€ 2.700,00	€	5
Construction period in years		5	#	
Desired minimum construction quality	*Drop-down*	Medium construction quality		
Expected construction costs per m² GFA (incl. VAT)		€ *1.800,00*	€	0
Additional costs (consultant costs, permit fees etc.)		€ 150.000,00	€	0

Preference criteria	Unit	X_1	Y_1	X_2	Y_2	X_0	Y_0
Internal Rate of Return (IRR)	%	0%	0	*5%*	*20*	100%	100

Output	Value	Unit	t = (months)
Net Present Value (NPV)	€ *70.894,30*	€	

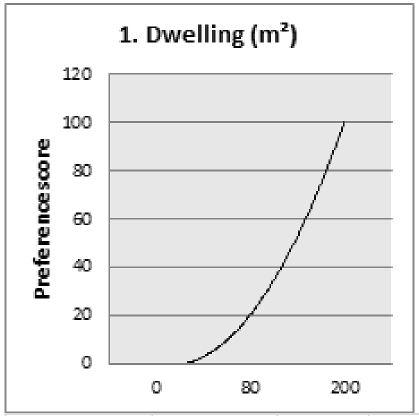
Database		Value	Unit	t = (months)
Manual input construction costs	*Optional*	Input required	€ per m² GFA	
High construction quality		€ 2.300,00	€ per m² GFA	
Medium construction quality		€ 1.800,00	€ per m² GFA	
Basic construction quality		€ 1.400,00	€ per m² GFA	
Construction period (halfway)		2		

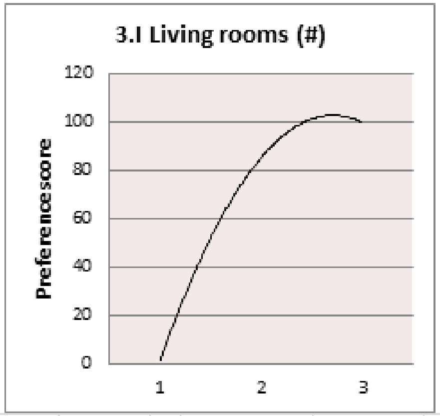


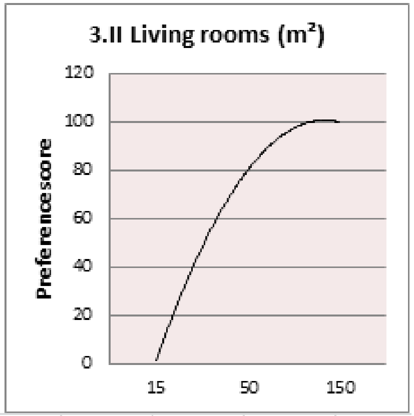
Appendix 1b | Automated NPV calculations

Internal Rate of Return	10,72%										
t (years)	0	1	2	3	4	5	6	7	8	9	10
Costs											
Land acquisition	€ 500,00	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Construction	€ 72.000,00	€ -	€ 72.000,00	€ -	€ -	€ 72.000,00	€ -	€ -	€ -	€ -	€ -
Additional	€ 150.000,00	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Total costs	€ 222.500,00	€ -	€ 72.000,00	€ -	€ -	€ 72.000,00	€ -	€ -	€ -	€ -	€ -
Revenues											
Sale	€ -	€ -	€ -	€ -	€ -	€ 540.000,00	€ -	€ -	€ -	€ -	€ -
Total revenues	€ -	€ -	€ -	€ -	€ -	€ 540.000,00	€ -	€ -	€ -	€ -	€ -
Cashflow	€ -222.500,00	€ -	€ -72.000,00	€ -	€ -	€ 468.000,00	€ -	€ -	€ -	€ -	€ -
Present value	€ -222.500,00	€ -	€ -64.688,57	€ -	€ -	€ 358.082,88	€ -	€ -	€ -	€ -	€ -
NPV	€ 70.894,30										

