THE FINANCIAL IMPLICATIONS OF BUILDING DESIGN

A developer and consumer preference-based residential design system

Graduation Thesis

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Abstract

As of yet, there are virtually no practical tools available for incorporating both developer and consumer preferences within a floorplan design. This study aims to deliver a proof of concept for such preference-based design systems, and their application within the commercial property development process. A research model is presented that is able to generate residential floorplan design alternatives, which are optimized for both developer and consumer preferences. At the foundation of this model lies the concept of Preference Function Modelling. With the use of a case study, the research model is shown to reflect reality to an accurate degree. The results indicate that the research model has generated floorplan design alternatives that are associated with a higher aggregated preference score than the actually realized floorplans for the case study. As this was the intended purpose of the research model, a proof of concept has been delivered. In conclusion, further exploration of the potential utility and applications of similar preference-based design systems is encouraged by the outcomes of this study.

Keywords: Preference-Based Design System, Preference Function Modelling, Operations Research, Multi-Actor Multi-Criteria Analysis, Design Alternatives, Optimization, *What'sBest!*

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.

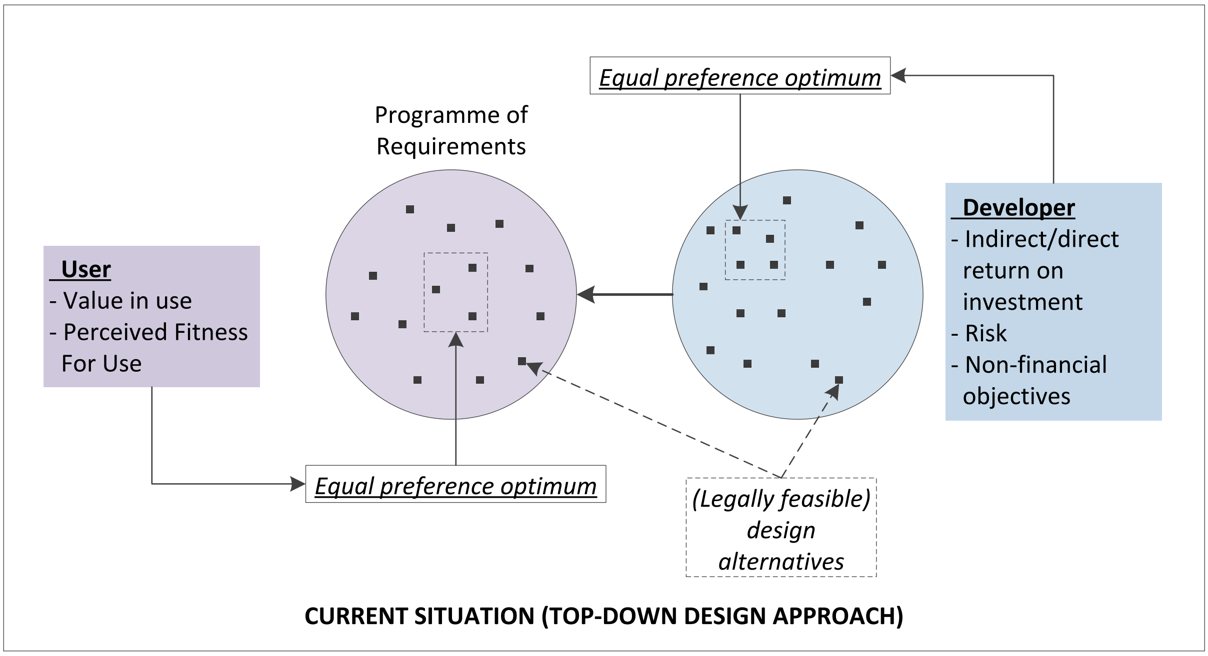


Figure 1. A standard top-down design approach

Research questions

This study aims to answer the following main research question:

Does the application of a preference-based design system lead to residential design alternatives that are more in line with developer and consumer preferences, over design processes without the application of a preference-based design system?

To answer this question, such a preference-based design system first needs to be devised and tested. Secondly, the outcomes of this system need to be compared to a design process without the application of such a design system.

In order to do so, the following sub-questions will be answered:

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 has been designed to ensure an empirically validated definitive model. Also, after final calibration, the definitive model will be used to answer the main research question.

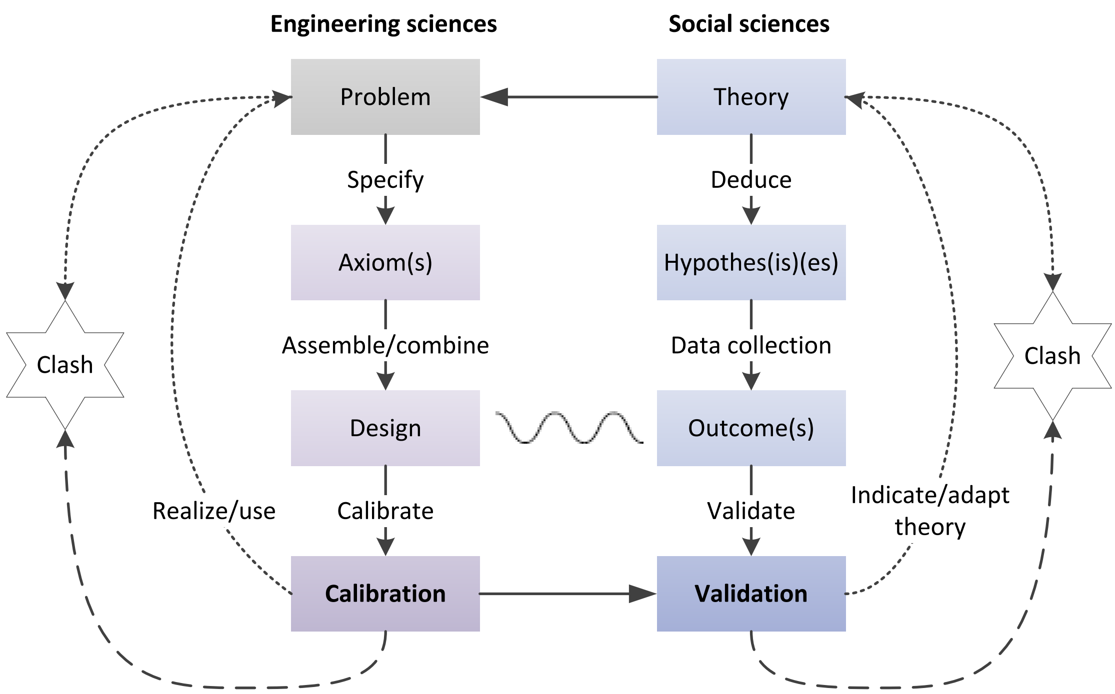


Figure 2. Proposed combined research approach (own ill. based on Barendse et al., 2012)

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 selected for this purpose.

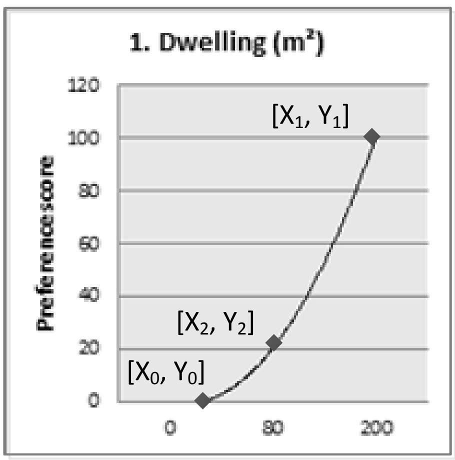


Figure 3. Example of a Lagrange curve

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.

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

Figure 4. The method applied to calculate individual preference ratings per design alternative (own ill. based on Borst, 2014)

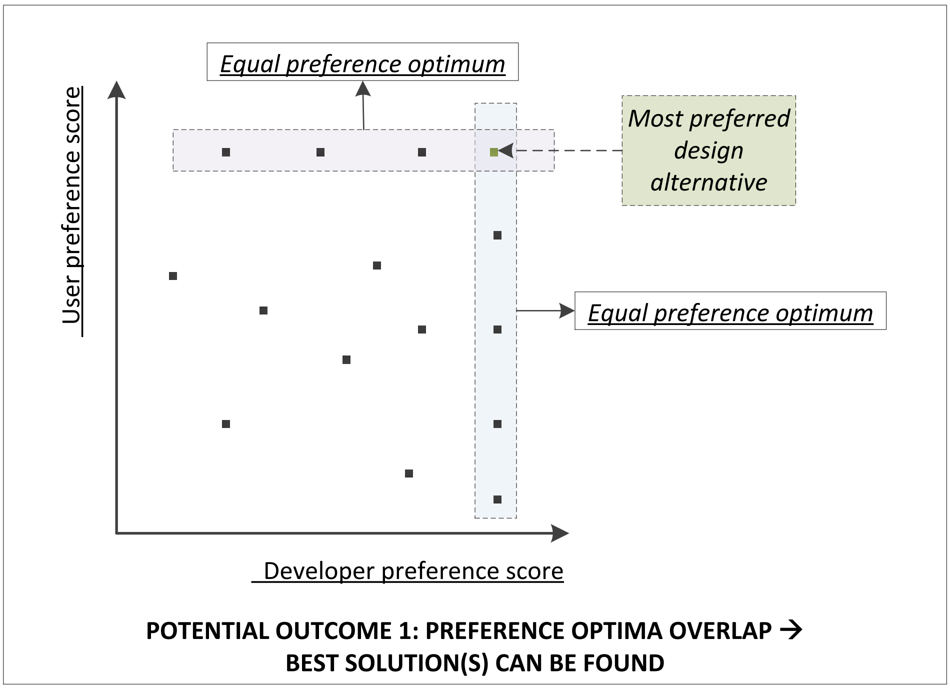


Figure 5. Visualisation of method to select the most preferred design alternative

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	Case study data
Construction costs (incl. unforeseen expenses)	Input from developer	Based on contractor quotations
Additional costs (permit fees, consultants, etc.)	Input from developer	Based on contractor quotations
Lease costs	Input from developer	Based on lease contract
Expected rent revenue	Automated input	Results from rent price point system
Inflation rate	Input from developer	Based on expected average annual inflation rate
Rent increase	Input from developer	Based on expected average annual rent increase
Internal Rate of Return (IRR)	Automated output	Resulting developer's annual profit

Table 1. Financial variables

Design variable	Most preferred (Apollo, 2015)	Most preferred (Wäckerlin, 2015)
Independent or shared housing	Independent	-
Number of housemates (shared housing)	Between 3 and 5	Between 2 and 12; approximately 7
House size (independent housing)	20 - 24 m² GFA	-
Size of bedroom (shared housing)	14 - 15 m² GFA and 20 - 24 m² GFA	Diminishing preference curve after 17 m² GFA
Rent price (independent housing)	> €500	-
Rent price (shared housing)	Between €350 and €399	Preference curve approaches linear function; 'the less the better'

Table 2. Selected design variables

The relations between all selected variables is visualised in figure 6. In this figure it is shown how combinations of 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.

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 for the project. Based on figure 7, four possible strategies were devised for the case study. The research model will be applied to determine which strategy would benefit both the developer and consumers the most (see figure 8).

As input for the model, preference curves have been determined for both the consumers of the case study (the potential target groups) and the developer (based on financial profitability).

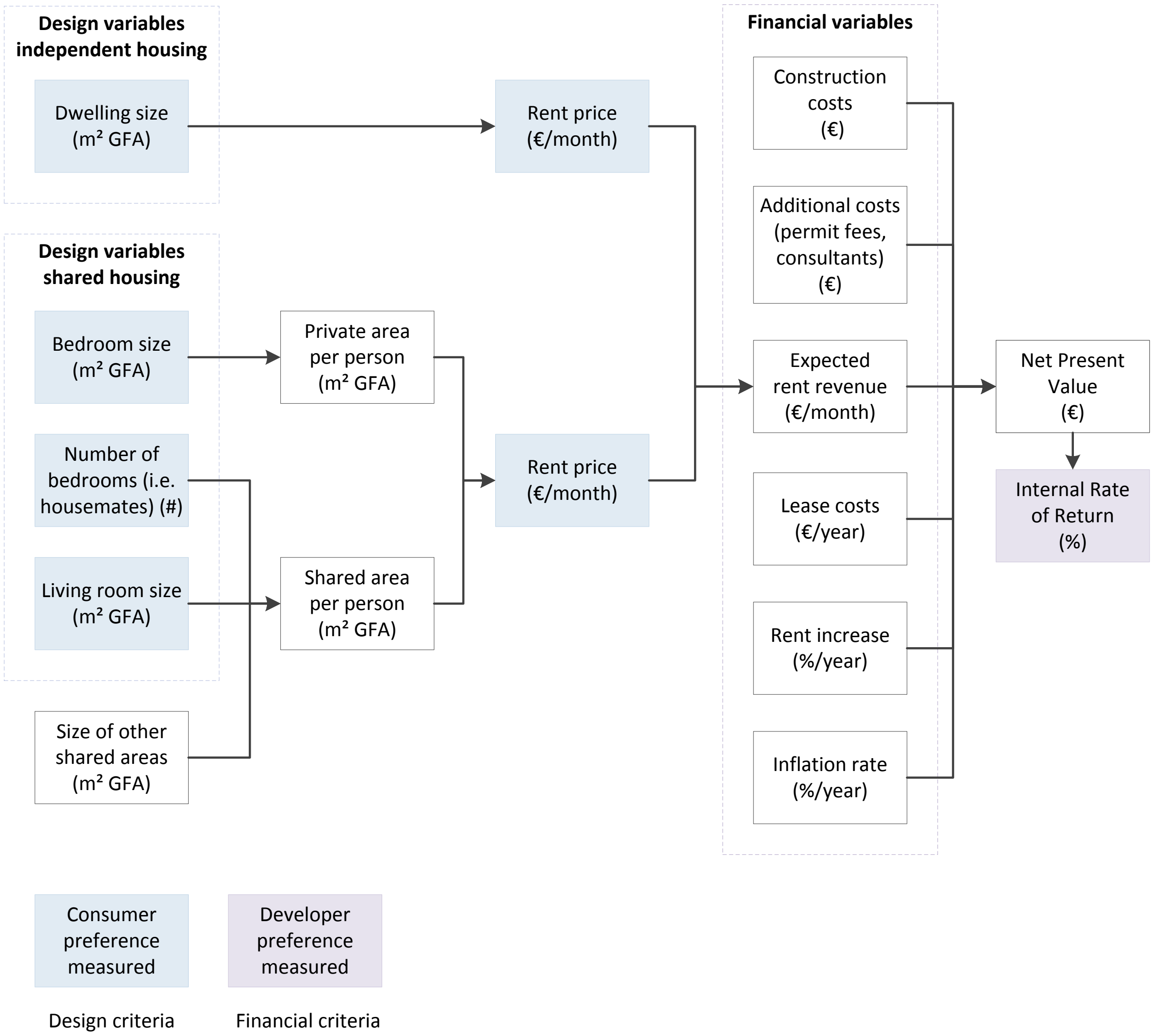


Figure 6. Conceptualisation of the relations between variables included in the research model

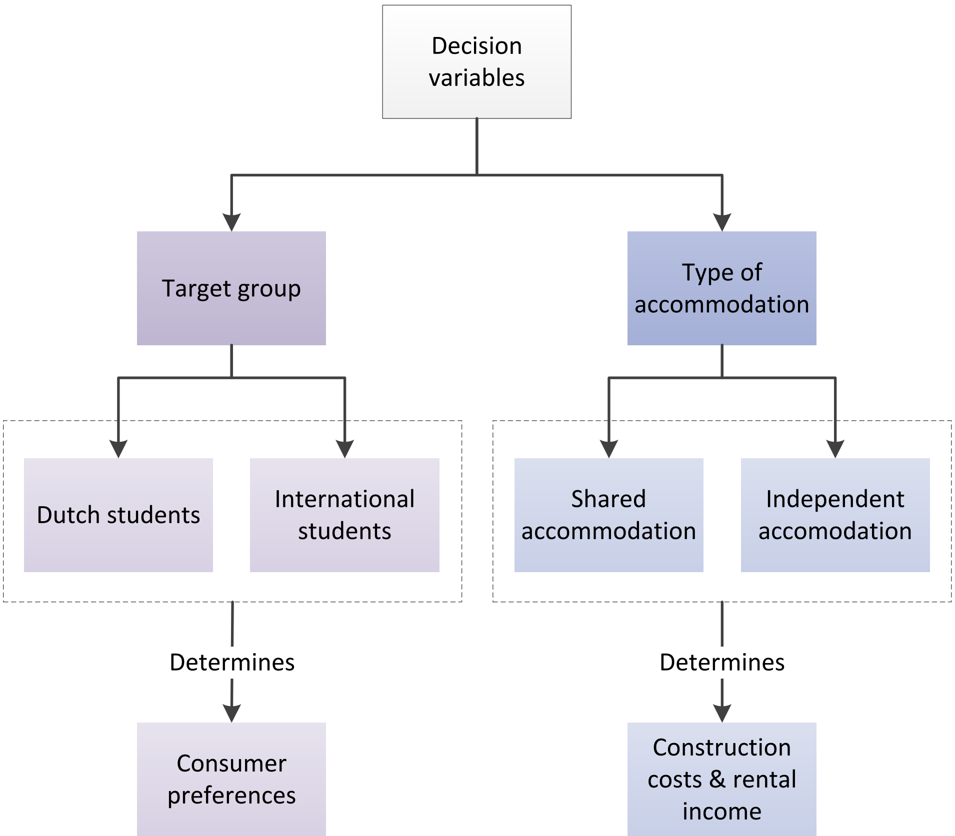


Figure 7. Initial decision variables the developer was faced with in the Zusterflat case

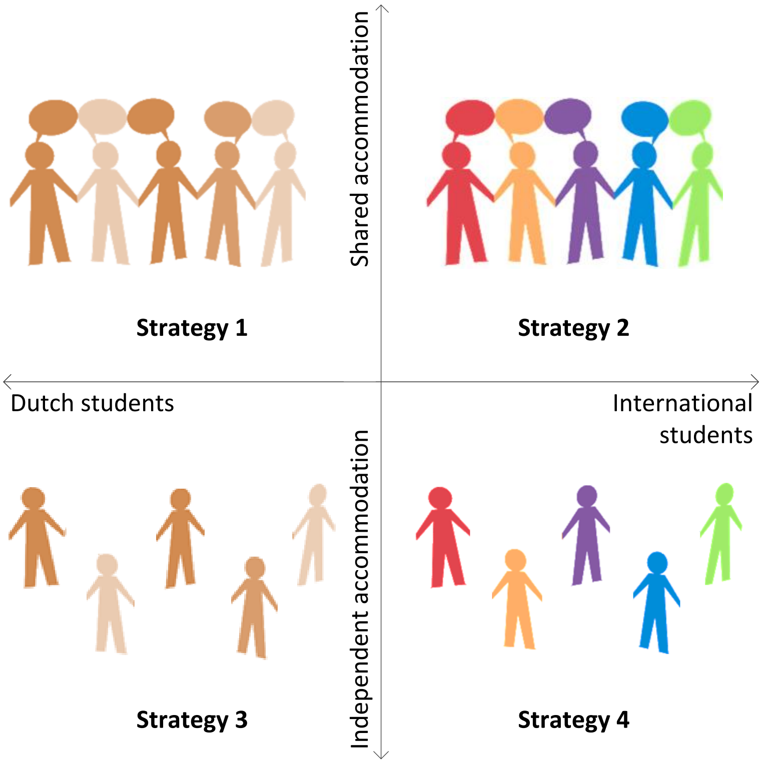


Figure 8. Strategies based on the two main decision variables for the Zusterflat case

Results

Of the possible strategies (see figure 8), independent housing was not deemed financially feasible. Also, the group of international students living independently was considered too small and (on average) had too little financial means to form a main strategy. Strategies 3 and 4 were therefore rejected.

Regarding the shared housing strategies; it was concluded that that the research model had generated multiple design alternatives that could achieve higher aggregate (group) preference scores than the actually realized design alternatives (see table 3). Whether this would be the case depends on the selected consumer and developer decision maker weights (see figure 9). Configurations 1 and 2 of figure 9 were actually realized by the developer in the case study project. Configurations 3, 4 and 5 have been designed by the model.

Design configuration	**Related alternatives**	**Group preference score margin**	**Ranking** (based on group pref. score margin)
1	Realized for Dutch students (1)	25 - 33	5
2	Realized for international students (2)	29 - 34	4
3	Optimized for developer (3) and group total (4, 5 & 6) preferences	49 - 75	1
4	Optimized for consumer total (7) preferences	24 - 47	3
5	Optimized for Dutch students (8) and international students (9) preferences	26 - 49	2

Table 3. Ranking of shared housing design configurations

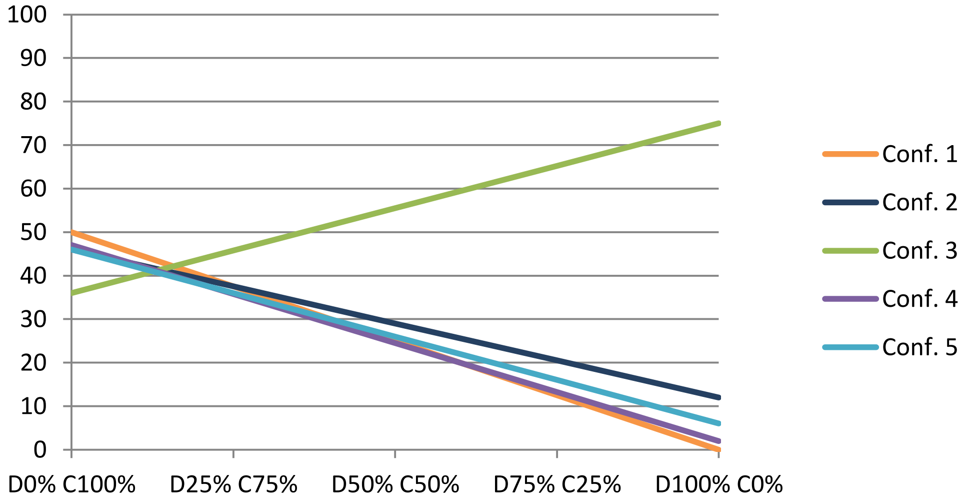


Figure 9. Aggregated preference scores (y-axis) depending on decision maker weight division (x-axis)

Based on the results generated by the model, it is determined that strategy 2 (shared housing for international students) could potentially deliver a higher aggregate preference score than the realized strategy. This leads to the conclusion that a proof of concept for preference-based design systems has been delivered, based on the research model, within the context of the selected case study. Additional research would be necessary to determine the more general potential utility and applications of preference-based design systems.

Acknowledgements

I would like to thank my supervisors, Ruud Binnekamp and Gerard van Bortel, for all their support and efforts the past year. I would like to thank them specifically for pushing me towards delivering the best possible results. I have learned a lot from the critiques you have offered me and enjoyed the motivating discussions throughout my graduation process. Additionally, I want to state my appreciation for providing me with the opportunity to perform research on a topic of my personal choice.

I also want to thank Nico Nieboer, for the insights and reflection he has provided as an external examiner.

Lastly, I want to thank Leo for supporting me during the times when I doubted myself, for the occasional lessons in mathematics and his overall feedback.

Content

PART I INTRODUCTION

This is the final version (P5) of the graduation thesis to be handed in for the master track Management in the Built Environment at Delft University of Technology. The aim of this graduation thesis is to add knowledge to the existing body of literature, within the theoretical field of the chosen research topic, as well as to provide insights for future research. This report and the presentation thereof, which will take place on June 28th 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

2.1 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)

So, it is undesirable for both developers and consumers themselves if consumers do not have a direct influence on the configuration of the future housing stock. Real estate developers regularly perform market research, but appear to easily disregard many possible design alternatives even though they might prove financially feasible. Because the design process needs to be quick, or because another design alternative already achieves the desired financial results. As end-consumers are often kept out of the decision making process during the design phase, it is difficult to ensure that their interests are sufficiently represented at this point. Simultaneously developers lack a clear overview of all possible design alternatives, and which might be best adjusted to the actual market demand. Taking consumer preferences into consideration may not necessarily be complicated or pose a burden, if the right method is developed. As such, resources could be allocated more effectively within the (capital-intensive) residential property industry. Ideally, this would lead to an increased profit-margin for developers while concurrently increasing the consumers' satisfaction.

2.2 Scientific relevance

Thus, to a certain extent, developers need consumer preference focussed buildings - which can be achieved through adjusting 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 design system (e.g. Arkesteijn et al., 2015; Van Loon, 2009). Based on the results achieved by these examples, it is assumed that such systems still hold a lot of undiscovered potential and could possibly be of significant value to the academic field of real estate. However, 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 and practical potential. With regard to preference based design as a technique to determine the optimal floorplan composition 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. This study aims to provide such an approach.

2.3 Research demarcation

A clear research 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, there is more socially founded motivation to include consumer preferences in the residential design process. Plus, 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 results more socially relevant. A specific emphasis will be put on a case study related to student housing, as the student housing market is expected to continue to grow significantly the upcoming years (Apollo, 2015). Also, the developer involved with the case study stated that defining consumer preferences is crucial to the financial feasibility of student housing projects, due to the relatively low average spendable income of students (L. Roose, personal communication, April 26, 2016).

2.4 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 the realized designs with market demand. The same concept could be applied by non-profit project developers, such as housing corporations. While generating profit is usually not their primary aim, 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 is 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.). 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 variables 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 better facilitate 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, an architect is commissioned to deliver a design which takes user preferences into consideration. The design alternatives represented in figure 2 are any design alternatives that theoretically fit the specific developer's and user's requirements.

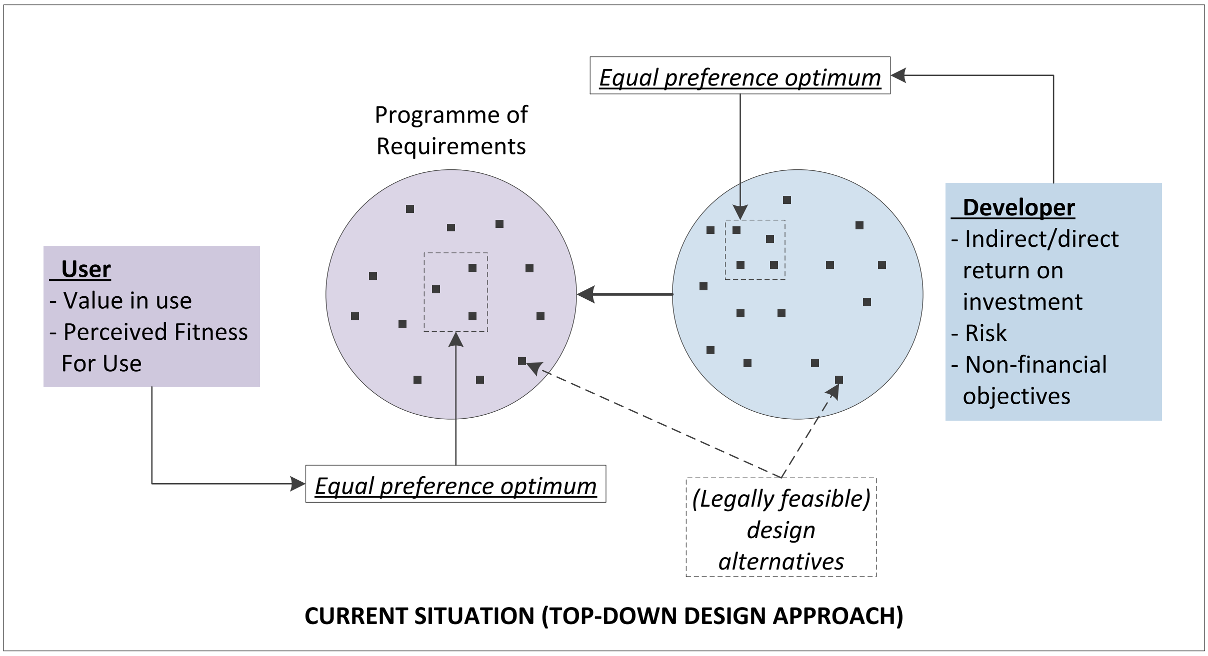


Figure 2. A standard top-down design approach

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.

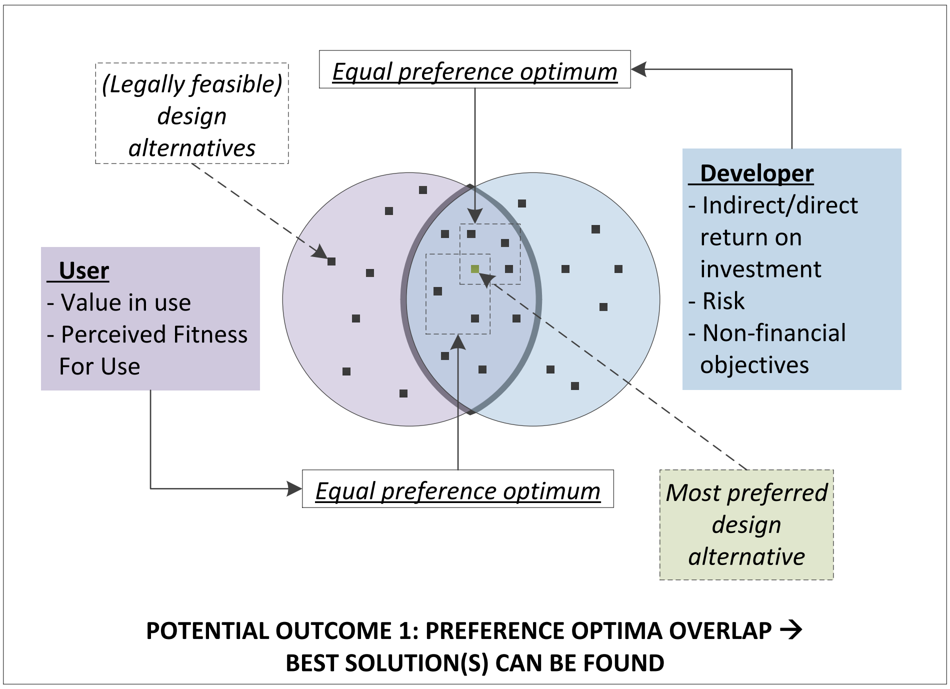


Figure 3a. Potential outcome of proposed mathematical modelling design approach

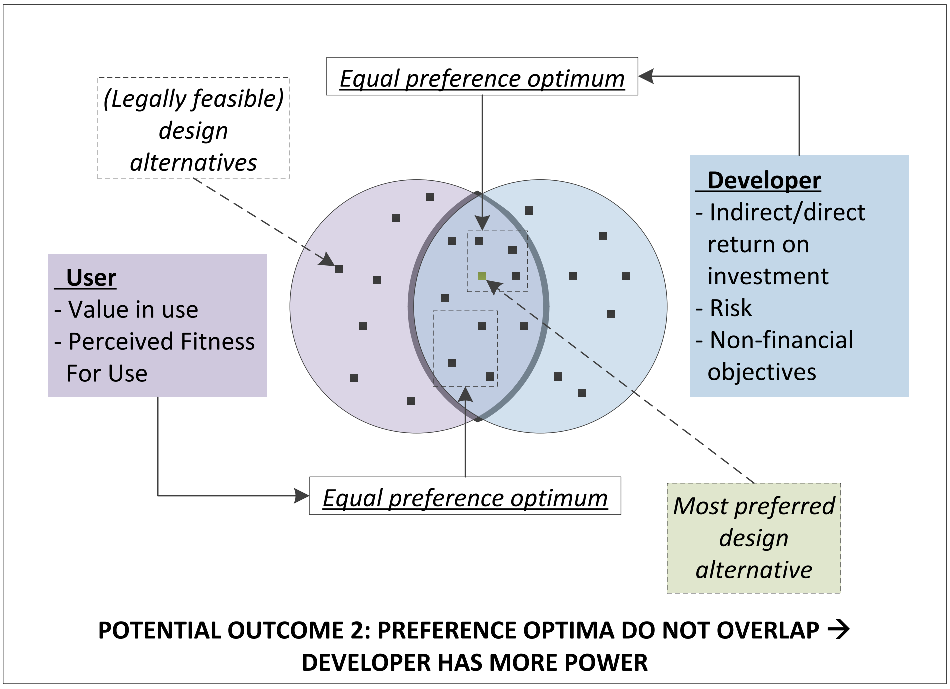


Figure 3b. Alternative outcome of proposed mathematical modelling design approach

4. Research questions

4.1 Main research question

This study aims to answer the following main research question:

Does the application of a preference-based design system lead to residential design alternatives that are more in line with developer and consumer preferences, over design processes without the application of a preference-based design system?

To answer this question, such a preference-based design system first needs to be devised and tested. Secondly, the outcomes of this system need to be compared to a design process without the application of such a design system.

In order to provide an initial scope for the variables to be included in this research, the following assumptions are made:

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.

4.2 Sub-questions

The following sub-questions will help provide a research structure to generate the findings relevant for answering the main research question:

1) 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.

2) 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.

3) 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.

4) 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 occupation 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.

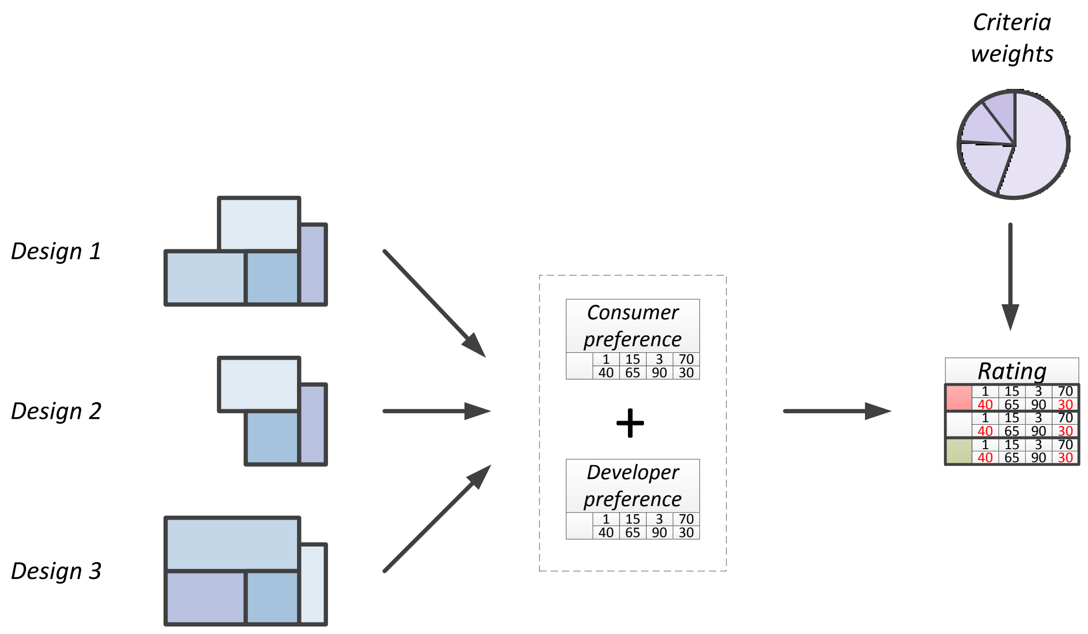
4.3 Application possibilities

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.

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.

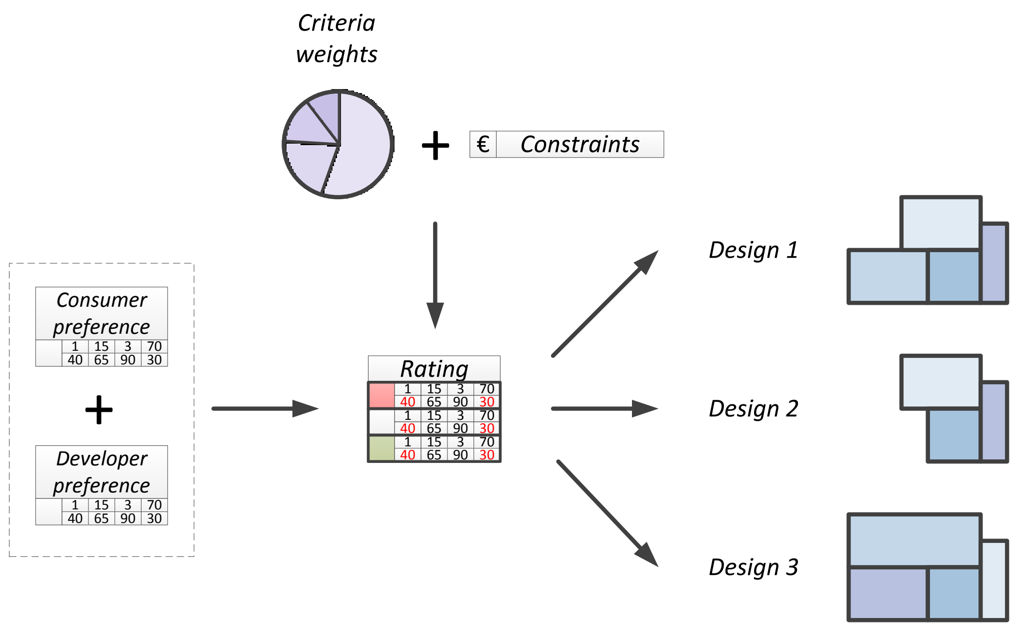
The second option (figure 4b) shows how the model could generate new design alternatives, based on specific criteria and stakeholder preferences. The outcome the model generates will depend on the selected optimization criteria (e.g. highest NPV, IRR, consumer preference score or aggregated preference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



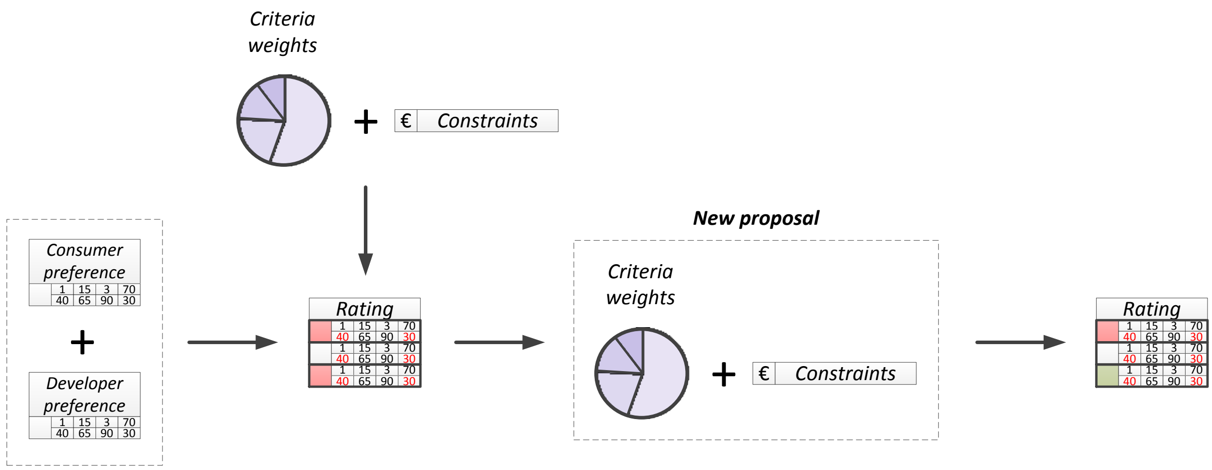
Option 1 | Comparing design alternatives

Figure 4a. First potential application of research results



Option 2 | Generating design alternatives

Figure 4b. Second potential application of research results



Option 3 | Determining conflicting interests

Figure 4c. Third potential application of research results

5. Research design and methodology

In order to generate an in-depth understanding of the interaction between different stakeholder interests, within a residential real estate development project, qualitative research will be performed. 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 constructs the second part of the theoretical framework. It will offer an initial foundation for answering the posed research questions. It will also generate theoretically valid assumptions with which the appropriate variables for the model will be selected.

The operations research approach allows for an analytical and problem-solving attitude towards a 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. The existing theory, on which the concept of the research model is based, forms the first part of the theoretical framework.

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 before reaching the desired end result.

5.1 Empirical research

Through thorough data collection and interpretation a clear theoretical framework has been established, after which a relevant case study could be selected and analysed. This empirical exploration also offers initial validation for the criteria and variables used in the model.

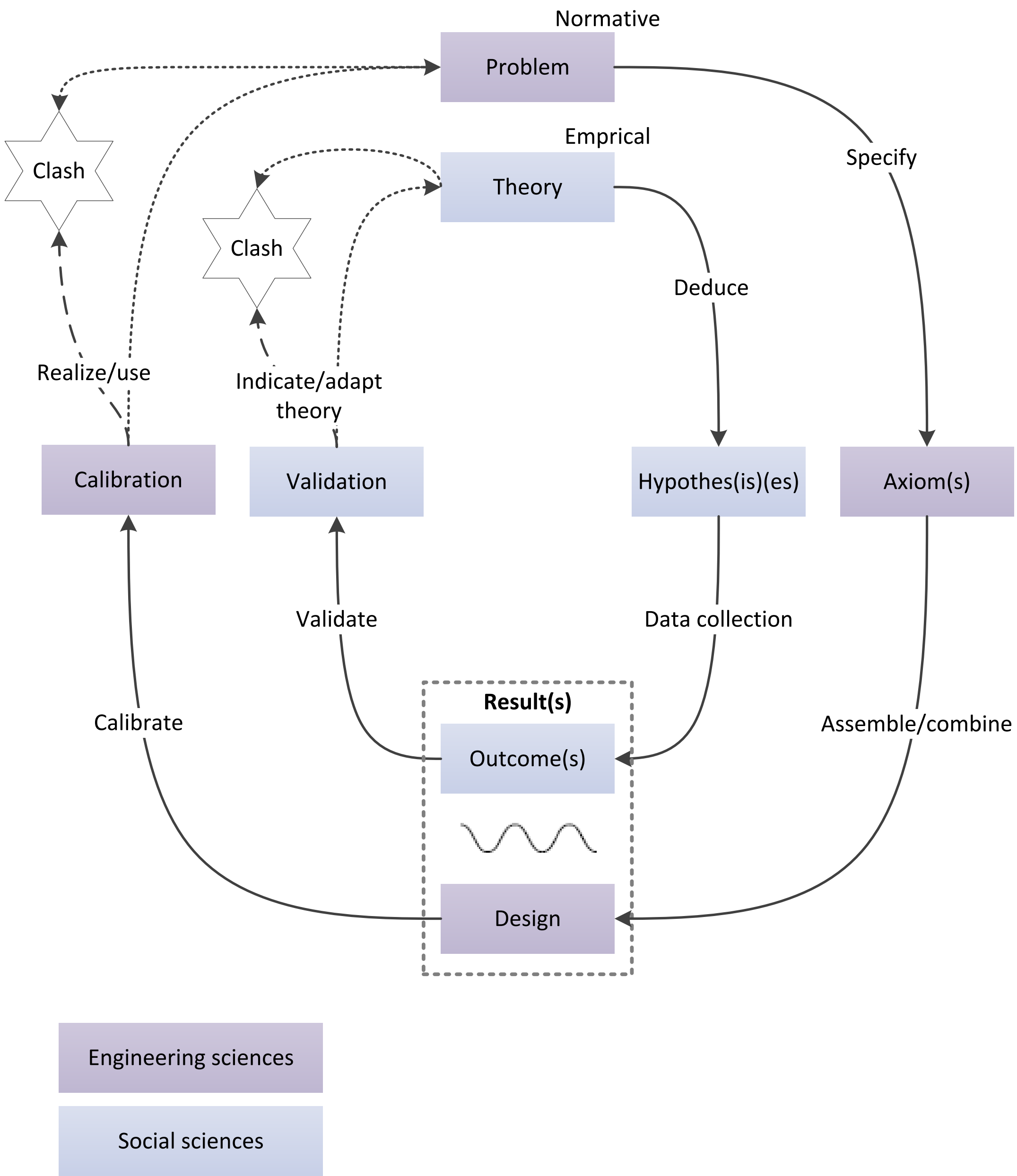


Figure 5. Formal and empirical sciences (own ill. based on Barendse et al., 2012)

Three main methods of data collection were applied. The first method, used to determine the context of the research problem and to provide existing insights for the case study, was *literature research* - a 'secondary source' method (Kumar, 2011, p. 139). The literature study consists of two components: a theoretical background on Preference Function Modelling, and an analysis of residential design variables related to developer and consumer preferences (both in general and specified to the selected case).

During the case study itself two 'primary source' methods were used to ensure the validity of the research results. First, a preference-measurement *questionnaire* was held among the consumer target groups related to the selected case study. This way their individual perception of relevant concepts and variables could be compared somewhat more objectively than through the application of unstructured interviews (Kumar, 2011, p. 145). As none of the respondents were familiar with the preference measurement technique applied in the questionnaire, it was always taken under supervision so respondents could ask for clarification if needed. The first questionnaires were taken in a group-setting, so any feedback from respondents regarding the questionnaire itself could be rapidly processed and discussed with the other respondents if necessary.

Secondly, unstructured *in-depth interviews* were held with a respondent from the questionnaire, as well as with the involved developing party. The functioning of the model itself and the generated results were discussed. As the posed hypothesis could only be tested by a research model that adequately reflects reality, these validation interviews were crucial to constructing an appropriate model and drawing comprehensive conclusions.

Sample and sample size

The studied *sample* for both primary source methods consists of decision makers that were involved with the project of the selected case study. While the sample size is insufficient to make generalized statements regarding the preferences of the entire target group, this study does not focus on producing a quantitative analysis on the housing preferences of a certain population. It focusses on delivering a proof of concept for a design related multi-actor multi-criteria decision making system. Both the posed hypothesis and research questions can be best tested and answered through a (small scale) qualitative case study. Therefore, the statistical significance of the preference data put into the model does not undermine the effectiveness of the system itself. If a proof of concept can be delivered, based on a relatively small scale study, it is one of the first times such a system has been tested and validated by practice in the architecture and construction field. It may then successfully be replicated in the future, for example to produce more generalizable outcomes.

5.2 Operations research

This approach will offer a more practical framework to ensure relevance and validation of the constructed research model itself. The main research method applied for this approach is the *case study*. The case study selected had to fulfil the following requirements:

1) A residential real estate development case study; to maximize societal relevance.
2) The involved stakeholders should be willing to cooperate with the research and provide relevant data when necessary.
3) A project from an area or market segment for which the existing real estate supply is not too homogeneous; otherwise the amount of possible design alternatives is likely to be very limited, and the constructed model may thus be of very little use to practice.
4) A project for which the expected costs and generated revenue for the different design alternatives can be calculated objectively; so there is less chance of the results being influenced by subjective (valuation) perspectives of the researcher.
5) An *ex post* case study; so actual decision making had already taken place and the stakeholders involved could sufficiently reflect on the results generated by the research model.

Largely in line with the iterative research process as visualized by Barendse et al. (see figure 5), the following four stages have originally been identified by Ackoff and Sasieni 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.

These stages will be leading for deriving the appropriate model for the selected case study. While multiple operational methods exist to measure preferences and to model multi-actor-multi-criteria decision making problems, the one with the most mathematical accuracy is Preference Function Modelling (PFM). Therefore, this method is selected for constructing the case-study based research model. For an extensive background and motivation for the selection of this method see chapter 7 on PFM.

5.3 The combined approach

Figure 6 illustrates the applied combined research approach. It shows how empirical theory is used to substantiate the operations research case study model. Both processes are followed almost simultaneously. While the iteration in both approaches is separated, a reflection moment is incorporated after the model has been designed to ensure the definitive model corresponds with all empirical findings. Also, after final calibration, the model will be validated by practice and be used to test the formulated hypothesis. Figure 7 elucidates the position of the different research methods within the overall combined approach, and how they complement the other applied methods.

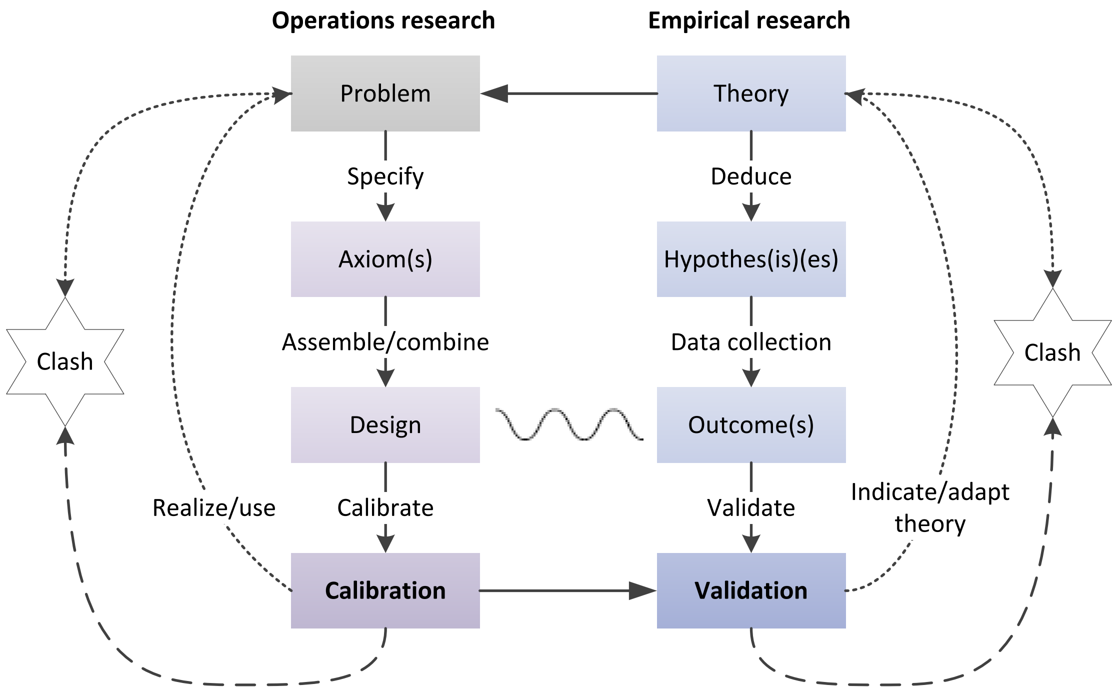


Figure 6. Applied combined research approach (own ill. based on Barendse et al., 2012)

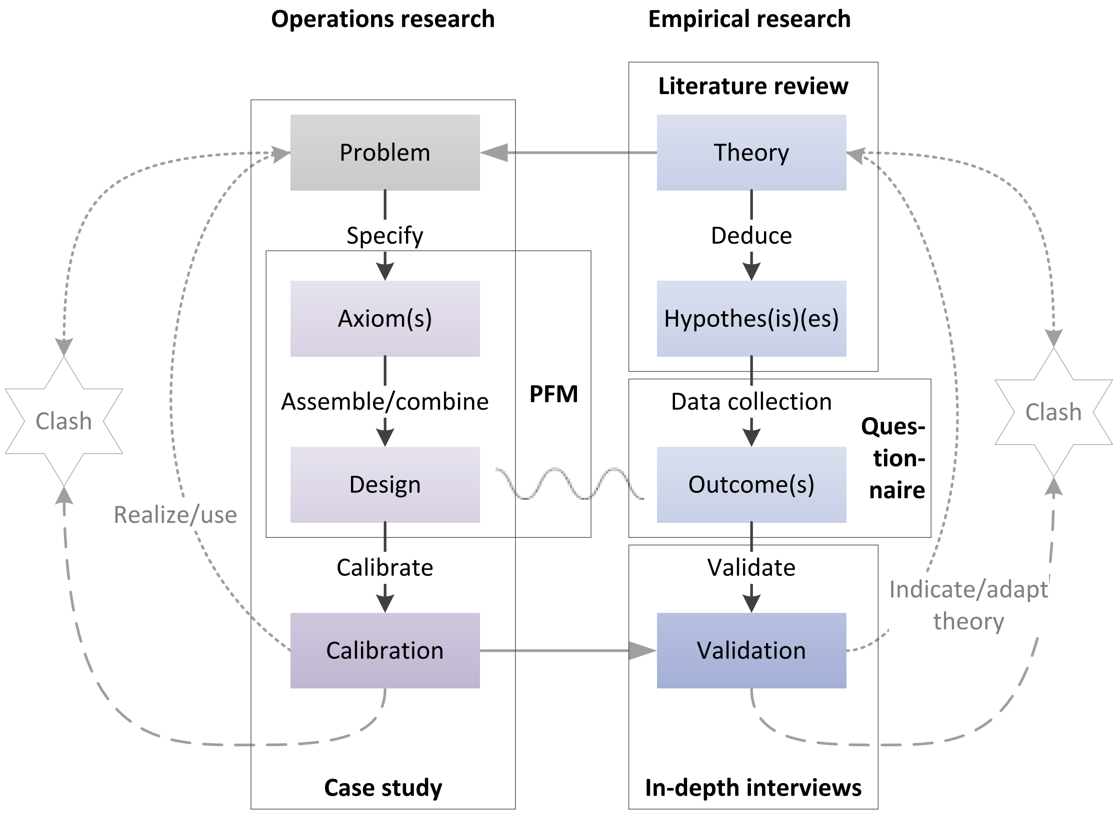


Figure 7. Applied research methods, placed within the combined approach principle

While it is labour-intensive to combine multiple different research methods, it is expected that important benefits will be derived from each approach. Because of a lack of previous studies that cover operations research based topics, especially within the field of real estate, a theoretical framework for this specific purpose has not yet been established. Thus an explorative literature review is necessary to provide insights on which exact variables might be related to the research problem. There is also a lack of appropriate data to use as input for the research model; so based on the literature review, a suitable questionnaire needs to be devised and held. A comprehensive understanding of Preference Function Modelling is necessary to construct an effective research model. A case study from practice should form the basis of the model, in order to draw substantiated conclusions regarding the stated hypothesis and research questions. Lastly, to validate the accuracy and effectiveness of the constructed research model, decision makers represented in the model should reflect on the model itself and the generated results in an interview.

For an overview of the different research phases and main related chapters, see table 2.

	Research phase (Barendse et al., 2012)	Related chapters
1.	**Theory**	2. Research relevance 8. Defining the decision variables
	Problem	3. Research objectives 9. Case study description
2.	**Hypothes(is)(es)**	4. Research questions
	Axiom(s)	7. Preference Function Modelling
3.	**Outcome(s)**	10. Questionnaire results 11. Developer preference curve
	Design	12. Research model
4.	**Validation**	14. Model validation
	Calibration	13. Model results
5.	**Theory**	15. Conclusions
	Problem	16. Reflection and recommendations

Table 2. Chapters related to each research phase

6. Expected results

After initial examination of the selected case study (the "Zusterflat" project), the following results are expected to be delivered at the end of this research process:

1. Possible adjustment of the 'current situation' (see chapter 3. 'Research objectives')., likely to reflect a more bottom-up design approach (see figure 8).

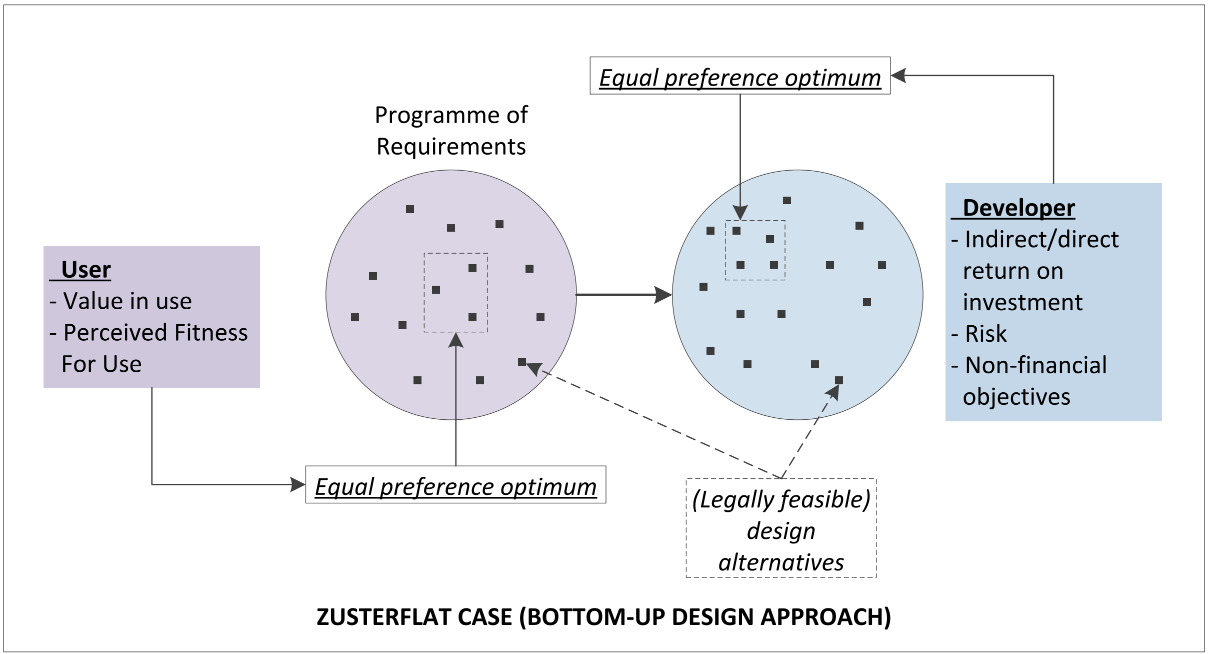


Figure 8. Proposed bottom-up design approach

2. Possible adjustment of the variables found in the literature review (see chapter 8 'Defining the decision variables') to reflect this specific residential development process.

3. Delivery of a detailed research model and generated design alternatives, 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).

PART II THEORETICAL FRAMEWORK

7. Preference Function Modelling

Binnekamp (2010) provides an overview of existing Multiple Criteria Decision Analysis (MCDA) methods (based on Belton and Stewart, 2003). Three main value measurement methods are reviewed against Barzilai's theory on mathematical proper scales for the measurement of preferences (Barzilai, 2010). For a brief summary of the review results as described by Binnekamp (2010) see table 3. Based on their analysis, the decision for Preference Function Modelling (PFM) as a foundation for the mathematical model in this thesis has been made.

This chapter will elaborate further on the choice for Preference Function Modelling, its mathematical foundation and how a research model can be in accordance with PFM principles.

Value measurement method:	Applied scales:	Mathematical foundation:
Multi Attribute Value Function (MAVF)	Interval	Incorrect; linear algebra and calculus not applicable
Analytical Hierarchy Process (AHP)	Ratio	Incorrect; linear algebra and calculus not applicable
Preference Function Modelling (PFM)	Reference alternatives	Correct; linear algebra and calculus applicable

Table 3. Value measurement methods review (based on Binnekamp, 2010)

7.1 The mathematical foundation to accurately measuring preference

In order to devise a preference-based design system that can then be evaluated, it will be necessary to determine developer and consumer preferences in a way that allows for mathematical operation of the data obtained. In other words, the collected evidence regarding both parties' preferences needs to be mapped into a mathematical system using proper scales (i.e. scales where the mathematical operations of addition and multiplication are enabled).

Weak scales vs. proper scales

The term *proper scales* is used to denote scales where the operations of addition and multiplication are enabled. For example, the quantity of money is measured using proper scales.

The term *weak scales* is used to denote scales where the operations of addition and multiplication are not enabled. For example, the quantity of beauty of an item. It is possible to state that someone finds one piece of art (much) more appealing or attractive than another, however it is not possible to state that something is considered e.g. exactly twice as attractive as another. At least, not without first mapping the perception of beauty into a mathematical system with proper scales.

In order for the operations of addition and multiplication to be enabled, the mathematical system needs to meet one of the following three criteria (Barendse et al., 2012, p. 26):

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 or an absolute one.

Preference has neither an absolute zero or an absolute one, since it has no objective minimum or maximum (similar to the general concept of “time”, or “temperature” before the absolute zero of temperature was discovered). Thus, in order to enable the operations of addition and multiplication to the preferences stated by the developer and consumers, the collected data will first need to be mapped into a system based on a one-dimensional affine space. This is different from the prevalent habit of asking people to state their preference “on a scale from one to five”, as every person could assign a different reference value to the number one, and a different reference value to the number five. This would be comparable to asking a person the temperature of their body on a scale from one to five, without stating which values have been empirically mapped to correspond with one and five.

Instead, to generate results that can be measured on proper scales, respondents should be asked to define their most preferred alternative and their least preferred alternative for each objectively quantifiable variable. Subsequently, a third reference point should be added in order to interpolate for all possible variable values in between of their personally defined “zero” and “one” alternatives. For example, instead of having respondents quantify their preference for a dwelling with one bedroom, a dwelling with two bedrooms, a dwelling with three bedrooms, etc., respondents need to define their least preferred alternative that is still an acceptable option to them (e.g. two bedrooms) and their most preferred alternative above which no significant additional preference is experienced (e.g. five bedrooms). On this scale from “zero” (two bedrooms) to “one” (five bedrooms), a third alternative should be scored by the respondent (e.g. the three bedrooms alternative could be placed on the 0.5 mark of the preference scale).

Figures 9a and b illustrate the subtle difference between a measurement system with proper scales (figure 9a) and a measurement system with weak scales (figure 9b). The prevalent approach (figure 9b) leaves room for individual interpretation. A respondent might reason “I prefer a dwelling with two bedrooms over a dwelling with one bedroom” and thus allocate the rating 2 out of 5 to the two bedrooms alternative. This does not show that this respondent is only willing to accept alternatives with a rating of 2 out of five and higher. Therefore, it still does not provide any information on the *meaning* of the assigned scores to the respondent. Further, the results from this variable score can’t be added to the scores of other variables (e.g. the number of bathrooms). If the respondent would be indifferent regarding the number of bathrooms, or if they are simply already satisfied with the smallest possible amount of bathrooms, they might assign every possible alternative a similar score, or assign all of them a score of 3 out of 5 or higher. Because this frame of reference might differ for every single variable, the resulting preference scores have no mathematical meaning.

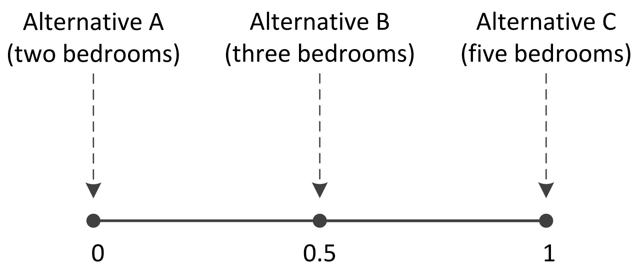


Figure 9a. Example of proper scales for measuring preference (respondent determines which alternative is assigned to each end of the scales, with a third alternative scored somewhere on this scale)

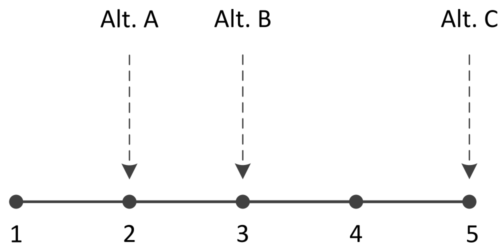


Figure 9b. Example of weak scales for measuring preference (the scale range is not mathematically defined by variable values)

If the measurement system in figure 9a is applied, there will be a clear consensus on the mathematical meaning of each possible preference score. This meaning will be the same for each of the variables. Therefore, mathematical operations can be applied to each score, and the scores for different variables can be combined to determine the respondent's overall preference score for a specific combination of variables.

It should be noted that for the purpose of mathematical operations, it is irrelevant whether the minimum and maximum boundary of the scale are assigned the numbers zero and one. This may be changed, if desired. Thus, a scale from one to five could be applied as well. It only matters that the respondent determines which alternatives (i.e. which variable values) constitute the maximum and the minimum end of the scales, and that a third alternative is scored so that interpolation can be performed.

The application of Discrete Choice Analysis

Brand		SONY	LG
Price	$500	$300	$400
Resolution	480x720	720x480	1280x800
Size			

Figure 10. The concept of DCA: ranking several alternatives (e.g. cell phone configurations) with different attributes (i.e. variable values), to determine relative consumer preferences (SurveyAnalytics, 2016)

The practice of Discrete Choice Analysis (DCA) is often used to determine which alternatives are preferred over other alternatives (e.g. which type of cell phone or car people want to buy). While this method may provide some insight into general preference trends, it does not determine the frame of reference of the respondents. This means weak scales are applied to generate data. This limits the precision of DCA. Therefore it is less suitable than Preference Function Modelling for construction of an accurate, reality reflecting preference model.

7.2 Limitations of statistical analysis

Statistical analysis focused on preference measurement typically generates data concerning the *probability* of a consumer's appreciation of a certain characteristic (i.e. variable value). Depending on the applied technique and the exact formulation of survey questions, such studies may specify the studied sample's most preferred variable values, their minimum requirements regarding variable values (or maximums for price limits etc.), a generalized order of variables ranked according to importance, or other preference related issues. If the selected sample size is sufficiently large enough, the probability of any person (within the target group) providing a certain answer could be expected to be predicted by the probability function of that question or variable, based on data provided by the studied sample. Such a probability function is then likely to resemble a normal distribution. Figure 11 illustrates this concept: two of such normally distributed probability functions, in this case a 'minimum required' variable value function and a 'most preferred' variable value function, are shown. For the sake of this example we can assume the variable for which preference was measured is the number of bedrooms for a single-family home. The functions might be expected to overlap somewhat and the data collected would not have included any negative variable values. If a residential property developer, whom is interested in the development of single family homes, would apply such data, it can be expected that they would decide in favour of floor plans with at least μ_1 bedrooms (to adhere to the minimum requirements of at least 50% of the target group) - or perhaps a little less than μ_1 bedrooms if the current market situation entailed few potential buyers. Also, it would be rational not to select floor plans with numbers of bedrooms that significantly surpass μ_2, as consumers are likely not willing to pay more for bedrooms above their 'most preferred' alternative. Clearly these decisions will be influenced by the developer's strategy as well; are they targeting the mass-market or a particular niche market, which specific costs and revenues are associated with constructing a bedroom, etc. These factors are excluded from this example as they would not directly affect the consumers' preferences, even though they would affect the available market supply and thus indirectly the equilibrium market price.

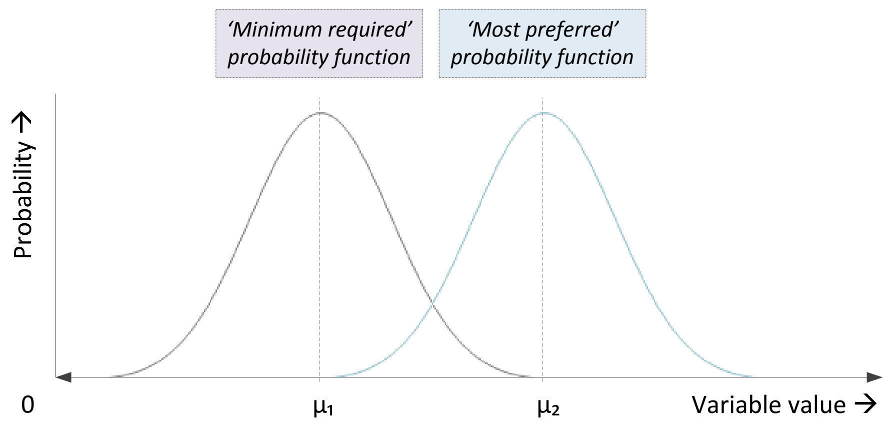


Figure 11. Conceptual illustration of empirically constructed consumer preference data

One crucial limitation of such empirical research methods follows from the fact that they do not provide insight into the actual preference function itself. Only the number of respondents that perceives a certain value to be the correct answer to a subjective question is being measured. These methods do not produce an explicit supposition of the degree of preference increase or decrease below or above the value selected by a person within the sample.