Appendix 1c | Consumer preference curves







Criteria	Unit	Weight	X_1	Y_1	X_2	Y_2	X_0	Y_0	X_p	Y_p
1. Dwelling	Total m² GFA	100%/N_C	0	0	80	20	200	100	200,00	100,00
2. Floors	#	100%/N_C	1	0	2	70	3	100	2,00	70,00
3. Living rooms	#	100%/N_C	1	0	2	85	3	100	1,00	0,00
	Total m² GFA	100%/N_C	15	0	50	80	150	100	43,04	67,11
4. Kitchens	#	100%/N_C	1	0	1,5	90	2	100	1,81	105,62
	Total m² GFA	100%/N_C	8	0	15	75	40	100	25,92	132,59
5. Bedrooms	#	100%/N_C	1	0	3	60	5	100	2,13	36,44

Appendix 1d | Design variables

Variable name	Description	Unit	Value constraints				
S_DWELLING	Size of each dwelling	m2 (GFA)	0	<=	*200,0*	=<=	200
N_FLOORS	Number of floors	#	1	=<	*Value*	=<	3
S_FLOORS	Size of each floor	m2 (GFA)	20	=<	*Value*	=<	200
H_GF_CEILING	Height of ceiling on ground floor	m	2,70	=<	*Value*	=<	3,20
H_UF_CEILING	Height of ceiling on upper floors	m	2,70	=<	*Value*	=<	2,70
N_LIVINGROOMS	Number of living rooms	#	1	<=	*2,9*	<=	3
N_KITCHENS	Number of kitchens	#	1	<=	*1,8*	<=	2
N_P_BEDROOMS	Number of primary bedrooms	#	1	<=	*2,1*	<=	5
N_S_BEDROOMS	Number of secondary bedrooms	#	0	<=	*4,6*	<=	5
N_P_BATHROOMS	Number of primary bathrooms	#	1	<=	*3,0*	=<=	3
N_S_BATHROOMS	Number of secondary bathrooms	#	0	<=	*3,0*	=<=	3
N_P_OUTDOORSPACES	Number of primary outdoor spaces (balconies/gardens)	#	1	<=	*3,6*	<=	4
N_S_OUTDOORSPACES	Number of secondary outdoor spaces (balconies/gardens)	#	0	<=	*4,0*	=<=	4
N_I_STORAGESPACES	Number of indoor storage spaces	#	1	<=	*3,6*	<=	4
N_O_STORAGESPACES	Number of outdoor storage spaces	#	0	<=	*2,0*	=<=	2
N_CORRIDORS	Number of corridors	#	Value	=<	*Value*	=<	Value
S_LIVINGROOMS	Size of living rooms	m2 (GFA)	15	=<=	*15,00*	<=	50
S_KITCHENS	Size of kitchens	m2 (GFA)	8	<=	14,30	<=	20
S_P_BEDROOMS	Size of primary bedrooms	m2 (GFA)	10	=<=	*10,00*	<=	20
S_S_BEDROOMS	Size of secondary bedrooms	m2 (GFA)	6	=<=	*6,00*	<=	12
S_P_BATHROOMS	Size of primary bathrooms	m2 (GFA)	6	<=	*6,27*	<=	10
S_S_BATHROOMS	Size of secondary bathrooms	m2 (GFA)	3	<=	*3,74*	<=	6
S_P_OUTDOORSPACES	Size of primary outdoor spaces (balconies/gardens)	m2 (GFA)	4	=<=	*4,00*	<=	100
S_S_OUTDOORSPACES	Size of secondary outdoor spaces (balconies/gardens)	m2 (GFA)	1	<=	*2,70*	<=	4
S_I_STORAGESPACES	Size of indoor storage spaces	m2 (GFA)	1	<=	*3,87*	<=	8
S_O_STORAGESPACES	Size of outdoor storage spaces	m2 (GFA)	2	<=	*6,73*	<=	15