If the sample size is sufficiently large, and if enough data regarding all the relevant variables is collected, it is possible to produce generalized predictive empirical models (e.g. through multi-regression analysis). Such models may predict with a certain degree of accuracy how much the average person, if they belong to the population represented by the studied sample, will be willing to pay for a certain object characteristic. But again, the practical use of these models is limited due to the fact that they can only predict generalized outcomes based on data provided by all respondents.

The point has been made that empirical research per definition focusses on generalized preference trends, which tell us practically nothing about a specific consumer's fluent perception of preference regarding a continuous object variable. Aside from this theoretical notion there are many practical limitations to these techniques as well. The hypothetical sample size might be too small to generate a realistic predictive model (e.g. when determining preferences for a very specific niche market), incorrect assumptions are easily made by researchers (e.g. regarding causal variable relations instead of plain variable correlations), explanatory models may be interpreted incorrectly due to a lack of established theory on the studied subject. This does not mean that empirical research has no use when studying preference at all - broad trends can be determined and theory or hypotheses may be formulated. But for the purpose of this study, its paradigm is not considered suitable.

	What do you want?	***What are your requirements?***	*Possible alternative 1*	*Possible alternative 2*	*Possible alternative 3*	*Possible alternative 4*	*Possible alternative ...*
1. Number of bedrooms	*4*	*≥ 2*	*4*	*2*	*3*	*2*	*...*
2. Total GFA of dwelling	*± 150 m²*	*≥ 100 m²*	*100 m²*	*110 m²*	*120 m²*	*140 m²*	*... m²*
3. Price	*± €200.000*	*≤ €220.000*	*€215.000*	*€200.000*	*€210.000*	*€220.000*	*€...*
(Implied) preference rating	***100***	***0***	***?***	***?***	***?***	***?***	***?***

Figure 12. Example of struggles experienced when applying measured consumer preferences in practice

7.3 Applications and limitations of PFM

Preference Function Modelling (PFM) has limitations, mostly practical. It can be time-consuming to explain the mathematics behind it, especially if the preferences of a large population are being measured. It is essential that all decision makers included in the model understand how their preferences are being calculated to ensure acceptation of outcomes (Binnekamp, 2010). And, even though general trends among the studied sample can be determined and analysed, it may be a less suitable method for such applications than empirical research techniques. The main benefit of PFM is the fact that it allows a sample's (i.e. decision makers) specific preferences to be studied with great detail and mathematical accuracy. It can be used for challenging the status quo, to perfect vague theories or to produce extremely accurate solutions for allocation or efficiency problems with high complexity. For this latter characteristic, it has great potential for application to architectural design problems. It is when trade-offs have to be made (e.g. regarding resource allocation or optimizing stakeholder satisfaction) that every minor improvement might be relevant to the actors involved with the problem. Thus, PFM can be used for more informed decision making and perhaps facilitate negotiations between stakeholders.

The case study revolves around a residential floorplan design 'problem': which floorplan design fits a consumer's preferences as closely as possible, while simultaneously optimizing the developer's profits? While the empirical concept of willingness-to-pay (WTP) immediately comes to mind here, it is not sufficient to just look at a consumer's WTP for separate design characteristics for two reasons. First, how much a consumer is willing to pay for a house depends on the composition of the entire object. If a property has two bedrooms, theoretically they might be willing to pay €20.000,- more if a third bedroom would be added. However if a property already has four bedrooms there might not exist any willingness to pay for an additional bedroom, for example because it adds no additional utility for the consumer or because their budget is insufficient. Of course, it would not be feasible to ask a consumer to how much they would be willing to pay for every single potential variable value within the context every single possible floorplan composition. Secondly, considering the requirement to devise a high-accuracy solution to the stated problem, it is highly unlikely that anybody can predict their own WTP for specific building characteristics with adequate precision. Constructing a predictive statistical model for this purpose would, not lead to an actual existing consumer's preference curve but rather to a general population based trend estimation. There is also the risk of the research population being too small to deliver accurate results. PFM is not constricted to these issues.

7.4 Constructing a model according to PFM principles

In order to design a research 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*, see figure 12) 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.

These steps align with the mathematical foundations of PFM as described in paragraph 7.1. To correctly measure preference, a decision maker will be asked to rate their preference for each criteria 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:

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

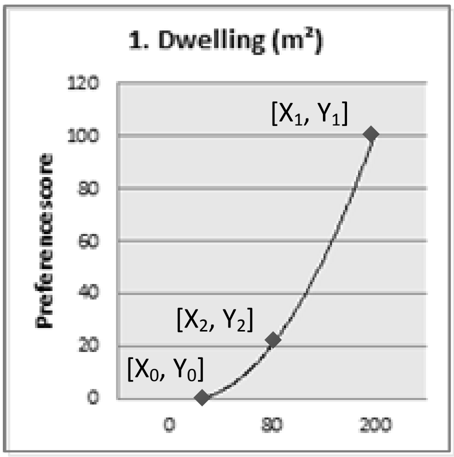


Figure 13. Example of a Lagrange curve, based on three measurement points

The predictive model constructed for the case study will calculate both the consumer's preference regarding a specific dwelling's rent price, and their preference regarding the entire floorplan composition. Simultaneously the profit made by the developer will be evaluated with the use of the developer's stated preferences. Adjustable criteria weights will be applied to make the model approach the consumer's preference more accurately.

Figure 14 illustrates how individual preference ratings per design alternative will be generated. How this concept exactly will be applied to the selected case study will be more elaborately described in chapter 12. 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 initial results, a weighted sum calculation will be sufficient. This means each preference score is multiplied with the weight assigned to its criteria. For thorough validation of the model the results will be checked with software called Tetra, based on an algorithm developed specifically for PFM by Barzilai. This check will fit the purpose of a general model sensitivity analysis.

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

► Selecting the best alternative

Figure 14. The method applied to calculate individual preference ratings per design alternative (own ill. based on Borst, 2014)

In order to deliver a model that is able to 'design' the most preferred housing composition, the PFM method will be applied within an optimization framework (i.e. a set of constraints defining a set of feasible alternatives). Such a framework can be used to express the interests or criteria of each decision maker involved in the design process (Binnekamp, 2010, p. 86). It will also limit the set of possible alternatives the model takes into consideration, which would otherwise become very extensive.

7.5 Preference curve conditions

The Lagrange forms, or *polynomials*, in figure 15 represent interpolated stated preferences. In order to be able to calculate every single possible preference score, a minimum of three data points will be required (Binnekamp, 2010, p. 89). If only two data points are known, the resulting preference function would always be linear (unless additional trend-data regarding preference functions regarding that particular variable would be available; however such a situation would call for additional mathematical modelling approaches).

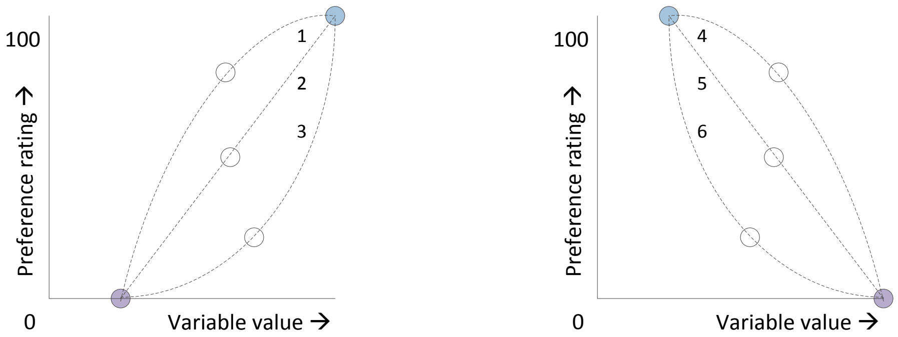


Figure 15. Six examples of Lagrange curves, each with three data points

The reliability of a calculated Lagrange form - in this context the extent to which it approaches the actual preference function - depends on both the number of data points and the distribution of the x and y values of the data points (Heath, 1997, p. 223). In essence, if the number of data points increases, the polynomial can be constructed with greater accuracy. However, this principle does not hold if many of the data points are *equispaced*; as this would lead to oscillations that actually reduce the accuracy of the polynomial (Heath, 1997, p. 231). This mathematical effect is known as *Runge's phenomenon* (Epperson, 1987). The oscillation can be minimized by using less data points, or by using data points that are distributed more densely towards the edges of the interval (Heath, 1997, p. 231). Another possibility is to make *all* data points equispaced and include data points for the edges of the interval. While such oscillations are typically less of an issue for low-degree polynomials, such as the second degree polynomials shown in figure 3, they will be prevented in the latter manner by collecting equispaced data points for y = 0, y = 50 and y = 100 (i.e. the variable values for which a person's preference rating respectively equals zero, fifty and hundred). For both this reason and for curve comparison purposes the Y-axis interval is standardized to [0;100].

In the context of this study, a preference rating of zero will be interpreted as the least preferred (but theoretically still acceptable) variable alternative. Subsequently, a preference rating of hundred will be interpreted as the most preferred variable alternative. While there are situations in which the value of the most preferred variable alternative is theoretically expected to be infinite (e.g. a developer's realized financial profits), it will become increasingly difficult to determine the extent of such preference. For instance, how much more would a developer prefer a GIY of 95% - which is already particularly unrealistic - over a GIY of 90%? Above a certain variable value the preference curve will continue to approach the preference rating limit of 100 while never actually reaching it. Therefore the variable alternative with the preference rating of hundred will be considered the value after which no *significant* additional utility can be created, from the perspective of the person whose preference is being measured.

8. Defining the decision variables

This chapter discusses the outcomes of the performed literature review. Insights are added to these findings based on the in-depth interviews. As the proposed model aims to optimize development profit, while simultaneously adjusting the design characteristics to be more preferred by consumers, the discussed variables are divided into financial variables and design variables.

8.1 Financial variables

Real estate developers typically assess the expected profit for potential projects through discounted cash flow (DCF) calculations. The DCF method is extensive and widely used in practice. It was also used by the developer of the selected case study, for determining the financial feasibility of the project. In order for the research model to achieve accurate results, that correspond with property investment evaluation as performed in practice, the developers' preference will be measured based on the main product of automated DCF calculations: the Internal Rate of Return (IRR).

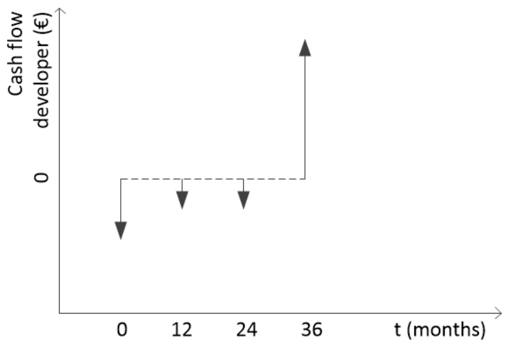


Figure 14. Example of develop-and-sell cash flow diagram

Figure 14 is a simplified illustration of how cash flow models set out different costs and revenues against time. The costs and revenues for each period (e.g. per year or month) are added up. Consequently, a discount rate is applied to each of these 'cash flows', in order to compensate for inflation and any investment risks associated with the specific project. All cash flows are then added up together. This leads to a valuation of the entire project (from an investment perspective); the Net Present Value (NPV). The IRR is the annual profit percentage made on the investment, based on this NPV.

As the NPV does not provide insight into the relative return made on the total investment sum, the IRR is the appropriate criteria to measure actual profit with.

While the Gross Initial Yield (GIY) method is also often used in practice for evaluating real estate investment opportunities, this was not the method of choice for the developer of the selected case study (L. Roose, personal communication, April 26, 2016). It will therefore not be included as a variable or criteria in the research model.

Table 4 shows all the financial variables that are considered relevant for DCF implementation within the proposed model. For each variable the data source for the case study is listed. Additional theory on the rent price point system will be provided, as this system determines the expected rent revenue for the case study. Consequently, it determines for a large part the IRR achieved for each dwelling design.

Financial variable	Input type	Case study data
Construction costs (incl. unforeseen expenses)	Input from developer	Based on contractor quotations
Additional costs (permit fees, consultants, etc.)	Input from developer	Based on contractor quotations
Lease costs	Input from developer	Based on lease contract
Expected rent revenue	Automated input	Results from rent price point system
Inflation rate	Input from developer	Based on expected average annual inflation rate
Rent increase	Input from developer	Based on expected average annual rent increase
Internal Rate of Return (IRR)	Automated output	Resulting developer's annual profit

Table 4. Financial variables

The rent price point system

The rent price point system is a method to calculate the maximum rent price (excluding service fees) that may be charged for a rental residence, based on points awarded for aspects such as size and overall quality of the property. It differentiates between shared housing, in which multiple tenants reside and facilities are typically shared, and independent housing, in which only a single tenant (or family household) resides per housing unit. The system is legally binding for all rental agreements, except for independent housing contracts that specifically deviate from its requirements - so called 'liberalized leases' (Rijksoverheid, 2016). It also limits the maximum annual rent increase to a percentage that is to be determined each year by the national government, from which liberalized leases are exempt. From the year 2013 and onwards an income dependent rent increase percentage was administered (ranging from 4 to 6,5 percent) (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2014). Because the decisions regarding the case study configuration were made before October 2015, the specific rent price point system that was valid at that time will be used for the research model as well. This will increase the model's reflection of reality.

The main factors that help determine the amount of points to be awarded for a house are visualised in figure 15. This figure shows in blue the specific characteristics that are relevant to the design problem of the selected case study. However, all characteristics have been included in the research model as input for the maximum allowed rent price per residential unit (i.e. per tenant), corresponding with the actual rent price point system. As the values for the fixed characteristics (shown in white in figure 15) will not be adjusted by the model, these are characteristics are not considered design variables.

As independent housing was not considered by SHS Delft there is no data available on related revenue projections. Thus, the rent price point system is also applied in the research model for pricing the independent housing alternatives (instead of liberalized lease prices). Determining the liberalized rent revenue expectations for such housing during the initiative phase of the Zusterflat project would lead to hindsight speculation, based on achieved market prices for similar properties. Such a method would produce speculative results, which would not add insight into the decision making process at the time.

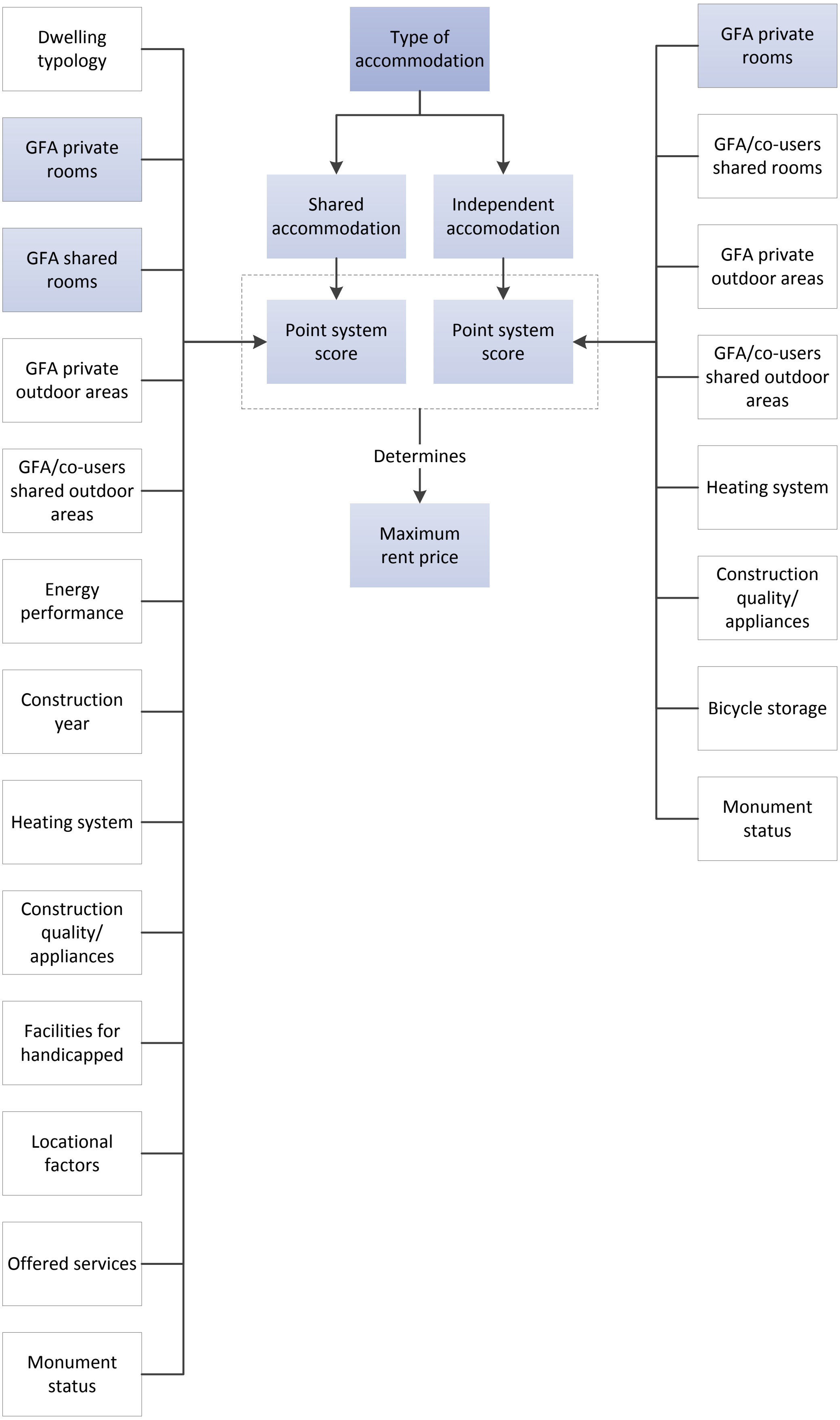


Figure 15. Rent price point system score determinants

Figures 16a and b show which rent prices are associated with which point scores for shared and independent housing respectively. For shared housing the slope is approximately €1,964 per point, until a score of 180 points has been reached. If more than 180 points are awarded, the maximum rent price is calculated as followed:

Maximum rent price = (€1,964 x 180) + ((point score - 180) x €1,017)

For independent housing the maximum rent price is standardized at €183,46 until a score of 40 points has been reached. If more than 40 points are awarded, the maximum rent price can be found through the following calculation:

Maximum rent price = point score x €4,586

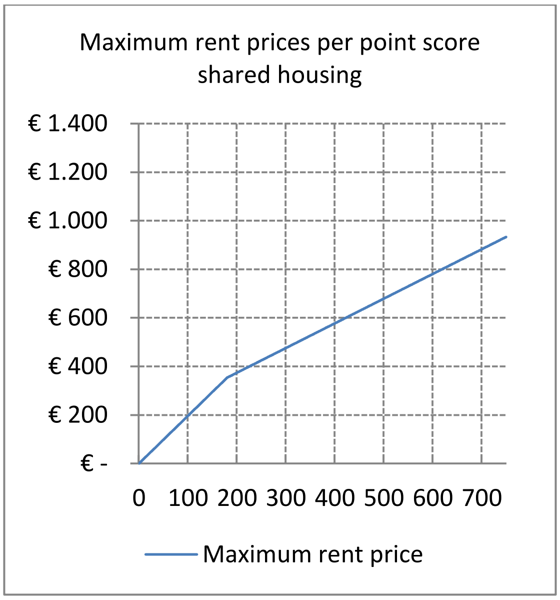


Figure 16a. Maximum rent prices for shared housing according to rent price point system per 1 July 2013

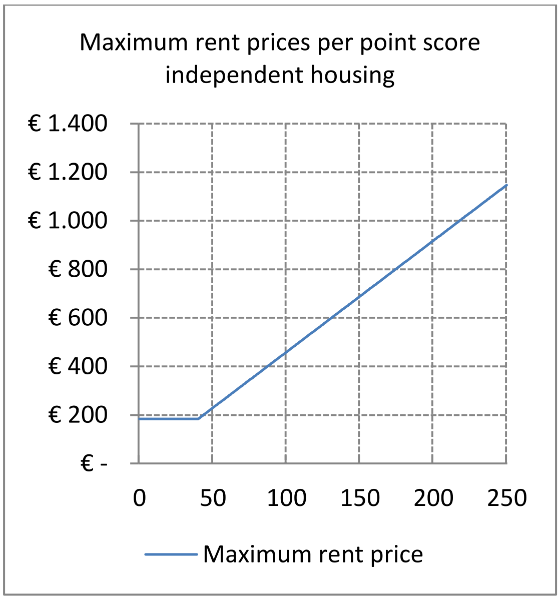


Figure 16b. Maximum rent prices for independent housing according to rent price point system per 1 July 2013

8.2 Design variables

So far, no previous research or literature exists in which the Preference Function Modelling method was applied to any form of housing preferences. Therefore, other existing literature has been examined in search of potentially relevant design variables.

Chin and Chau (2003) have thoroughly described which hedonic pricing studies have been performed in regard to residential properties. They make a clear distinction between locational, structural and neighbourhood attributes. As locational and neighbourhood attributes can not be altered through architectural design, these will be excluded from the research model. The found structural attributes are listed in table 5.

Structural attribute	Relation to property value	Source
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 5. Structural attributes described by Chin & Chau (2003)

While correlation results give an indication on whether or not a certain characteristic is generally 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. Other attributes change with e.g. culture, the tradition of building style or local climate. It is thus important to base the preference curve for all design variables on the (stated) preferences of the specific target group related to the design problem. For the case study this means that additional data is required on the housing preferences of both Dutch students and international students, studying in Delft. As such data specifically on students in Delft is limited, the outcomes of two studies will be reviewed. The first was a nationwide questionnaire among Dutch students. The second was a considerably smaller survey that was administered specifically among students living in Delft. Each study was conducted in the year 2015. After brief review of both studies, a summary is provided of the results relevant to the case study.

In the nationwide survey, the National Monitor Student Housing 2015 (Apollo, 2015), students with a desire to move within one year were asked to state their preference for future housing. 71 percent stated to prefer some type of independent housing; either a studio-apartment or an entire residence (see figure 18). Almost all respondents that showed interest in moving to a shared house stated they would prefer to move into a larger bedroom: especially bedrooms of 14-15 m² and 25-29 m² were stated as 'most preferred' bedroom size (see figure 17). Of all shared facilities, students were willing to share the kitchen with the relatively largest amount of housemates (see figure 19; current situation stated between brackets). However, compared to their current housing situations, students stated they preferred to reduce the amount of housemates they were sharing facilities with. An estimation based on these numbers indicates that roughly three quarters of all students would prefer to share their facilities with three to five housemates, while approximately 20 percent prefers to do so with only one or two housemates.

Figure 20 shows the preferred rent price among the same population of figures 17 - 19. These numbers are also representative of the national student housing market and it is likely that a city such as Delft shows a different market demand than e.g. a city such as Amsterdam. However, one general conclusion that may be drawn is the fact that there is a clear difference between student willingness-to-pay for shared housing and independent housing. Seven out of ten students were willing to pay over €450,- per month for independent housing, while only two out of ten students were willing to do so for shared housing. The figure also indicates that the maximum rent price for shared housing of €300,- (which was administered by SHS Delft) might have been a somewhat low compared to students' actual willingness-to-pay.

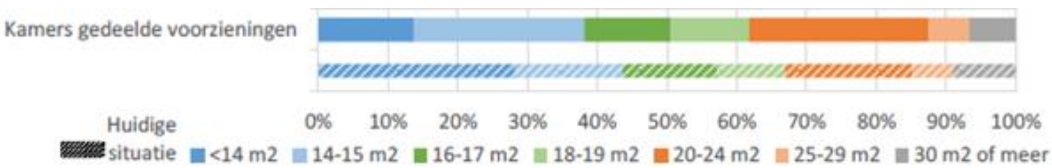


Figure 17. Preferred bedroom size of students planning to move within a year (Apollo, 2015)

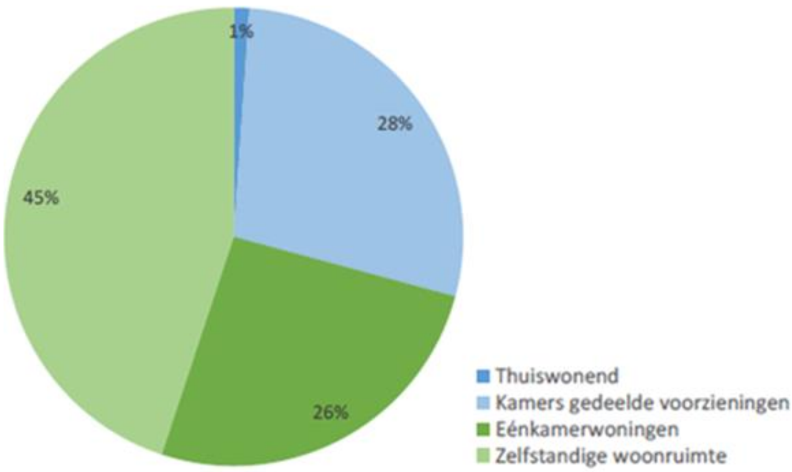


Figure 18. Preferred housing type of students planning to move within a year (Apollo, 2015)

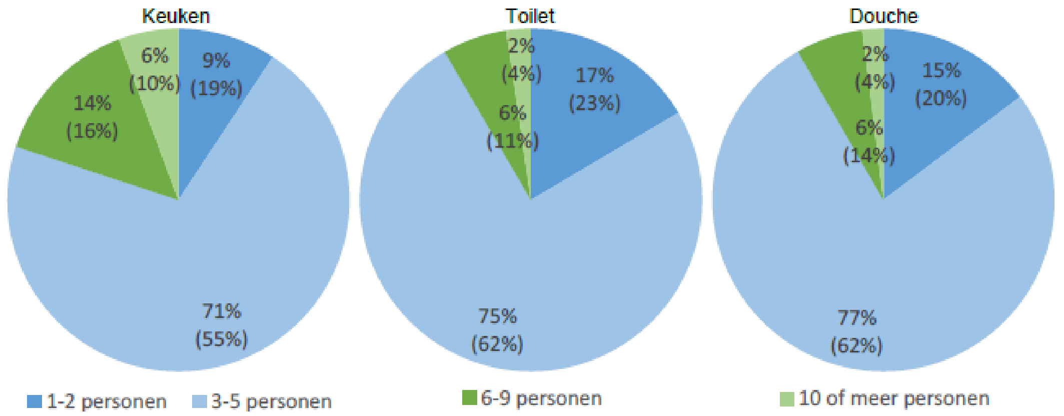


Figure 19. Preferred number of housemates to share facilities with (Apollo, 2015)

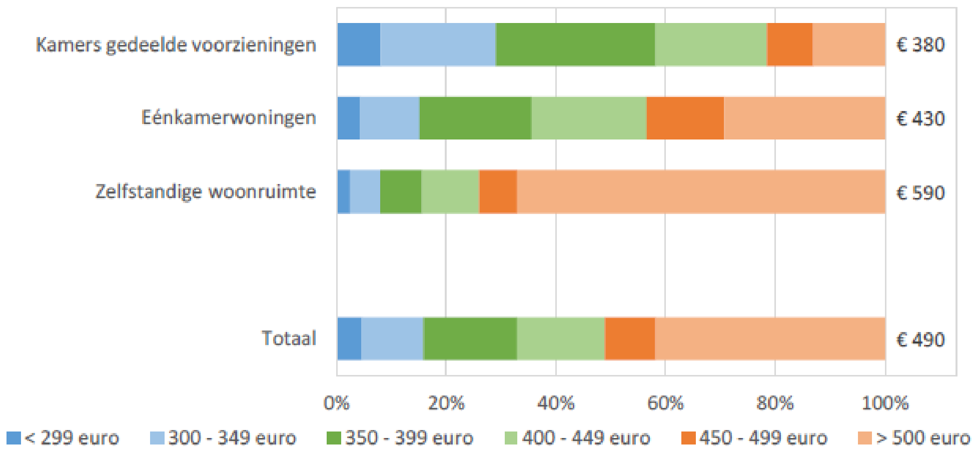


Figure 20. Preferred rent price of students planning to move within a year (Apollo, 2015)

The primary aim of the second study, a conjoint analysis, was to determine which housing characteristics were considered most important by Delft students (Wäckerlin, 2015). The sample size consisted of 90 students. The amount of characteristics that were taken into account was relatively small, and thus the predictability of the model was also limited (R^2 = 18,9%). The study can however provide insight on which specific characteristics should not be overlooked for establishing a reliable research model. Also, the overall shape that may be expected for some of the measured preference curves can be construed from the outcomes.

The most preferred number of housemates, according to Wäckerlin, should be approximately seven housemates, but in any case is more than two and less than twelve (see figure 21). Regarding the preferred rent price, as expected a linear decreasing preference function was found for an increasing rent price (see figure 21). Students also (as expected) preferred an increase in bedroom size. There was a more steep linear preference function per additional square meter for smaller bedrooms (12 - 17 m^2) as compared to larger bedrooms (17 - 22 m^3) (see figure 21).

Characteristic:	Lowest B-weight	Highest B-weight	Range	Impact on model
Rent price	-0,694	0,563	1,257	30,8%
Bedroom GFA (m²)	-0,352	0,218	0,570	14,0%
Distance to city centre	-0,267	0,267	0,534	13,1%
Distance to campus	-0,257	0,257	0,514	12,6%
Outdoor area	-0,181	0,181	0,362	8,9%
Shared bathroom facilities	-0,171	0,171	0,342	8,4%
Distance to train station	-0,128	0,209	0,337	8,3%
Number of housemates	-0,084	0,084	0,168	4,1%

Table 6. Ranking of characteristics according to impact on model (based on Wäckerlin, 2015)

The data from table 6 was converted into the initial preference curve estimations in figure 21. Even though the accuracy of the model construed by Wäckerlin may be limited, the study entailed a large enough sample size to estimate general preference functions. These functions can be used to help determine the relevance of a structural attribute for the case study.

Order of importance:	Final question based	Rating based	Choice based
1	Rent price	Rent price	Number of housemates
2	Bedroom GFA (m²)	Bedroom GFA (m²)	Shared bathroom facilities
3	Number of housemates	Distance to city centre	Distance to train station
4	Outdoor area	Distance to campus	Distance to campus
5	Shared bathroom facilities	Outdoor area	Distance to city centre
6	Distance to city centre	Shared bathroom facilities	Bedroom GFA (m²)
7	Distance to campus	Distance to train station	Outdoor area
8	Distance to train station	Number of housemates	Rent price

Table 7. Potential orders of importance of student housing characteristics (based on Wäckerlin, 2015)

The outcomes regarding the actual order of importance of characteristics were inconclusive. Table 7 shows the three different rankings that were configured based on the students' stated preferences. The cells containing structural attributes have been coloured light blue. While rent price and bedroom size were twice ranked as the most and second most important characteristic respectively, placing of all other characteristics significantly fluctuated per ranking.

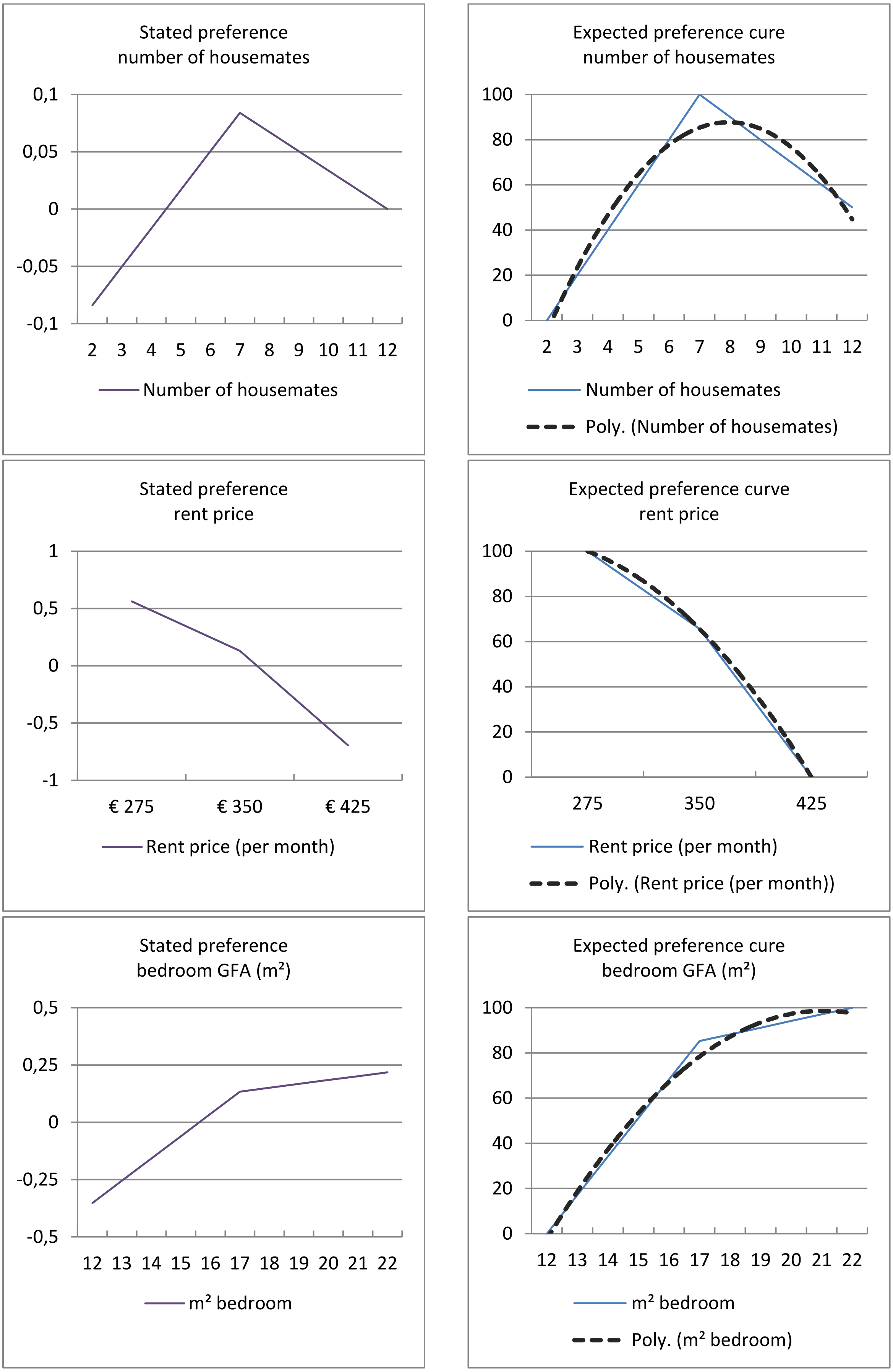


Figure 21. Estimated student preference curve functions based on Wäckerlin (2015)

Selected design variables

Since the objective of this research is to determine whether developers are (theoretically) able build better housing - 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 numerically measurable in order to determine and compare design alternatives' consumer preference scores.

While neither of the available studies could provide direct input for the research model, there do appear to be some consistencies that lead to structural housing attributes which are of importance to Dutch students. Both surveys illustrated that preference patterns exist regarding rent price, house (or bedroom) size and number of housemates. This finding corresponds with the perspective of Kohlhase (1991) that size is universally considered an important housing attribute. Unfortunately, neither survey provided useful data on the weight assigned to the different attributes by the respondents. Even when preference was determined, the extent of its effect on the decision making process of students active on the housing market is unclear.

A list of design variables resulting from both studies can be found in table 8. These are selected on their relevance to the case study, so only structural attributes have been included. This list differs from table 5. For shared student housing the number of bedrooms usually determines the number of housemates, which is therefore excluded as an additional variable. The number of bathrooms is indirectly taken into account as part of the rent price point system, but excluded as a separate design variable. This is due to the current floorplan of the building in the case study, and for feasibility reasons. The same decision was made for lot size and the presence of a basement/garage or patio; these variables are not part of the design problem in the case study. They will therefore not be included in the research model. As housing quality is difficult to measure, and again not specifically relevant to the case study, this variable will also not be applied. Fireplaces and other architectural elements, including materialization, are specifically not taken into consideration in this study. There was no existing research that substantiated the expectation that certain aesthetic characteristics are preferred by students. Thus, this research is limited to evaluating design alternatives based on the variables in table 8.

Design variable	Most preferred (Apollo, 2015)	Most preferred (Wäckerlin, 2015)
Independent or shared housing	Independent	-
Number of housemates (shared housing)	Between 3 and 5	Between 2 and 12; approximately 7
House size (independent housing)	20 - 24 m² GFA	-
Size of bedroom (shared housing)	14 - 15 m² GFA and 20 - 24 m² GFA	Diminishing preference curve after 17 m² GFA
Rent price (independent housing)	> €500	-
Rent price (shared housing)	Between €350 and €399	Preference curve approaches linear function; 'the less the better'

Table 8. Design variables

The amount of design variables included in the research model, based on existing literature, remains limited. During an in-depth interview with a respondent from the 'consumer' target group, the established list of design variables was nonetheless deemed to be conclusive. While other design variables may exist, they are likely not given significant enough weight by respondents to influence the outcomes produced by the research model (see chapter 14 "Model validation").

8.3 Relations between variables, criteria and constraints

The relations between all selected variables are visualised in figure 22. In this figure it is shown how design variables together deliver the input for the financial variable ‘expected rent revenue’. All other financial variables need to be specified by the developer. If no specific set of design alternatives exists, the research model can generate design alternatives based on optimisation of either consumer or developer preferences (or a combination of both, depending on the assigned decision maker weights). For example, if the developer receives a decision maker weight of 100%, the model will generate the design alternative which achieves the IRR that is most preferred by the developer (as far as the design constraints allow). The model will simultaneously calculate the alternative’s achieved consumer preference score for each design variable, even though this score will not affect the generated alternative.

The selected variables for which decision maker preference will be measured, to reflect the case study (see figure 22), are considered the design criteria and financial criteria for the research model. As all variables may be adjusted, either manually or by the model itself, only those for which preference is measured will eventually be used to compare different design alternatives.

Two main design constraints that have resulted from the case study. The first design constraint is the exact amount GFA per floor to be allocated by the research model. The second is a limitation to the specific placement of interior walls. These constraints will be further elaborated on in chapter 9.

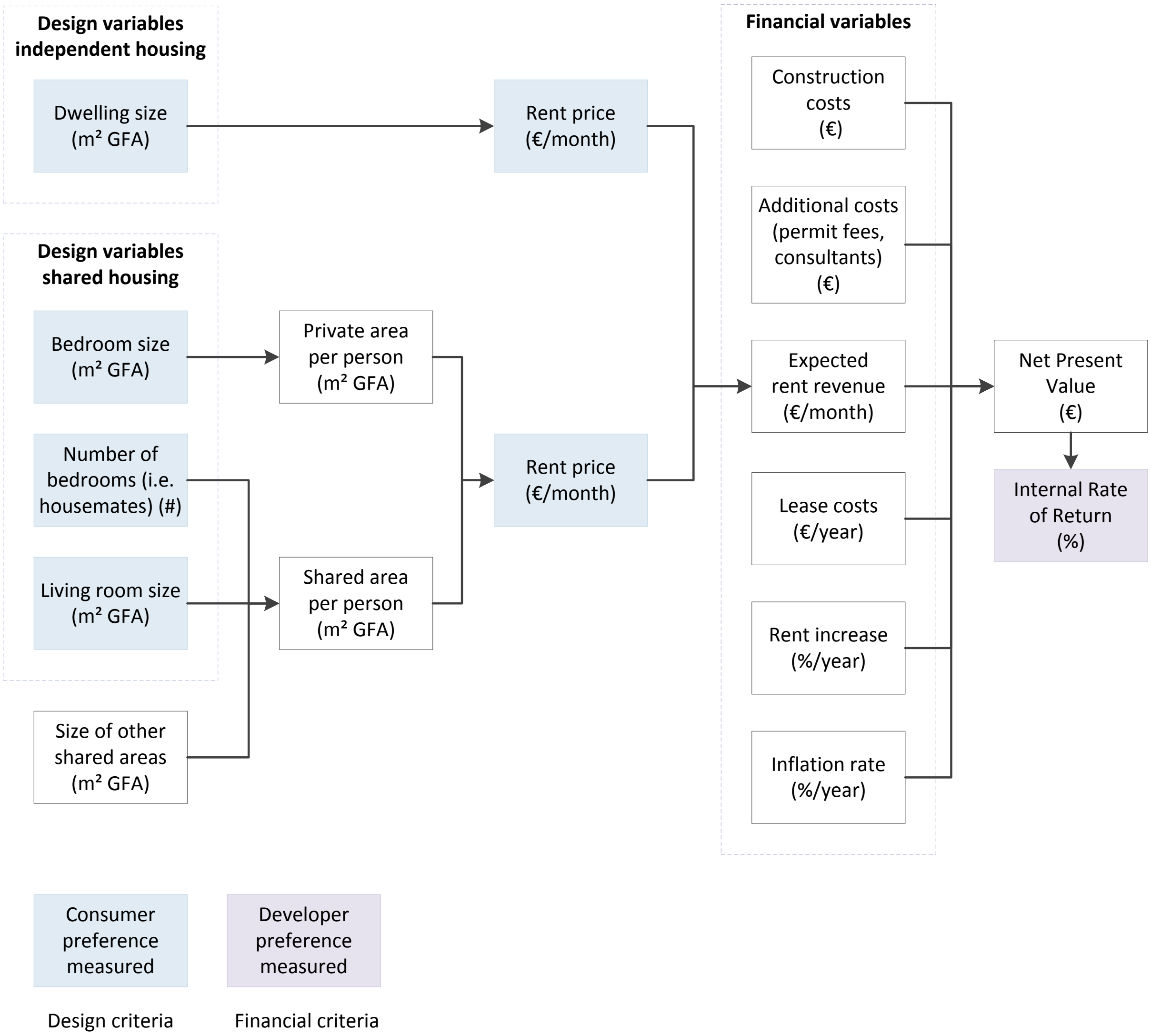


Figure 22. Conceptualisation of the relations between variables included in the research model

PART III CASE STUDY

9. Case study description

Based on the research problem description and case study selection criteria (see chapter 5), a case from practice was selected. This case will be used as a realistic foundation for the research model, so the posed hypothesis can be tested. The case selected was the “Zusterflat project”. It entails the transformation of a long-term vacant office building in Delft into student housing. The student housing market is an actively developing market, which provides many different possible design alternatives, and has an objective revenue determining system (i.e. the rent price point system). The stakeholders involved with the design of the project were limited to a developer and a foundation that represented the local students, which allows for modelling of decision maker preferences as described in the problem definition. Also, the project has already been completed and delivered, so a comprehensive analysis of actual decision making can take place. The existing building also ensured a clear set of design constraints, as to prevent the number of possible design alternatives to become exceptionally large (see chapter 7).

Figure 23. The Zusterflat in Delft (SHS Delft, 2012)

9.1 Determining the (design) problem

In 2014 the Zusterflat, a former office building, was transformed into 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. The temporality of the project was also due to the prevailing zoning plan, which assigns a 'social purposes' function to the building. A student housing project could thus only be allowed by the municipality for a maximum operating period of ten years. Figure 23 shows the exterior of the property (as seen from the south). Table 9 provides an overview of the building's main characteristics. See appendix 3 for an exemplary floor plan before and after the transformation into student housing.

Building characteristics	
Name	Zusterflat
Address	Aan 't Verlaat 31, Delft
Owner	Semi-public healthcare institution
Zoning plan	Noordoost Delft
Original function (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 9. Characteristics of the Zusterflat case (based on SHS Delft, 2012)

9.2 Floorplan analysis and technical limitations

The building consists of two linked sections: a twelve storey flat and a three storey low-rise extension (see appendix 3). The flat has a square floorplan, which is fairly repetitive for each floor (see figure 24). Each of the twelve rooms adjoining the façade is 11 m² (3,30 m x 3,30 m). There are three entrances to each level. Two from the inner staircase and elevators and one from the outer staircase, which primarily functions as a fire escape. Two toilets and two showers are installed at the centre of each floor. The centre wall, around which a corridor is located, is a concrete load bearing wall. The façade is attached to load bearing columns situated 3,30 m. apart. It consists of large, horizontally oriented windows and does not allow for interior walls to be attached in between the columns. These can only be attached to the columns themselves. Central heating is available in each room.

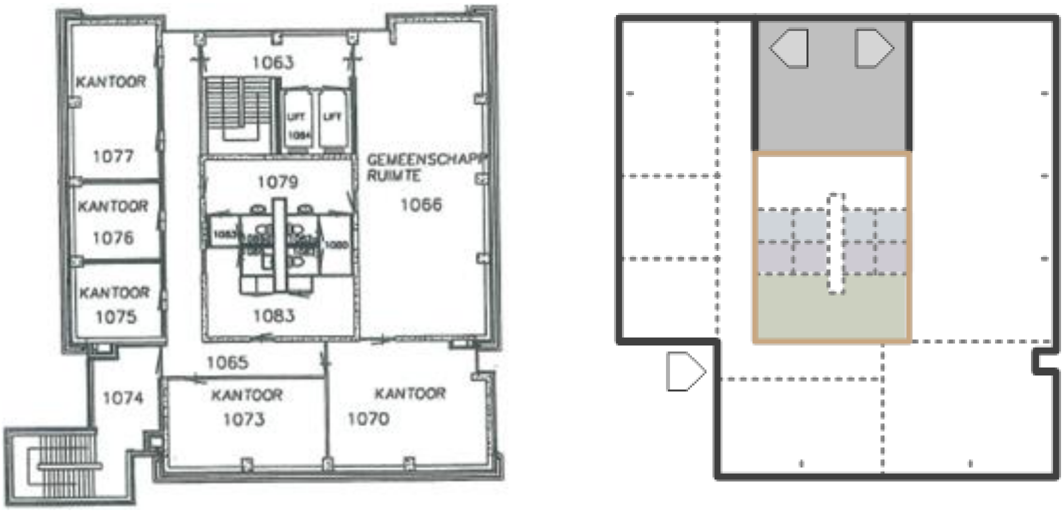


Figure 24. Flat 2nd floor original floorplan (left) and floorplan analysis

The original floorplan differs very slightly for each floor. These (minor) differences all involve interior walls that are either added to or absent from the general design (see figure 25). The costs involved with placing or removing such interior walls are relatively small, and no additional construction permit is required for such interventions, so it will be the main tool for determining the new floorplan compositions. Uncertainty regarding costs will play a large role in the reliability of the projected developer profit per design alternative. Replacing interior walls will allow for a large enough degree of variation in design alternatives to generate significantly different preference scores from both consumers and the developer (see chapter 13).

The low-rise extension has a similar floorplan design as the flat (see figure 26). Each room is 11 m², however the layout is rectangular instead of a more square shape. Sixteen of the rooms are suitable for living room or bedroom use (due to daylight entry requirements and the wish of the developer not to alter the façade). There is one load bearing interior wall across the length of the floor. The level has two exits: one leads to the interior staircase and one leads to an exterior fire escape. The upper two of the three floors are identical, but the ground floor used to be a cafeteria for the business units in the building. Together, SHS Delft and the commercial developer involved with the project decided to transform a major part of the ground floor into a leisure area for the future tenants of the building. Therefore the ground floor will not be included in the residential design research model. This would confuse financial comparisons between generated design alternatives and the actually realized design alternative.

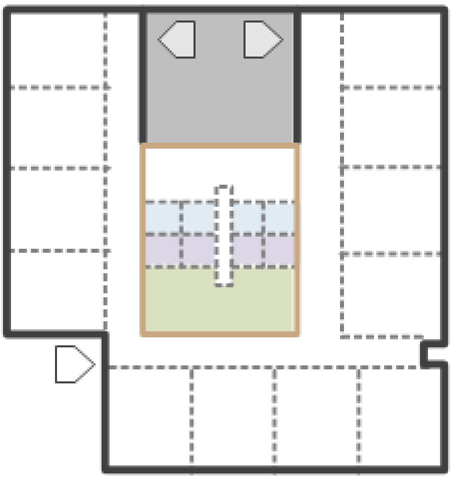


Figure 25. Generalized flat floorplan analysis

Additional to the technical limitations of the existing floorplans, there is some regulation that needs to be taken into consideration (see table 10). Especially the emergency routes are of great importance when determining possible independent housing designs. The current floorplans are already suitable in this regard for shared housing.

Figure 26. Low-rise 2nd floor original floorplan (above) and floorplan analysis

Enforcing party:	Shared housing constraints:	Independent housing constraints:
Delft fire department	Two emergency routes, accessible from each *private bedroom*	Two emergency routes, accessible from each apartment's *front door*
	Fire-resistant walls between dwellings and shared areas	Fire-resistant walls between dwellings and shared areas
Municipality (construction regulations)	Minimal intervention in existing load-bearing construction	Minimal intervention in existing load-bearing construction
	Daylight accessibility in all living rooms (including bedrooms)	Daylight accessibility in all living rooms (including bedrooms)
Developer	Minimal intervention in existing façade (due to permit complications)	Minimal intervention in existing façade (due to permit complications)

Table 10. Design limitations

9.3 Potential project strategies

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 consumer target groups which 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 27 illustrates how these two important decision variables would together influence the consumer preferences and financial feasibility of the project.

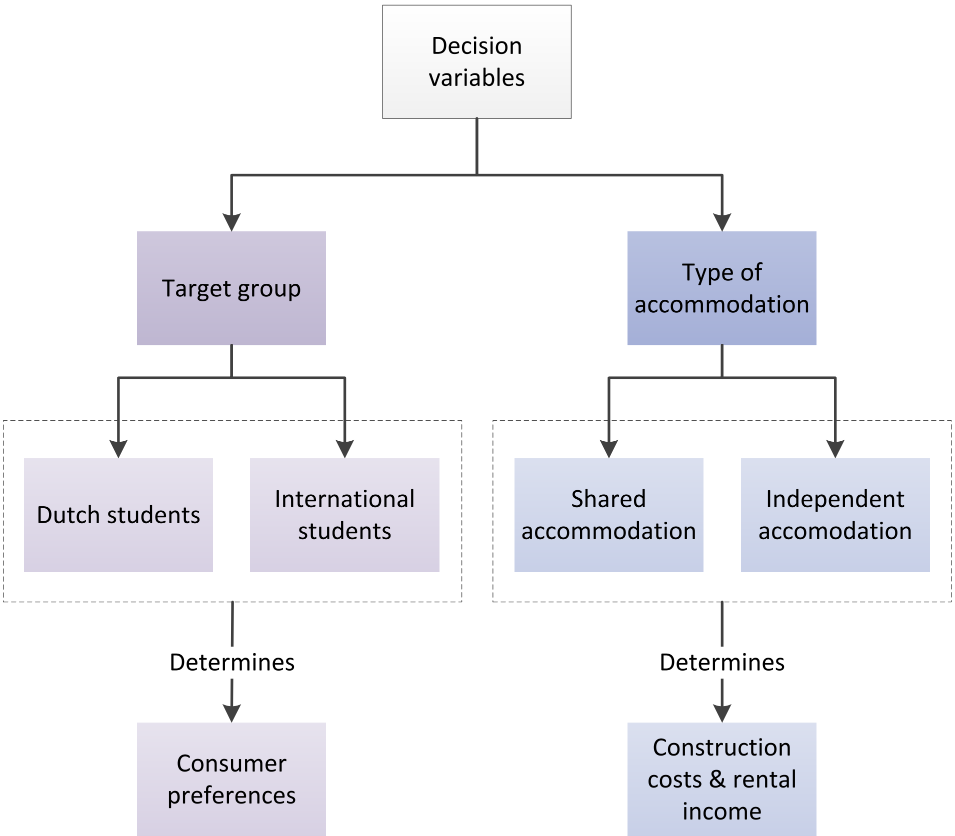


Figure 27. Initial decision variables the developer was faced with in the Zusterflat case (own ill.)

Based on these two variables a decision analysis can be applied by utilizing the outcomes to be produced by the research model. Because each decision variable is related to a major component of this research (consumer preferences and financial feasibility), it is expected that including them all will lead to sufficient feedback and data to test the posed hypothesis.

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 potential case strategies have been defined. Figure 28 visualizes the differences and similarities between these strategies. All three possible applications of the model will be used (see chapter 4) to achieve relevant results through this strategy analysis. First, it will be used to calculate the optimal space configuration (room types, numbers and sizes) for each shared housing strategy. This calculation will be based on both developer and consumer preferences. Second, the model will be used to evaluate the actually realized design and the manually designed independent housing alternatives. Then, these optimal configurations (i.e. most preferred design alternatives) are then compared to each other as visualized in figure 29. Lastly, 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.

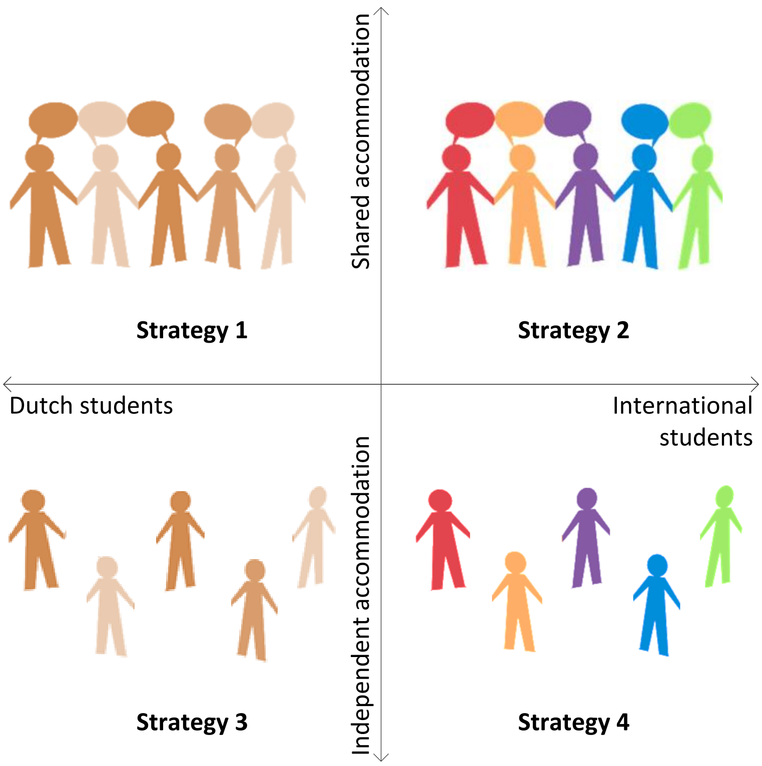


Figure 28. Strategies based on the two main decision variables for the Zusterflat case

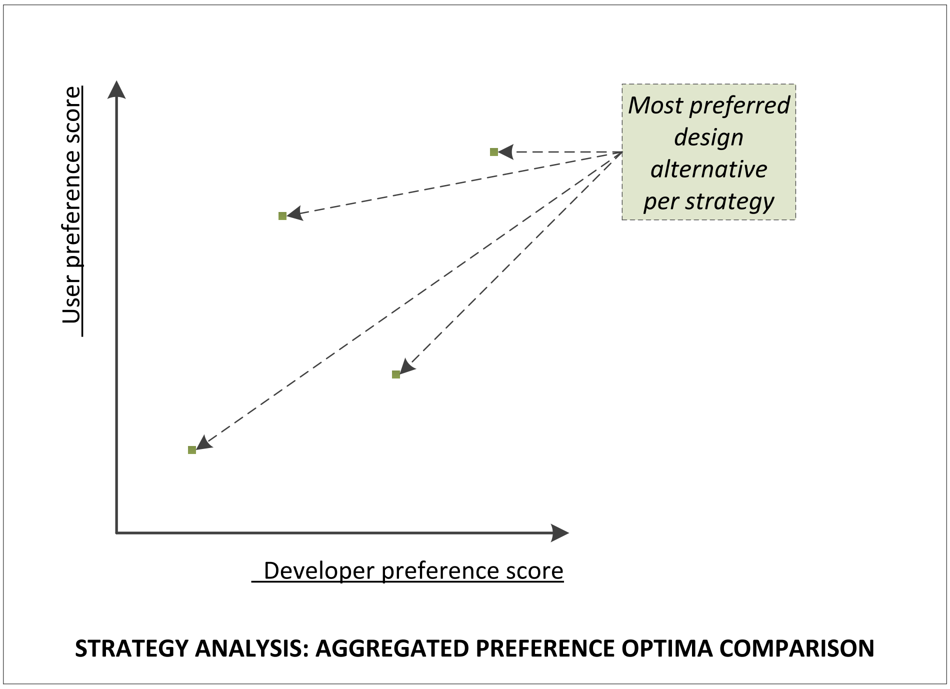


Figure 29. Aggregated preference optima comparison method

10. Questionnaire results

10.1 Shared housing

Respondents were asked to determine three data points for each personal preference curve. One data point related to an alternative with preference rating zero, one related to an alternative with preference rating ten and the third data point was to be determined by the respondent themselves. If hesitant, respondents were advised to select an alternative with a preference rating of five as the 'middle' alternative speaks more to the imagination than another random preference rating. Afterwards all scores were converted into a 0 - 100 measurement scale. The 0 - 10 scale was applied because respondents found it less difficult to apply; this may be because people are more used to a 0 - 10 (or 1 - 10) measurement scale, which is often used for educational grades and such.

Some respondents were unsure as where to draw the metaphorical line for characteristics that were associated with an infinite linear preference function. For example, some respondents considered an increase of living room size per definition as an improvement. This lead to confusion as to how many square meters should be selected as the most optimal alternative. They were instructed to imagine the hypothetical boundary for which no *significant* additional preference would be experienced per m² continuous increase. This clarification generated useful results. The surveys that were taken are added in appendix 1.

Dutch students

Living room GFA (m²) - Respondent:	Preference rating 0	Preference rating 50	Preference rating 100
1	18	30	45
2	20	60 (p.r. 80)	120
3	20	24	35
4	24	60	100
5	10	20	35
6	12	20	80

Table 11a. Consumer preference ratings - living room GFA

Bedroom GFA (m²) - Respondent:	Preference rating 0	Preference rating 50	Preference rating 100
1	8	18	30
2	10	16	25
3	10	15	24
4	10	20	30
5	10	17	25
6	12	25	50

Table 11b. Consumer preference ratings - bedroom GFA

Number of housemates - Respondent:	Preference rating 0	Preference rating 100	Preference rating 0
1	3	8	16
2	2	5	10
3	2	6	14
4	2	5	10
5	2	9	14
6	2	8	15

Table 11c. Consumer preference ratings - number of housemates

Rent price (€) - Respondent:	Preference rating 0	Preference rating 50	Preference rating 100
1	€450	€290	€0
2	€600	€350	€0
3	€500	€300	€100
4	€450	€300	€0
5	€450	€300	€0
6	€550	€470	€0

Table 11d. Consumer preference ratings - rent price

Preference weights - Respondent:	Living room GFA	Bedroom GFA	Number of housemates	Rent price	*Total*
1	25%	20%	40%	15%	*100%*
2	35%	20%	35%	10%	*100%*
3	20%	25%	35%	20%	*100%*
4	30%	25%	25%	20%	*100%*
5	25%	30%	30%	15%	*100%*
6	35%	20%	30%	15%	*100%*

Table 11e. Consumer preference weights

Trends

The preference curves for the shared living room size can be divided into two groups that both consist of three respondents. The first group consists of respondents with an optimum room size of 35 to 45 m^2. The respondents from the second group prefer much larger living rooms: 80 to 120 m^2. While these optimum values overall differ significantly, the minimum requirement values appear to be slightly more uniform. Each respondent answered their minimum living room size to be between 10 and 24 m^2. However, it is interesting to see that a larger living room size optimum is not necessarily linked to a larger living room size minimum. One respondent rated a living room of 80 m^2 as optimum size, while their minimum size was 12 m^2. Also, they rated a living room of 20 m^2 with a preference score of 50, which is comparable to the preference ratings of two respondents from the 'smaller living rooms' group. In addition, for four out of six respondents the preference curve resembled a linear function, while for the other half of the group a clear kink can be observed in the preference function.

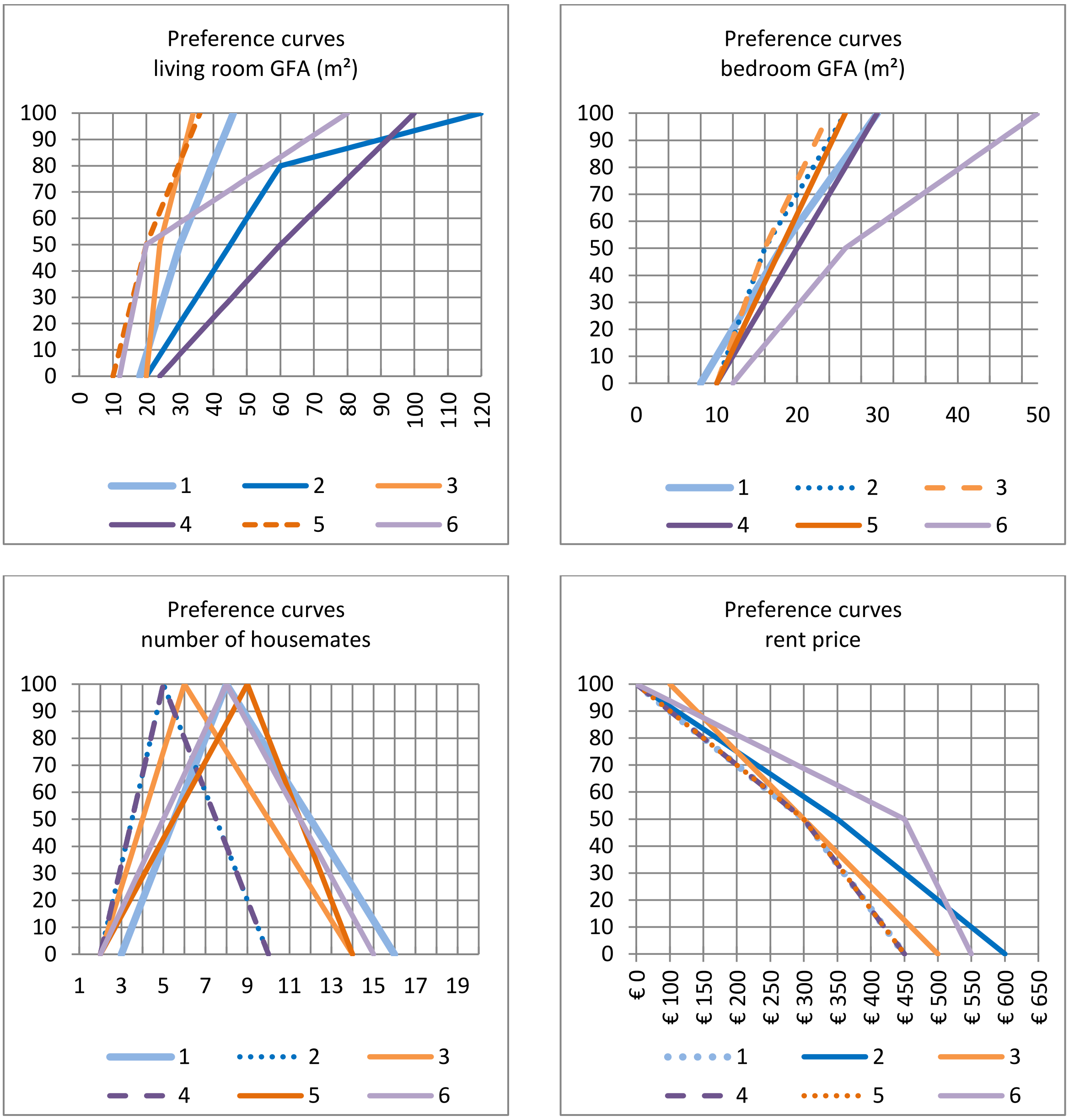


Figure 30. Shared housing preference curves as determined by current Zusterflat tenants

All respondents were much more in agreement on the matter of preferred bedroom size. Each minimum value lies between 8 and 12 m². Five out of six respondents chose their optimal bedroom size between 24 and 30 m². One outlier preferred a bedroom size of 50 m². This was also the only respondent for whom the preference curve showed a clear kink. This kink was still much less substantial than the kinks observed for the living room preferences.

Regarding number of housemates, the respondents were less in accordance. All but one respondent answered their minimum number of housemates to be two persons (including themselves). The remaining minimum number was three persons, again including themselves. Nonetheless the optimum number varied significantly per respondent: answers differed from five to nine persons. Two separate groups can be identified for the maximum amount of housemates. Two respondents required their house to be shared with a maximum number of ten persons in total. The remaining four respondents held a maximum limit of fourteen to sixteen housemates. Not one of the respondents considered their number of housemates preference curve to be a linear function. Unlike living room and bedroom size there was always a clear optimum after which their preference rating started to decline again, until it reached their maximum limit value.

All but one respondents stated their optimum monthly rent price (including service fees and possible rent benefit) to be €0,-. One person stated their preferred rent price was €100,-, for they disapproved of the notion of living somewhere for (nearly) nothing. Four respondents stated their preference rating would be 50 for a rent price of €290 or €300,-. The other two respondents were willing to pay higher rent prices for an equal preference rating (€350,- and €470,-). These respondents also stated to have a somewhat higher maximum rent price limit (€600,- and €550,- respectively) than the other four (€450,- to €500,-).

Regarding the preference weight assignment, the number of housemates and living room size showed the most fluctuation. Assigned weights differed from 25 to 40 percent and 20 to 35 percent respectively. When comparing the individual preference curves to the respondent's corresponding preference weights, it can be observed that persons who preferred an exceptionally large living room also assign slightly more weight than average to this characteristic. For the other three variables no such trend was established. However, to draw any valid conclusions on whether the assigned preference weights actually show any direct relationship to the stated preference curves, a larger group of respondents would be required.