W_LIVINGROOMS	Width of living rooms	m	3	=<=	*3,00*	<=	15,00
L_LIVINGROOMS	Length of living rooms	m	3	<=	*5,00*	<=	9,00
W_KITCHENS	Width of kitchens	m	2	<=	*2,18*	<=	19,65
L_KITCHENS	Length of kitchens	m	2	<=	*6,55*	=<=	6,55
W_P_BEDROOMS	Width of primary bedrooms	m	2	=<=	*2,00*	<=	15,00
L_P_BEDROOMS	Length of primary bedrooms	m	2	<=	*5,00*	<=	6,00
W_S_BEDROOMS	Width of secondary bedrooms	m	2	<=	*2,27*	<=	7,92
L_S_BEDROOMS	Length of secondary bedrooms	m	2	<=	*2,64*	<=	6,82
W_P_BATHROOMS	Width of primary bathrooms	m	2	<=	*2,29*	<=	8,21
L_P_BATHROOMS	Length of primary bathrooms	m	2	<=	*2,74*	<=	6,87
W_S_BATHROOMS	Width of secondary bathrooms	m	1	<=	*2,39*	<=	4,70
L_S_BATHROOMS	Length of secondary bathrooms	m	1	<=	*1,57*	<=	7,17
W_P_OUTDOORSPACES	Width of primary outdoor spaces (balconies/gardens)	m	1	<=	*3,46*	=<=	3,46
L_P_OUTDOORSPACES	Length of primary outdoor spaces (balconies/gardens)	m	1	<=	*1,15*	<=	10,39
W_S_OUTDOORSPACES	Width of secondary outdoor spaces (balconies/gardens)	m	1	<=	*1,64*	<=	4,93
L_S_OUTDOORSPACES	Length of secondary outdoor spaces (balconies/gardens)	m	1	<=	*1,64*	<=	4,93
W_I_STORAGESPACES	Width of indoor storage spaces	m	1	<=	*1,97*	<=	5,90
L_I_STORAGESPACES	Length of indoor storage spaces	m	1	<=	*1,97*	<=	5,90
W_O_STORAGESPACES	Width of outdoor storage spaces	m	1	<=	*1,50*	<=	13,48
L_O_STORAGESPACES	Length of outdoor storage spaces	m	1	<=	*4,49*	=<=	4,49
W_CORRIDORS	Width of corridors	m	1	=<	*Value*	=<	999
L_CORRIDORS	Length of corridors	m	1	=<	*Value*	=<	999

Appendix 1e | Design alternatives and consumer preference output

Criteria:		1	2	3		4		5				6				7		
Sub-criteria:				I (#)	II (m^2)	I (#)	II (m^2)	a.I (#)	a.II (m^2)	b.I (#)	b.II (m^2)	a.I (#)	a.II (m^2)	b.I (#)	b.II (m^2)	a.I (#)	a.II (m^2)	b.I (#)
Alternative	**Data type**	**Design values and automatically computed resulting consumer preference scores**																
A_1	**Values**	$V_{1,1}$	$V_{1,2}$	$V_{1,\ldots}$														
	Scores	$S_{1,1}$	$S_{1,2}$	$S_{1,\ldots}$														
$A_{\ldots}$	**Values**	$V_{\ldots,1}$	$V_{\ldots,2}$	$V_{\ldots,\ldots}$														
	Scores	$S_{\ldots,1}$	$S_{\ldots,2}$	$S_{\ldots,\ldots}$														
A_m	**Values**	$V_{m,1}$	$V_{m,2}$	$V_{m,\ldots}$														
	Scores	$S_{m,1}$	$S_{m,2}$	$S_{m,\ldots}$														
Design 1	**Values**	200	*2*	*1*	*43*	*2*	*26*	*2*	*21*	*5*	*27*	*3*	*19*	*3*	*11*	*4*	*14*	*4*
	Scores	100	70	0	67	106	133	36	11	94	55	100	76	100	90	98	16	100
Design 2	**Values**	90	*1*	*1*	*35*	*2*	*18*	*2*	*28*	*1*	*10*	*2*	*12*	*0*	*0*	*2*	*30*	*0*
	Scores	24	0	0	50	100	98	33	18	27	22	40	42	0	0	55	40	0
Design 3	**Values**	110	*3*	*2*	*20*	*2*	*10*	*3*	*80*	*0*	*0*	*1*	*15*	*2*	*10*	*1*	*30*	*0*
	Scores	34	100	85	14	100	24	60	75	0	0	0	58	70	85	0	40	0