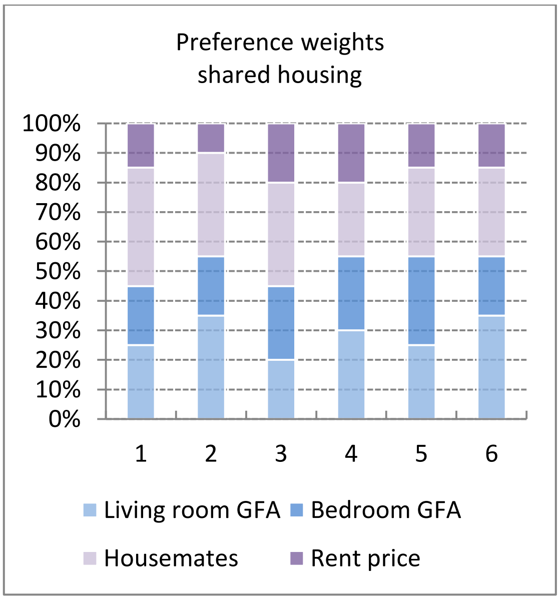


Figure 31. Shared housing preference weights as determined by current Zusterflat tenants

International students

Living room GFA (m²) - Respondent:	Preference rating 0	Preference rating 50	Preference rating 100
1	0	15	25
2	5	10	15
3	0	18	22
4	8	20	40
5	10	15	20

Table 12a. Consumer preference ratings - living room GFA

Bedroom GFA (m²) - Respondent:	Preference rating 0	Preference rating 50	Preference rating 100
1	10	15	20
2	10	16	24
3	8	14	20
4	12	20	25
5	14	25	30

Table 12b. Consumer preference ratings - bedroom GFA

Number of housemates - Respondent:	Preference rating 0	Preference rating 100	Preference rating 0
1	1	4	8
2	2	4	6
3	1	3	11
4	1	5	14
5	2	4	9

Table 12c. Consumer preference ratings - number of housemates

Rent price (€) - Respondent:	Preference rating 0	Preference rating 50	Preference rating 100
1	€450	€280	€0
2	€480	€300	€0
3	€400	€275	€0
4	€400	€300	€0
5	€450	€325	€0

Table 12d. Consumer preference ratings - rent price

Preference weights - Respondent:	Living room GFA	Bedroom GFA	Number of housemates	Rent price	*Total*
1	10%	30%	20%	40%	*100%*
2	20%	25%	25%	30%	*100%*
3	10%	25%	25%	40%	*100%*
4	5%	30%	15%	50%	*100%*
5	10%	20%	30%	40%	*100%*

Table 12e. Consumer preference weights

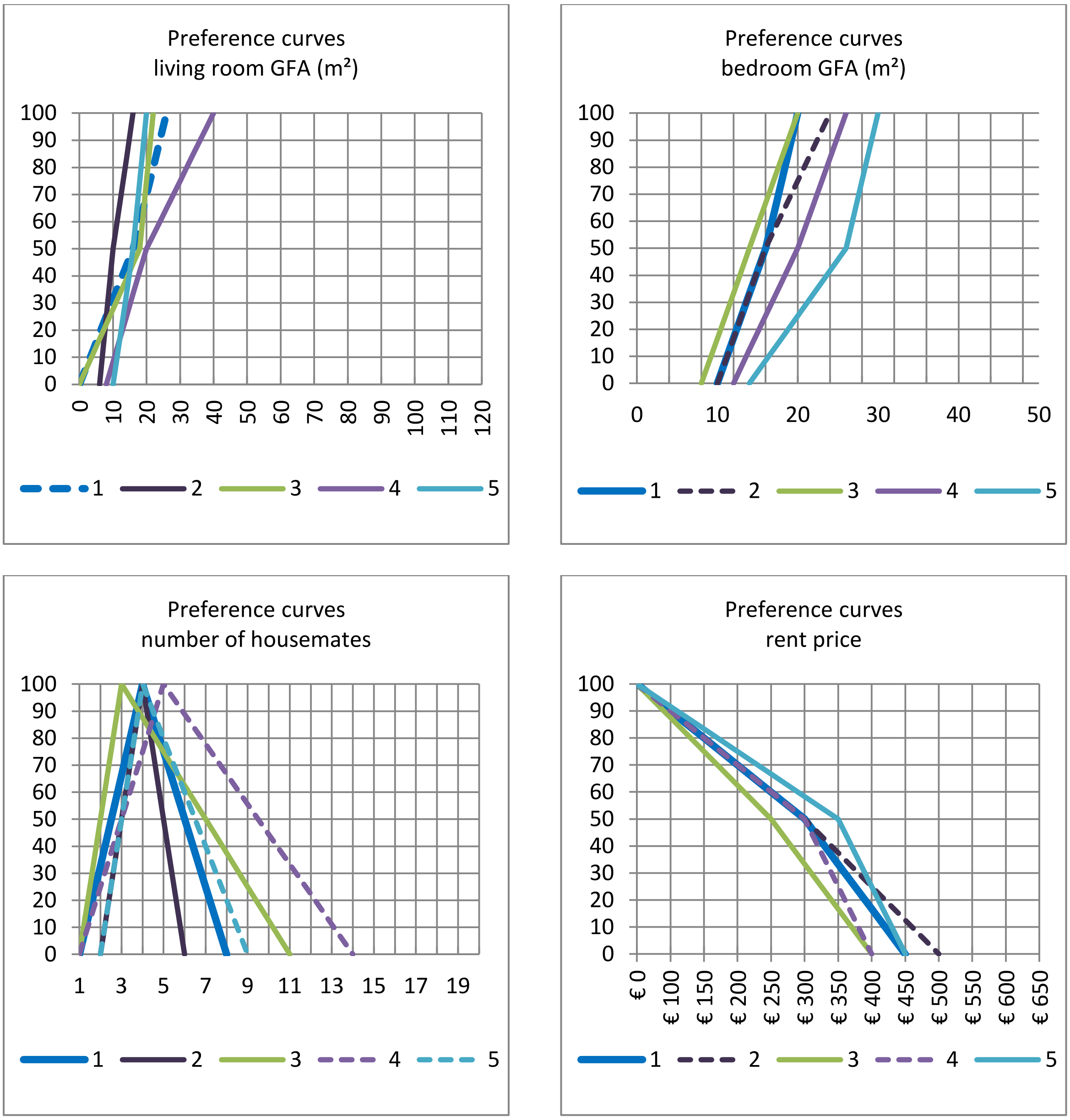


Figure 32. Shared housing preference curves as determined by international students

Trends

In contrast to Dutch students, two international students stated they did not require the presence of a shared living room area. The remaining three respondents stated they did require a shared living room, but preferred a smaller size than many of the Dutch students.

The minimum requirements for a bedroom were similar to the answers provided by the Dutch students: minimum 8 to 14 m² and a preference optimum of 20 to 25 m² (except for one outlier of 30 m²). Except for the one outlier, all preference curves approached linear functions.

International students stated to prefer less housemates than Dutch students: three would accept independent housing, but preference optimums differed between three to five housemates. The maximum number of housemates differed significantly for each respondent. Answers varied from six to fourteen persons.

All respondents decided on a maximum rent price in the region of €400,- to €480,-. On average, this is a little bit less than for Dutch student. This was expected, based on the results from the literature review. The international students also put significantly more weight on rent price than the Dutch students. In turn, living room size and number of roommates proved much less important to international students (see figure 33).

Overall, it can be concluded that international students appear to be slightly less demanding of the available space than Dutch students. This might be due to cultural differences, the fact that they live in the country for a relatively short period of time, or because their financial budget is more limited (which might affect their expectations). Conversely, they generally prefer to share their housing with less housemates than Dutch students. According to the rent price point system (see chapter 8) this is related to a higher rent price, which seems contradictory to the budget constraint. Nonetheless, each respondent did prefer to live with (a few) housemates as compared to living independently.

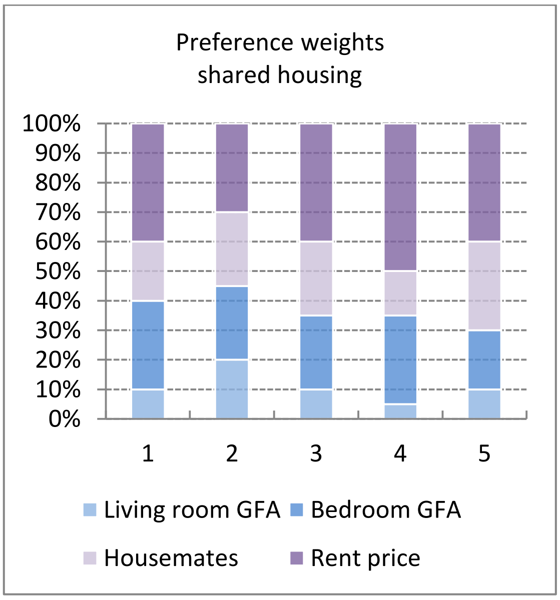


Figure 33. Shared housing preference weights as determined by international students

10.2 Independent housing

Independent housing was not part of the actual Zusterflat project. Therefore consumer preferences for this group of potential tenants are based on the stated preferences of students in Delft that either already live in independent student housing, or who have attempted to move to independent student housing within the past twelve months. Participants were instructed not to let their preferences be influenced by actual market circumstances, so e.g. their maximum preferred house size would not be limited based on the expected price for such a house.

Dutch students

House GFA (m^2) - Respondent:	Preference rating 0	Preference rating 50	Preference rating 100
1	22	32	45
2	24	35	50
3	35	45	55
4	20	30	40
5	50	80	100

Table 13a. Consumer preference ratings - house size GFA

Rent price (€) - Respondent:	Preference rating 0	Preference rating 50	Preference rating 100
1	€400	€250	€0
2	€550	€300	€0
3	€800	€500	€0
4	€500	€350	€0
5	€700	€400	€100

Table 13b. Consumer preference ratings - rent price

Preference weights - Respondent:	House size	Rent price	*Total*
1	50%	50%	*100%*
2	40%	60%	*100%*
3	40%	60%	*100%*
4	35%	65%	*100%*
5	50%	50%	*100%*

Table 13c. Consumer preference weights

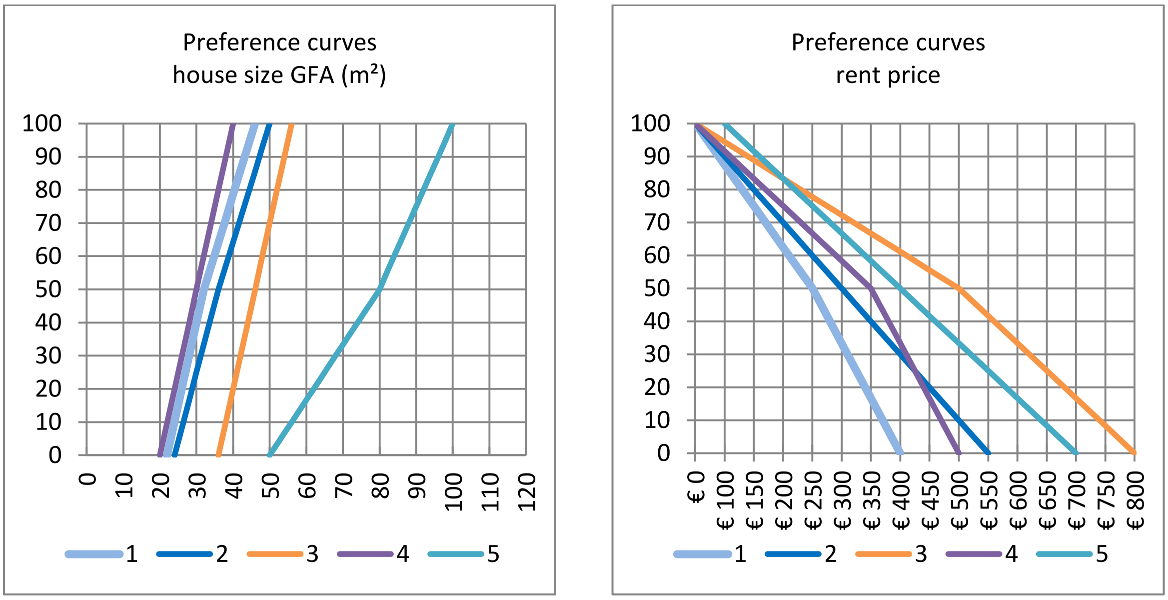


Figure 34. Independent housing preference curves as determined by non-Zusterflat tenants

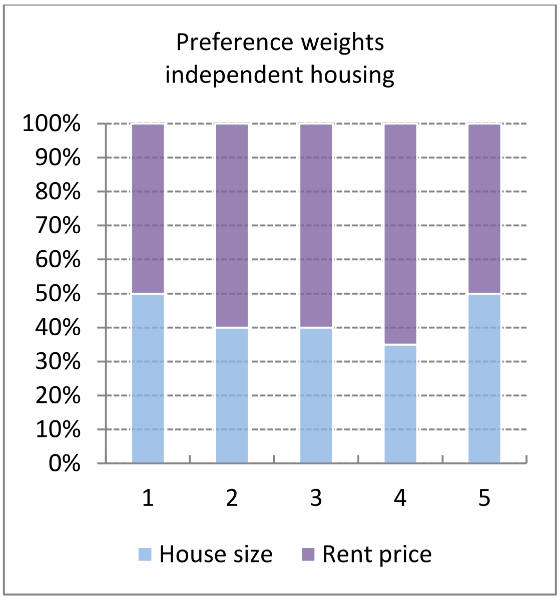


Figure 35. Independent housing preference weights as determined by non-Zusterflat tenants

Trends

As observed for shared housing, there are some main trends that can be identified for the studied sample. Most respondents stated their minimum house size requirement to be relatively close to their optimal house size: these 0 and 100 alternatives were often no more than 20 m² apart. One respondent was an exception to this trend. Not only did they require their home to be at least 50 m², which is larger than most respondents' optimal house size, they also stated a significant increase in preference score for house sizes up to 100 m².

Coincidently, for this target group there was also one respondent who stated they would prefer to pay at least €100,-. For the Dutch students in the shared housing group this was the case for a single respondent as well. All other respondents would prefer to not pay rent, if possible. The maximum rent price requirements that were stated differed considerably between respondents. Answers fluctuated between €400,- and €800,-. Respondents were all instructed to include service costs and exclude rent benefit, thus these variations are unlikely to be caused by a different interpretation of the survey question. It is plausible that students with a larger monthly income prefer to live independently, while students who reside in shared housing have a more standardized income. However, three out of five respondents stated maximum rent prices similar to the Dutch students in the shared housing group. So while there is more differentiation in the rent price limit for independently living students, this does not mean that all students from this target group are able to spend more than those from the shared housing group.

Regarding the preference weights, the primary trend is roughly a 50-50 division between house size and rent price. Three out of five respondents stated they put slightly more importance on rent price than on house size. No substantial outliers were observed.

International students

The percentage of international students in Delft is significant and has been rising continuously for the past decade (from 10 percent in 2005 to 18 percent in 2015) (TU Delft, 2016). In the year 2013 the total amount of international students was 2.882 to be precise (TU Delft, 2016). This specific group of students has a 10 percent lower average spendable income than Dutch students: only €630,- per month, of which they on average spend 75 percent on housing (Apollo, 2015). This means their average rent price paid is roughly €472,50 including service costs. Another contrast to the Dutch student population is the percentage living independently: 29 percent of Dutch students live independently, compared to 15 percent of international students (Apollo, 2015). For the year 2013, this translates into only 2,4 percent of all students being independently living international students. It is probable that, in reality, this figure is even lower. The 15 percent mentioned is a national average and in Delft specifically there is a shortage for independent student housing (Apollo, 2013). The majority of independent student housing is owned and operated by housing corporations. As these institutions typically assign dwellings to students who have already been a member of their corporation for a few years, and thus have accumulated 'waiting time', it is likely that international students are not often assigned an independent dwelling. In fact, in 2013 the required waiting time for an independent student dwelling in Delft was no less than 31 months (DUWO, 2014).

While conducting the student preferences study, this statistic was found to cause problems regarding data collection. Additionally, the particularly limited size of this niche group, their lower average spendable income and their reluctance to move during their stay in the Netherlands (Apollo, 2015) made them an illogical target group for the Zusterflat project. This also clarifies why this group was never actually considered during the project's initiative phase.

It is not the aim of this study to perform a primarily speculative analysis on an (currently) almost non-existent market segment. Therefore, due to lack of reliable data (i.e. the measured preferences of international students who have actually had the opportunity to live in independent student housing in Delft) and the relatively small number of potential decision makers that form this demographic group, the strategy of 'independent housing for international students' is omitted from the rest of this research.

11. Developer preference curve

Based on an interview held with the developer involved with the case study, an IRR (internal rate of return) based preference curve was drawn. Lagrange interpolation was applied to determine the preference values for each IRR value. An approximation of this curve can be seen in figure 36.

When constructing the research model it appeared that the What'sBest! add-in used for the model (see chapter 12) was not compatible with the IRR calculation function in Microsoft Excel. To solve this problem, the rent revenue values associated with the three data points for the IRR curve were used instead. This resulted into a preference curve with a small deviation from the original (see figure 37). While this adjustment slightly reduces the model's accurateness regarding the case study, this deviation would not affect the preference based design system's delivered proof of concept.

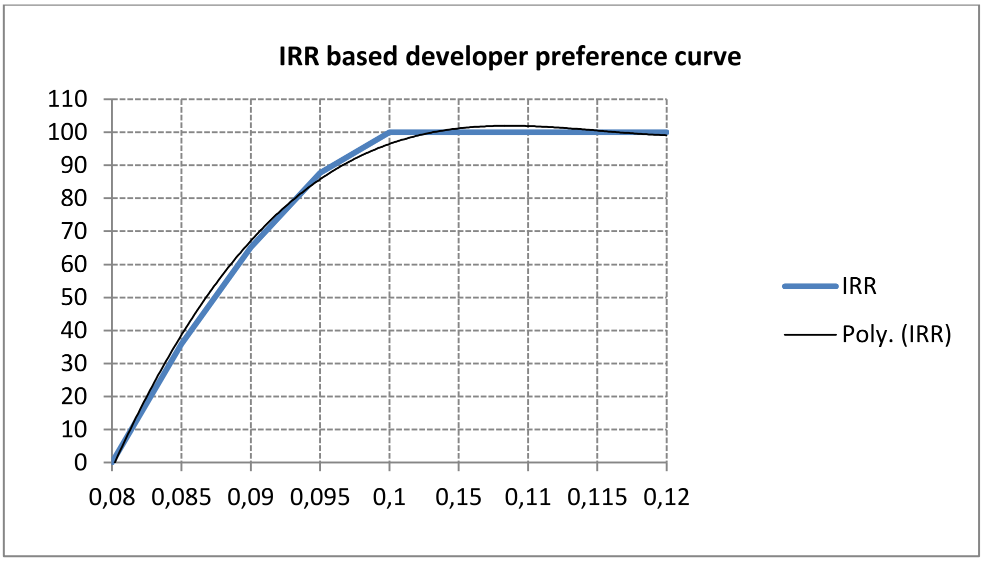


Figure 36. Approximation of the IRR based developer preference curve

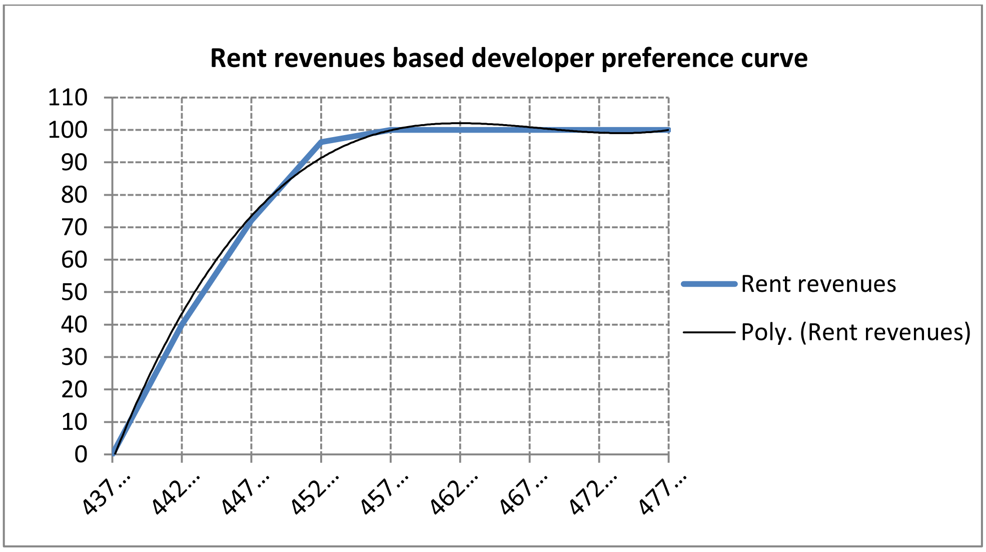


Figure 37. Approximation of the rent revenues based developer preference curve

PART IV RESEARCH MODEL

12. Model specification

The research model will be created in Microsoft Excel. This software is relatively easy to use and allows for plenty mathematical functions to achieve the model's objectives. A Microsoft Excel suitable add-in called What'sBest! (created by LINDO Systems) will be used to generate new design alternatives, optimized for the relevant criteria. For screenshots of the model, see appendix 6.

12.1 Constructing the model

In order to test the model, and to generate valid outcomes for the posed research questions, the model needs to adequately reflect the Zusterflat project's context. Aside from configuring the consumer preferences to correspond with those of the relevant end-users, the selected variables first need to be processed into the model. Chapter 8 discussed these variables.

Also, the model needs to incorporate the technical and legislative limitations of the Zusterflat building. It should only produce realistic design alternatives, that could actually be realized. This means that the model will be specified to only generate design configurations for which interior walls are placed correctly (i.e. attached to the load bearing columns). This results in twelve 'areas' of 11 m² that should be allocated by the model for the flat, or sixteen for the low-rise extension. As the shared facilities (kitchen, bathrooms, toilets) are already situated in the centre of each floor, only a living room and bedrooms need to be assigned per floor. The area where the shared facilities are currently located does not have any daylight accessibility; it is thus not suitable for transformation into a living room or bedrooms.

The rent price point system is indifferent of the number of shared rooms. It only takes into account the total number of square meters for all shared rooms. Therefore, the model will not assign more than one living room per shared dwelling. The size of this living room, which does directly affect the maximum allowed rent price, will be determined by the model for each generated design alternative. This is also true for the number of bedrooms per shared dwelling (which equals the number of housemates), and the size of each bedroom.

> The research model constructed for exploring shared housing design alternatives will not be suitable for generating independent housing alternatives. This is mainly due to the additional emergency routes that need to be included in the design for independent housing, and the different types of areas that would need to be allocated. The model could be adjusted, but this would mean significant alterations need to be made to every single aspect of the model. As this is not feasible within the limited timeframe for this graduation thesis, the choice was made to manually construct multiple independent housing design alternatives. The research model will then be applied to evaluate these design alternatives, based on the measured consumer preferences for independent housing.

Tables 14 and 15 provide an overview of all input required for the model. The input for the financial variables will be based on the actual parameters applied to the Zusterflat case. Figures 38 and 39 illustrate how the model determines the preference scores on which design alternatives will be compared. The coloured boxes indicate where input is needed. The white boxes indicate output delivered by the model. Because the independent housing alternatives will only be evaluated by the model, as they are manually generated, there is no automated optimization cycle for this housing type. The design constraints and financial constraints in the figures symbolize the practical limitations to the possible design alternatives. Fixed financial variables, which are not included as preference criteria (see bottom row of table 14), are included in the figures as they influence the IRR value achieved by each design alternative.

Input	Measurement	Criteria/variable
Consumer preferences (shared housing)	3 points of Lagrange curve; (x0, y0), (x1, y1) and (x2, y2) and criteria weights	1. Size of living room
		2. Size of bedrooms
		3. Number of housemates
		4. Rent price
Consumer preferences (independent housing)	3 points of Lagrange curve; (x0, y0), (x1, y1) and (x2, y2) and criteria weights	1. Size of dwelling
		2. Rent price
Developer preferences	3 points of Lagrange curve; (x0, y0), (x1, y1) and (x2, y2)	1. Internal Rate of Return
Design constraints (shared housing)		1. Total GFA to be allocated per floor
		2. Placing of interior walls (the GFA for each room must be a plurality of 11 m²)
Financial constraints		1. Rent price point system settings
Financial variables (included in DCF calculations)		1. Construction costs
		2. Additional costs
		3. Lease costs
		4. Inflation rate
		5. Rent increase

Table 14. Research model input

Output	Value	Unit of value
Design output (shared housing)	1. Size of living room	m² GFA
	2. Size of bedrooms	m² GFA
	3. Number of bedrooms (= number of housemates)	# (per bedroom size)
	4. Rent price	€/month
Financial output	1. Internal Rate of Return	%
Consumer preference score	Weighted sum of all design criteria preference ratings	Score between 0 - 100
Developer preference score	Financial criteria preference rating	Score between 0 - 100
Overall preference rating	Weighted sum of all decision makers' preference scores	Score between 0 - 100

Table 15. Research model output

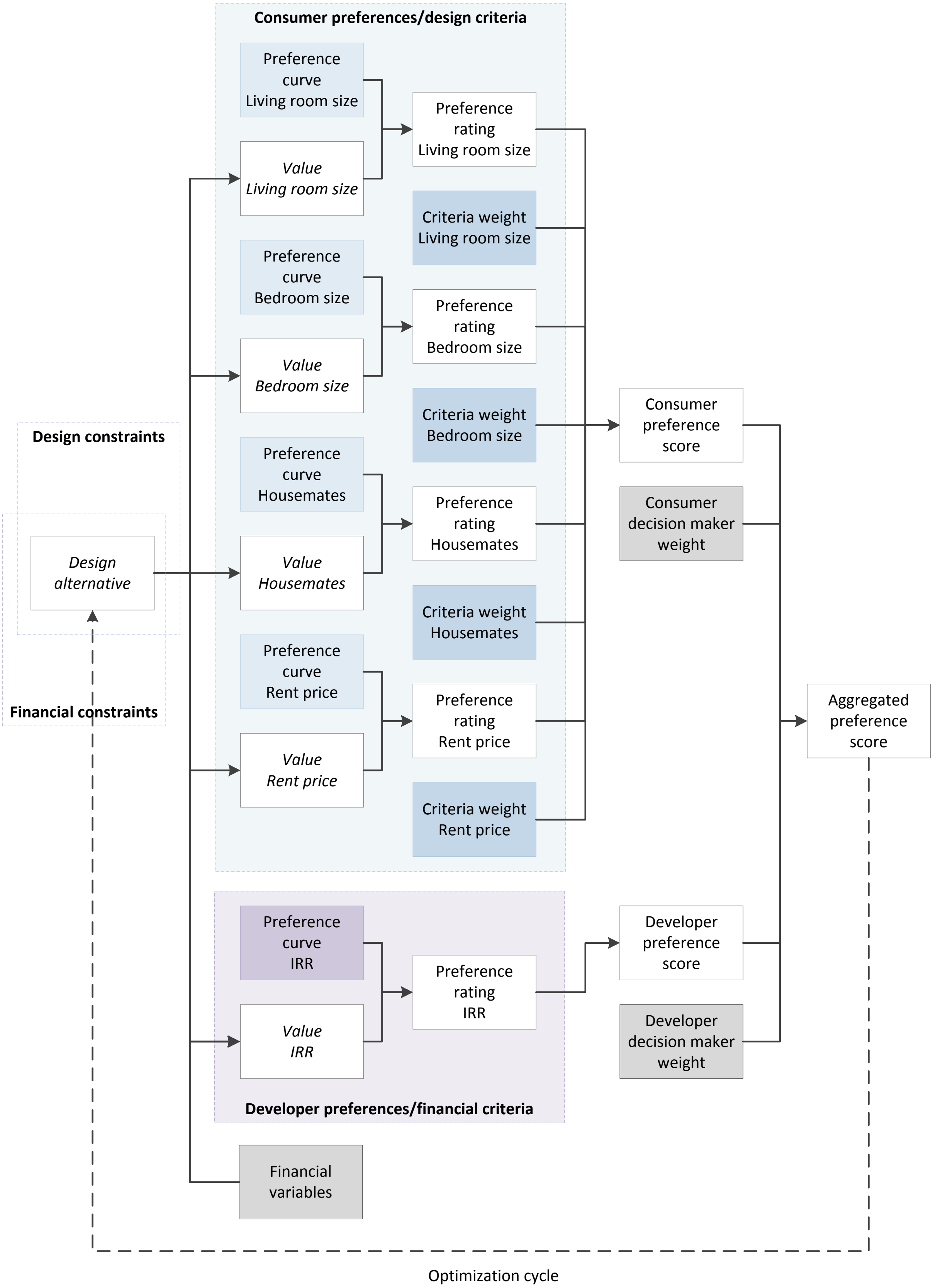


Figure 38. Shared housing research model visualisation

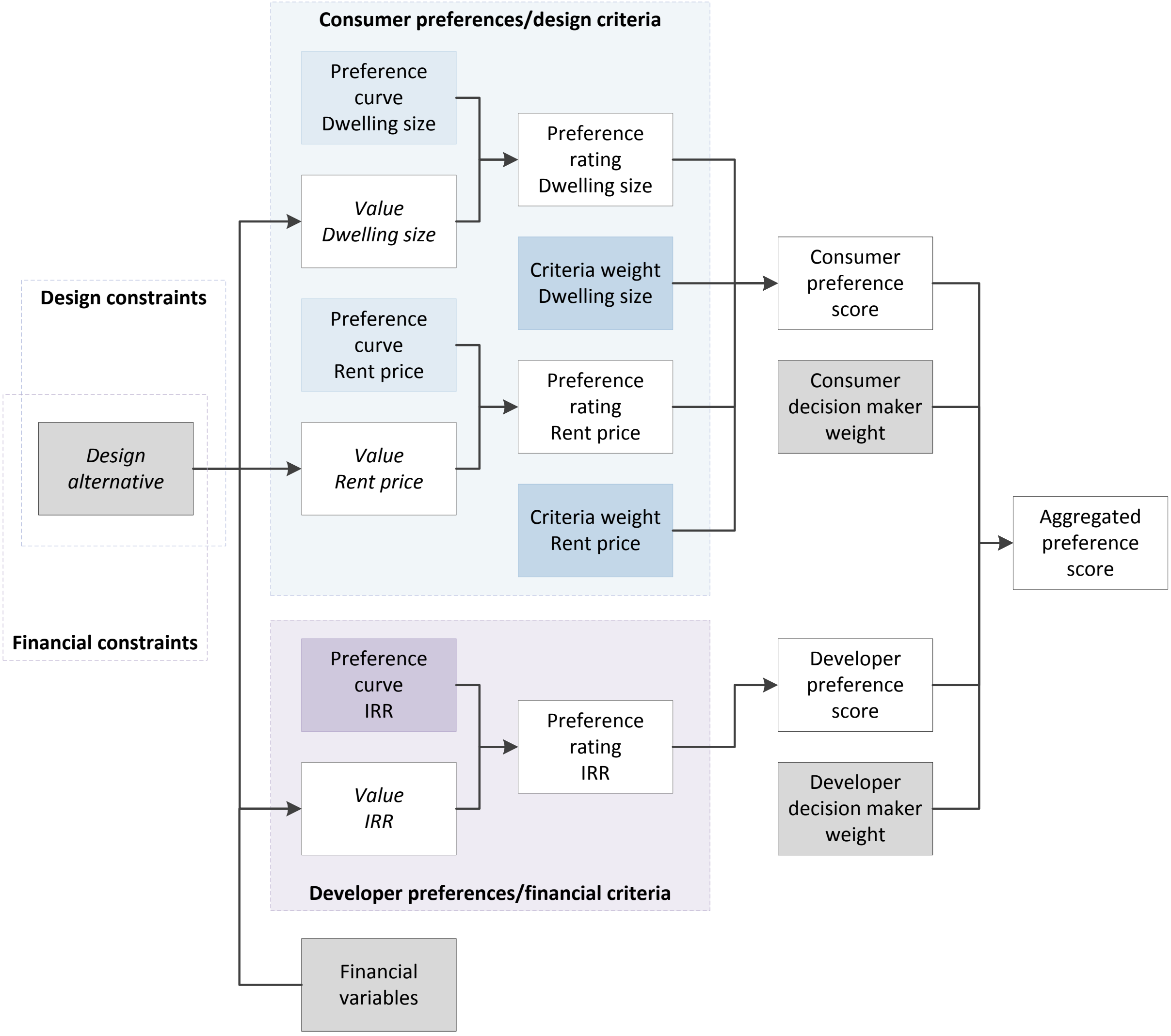


Figure 39. Independent housing research model visualisation

Figures 40a and b illustrate the concept of how the most preferred design alternative is selected by the model. Based on the validation interviews, the developer might 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.

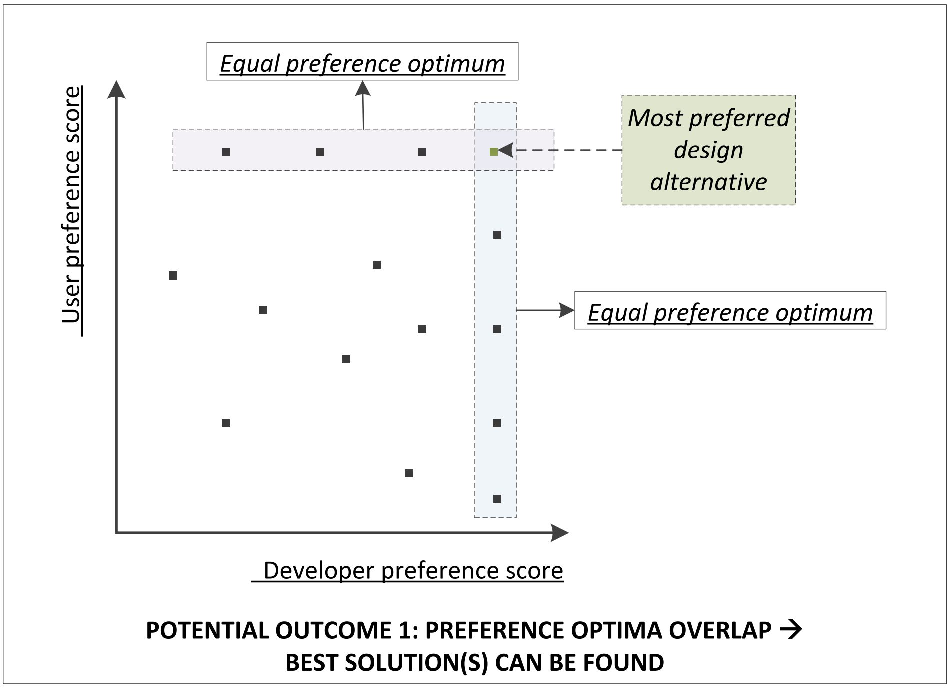


Figure 40a. Visualisation of method to select the most preferred design alternative

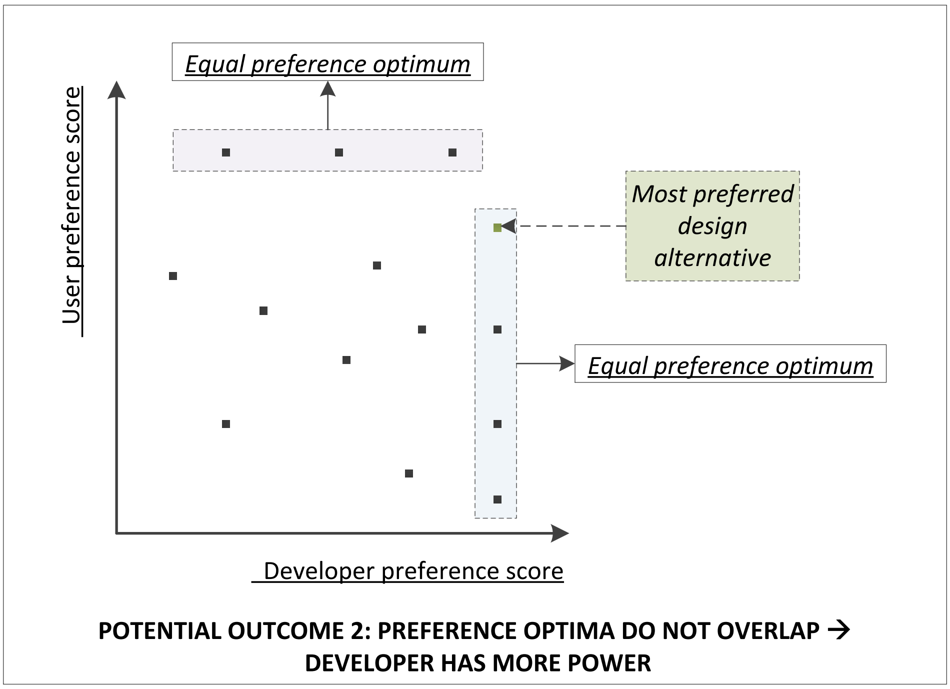


Figure 40b. Visualisation of alternative method to select the most preferred design alternative

PART V RESULTS AND CONCLUSIONS

13. Model results

13.1 Shared housing

For the flat floorplan design, there are 105 different possible alternatives that can be generated by the model. For the low-rise floorplan there are even more; 762 different possible design alternatives.

Of course, the design alternative (i.e. floorplan composition) which is selected by the model depends on the consumer and developer preferences that are put into the model. Seven interesting design alternatives that were generated by the model were selected to be compared to the actual realized floorplan designs (also included below as alternatives 1 and 2). These seven alternatives (alternatives 3 through 9) were based on the three possible strategies (see chapter 9). As some alternatives generated the same (floorplan) design configuration, not each alternative will be evaluated on different decision maker weights. These evaluations are referred to as 'analysis a' and 'analysis b' (see below).

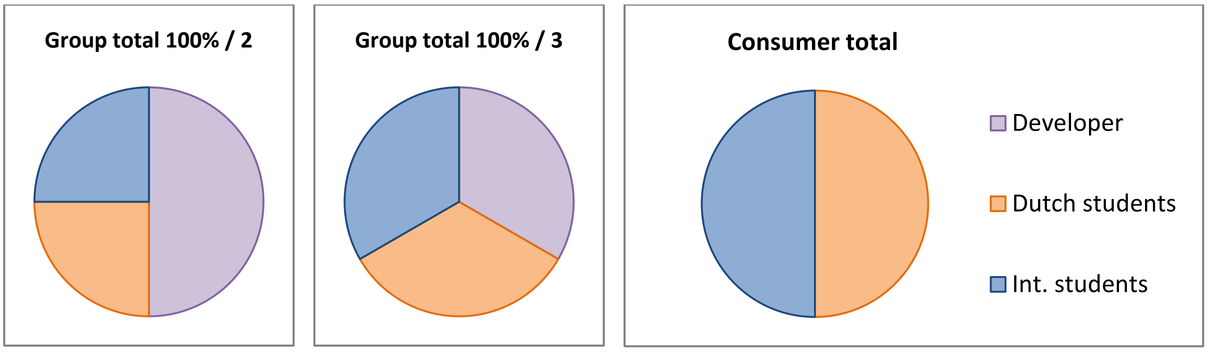


Figure 41. Decision maker weight divisions: analysis a (left), analysis b (middle), and consumer total (right)

Alternative 1 - Actually realized floorplans for Dutch students

- Analysis 1a (preference weight developer 50%, Dutch students 25%, international students 25%)
- Analysis 2b (preference weight developer 33,3%, Dutch students 33,3%, international students 33,3%)

Alternative 2 - Actually realized floorplans for international students

- Analysis 2a (preference weight developer 50%, Dutch students 25%, international students 25%)
- Analysis 2b (preference weight developer 33,3%, Dutch students 33,3%, international students 33,3%)

Alternative 3 - Optimized for developer preferences (preference weight developer 100%, Dutch students 0%, international students 0%)

- Analysis 3a (preference weight developer 50%, Dutch students 25%, international students 25%)
- Analysis 3b (preference weight developer 33,3%, Dutch students 33,3%, international students 33,3%)

Alternative 4 - Optimized for total group preferences

- **Alternative 4a** (preference weight developer 50%, Dutch students 25%, international students 25%)

- **Alternative 4b** (preference weight developer 33,3%, Dutch students 33,3%, international students 33,3%)

Alternative 5 - Optimized for developer preferences and Dutch students preferences (preference weight developer 50%, Dutch students 50%, international students 0%)

Alternative 6 - Optimized for developer preferences and international students preferences (preference weight developer 50%, Dutch students 0%, international students 50%)

Alternative 7 - Optimized for overall consumer preferences (preference weight developer 0%, Dutch students 50%, international students 50%)

- Analysis 7a (preference weight developer 50%, Dutch students 25%, international students 25%)
- Analysis 7b (preference weight developer 33,3%, Dutch students 33,3%, international students 33,3%)

Alternative 8 - Optimized for Dutch students preferences (preference weight developer 0%, Dutch students 100%, international students 0%)

- Analysis 8a (preference weight developer 50%, Dutch students 25%, international students 25%)
- Analysis 8b (preference weight developer 33,3%, Dutch students 33,3%, international students 33,3%)

Alternative 9 - Optimized for international students preferences (preference weight developer 0%, Dutch students 0%, international students 100%)

For the group preference score (i.e. the aggregated preference score of all decision makers, based on the generated design configuration and selected decision maker weights) of each alternative see table 16a. Table 16b summarizes which alternatives are related to which design configuration, and specifies the decision maker preference scores for each configuration. For the exact composition of each design configuration a clear overview is provided on pages 83 - 87.

Alternative/ analysis	Design configuration	Group preference score	Ranking (based on group pref. score)
1	1	-	-
1a		25	12
1b		33	8
2	2	-	-
2a		29	10
2b		34	8
3	3	75	1
3a		56	3
3b		49	5
4	-	-	-
4a	3	56	3
4b	3	49	5
5	3	54	4
6	3	58	2
7	4	47	6
7a		24	13
7b		32	9
8	5	44	7
8a		26	11
8b		33	9
9	5	49	5

Table 16a. Group preference score per alternative

Design config.	Related alternatives	Group preference score margin	Developer preference score	Dutch students preference score	Int. students preference score
1	Realized for Dutch students (1)	25 - 33	0	49	51
2	Realized for international students (2)	29 - 34	12	42	49
3	Optimized for developer (3) and group total (4, 5 & 6) preferences	49 - 75	75	32	40
4	Optimized for consumer total (7) preferences	24 - 47	2	44	49
5	Optimized for Dutch students (8) and international students (9) preferences	26 - 49	6	43	49

Table 16b. Alternatives per design configuration (generated by the model)

Each design configuration will be evaluated as described in chapter 9 (see figure 29). In order to do so, while taking into account the two different decision maker weight divisions, each decision maker preference score has been adjusted to reflect analysis a and b (see table 17). These figures have been visualised in figures 42a and b.

Design configuration	Developer preference score	Adjusted developer preference rating	Total consumer preference score	Adjusted consumer preference score
	Analysis a (0,50)	Analysis b (0,33)	Analysis a (0,50)	Analysis b (0,66)
1	0	0	50	60
2	12	7	46	55
3	75	45	36	43
4	2	1	47	56
5	6	4	46	55

Table 17. Adjusted preference scores per design configuration

DECISION MAKER WEIGHT DIVISION
50% – 25% – 25% (analysis a)

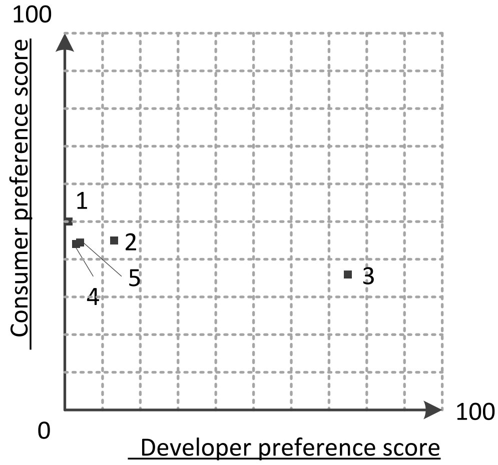


Figure 42a. Preference scores per design configuration corresponding with analysis a

DECISION MAKER WEIGHT DIVISION
33,3% – 33,3% – 33,3% (analysis b)

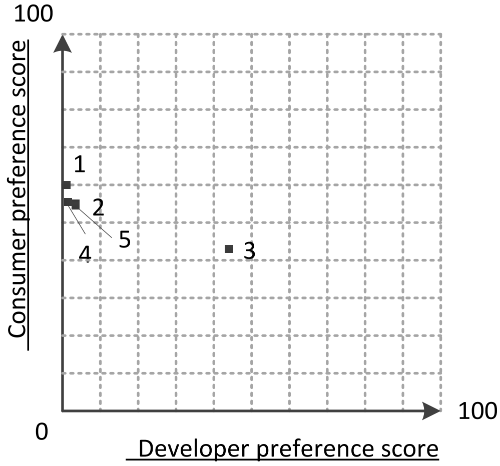
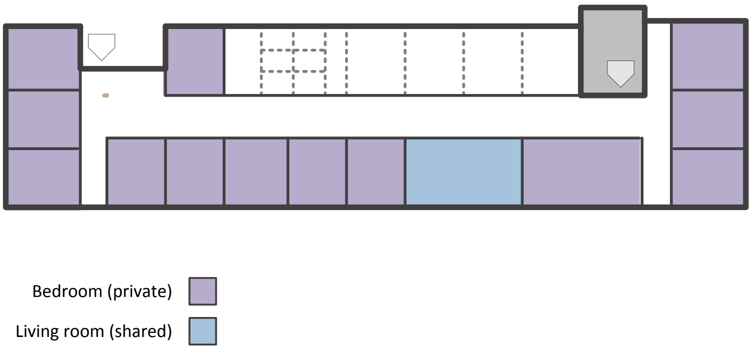


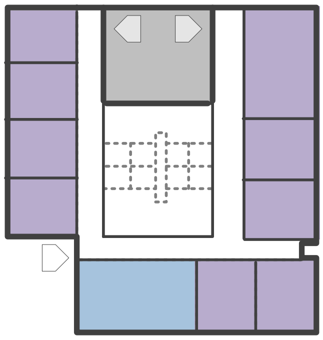
Figure 42b. Preference scores per design configuration corresponding with analysis b

Figures 42a and b show how different decision maker weight divisions influence the outcome of each analysis. While design configuration 3 is the most preferred configuration for the developer in both cases, its relative preference score is greatly affected by the assigned weights.

It is interesting to see that the two realized configurations (1 and 2) have very low developer preference scores. This indicates that the developer for this project has put a lot of emphasis on consumer preferences when designing the selected floorplans. Also, configuration 1 has a higher consumer preference score than the configurations generated by the model that were optimized for consumer preference scores. This is because this configuration generates an IRR of 7,7 percent, which is below the model's minimum constraint of 8,0 percent. This deviation between stated developer preference and the realized configuration has to do with the fact that configuration 2 (realized as well) achieves an IRR of 8,3 percent. This compensates for the missing rent revenues of configuration 1. Such a combined strategy shows again how the developer has attempted to accommodate student preferences as much as possible, without jeopardizing the project's financial feasibility.

Design configuration 1 | Actually realized floorplan composition for Dutch students





Type	Size (m²)	Flat Quantity	Flat Rent points	Flat Uncapped rent	Flat Capped rent	Low-rise Quantity	Low-rise Rent points	Low-rise Uncapped rent	Low-rise Capped rent
Living room	22	1	-	-	-	1	-	-	-
Bedroom	11	8	100	196,46	196,46	12	89	174,83	174,83
Bedroom	22	1	163	320,17	300,-	1	152	298,58	298,58
Bedroom	33	-	-	-	-	-	-	-	-
Bedroom	44	-	-	-	-	-	-	-	-
Tenants		9				13			
Rent per floor				1.891,85	1.871,68			2.396,54	2.396,54
Total rent revenue				22.702,20	22.460,16			4.793,08	4.793,08
Overall IRR		7,7%							

Table 18. Actually realized floorplan composition for Dutch students

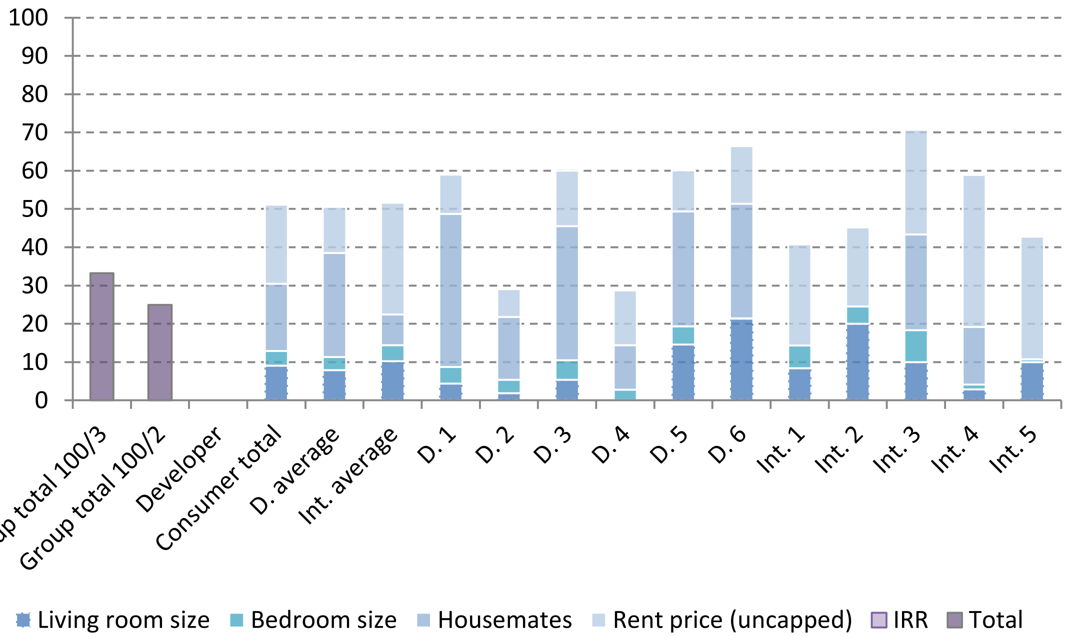
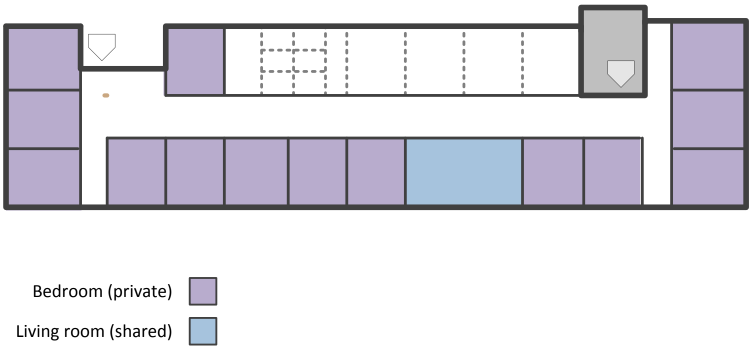
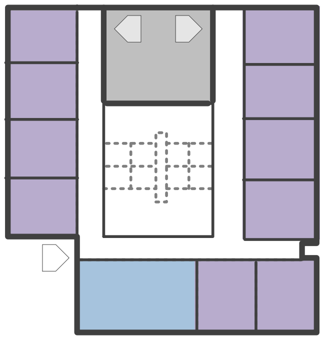


Figure 43. Preference scores for actually realized floorplan composition for Dutch students

Design configuration 2 | Actually realized floorplan composition for international students





Type	Size (m²)	Flat Quantity	Flat Rent points	Flat Uncapped rent	Flat Capped rent	Low-rise Quantity	Low-rise Rent points	Low-rise Uncapped rent	Low-rise Capped rent
Living room	22	1	-	-	-	1	-	-	-
Bedroom	11	10	98	192,52	192,52	14	88	172,88	172,88
Bedroom	22	-	-	-	-	-	-	-	-
Bedroom	33	-	-	-	-	-	-	-	-
Bedroom	44	-	-	-	-	-	-	-	-
Tenants per floor		10				14			
Rent per floor				1.925,20	1.925,20			2.420,32	2.420,32
Total rent revenue				23.102,40	23.102,40			4.840,64	4.840,64
Overall IRR		8,3%							

Table 19. Actually realized floorplan composition for international students

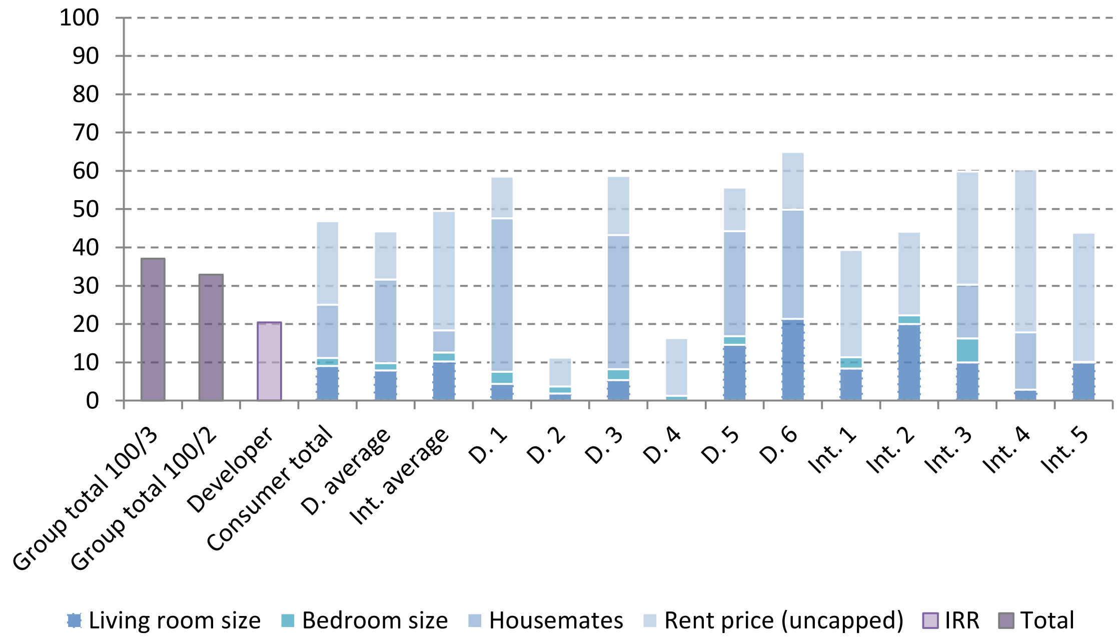
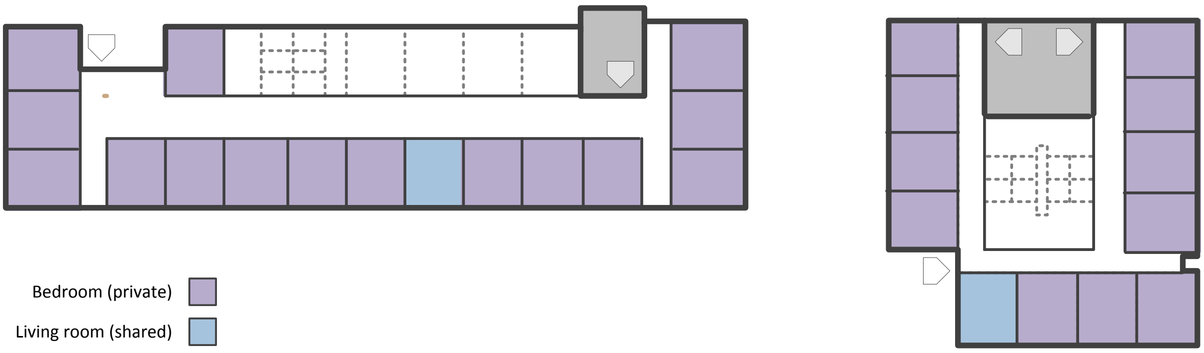


Figure 44. Preference scores for actually realized floorplan composition for international students

Design configuration 3 | Floorplan composition optimized for developer and group total



Type	Size (m²)	*Flat* Quantity	Rent points	Uncapped rent	Capped rent	*Low-rise* Quantity	Rent points	Uncapped rent	Capped rent
Living room	11	1	-	-	-	1	-	-	-
Bedroom	11	11	89	174,83	174,83	15	84	165,02	165,02
Bedroom	22	-	-	-	-	-	-	-	-
Bedroom	33	-	-	-	-	-	-	-	-
Bedroom	44	-	-	-	-	-	-	-	-
Tenants		11				15			
Rent per floor				1.923,13	1.923,13			2.475,30	2.475,30
Total rent revenue				23.077,56	23.077,56			4.950,60	4.950,60
Overall IRR		9,2%							

Table 20. Floorplan composition optimized for developer and group total

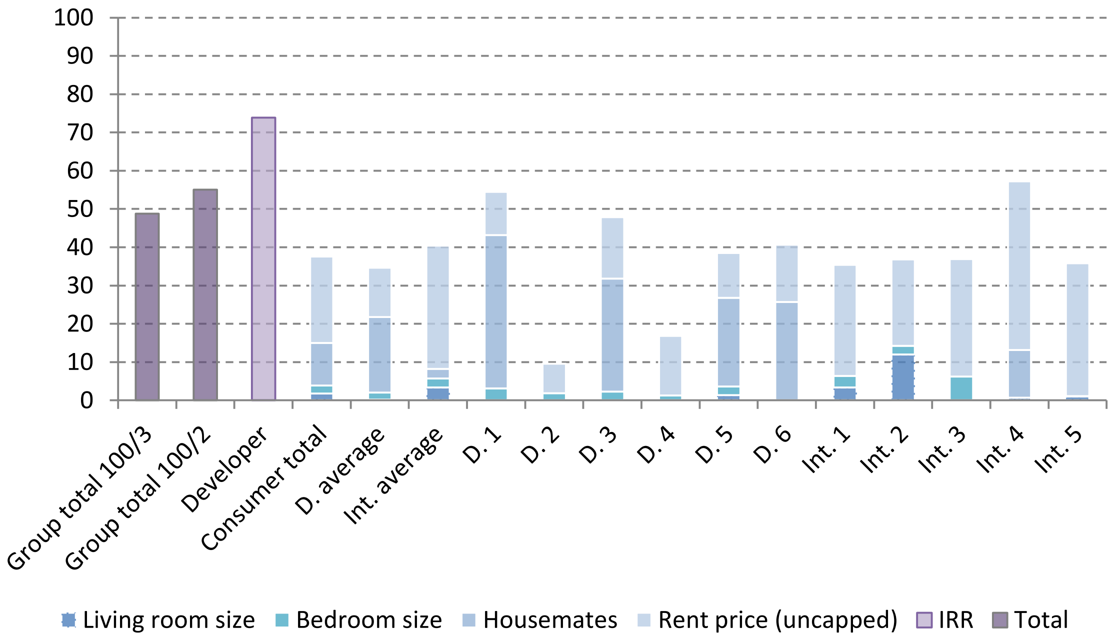
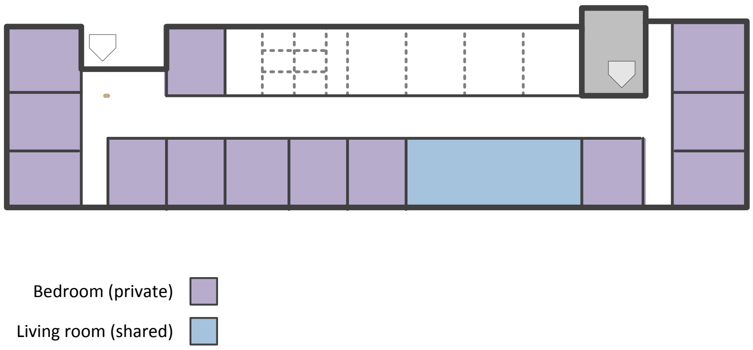
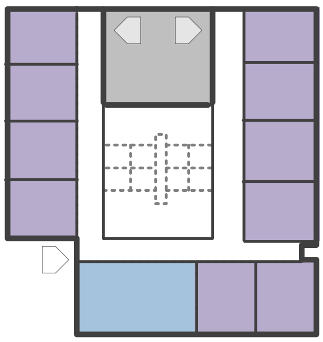


Figure 45. Preference scores for floorplan composition optimized for developer and group total

Design configuration 4 | Floorplan composition optimized for consumer total





Type	Size (m²)	Flat Quantity	Flat Rent points	Flat Uncapped rent	Flat Capped rent	Low-rise Quantity	Low-rise Rent points	Low-rise Uncapped rent	Low-rise Capped rent
Living room	22	1	-	-	-	-	-	-	-
Living room	33	-	-	-	-	1	-	-	-
Bedroom	11	10	98	192,52	192,52	13	93	182,69	182,69
Bedroom	22	-	-	-	-	-	-	-	-
Bedroom	33	-	-	-	-	-	-	-	-
Bedroom	44	-	-	-	-	-	-	-	-
Tenants per floor		10				13			
Rent per floor				1.925,20	1.925,20			2.374,97	2.374,97
Total rent revenue				23.102,40	23.102,40			4.749,94	4.749,94
Overall IRR		8,2%							

Table 21. Floorplan composition optimized for both consumer target groups

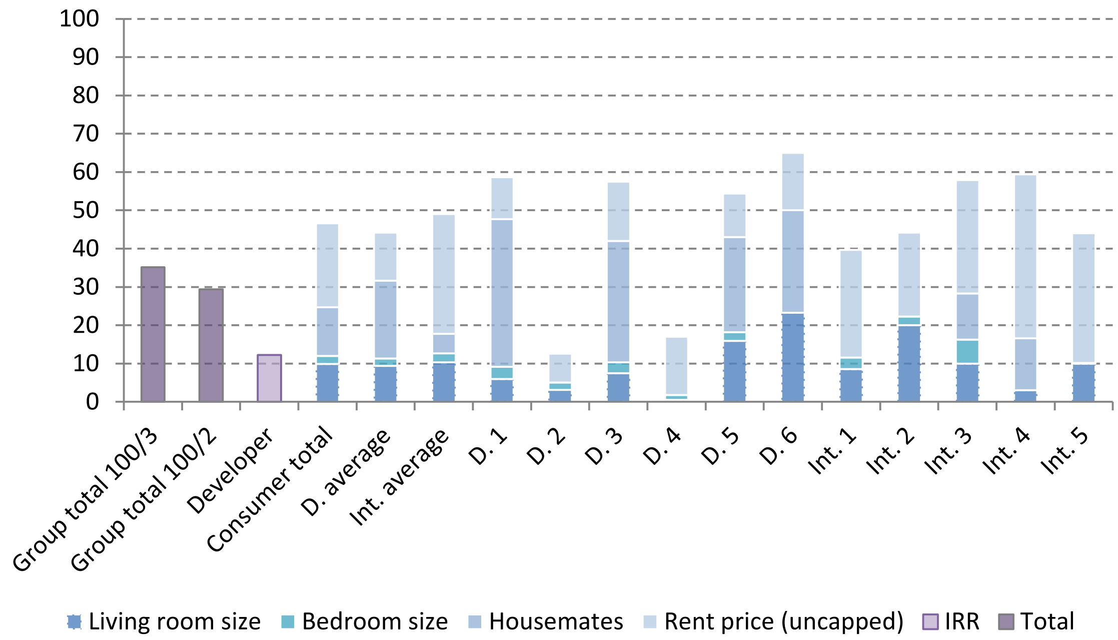
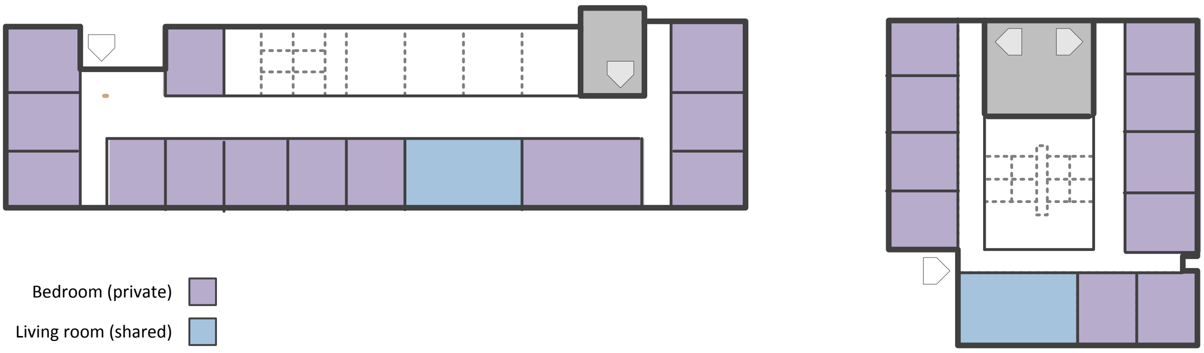


Figure 46. Preference scores for floorplan composition optimized for both consumer groups

Design configuration 5 | Floorplan composition optimized for Dutch and international students



		Flat				*Low-rise*			
Type	**Size (m²)**	**Quantity**	**Rent points**	**Uncapped rent**	**Capped rent**	**Quantity**	**Rent points**	**Uncapped rent**	**Capped rent**
Living room	22	1	-	-	-	1	-	-	-
Bedroom	11	10	98	192,52	192,52	12	89	174,83	174,83
Bedroom	22	-	-	-	-	1	152	298,58	298,58
Bedroom	33	-	-	-	-	-	-	-	-
Bedroom	44	-	-	-	-	-	-	-	-
Tenants per floor		10				13			
Rent per floor				1.925,20	1.925,20			2.396,54	2.396,54
Total rent revenue				23.102,40	23.102,40			4.793,08	4.793,08
Overall IRR		8,2%							

Table 22. Floorplan composition optimized for Dutch and international students

Figure 47. Preference scores for floorplan composition optimized for Dutch and international students

13.2 Independent housing

Based on the existing floorplan designs and the design limitations of table 10, two potential independent housing compositions have been made for the flat and low-rise (see figures 48 and 51). Each apartment has two emergency routes and the load bearing structure in the centre of the floor is left as intact as possible. Each bedroom and living room has proper daylight accessibility. The maximum rent prices for each apartment, according to the rent price system of 2013, are shown in tables 23 and 24a and b. Service costs for each apartment are estimated based on service cost projections for the realized shared housing alternatives. Information on rent benefit eligibility per apartment is provided as well.

2013 Rent price limits for rent benefit eligibility - tenant 18 - 22 years of age: €222,18 - €374,44

2013 Rent price limits for rent benefit eligibility - tenant 23 - 64 years of age: €222,18 - €681,02

Rent benefit rent price limits include any monthly service fees (Belastingdienst, 2016).