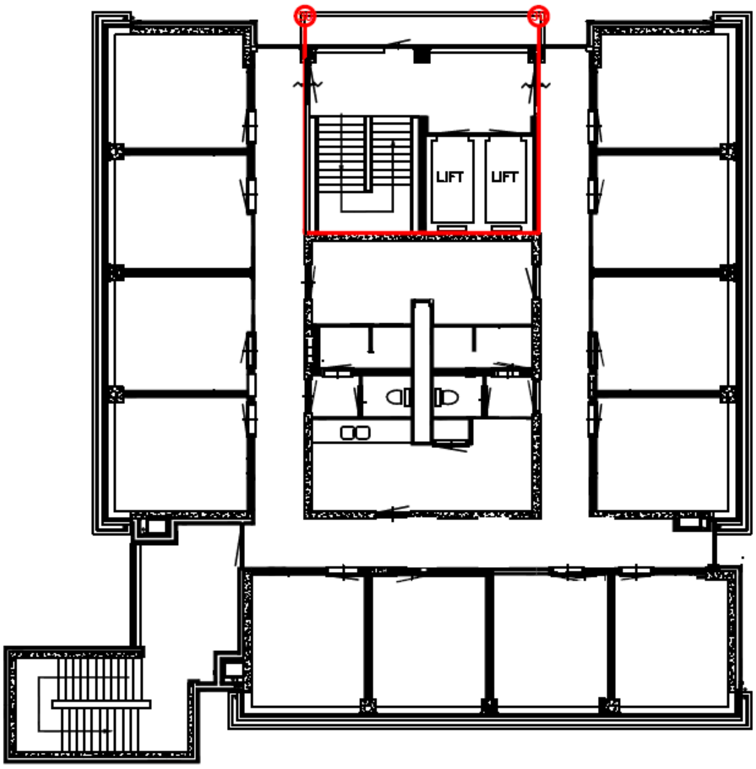
Appendix 1f | Alternatives and consumer preference output

Stakeholder:	Developer	Consumer	Consumer
Power:	60%	40%	40%

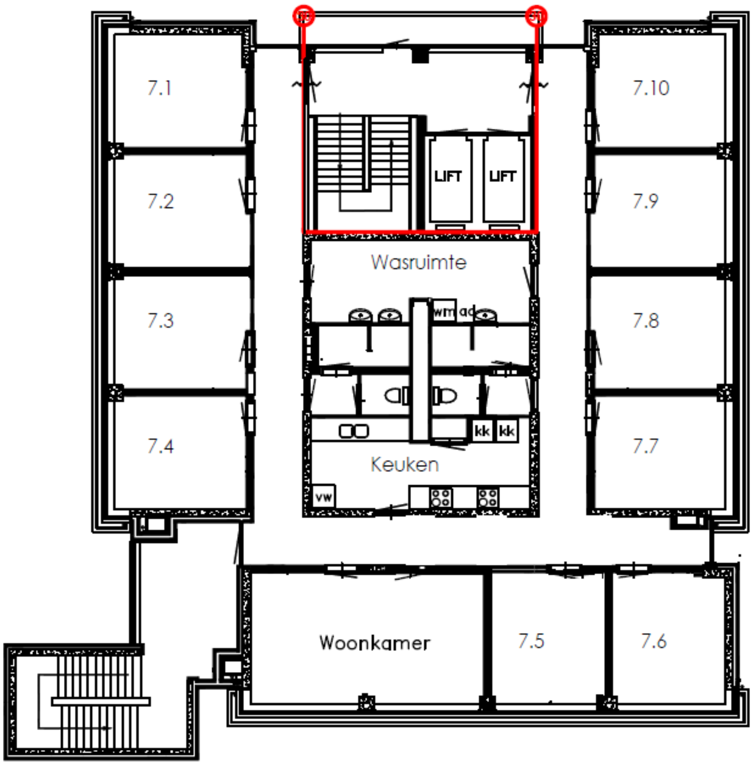
Criteria:	1	2	3		4		5				6			
Weights:	12,50%	12,50%	12,50%		12,50%		12,50%				12,50%			
Sub-criteria:			I (#)	II (m²)	I (#)	II (m²)	a.I (#)	a.II (m²)	b.I (#)	b.II (m²)	a.I (#)	a.II (m²)	b.I (#)	b.II (m²)
Sub-weights:			50%	50%	50%	50%	25%	25%	25%	25%	25%	25%	25%	25%
Effective sub-weights:			6,25%	6,25%	6,25%	6,25%	3,13%	3,13%	3,13%	3,13%	3,13%	3,13%	3,13%	3,13%