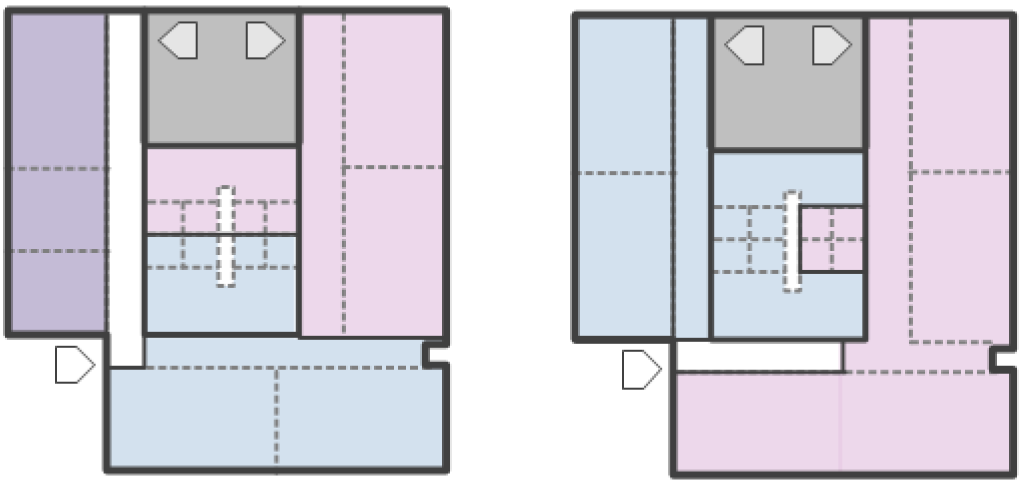


Figure 48. Flat floorplan analysis for independent housing compositions (left: three apartments; right: two apartments)

Apartment nr.	F1	F2	F3	F4	F5
Size (m²)	44	71,2	71,2	89,2	98,6
Type	Independent housing			Independent housing	
Points	75	99	99	116	125
Maximum rent	343,95	462,53	462,53	548,10	593,42
Total rent revenue	1.269,01			1.141,52	
Service fee	84,80	84,80	84,80	106	106
Gross rent price	428,75	547,33	547,33	654,10	699,42
Rent benefit	Age >= 23 164,-	Age >= 23 241,-	Age >= 23 241,-	Age >= 23 281,-	-
Net rent price	264,75	306,33	306,33	373,10	699,42
Tenants	1	1	1	1	1

Table 23. Independent housing flat compositions characteristics

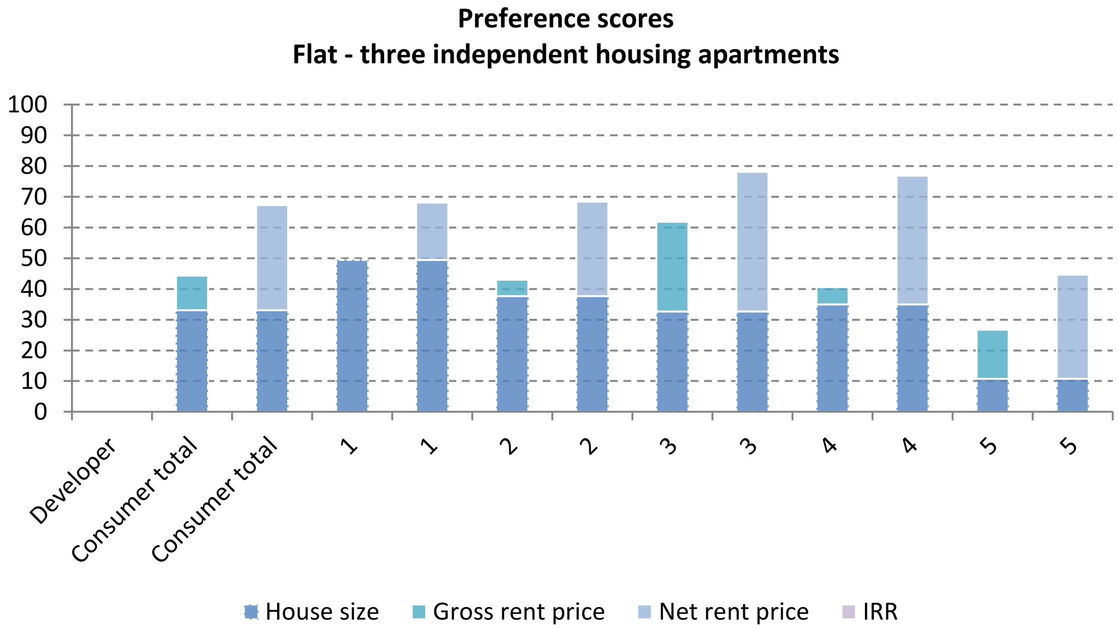


Figure 49. Preference scores for flat design with three independent housing apartments

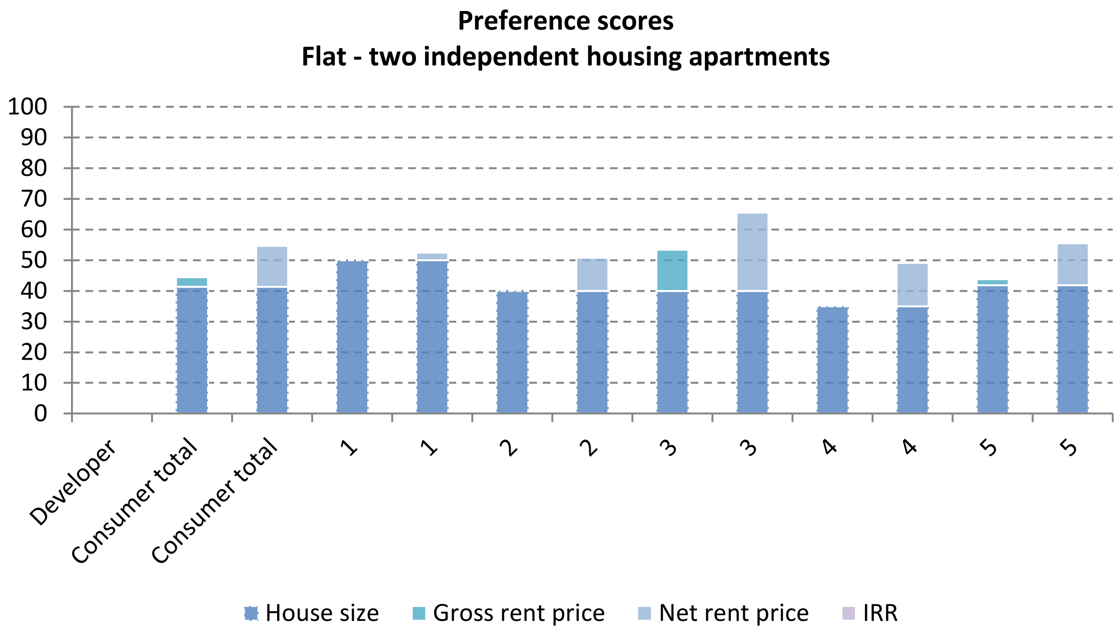
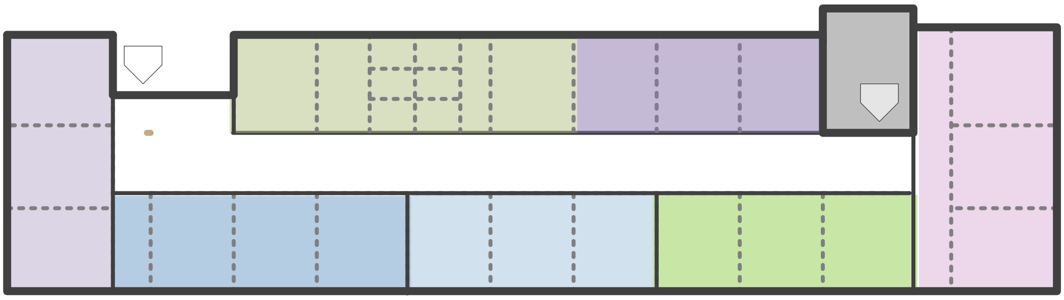


Figure 50. Preference scores for flat design with two independent housing apartments



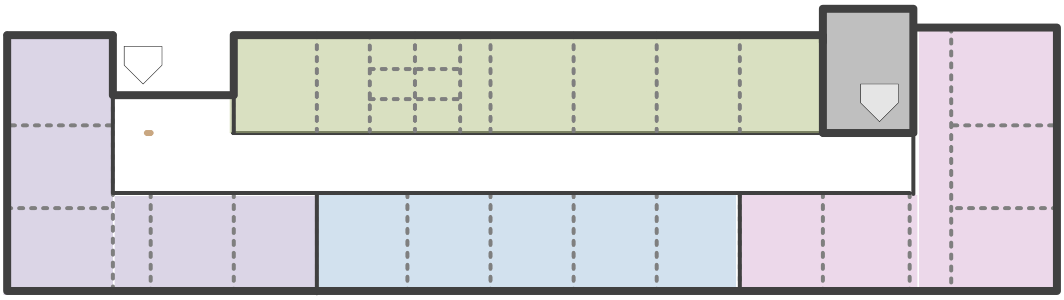


Figure 51. Low-rise floorplan analysis for independent housing compositions
(top: seven apartments; bottom: four apartments)

Apartment nr.	L1	L2	L3	L4	L5	L6	L7
Size (m²)	33	36,3	33	33	42,9	33	44
Type	Independent housing						
Points	66	68	66	66	74	66	75
Maximum rent	302,69	311,85	302,69	302,69	339,36	302,69	343,95
Total rent revenue	2.205,92						
Service fee	63,60	63,60	63,60	63,60	84,80	63,60	84,80
Gross rent price	366,29	375,45	366,29	366,29	424,16	366,29	428,75
Rent benefit	Age >= 18 129,-	Age >= 18 138,-	Age >= 18 129,-	Age >= 18 129,-	Age >= 23 160,-	Age >= 18 129,-	Age >= 23 164,-
Net rent price	237,29	237,45	237,29	237,29	264,16	237,29	264,75
Tenants	1	1	1	1	1	1	1

Table 24a. Independent housing low-rise seven apartments composition characteristics

Apartment nr.	L8	L9	L10	L11
Size (m²)	58,3	55	64,9	77
Type	Independent housing			
Points	87	84	94	104
Maximum rent	402,10	386,99	437,34	487,69
Total rent revenue	1.714,12			
Service fee	84,80	84,80	84,80	106
Gross rent price	486,90	471,79	522,14	593,69
Rent benefit	Age >= 23 201,-	Age >= 23 192,-	Age >= 23 224,-	Age >= 23 257,-
Net rent price	285,90	279,79	213,34	230,69
Tenants	1	1	1	1

Table 24b. Independent housing low-rise four apartments composition characteristics

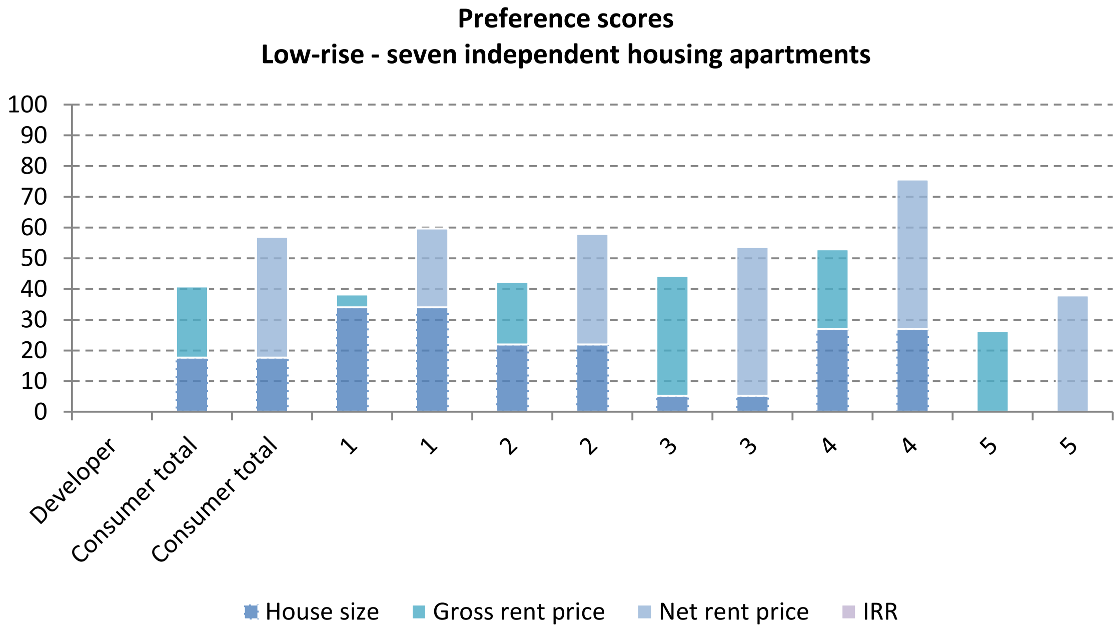


Figure 52. Preference scores for low-rise design with seven independent housing apartments

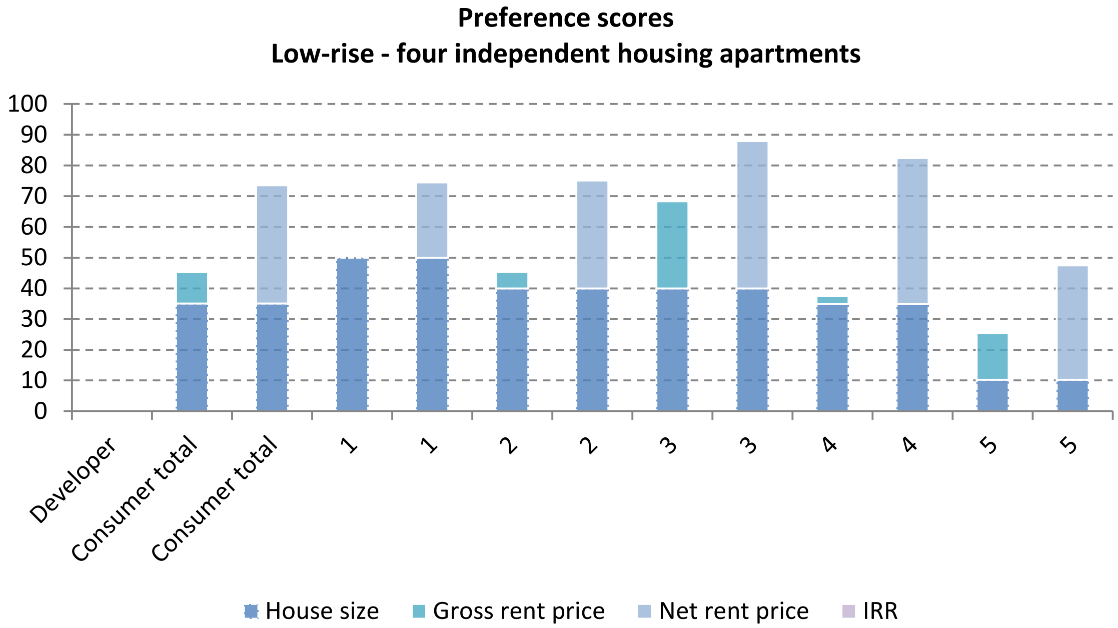


Figure 53. Preference scores for low-rise design with four independent housing apartments

Independent housing preference score analysis

All independent housing alternatives (i.e. two for the flat and two for the low-rise) have been scored for each respondent individually. The results have been visualized in figures 49 - 53. Because rent benefit eligibility is age dependent, each alternative is scored separately for two scenarios; one with rent benefit for the tenant and one without rent benefit. This difference in rent price has a major influence on consumer preference scores. Many respondents could not even afford the gross rent prices (i.e. without rent benefit). Because SHS Delft has the objective to realize affordable student housing and the majority of all students are below the age of 23, a design alternative which is only financially accessible to students aged 23 years or older would not be considered acceptable. Therefore, when determining the total aggregate consumer preference scores per alternative (see table 25), only gross rent price scores are included. One exception is the low-rise alternative with seven apartments. For this alternative rent benefit would be accessible to all students above the age of 18 years, hence net rent price scores are applied. To elucidate the differences between gross and net rent scores, both are included in table 25.

	Aggregate consumer preference score per variable			Total aggregate consumer pref. score per alternative
	House size	Gross rent price	Net rent price	
Aggregate preference weight	43%	57%		
Flat three apartments	**79**	**20**	*59*	45
Flat two apartments	**97**	**5**	*23*	45
Low-rise seven apartments	**43**	*40*	**69**	58
Low-rise four apartments	**84**	**18**	*67*	46

Table 25. Aggregated consumer preference scores for independent housing alternatives

Three out of four alternatives scored 79 or higher regarding house size. Unfortunately, neither gross nor net rent prices scored very well. With a score of 69 the low-rise alternative with seven apartments scored best. Since the aggregated preference weight for rent price is significantly higher than for house size, this is also the alternative which achieved the highest total aggregate consumer preference score out of the four alternatives. Still, the highest score is only 58. This would leave much room for competition from other student housing suppliers. It is also likely that other floorplan compositions would be more optimized for consumer preferences. Given the fact that SHS Delft required that students below 23 years of age are also included in the selected target group, it is unlikely that independent housing could in practice have been realized. Alternatives with high scores for house size rank poorly for rent price and vice versa.

	Low-rise – seven apartments	Low-rise – four apartments
Flat – three apartments	(1269,01*12)+(2205,92*2)= **€19.639,96** **IRR = -15,6%**	(1269,01*12)+(1714,12*2)= **€18.656,36** **IRR = -18,9%**
Flat – two apartments	(1141,52*12)+(2205,92*2)= **€18.110,08** **IRR = -21,1%**	(1141,52*12)+(1714,12*2)= **€17.126,48** **IRR = -25,8%**

Table 26. Independent housing compositions monthly revenue stream and annual IRR result

As for the other decision maker included in this case study, the developer, none of the alternatives proved to be acceptable. Every possible combination of flat and low-rise alternatives for independent housing would achieve a negative IRR (see table 26). One explanation for this are the costs associated with transforming an out-dated office building into student housing. While many shared housing design alternatives proved to be financially feasible, the Zusterflat building has technical constraints that limit the number of options for independent housing floorplans. The construction costs for realizing independent housing would also be much greater than for shared housing. Fire-resistant walls between dwellings and additional plumbing, electrical wiring and kitchens and bathrooms for each unit would all add up rather quickly. Simultaneously the revenue generated by independent housing would be less than for shared housing. Together these factors lead to very low IRR's for the explored independent housing alternatives. The developer preference score for each alternative would thus be zero.

14. Model validation

14.1 Model validation by consumer

Based on a floorplan composition optimized for their specific preferences (see table 27 and figure 54), generated by the research model, a validation interview was held with respondent D. 6. This validation interview took place approximately three weeks after the shared housing preferences survey was held. The respondent was not reminded of their personal stated preferences before the validation interview, as to test both the model itself and the reliability of the answers provided by respondent some weeks earlier.

The respondent was shown the floorplan composition that had been generated by the model as their personal 'most preferred' design alternative. They were also provided with information on the rent price per room, the number of housemates per floor and the square footage of both the living room and the bedrooms. The floorplan composition encompassed two designs; one for the flat floors and another for the low-rise floors. The respondent was asked to comment on the floorplans themselves and the additional information provided.

Floorplan composition assessment

The respondent stated that there were no improvements they could think of for the low-rise floorplan, given the technical and legal limitations that the building was subject to. Even after continuous discussion on possible alterations that could be made to the floorplan, the floorplan composition as designed by the model remained their preferred alternative.

Regarding the flat floorplan, it was stated that there was one bedroom that they considered too small. In this case the model took into consideration that either the living room had to be reduced from 33 m² to 22 m², or one bedroom had to be reduced from 22 m² to 11 m². This former option seemed more appealing to the respondent. However, if the respondent themselves were not obligated to inhabit the small bedroom, but instead could occupy one of the four larger bedrooms of 22 m², they stated that the floorplan configuration as designed by the model was indeed their most preferred alternative.

When asked, the respondent could not think of any design variables that were missing from the model.

Preference score assessment

Lastly the respondent was asked to reflect on the preference scores that both floorplans had been assigned by the model (based on their answers in the survey). The low-rise floorplan had a preference score of 74 (both per room and on average) while the flat had a preference score of 67 on average, with the preference score for the 22 m² bedrooms being 69 and 58 for the 11 m² bedroom. The respondent stated that these preference scores all appeared accurate. The low-rise floorplan would be preferred over the flat floorplan, but both were considered fairly good alternatives. The only exception was the small bedroom in the flat, which achieved a meagre preference score of 58. Due to the size of the living room, the rent price and the number of roommates al being to the respondent's satisfaction, this preference score was deemed appropriate.

While further improvements to the low-rise floorplan were not imaginable to the respondent, theoretically there were still alternatives for housing compositions that they would prefer over this specific design. Given the technical and legal restrictions of the building such improvements could not be made. Therefore the 'most preferred' low-rise floorplan preference score did not reach a 100, which would be the case for the theoretically most preferred design alternative.

Type	Size (m²)	*Flat* Quantity	Rent points	Uncapped rent	Capped rent	*Low-rise* Quantity	Rent points	Uncapped rent	Capped rent
Living room	33	1	-	-	-	1	-	-	-
Bedroom	11	1	127	249,48	249,48	-	-	-	-
Bedroom	22	4	190	363,74	300,-	5	176	345,71	300,-
Bedroom	33	-	-	-	-	1	240	414,59	300,-
Bedroom	44	-	-	-	-	-	-	-	-
Tenants per floor		5				6			
Rent per floor				1.704,44	1.449,48			2.143,14	1.800,-
Total rent revenue				20.453,28	17.393,76			4.286,28	3.600,-
Overall IRR		4,2%							

Table 27. Floorplan composition optimized for consumer preferences of respondent D. 6

Flat

Room nr.	Rating
2	70
3	79
4	79
5	79
6	79
7	-
8	-
9	-
10	-
11	-
Average	77

Lowrise

Room nr.	Rating
2	74
3	74
4	74
5	74
6	74
7	85
8	-
9	-
10	-
11	-
12	-
13	-
14	-
15	-
16	-
Average	76

Figure 54. Preference scores of respondent D. 6, generated by the model and specified per bedroom

14.2 Model validation by developer

A second validation interview was held, with the developer involved with the case study. As only one criteria was included in the model for measuring the developer's preference score, this validation interview focussed primarily on the design and financial variables applied in the research model. Also, the developer was asked to assess the utilization potential in practice for the preference based design system in a more broader context than merely the selected case study.

Assessment of variables included in the model

The developer stated that the most important variable missing from the model, for a more general application than just the selected case study, was the construction costs variable. These expenses were added to the model, but only as a fixed estimation of construction costs that was equal for each design alternative. Such a variable should have been added and made dependent on the total realized cubic meters, as well as on the realized building height (as this also significantly influences the construction costs for a project). For the case study, this would still have led to the same construction costs for each design alternative. It is therefore not considered a limitation of the constructed research model.

For a broader application of the research model it could also be useful to include a separate variable for the preferred bathroom size. As this room was not relevant to the design problem of the case study, this is also not a relevant limitation of the applied research model.

The developer considered the method for measuring the preferred rent price by students to be accurate: respondents were told to include service costs in their stated rent prices, and to exclude any possible rent benefit they may receive. In their own experience many developers often attempt to reduce monthly service costs, so the basic rent price can be slightly increased without increasing the total rent price per month (if the rent price point system still allows such a rent increase). It is therefore useful to measure a student's total willingness-to-pay, and to only consider their overall monthly housing budget.

Two financial variables could have been excluded from the model, according to the developer. As the additional costs and lease costs (or in other cases, acquisition costs) are usually not dependent on the realized design alternative, these do not necessarily need to be included in the model. It is also not required to perform an entire NPV calculation for each design alternative. While costs and revenues may differ per alternative, the moment on which these are occurred will remain the same. A revenue streams/construction costs ratio could thus be just as useful. For project in which land has been acquired (as opposed to the case study) a simple GIY calculation could be sufficient. This also means that economic parameters, such as the expected annual inflation rate or rent increase, could also be excluded from the model. These variables would be the same for every alternative and are only relevant if a NPV calculation is performed.

See table 28 for a clear overview of the applied variables/criteria, and those recommended by the developer for more general applications.

Assessment of the preference based design system's utilization potential

The developer stated they thought such design systems could easily be sold to real estate developers. The market segments for which it would be most appropriate would be social housing (i.e. any type of shared housing, or independent housing below the liberalized leases rent limit). It could also prove to be a valuable tool for market segments in which there is much competition from other developers, as in such a market consumers will be able to select the dwelling that fits most of their preferences.

Input	Criteria/variable applied in research model	Criteria/variable recommended by developer
Consumer preferences (shared housing)	1. Size of living room	1. Size of living room
	2. Size of bedrooms	2. Size of bedrooms
	3. Number of housemates	3. Number of housemates
	4. Rent price	4. Rent price
		5. Size of bathroom
Consumer preferences (independent housing)	1. Size of dwelling	1. Size of dwelling
	2. Rent price	2. Rent price
		3. Size of bathroom
Developer preferences	1. Internal Rate of Return	1. Internal Rate of Return; or revenue stream/construction costs ratio *(similar to GIY method)*
Design constraints (shared housing)	1. Total GFA to be allocated per floor	-
	2. Placing of interior walls (the GFA for each room must be a plurality of 11 m²)	1. Placing of interior walls *(dependent on construction method)*
		2. Gross/net floor area ratio *(to determine total building volume)*
Financial constraints	1. Rent price point system settings	1. Rent price point system settings
Financial variables (included in DCF calculations)	1. Construction costs	1. Construction costs *(per m³, dependent on building height)*
	2. Additional costs	-
	3. Lease costs	-
	4. Inflation rate	2. Inflation rate *(only if IRR is calculated, not relevant for GIY)*
	5. Rent increase	3. Rent increase *(only if IRR is calculated, not relevant for GIY)*

Table 28. Research model input recommended by developer

While the developer was familiar with the annual student housing survey held by Kences (Apollo, 2013 & 2015) they did not often apply such data to their decision making process. Most often, an architect would be asked to draw some design alternatives, based on which the developer would further specify the design criteria for the definitive design. In their opinion including a preference based design system in the initiative phase would prove very helpful in making more substantiated design decisions. The PFM preference measurement method itself was also deemed very interesting for practitioners. When asked whether architects might find the design system helpful, the developer stated it was unlikely that architects would see the benefit of such a system. It would therefore be of most use for the developer themselves, early on in the development process (i.e. the initiative phase).

The developer thought the most important limitation of the proposed preference based design system would be the fact that separate locations can not be compared. While certain rent prices might be accepted by consumers for one specific location, this might not be the case for another area or neighbourhood. Consequently, it remains important that the output delivered by a model is interpreted correctly, preferably by a local, experienced practitioner.

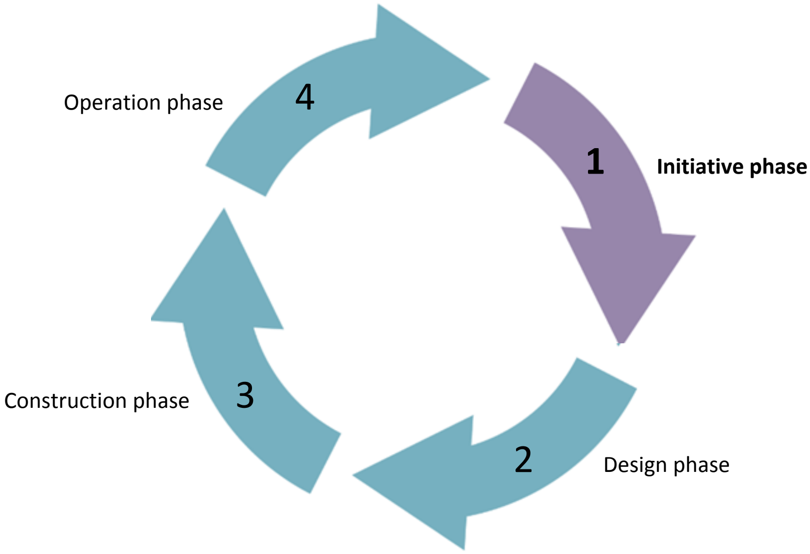


Figure 55. Project phase in which the constructed model could be of most value, according to the developer involved with the case study

14.3 Model sensitivity analysis using Tetra

Tetra is software that applies proper scales to solve multi-criteria problems. Chapter 7 described the definition and necessity of proper scales for solving preference related problems. As the research model reflects a multi-criteria and multi-decision maker preference problem, Tetra will be used to perform a sensitivity analysis on the results generated by the research model. In order to provide a broad scope, the analysis includes the preference scores for respondent D.1 individually, the aggregated preference score for all Dutch students, the aggregated preference score for all international students and the aggregated preference score for all students (both Dutch and international). Because only a single, separate preference criteria (i.e. financial profit) was included in this study for the developing party, this decision maker could not be included in the sensitivity analysis.

While it is able to process multi-criteria problems, Tetra is not very well suited for multi-decision maker problems. This is because only one criteria weight division can be assigned while in this study each respondent has devised their own criteria weight division. This was solved by devising an aggregated criteria weight division. The results of the sensitivity analysis are shown in table 29.

Overall, the trend (regarding the score difference between Tetra and the research model) appeared to be that the more a preference score deviates from 50, the more points are added or subtracted by Tetra's algorithm. For scores above 50, points are added. For scores below 50, points are subtracted. However, there are quite a few anomalies (see blue marked cells) that can not be sufficiently explained without insight into the algorithm of Tetra. Unfortunately this algorithm has not been made publicly available by its developers as of yet.

Decision maker	Model	Nr. 1	Nr. 2	Nr. 3	Nr. 4	Nr. 5
		Design configuration				
		Preference score				
D.1	Research model	58	56	51	59	57
	Tetra	59	57	51	60	59
	Difference	*+ 1*	*+ 1*	-	*+ 1*	*+ 2*
		+ 1.7%	*+ 1.8%*	-	*+ 1.7%*	*+ 3.5%*
Dutch students	Research model	49	42	32	44	43
	Tetra	48	40	29	43	41
	Difference	*- 1*	*- 2*	*- 3*	*- 1*	*- 2*
		- 2.0%	*- 4.8%*	*- 9.4%*	*- 2.3%*	*- 4.7%*
International students	Research model	51	49	40	49	49
	Tetra	52	49	39	50	50
	Difference	*+ 1*	-	*- 1*	*+ 1*	*+ 1*
		+ 2.0%	-	*- 2.5%*	*+ 2.0%*	*+ 2.0%*
Dutch and International students	Research model	50	45	36	47	46
	Tetra	52	47	34	48	48
	Difference	*+ 2*	*+ 2*	*- 2*	*+ 1*	*+ 2*
		+ 4.0%	*+ 4.4%*	*- 5.6%*	*+ 2.1%*	*+ 4.4%*

Table 29. Comparison of preference scores generated by the research model and Tetra

For all compared scores, the differences are spread between plus two and minus three points. This is a spread of plus 4.4% and minus 9.4%. Such a spread would indicate that both models are relatively similar in their effectiveness, but that the search algorithm applied by Tetra does lead to some differences. These differences did not lead to a shift of the “most preferred” design configuration outcome for any of the included decision maker groups.

The practical applicability of Tetra for multi-decision maker problems may be somewhat limited, as for the Tetra model it would be necessary to first calculate all individual and aggregated preference scores and aggregated criteria weight division, while in the research model this was included as an automated calculation step.

15. Conclusions

15.1 Case study conclusions

While the proposed design configurations for independent housing achieved relatively high consumer preference scores, not one achieved the minimum IRR required by the developer (8,0 percent). Also, consumer preference scores for gross rent prices (i.e. rent prices without rent benefit) were exceptionally low. Thus, it is probable that in reality many students would not be willing to pay the rent prices assigned by the rent price point system. As the IRR for each configuration was already below the minimum requirement, a rent discount would not have been acceptable to the developer. The potential target group of international students was too small in size to base a case study on. Additionally, their average spendable income is even lower than that of Dutch students. This leads to the exclusion of both independent housing strategies (i.e. strategies 3 and 4, see figure 56).

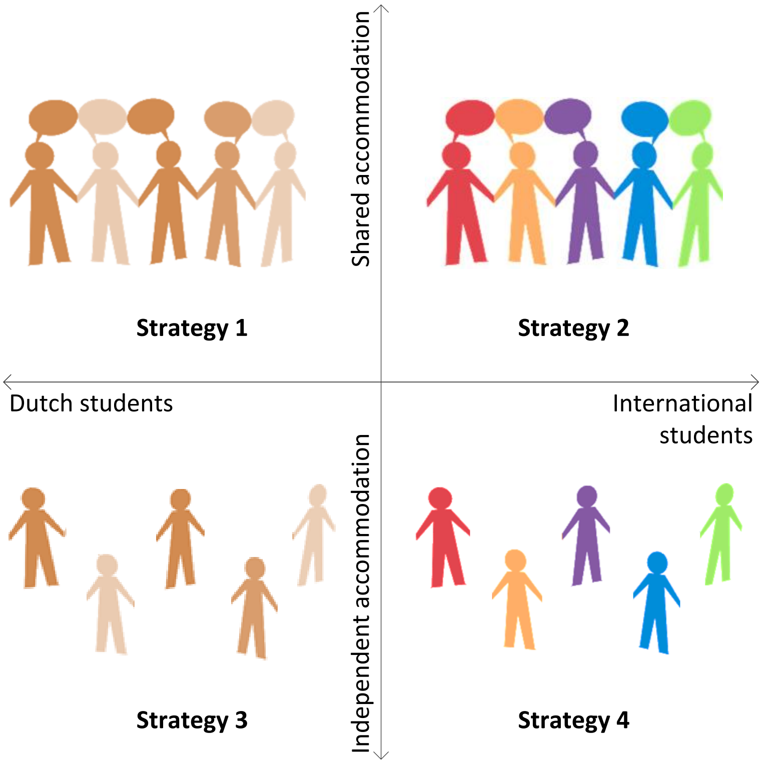


Figure 56. Strategies based on the two main decision variables for the Zusterflat case

For shared housing, the model results were more applicable. Purely based on group preference scores, a ranking has been established for each design configuration (see table 30). This ranking shows that the three design alternatives generated by the model achieved the highest group preference scores. When looking at the preference scores per decision maker, however, it can be seen that one of the realized design configurations (1) achieves by far the highest consumer preference score. The aggregate (group) preference score for the realized alternatives (1 and 2) would only surpass two of the generated design configurations (4 and 5) if the developer would be assigned barely any preference weight at all (see figure 57). And, even then the difference would be approximately only 2 points. Design configuration 3, which achieves the largest group preference score for both analysis a and analysis b, could be surpassed by the realized alternatives with up to 14 points. But this would only happen when the developer is assigned a decision maker weight of 15,7 percent or less. It can thus be concluded that regarding the case study project, the developer either:

a) assigned a very large decision maker weight to the consumer (> 84,3 percent); or

b) was not aware of the exact housing preferences of students and therefore could not take these accurately into consideration (i.e. he overestimated their requirements); or

c) was not capable of (or did not have the time or resources to) comparing all possible design configurations without the use of a preference based design system.

After consultation with the developer, it was determined that all three explanations hold a degree of truth. Because there was much risk associated with the project (due to lack of physical collateral), there was a very large developer interest to ensure market take-up. Therefore the consumer preferences were given much weight. At the same time, there was no detailed demand data available on which to base the exact floorplan design. Therefore the consumer preferences were estimated, based on consultations with SHS Delft and a few other knowledgeable parties. And it was difficult for the developer to accurately compare the different alternatives without a measurement system based on PFM.