Aggregated preference rating	Developer preference rating	Developer's IRR	Developer's NPV	Alternative	Consumer preference rating	Consumer preference scores													
56	41	10,72%	€ 70.894	*Design 1*	79	100	70	0	67	106	133	36	11	94	55	100	76	100	90
			-€ 15.500.000	*Design 2*	37	24	0	0	50	100	98	33	18	27	22	40	42	0	0
			€ 30.000.000	*Design 3*	52	34	100	85	14	100	24	60	75	0	0	0	58	70	85

Appendix 2 | Zusterflat floorplan (7th floor)



Floorplan 7th floor before transformation



Floorplan 7th floor after transformation

Appendix 3 | Detailed interview schedule

Name of interviewer: ………………………………………………………………………….

Name of interviewee: ………………………………………………………………………….

Date: ………………………………………………………………………….

Location: ………………………………………………………………………….

Permission for audio recording: …………………………………………………………………………. (signature)

Personal information

A During which period were you active as a board member for SHS Delft?

From …/20… (month/year)

Until …/20… (month/year)

B What positions did you hold during your board membership? *(check all that apply)*

President ◯

Secretary ◯

Treasurer ◯

Other *(please specify position)* ◯

………………………………………………………………………….

C Are you an international or Dutch student?

Dutch ◯

International *(please specify nationality)* ◯

………………………………………………………………………….

D During your years as a student, have you lived with family, roommates or alone? *(check all that apply)*

… (#) Family members ◯

… (#) Roommates ◯

Alone ◯

Other (please specify) ◯

……………………………………………………………………….

E What is your academic background? *(bachelor's & master's education and electives, if applicable)*

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F What was your academic background at the time of your board membership? *(bachelor's & master's education and electives, if applicable)*

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Type of accommodation (shared/independent housing)

G During your period as active board member, were there any adjustments proposed or made to the type of accommodation (shared/independent housing) in the Zusterflat building? If so, please describe these (proposed) changes as accurately as possible.

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H Which stakeholder in the decision making process first proposed these changes and what were their arguments for implementing them?

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I Were there any counterarguments against implementation of these (proposed) changes? If so, please describe them.

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Tenant target groups

J During your period as active board member, were there any adjustments proposed or made to the tenant target groups of the Zusterflat building? If so, please describe these (proposed) changes as accurately as possible.

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K Which stakeholder in the decision making process first proposed these changes and what were their arguments for implementing them?

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L Were there any counterarguments against implementation of these (proposed) changes? If so, please describe them.

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Floor plan design

M During your period as active board member, were there any adjustments proposed or made to the floor plan design for the Zusterflat building? If so, please describe these (proposed) changes as accurately as possible.

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N Which stakeholder in the decision making process first proposed these changes and what were their arguments for implementing them?

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O Were there any counterarguments against implementation of these (proposed) changes? If so, please describe them.

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- End of interview -

Number:	Concept:	Description:
01	Financial profitability	Costs, Revenues, Financial risk, Interest rates, etc.
02	Tenant target groups	Different types of target groups (e.g. international students, Dutch students).
03	Consumer preferences	Preference for accommodation type (number of roommates), floor plan design or other housing configuration related subjects.

Table 1. Interview coding concepts