Design configuration	Related alternatives	Group preference score margin	Ranking (based on group pref. score margin)
1	Realized for Dutch students (1)	25 - 33	5
2	Realized for international students (2)	29 - 34	4
3	Optimized for developer (3) and group total (4, 5 & 6) preferences	49 - 75	1
4	Optimized for consumer total (7) preferences	24 - 47	3
5	Optimized for Dutch students (8) and international students (9) preferences	26 - 49	2

Table 30. Ranking of shared housing design configurations

Design configuration	Developer preference score	Adjusted developer preference rating	Total consumer preference score	Adjusted consumer preference score
	Analysis a (0,50)	Analysis b (0,33)	Analysis a (0,50)	Analysis b (0,66)
1	0	0	50	60
2	12	7	46	55
3	75	45	36	43
4	2	1	47	56
5	6	4	46	55

Table 31. Adjusted preference scores per design configuration

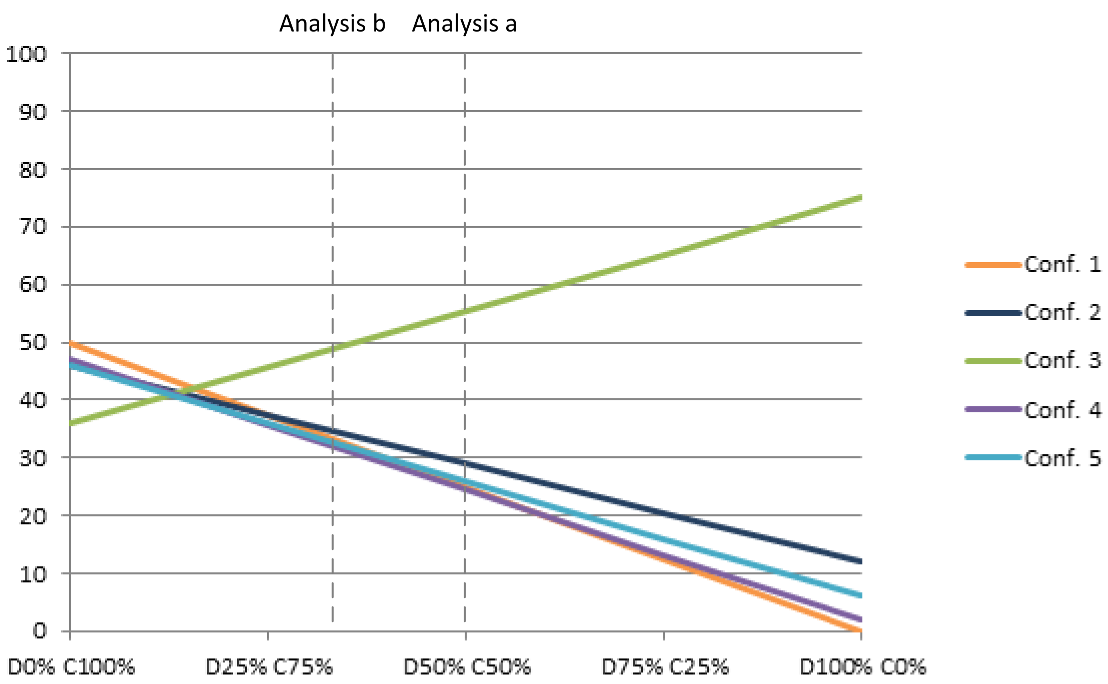


Figure 57. Aggregated preference scores (y-axis) depending on decision maker weight division (x-axis)

Based on this information and the data from chapter 13, it is concluded that a higher IRR could have been achieved by selecting shared housing design alternative 3. This would also - under most decision maker weight divisions - have increased the achieved group preference score. This configuration could be applied for both Dutch and international students, however it achieves much higher preference scores for international students than for Dutch students. As there is significant demand for housing for international students (Apollo, 2013), this would lead to a recommendation for the execution of proposed strategy 2 (see figure 56).

15.2 Research questions conclusions

The theoretical (i.e. the literature review) and practical (i.e. the case study) components of this study have led to the following answers regarding the research sub-questions:

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

Often a Net Present Value (NPV) calculation is made during the initiative phase to determine the financial feasibility of a potential project. This results into an Internal Rate of Return percentage, which is interpreted as the annual return made on the invested capital. Including such an extensive calculation in a preference based design system is not necessary if the model produces a clear cost/revenue ratio for each design alternative (e.g. a GIY based comparison of alternatives).

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

The financial requirements differ significantly per project. For projects without physical collateral, such as the selected case study, typically a return on investment of between 8 and 12 percent is demanded by financers. Depending the financer and specific project characteristics, this percentage can get as high as 18 percent. For projects that do involve physical collateral (i.e. the acquisition of land or a building) a minimum percentage of approximately 5 percent is generally demanded by private financers. When lending capital for such a project from a commercial bank, an interest rate as low as 3 percent may be charged, which should result into a lower return on investment requirement by the developer. The limitation of construction costs is not applicable for most development projects, as long as the return on investment is appropriate for the perceived project related risks. Similarly, income requirements are only related to achieving the projected return on investment.

Regarding the case study, the percentage of rooms that could become vacant before the required return on investment would be jeopardized was the main project risk determinant. In other words, expected market up-take was the most important factor for determining the investment risk.

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

For the proper application of a preference based design system, by far the most relevant financial variables for the developer are the construction costs associated with each design alternative (per cubic meter, also dependent on the realized construction height) and the generated revenues. Acquisition costs or additional costs (e.g. consultants' fees) are not as important, since these tend to be fixed for a project regardless of the realized design alternative.

There are many other design aspects, such as façade surface, window surface and ceiling height, that will affect the constructions costs of a design and are thus relevant in relation to the developer's financial profit. This study has not examined the extent to which these aspects (on average) influence a dwelling's construction costs. For the practical application of the constructed preference based design system, the developer involved with the case study stated that such detailed cost calculations could be useful, but are not required. During the initiative phase, when a detailed design has not yet been made, general cost estimations based on cubic meters and total construction height would suffice.

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

The literature study and the validation interview with a respondent from the consumer group led to the conclusion that the following design variables are relevant for student housing: (1) size of rooms, (2) number of housemates and (3) rent price. While location is a very important variable, according to both literature and the developer involved with the case study, this is not a variable that was relevant to the construction of a floorplan design system. It was therefore also not examined whether consumer preferences (e.g. regarding rent price) differed for certain housing locations. Such a differentiation could be relevant for constructing a preference based design system which compares different project locations, or for generating more detailed consumer preference input.

The design constraints included in the research model were solely based on the technical constraints that the case study's existing building entailed. The minimum and maximum requirements stated by the respondents could be used as fixed design constraints, to reduce the amount of potential design alternatives.

The main research questions that was posed was:

Does the application of a preference-based design system lead to residential design alternatives that are more in line with developer and consumer preferences, over design processes without the application of a preference-based design system?

In conclusion; the research model accurately generates residential design alternatives that are optimized for both developer and consumer preferences. Whether such a design system leads to more preferred residential designs over traditional design processes can not yet be confirmed for *all* projects. However, in the case study, the research model was found to be more efficient in optimizing a combination of preferences, of both the developer and the consumers, than the developer had been in reality. In order to avoid vacancy risk, the developer had given the consumers an exceptional amount of decision weight as to ensure the realized design would appeal to a large enough population. The research model generated a design alternative which was rated only slightly less by consumers, while it was rated much higher by the developer himself. Therefore, under most decision maker weight divisions, the aggregated preference score would have been much higher as well. As this was the purpose of the study and the research model, it can be concluded that a proof of concept for a preference-based design system for residential developments has been delivered.

16. Reflection and recommendations

16.1 Validity of the results

Partly due to feasibility reasons, there are certain limitations to the performed research. The main complications are:

1. Limited number of design variables included in the model

   Due to the time-consuming aspect of programming a detailed model, and because of a lack of applicable existing literature, only four main design variables were selected and included in the research model. However, it is unlikely that this has significantly affected the validity of the research results. There is still a large number of possible design alternatives that can be generated by the model (105 for the flat, 762 for the low-rise extension). Also, the reflection interview with a questionnaire respondent - based on the model's results - indicated that for this case study, the included number of design variables was sufficient. The model appeared to resemble the real decision making process for these consumers.

   Regarding the selected financial variable, the developer involved with the case study stated that within this specific project context the only financial criterion was annual return on investment (i.e. IRR). While different alternatives in reality would also entail different construction costs, these costs were not considered a criterion, as for a project with an appropriate IRR there would always be a party willing to finance it.

2. Construction costs were not adjusted to correspond with specific design alternatives

   The developer involved with the case study did not have any additional information on construction cost estimations for design alternatives other than the realized configuration. Also, for the transformation of this particular building, the costs for plumbing, electricity and technical installations determined approximately 2/3rd of the total constructions costs. The remainder of the costs consisted mostly of demolition and construction work for the interior walls and removal of asbestos. As the load-bearing structure did not need to be adjusted for any of the possible design alternatives, and the interventions made in the façade were very minor and needed for each possible design alternative, the differentiation in construction costs per design alternative is estimated between 0 and 6,4 percent (based on the actual contractor quotations for the realized design alternative). This would mean the total required investment sum could variate at the very most 4,5 percent. For the realized design alternative such a deviation affects the achieved IRR with a maximum of 1,0 percent point. While it would certainly add to the accuracy of the model results if the construction cost variable was adjusted to correspond with each specific design alternative, a 1,0 percent point accuracy margin does not indicate corrupted results. Due to the limited time available for this research, this accuracy margin was accepted and the construction costs were standardized to the actual contractor quotation for each design alternative.

3. Small sample size for the questionnaires

   As stated in the research design and methodology chapter, the three selected samples for the questionnaires were very limited (five to six persons per target group). Because the study had the objective to deliver a proof of concept for a preference based design system, through a qualitative approach, the decision was made to put more emphasis on the design of the model and the generated design outcomes than on the generalizability of the questionnaire results. As the consumer preference input for the model was accurately measured and reflected the perception of actual target group constituents, the generated output is still a valid result. Also, the concept of preference based group-decision making remains the same. However, the stated limitations need to be taken into account when interpreting the case study results and associated conclusions.

4. The applied independent housing design alternatives were not generated by the research model

   This decision was made because the pursued proof of concept could be delivered by only generating shared housing design alternatives with the model. Adjusting the entire model, to also generate independent housing alternatives, would require a lot more time to be spend on programming. Additionally, one of the three main applications of the model (as described in the research questions chapter) was applying the model to compare pre-determined design alternatives. While this study may not have proven conclusively that independent housing is not a financially feasible strategy for the Zusterflat project, the pre-determined floorplan designs have been adequately compared based on group-decision making principles corresponding with PFM theory. Still, the limited amount of compared design alternatives for independent housing needs to be taken into account when interpreting the case study results and associated conclusions.

5. The conclusions are based on only one case study (involving one building, and a very specific market segment)

   It is easy to get enthusiastic about research results that are commended by the involved practitioners. While a suitable application for the constructed preference based design system has been demonstrated, it may prove more difficult to generate relevant results within the context of a different project. However, because the amount of design variables included was still limited (including e.g. the different types of rooms to be allocated), it is expected that such design systems may have even greater potential when applied to other types of design problems.

Despite these limitations, it can be stated that the found results related to the research hypothesis are valid. The answers to the posed research questions and the case study conclusions need to be considered in the context of the available literature on non-location related housing preferences (which is limited), and the specific conditions of the case study project.

16.2 Utilization potential

The research model that has been constructed is not a universally applicable model. It has been designed to fit the variables and constraints of a specific case study.

The delivered research results are also based on that same case study. The sample size was small, so the trend analysis of the decision makers' stated preferences can not be generalized for the entire population that they represented. This is a consequence of the choice to perform a primarily qualitative study, in which the aim was to deliver a small scale proof of concept for a multi-actor preference based design system.

The constructed research model and the study's results and conclusions however may be utilized for the following purposes:

1. The applied combined research approach, which combines many different data collection methods, has been effective in delivering the specific types of data required for the case study-based research model. This approach may continue to be effective as a framework for future research on preference based design systems. It provides a clear overview of the different steps that need to be undertaken to

deliver a valid, reality-reflecting model, that is also founded on the existing (scientific) body of knowledge. Due to its complex nature however, this combined approach might be not be suitable for very time-pressed studies.

2. The literature review and questionnaire results may be used for determining the appropriate variables for similar preference based residential design systems. Regardless of whether the same or different residential target groups would be selected as 'decision maker', there is currently no other literature available which reflects on variables specifically suited for such a system.
3. The conclusions regarding the decision making process for the case-study may bring a new perspective to the general perception of conflicting developer and consumer interests. Relatively small adjustments to a residential floorplan design have been proven to significantly alter the project outcomes for both parties. The results from this study indicate that involving a model in the decision making process could lead to a more transparent initiative and design phase, in which each party's interests are very clearly defined and directly represented. Simultaneously a very large number of design alternatives can be evaluated and compared without much effort (except for the effort required to construct the model itself).

Regarding utilization of the study by practice:

1. The research model itself (and its description) may offer a foundation for future research that focusses on the optimization of revenue streams for property development projects. It incorporates aspects of the property development process that would typically only be estimated, instead of accurately measured (i.e. design preferences). This study shows how to combine, as well as automate, the concept of financial feasibility analysis with high accuracy consumer feedback. This provides an opportunity for developers to protect consumer interests in the design phase, without reducing their own sense of control over the decision making process.
2. Another group that might potentially 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, could help them in creating designs that are appreciated by the consumer as well as valued by the developer.

16.3 Personal reflection

While the research topic was my personal choice, and I have remained motivated to solve the research question throughout the process, performing this study has proven to be somewhat of a demanding task. The extent of the thesis assignment made it difficult to follow my conventional working method, of fifty percent of decent planning and fifty percent of following my intuition, to continuously uncover the next research step. If anything, this graduation process has taught me that a clear research structure is not superfluous at all.

My personal observation is that this thesis could have been more structured as well. While my main research objective has been reached (i.e. delivering a proof of concept for preference-based design systems), I had hoped to provide a clearer overview of the applied methods/reasoning. It is likely that, had my process been more structured, this additional quality could have been delivered.

One other point of reflection concerns the independence with which I am accustomed to work with. While my supervisors provided well-founded critiques and advice during the guidance sessions, my habit of figuring things out by myself has regularly gotten the better of me the past months. I did not make the most use of the resources that were available to me. The main lesson I would want to take away from writing this thesis is that feedback allows you to go forward, and need not be avoided.

All in all, I am satisfied with the lessons I have learned the past year. I probably threw myself more in the deep end than was necessary, but I have gained insights from that as well. Would I have needed to write another thesis, I would do the certain things differently (structuring my process more and asking for much more feedback). But with the level of complexity and unfamiliarity that this topic held for me in the beginning I am pleased with the results. I feel like I have made relevant new knowledge available to others, which is a satisfying feeling.

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Appendix 1 | Questionnaires

Questionnaire shared student housing preferences

Questionnaire independent student housing preferences

Survey shared student housing preferences

Date: ....

Name: ....

Date of birth: ....

Consider the following scale from 0 to 10:

0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

Least attractive alternative **Most attractive alternative**

Please determine for the following housing characteristics which alternative *you* would consider the least attractive of all possible alternatives (0 on the scale), the most attractive of all possible alternatives (10 on the scale) and rank a third alternative somewhere along the scale (anywhere between 0 and 10). The number 5 has been filled in to represent the alternative exactly in between of 0 and 10, but you can also provide an answer based on a different number. In that case please write down the number you selected next to the corresponding alternative.

1. Preferred living room size in m² (shared housing):

0: .... m² (your absolute minimum space requirement for a shared living room)

5: .... m²

10: .... m² (in your view the perfect shared living room size)

2. Preferred bedroom size in m² (shared housing):

0: .... m² (your absolute minimum space requirement for a bedroom)

5: .... m²

10: .... m² (in your view the perfect bedroom size)

3. Preferred number of roommates (including yourself):

0: # .... (your absolute minimum number of roommates)

10: # …………… (in your view the perfect number of roommates)

0: # …………… (your absolute maximum number of roommates)

5: # …………… (optional)

4. Preferred rent price:

0: € …………… (your budget maximum, which you are willing to pay for a perfect house/room)

5: € ……………

10: € …………… (your budget minimum, for example €0,-)

5. Please determine how important each factor is to you when selecting a house, by dividing 100% between them. For instance, if all are equally important to you, assign 25% to each.

Living room size: ……………

Bedroom size: ……………

Number of roommates: ……………

Rent price: ……………

-- End of the survey --

Survey independent student housing preferences

Date: ……………………………….

Name: ……………………………………………………………………….

Date of birth: ……………………………….

Consider the following scale from 0 to 10:

0	1	2	3	4	5	6	7	8	9	10

Least attractive alternative **Most attractive alternative**

Please determine for the following housing characteristics which alternative *you* would consider the least attractive of all possible alternatives (0 on the scale), the most attractive of all possible alternatives (10 on the scale) and rank a third alternative somewhere along the scale (anywhere between 0 and 10). The number 5 has been filled in to represent the alternative exactly in between of 0 and 10, but you can also provide an answer based on a different number. In that case please write down the number you selected next to the corresponding alternative.

1. Preferred total house size in m²:

0: ………….. m² (your absolute minimum space requirement)

5: ………….. m²

10: ………….. m² (in your view the perfect house size)

2. Preferred rent price:

0: € ………….. (your budget maximum, which you are willing to pay for a perfect house)

5: € …………..

10: € ………….. (your budget minimum, for example €0,-)

3. Please determine how important each factor is to you when selecting a house, by dividing 100% between them. For instance, if both are equally important to you, assign 50% to each.

Total house size: ……………

Rent price: ……………

-- End of the survey --

Appendix 2 | 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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……………………………………………………………………………………………………

<u>Type of accommodation (shared/independent housing)</u>

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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<u>Tenant target groups</u>

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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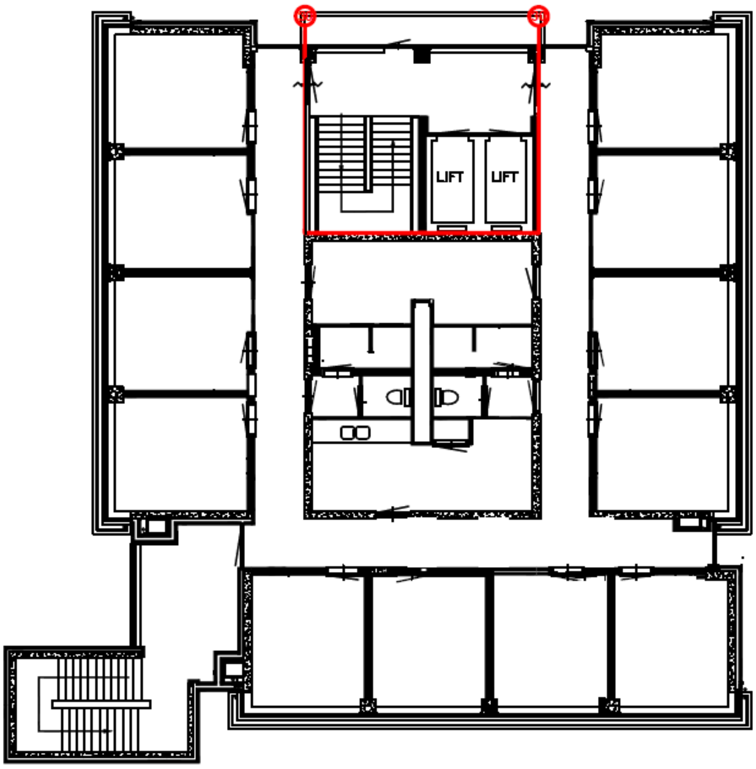
- End of interview -

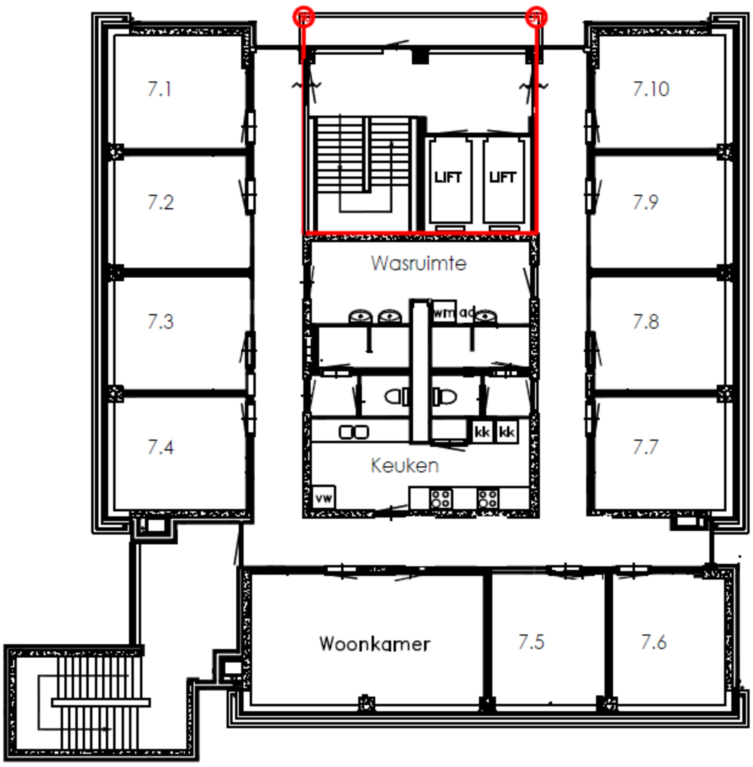
Number:	Concept:	Description:
01	Financial profitability	Costs, Revenues, Financial risk, Interest rates, etc.
02	Tenant target groups	Different types of target groups (e.g. international students, Dutch students).
03	Consumer preferences	Preference for accommodation type (number of roommates), floor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

Table 1. Interview coding concepts

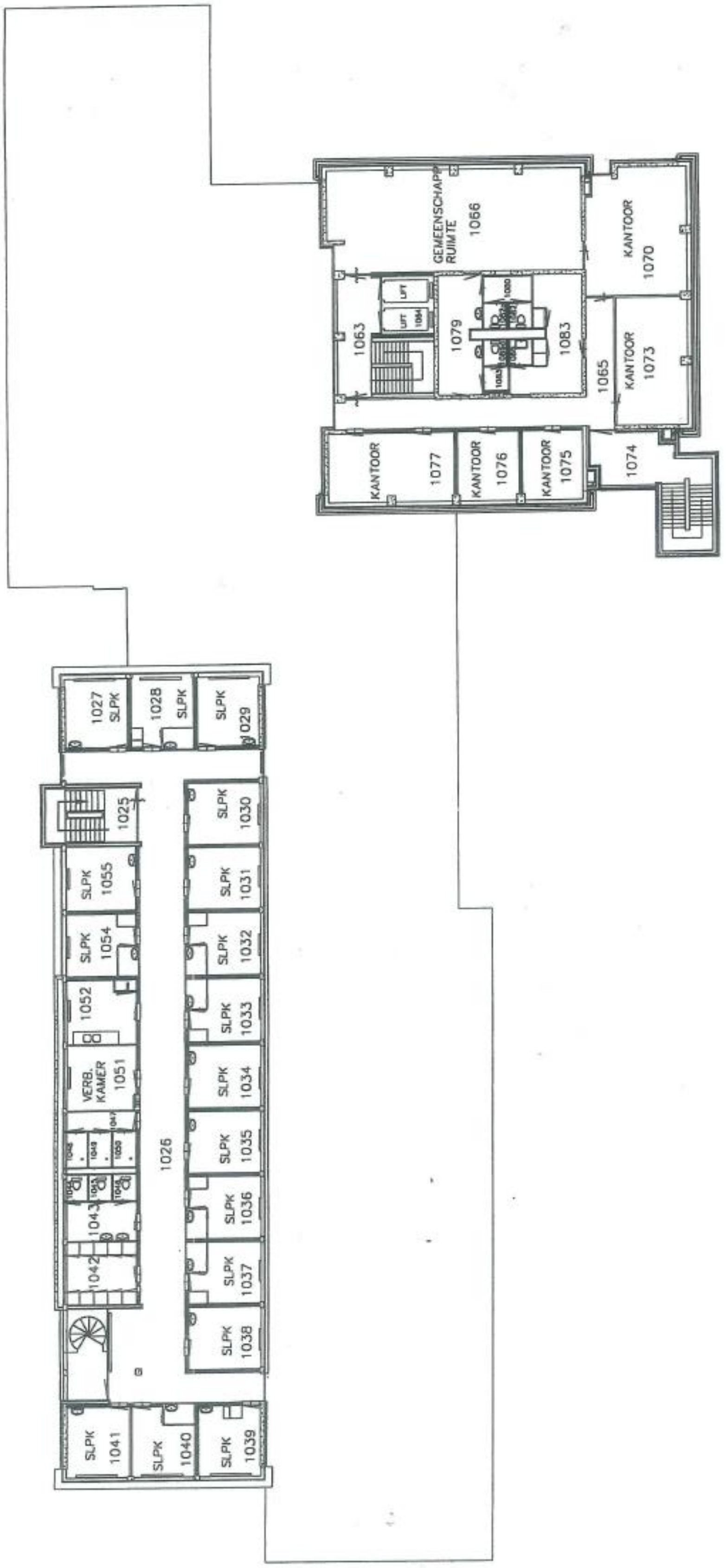
Appendix 3 | Zusterflat floorplans



Floorplan flat 7th floor before transformation



Floorplan flat 7th floor after transformation



Zusterflat floorplan (flat and low-rise) - 2nd floor

Appendix 4 | Financial and economic parameters applied to research model

Parameter:	Value:
Annual lease costs (indexation following inflation)	€50.000,-
Annual taxes	€31.887,-
Lease duration (months)	120
Maintenance costs (per month per floor)	€280,-
Operational costs (per month per room)	€21,20
Operational manager's fee (percentage of total rental income)	2,50%
Vacancy risk	100% covered by operational manager
Expected annual inflation	2,00%
Annual rent increase	2,50%

Appendix 5 | Model preference score results (example)

Input developer preferences | 50,00% (Decision maker weight)

Results developer preferences

Criteria	Unit	Weight	X_1	Y_1	X_2	Y_2	X_0	Y_0	X_p	Y_p
5. Internal Rate of Return (IRR)	%	100%	0,08	0	0,092	75	0,12	100	0,081	10,52

Group preference score: 28,16

Dutch students | 0,00% (Decision maker weight)

	Weight	X_1	Y_1	X_2	Y_2	X_0	Y_0	Flat X_p	Flat Y_p	Low-rise X_p	Low-rise Y_p	Total		Group
D. 1	25%	18	0	30	50	45	100	11,000	0,00	11,000	0,00	0	55,8488	40,247
	20%	8	0	18	50	30	100	12,100	21,42	20,625	61,87	5,43907		
	40%	3	0	8	100	16	0	10	100,00	8	100,00	40		
	15%	450	0	290	50	0	100	193,92	72,37	283,870	51,60	10,4098		
D. 2	35%	20	0	60	80	120	100	11,000	0,00	11,000	0,00	0	16,8485	
	20%	10	0	16	50	25	100	12,100	19,02	20,625	79,44	5,52976		
	35%	2	0	5	100	10	0	10	0,00	8	80,00	4		
	10%	600	0	350	50	0	100	193,92	75,18	283,870	61,23	7,31873		
D. 3	20%	20	0	24	50	35	100	11,000	0,00	11,000	0,00	0	57,6927	
	25%	10	0	15	50	24	100	12,100	22,93	20,625	87,28	8,03131		
	35%	2	0	6	100	14	0	10	100,00	8	100,00	35		
	20%	500	0	300	50	100	100	193,92	76,52	283,870	54,03	14,6614		
D. 4	30%	24	0	60	50	100	100	11,000	0,00	11,000	0,00	0	21,4666	
	25%	10	0	20	50	30	100	12,100	10,50	20,625	53,13	4,14732		
	25%	2	0	5	100	10	0	10	0,00	8	80,00	2,85714		
	20%	450	0	300	50	0	100	193,92	75,30	283,870	54,38	14,4621		
D. 5	25%	10	0	20	50	35	100	11,000	5,60	11,000	5,60	1,4	47,2115	
	30%	10	0	17	50	25	100	12,100	15,61	20,625	73,60	7,16894		
	30%	2	0	9	100	14	0	10	91,43	8	100,00	27,7959		
	15%	450	0	300	50	0	100	193,92	75,30	283,870	54,38	10,8466		
D. 6	35%	12	0	20	50	80	100	11,000	0,00	11,000	0,00	0	44,8524	
	20%	12	0	25	50	50	100	12,100	0,45	20,625	35,01	1,07686		
	30%	2	0	8	100	15	0	10	95,24	8	100,00	28,7755		
	15%	550	0	470	50	0	100	193,92	100,00	283,870	100,00	15		

International students | 50,00% (Decision maker weight)

	Weight	X_1	Y_1	X_2	Y_2	X_0	Y_0	Flat X_p	Flat Y_p	Low-rise X_p	Low-rise Y_p	Total		Group
Int. 1	10%	0	0	15	50	25	100	11,000	33,73	11,000	33,73	3,37333	39,743	45,8096
	30%	10	0	15	50	20	100	12,100	21,00	20,625	100,00	9,68571		
	20%	1	0	4	100	8	0	10	0,00	8	0,00	0		
	40%	450	0	280	50	0	100	193,92	69,66	283,870	49,03	26,684		
Int. 2	20%	5	0	10	50	15	100	11,000	60,00	11,000	60,00	12	39,8435	
	25%	10	0	16	50	24	100	12,100	18,72	20,625	81,23	6,9122		
	25%	2	0	4	100	6	0	10	0,00	8	0,00	0		
	30%	480	0	300	50	0	100	193,92	72,44	283,870	53,75	20,9313		
Int. 3	10%	0	0	18	50	22	100	11,000	0,00	11,000	0,00	0	54,3418	
	25%	8	0	14	50	20	100	12,100	34,17	20,625	100,00	10,8929		
	25%	1	0	3	100	11	0	10	56,25	8	100,00	15,625		
	40%	400	0	275	50	0	100	193,92	73,32	283,870	47,01	27,8239		
Int. 4	5%	8	0	20	50	40	100	11,000	13,91	11,000	13,91	0,69531	58,5626	
	30%	12	0	20	50	25	100	12,100	0,40	20,625	55,46	2,47903		
	15%	1	0	5	100	14	0	10	100,00	8	100,00	15		
	50%	400	0	300	50	0	100	193,92	84,82	283,870	56,50	40,3883		
Int. 5	10%	10	0	15	50	20	100	11,000	10,00	11,000	10,00	1	36,5572	
	20%	14	0	25	50	30	100	12,100	0,00	20,625	20,23	0,57807		
	30%	2	0	4	100	9	0	10	0,00	8	60,00	2,57143		
	40%	450	0	325	50	0	100	193,92	84,07	283,870	62,71	32,4077		

Appendix 6 | Model screenshots

	A	B	C	D	E	F	G	H	I	J	K
1											
2		**Financial input**			**Financial results shared housing**						
3		**Lease agreement**			**Return on investment**			**Cummulative revenues**			
4		Annual rent	€ 50.000,00		IRR per month	0,6%		Rent revenue	€ 4.329.881,04	Not >=	4377375
5		Annual taxes	€ 31.887,00		IRR per year	7,7%					
6		Lease duration (months)	120					**Cummulative costs**			
7					NPV	€ 523.775,42		Start-up costs	€ 1.289.626,29		
8		**Project start-up**									
9		Start-up costs	€ 1.289.626,29		GIY	-19,9%		Lease costs	€ 550.000,00		
10		Construction participation (Yes/No)	No								
11		Capped rent prices (1 = Yes/0 = No)	0					Taxes	€ 114.411,74		
12		Uncapped rent prices (1 = Yes/0 = No)	1								
13								Maintenance	€ 554.335,26		
14		**Maintenance**									
15		Maintenance costs per month per floor	€ 280,00					Operation	€ 523.239,69		
16											
17		**Operation**						**Cummulative Net Value**	**€ 1.024.655,97**		
18		Operational costs per month per room	€ 21,20								
19		Rental income percentage for Operational Manager	2,5%		**Financial results independent housing**						
20					**Return on investment**			**Cummulative revenues**			
21		**Revenue loss**			IRR per month	0,3%		Rent revenue	€ 3.952.104,98		
22		Annual vacancy (not covered by Operational Manager)	0%		IRR per year	3,7%					
23		Annual non-payment (not covered by Operational Manager)	0%					**Cummulative costs**			
24		Construction participation discount	0,00%		NPV	€ 235.533,47		Start-up costs	€ 1.289.626,29		
25											
26		**Economic parameters**			GIY	-18,2%		Lease costs	€ 550.000,00		
27		Inflation (annual)	2%								
28		Interest on debt (annual)	0%					Taxes	€ 114.411,74		
29		Rent increase (annual)	2,5%								
30		Discount rate (annual)	4,50%					Maintenance	€ 554.335,26		
31											
32								Operation	€ 523.239,69		
33											
34								**Cummulative Net Value**	**€ 1.024.655,97**		
35											
36											

WB! Status | **InputFinancial** | InputPrefShared | Rent shared total | Rent shared specification | Flat | Lowrise | Cashflow Shared | Points shared

Input consumer preferences for per room analysis (optional)

Criteria	Unit	Weight	X_1	Y_1	X_2	Y_2	X_0	Y_0
1. Living room size	m² GFA	35%	12	0	20	50	80	100
2. Bedroom size	m² GFA	20%	12	0	25	50	50	100
3. Number of roommates	#	30%	2	0	8	100	15	0
4. Rent price	€	15%	550	0	470	50	0	100

Results consumer preferences per room

Flat Room nr.	Flat Rating	Lowrise Room nr.	Lowrise Rating
2	65	2	41
3	65	3	41
4	65	4	41
5	65	5	41
6	65	6	41
7	65	7	41
8	65	8	41
9	65	9	41
10	74	10	41
11	0	11	41
		12	41
Average	66	13	41
		14	57
		15	0
		16	0
		Average	43

Input developer preferences 33,33% (Decision maker weight)

Criteria	Unit	Weight	X_1	Y_1	X_2	Y_2	X_0	Y_0
5. Internal Rate of Return (IRR)	%	100%	0,08	0	0,092	75	0,12	100
	€	100%	4377375	0	4483006	75	4778456	100

Results developer preferences

X_p	Y_p
0,077	0,00
4329881	0,00

Group preference score 33,27

Input consumer preferences

Dutch students 33,33% (Decision maker weight)

	Weight	X_1	Y_1	X_2	Y_2	X_0	Y_0	Flat X_p	Flat Y_p	Low-rise X_p	Low-rise Y_p	Total	Total	Group
D. 1	25%	18	0	30	50	45	100	22,000	17,65	22,000	17,65	4,41358	57,8057	
	20%	8	0	18	50	30	100	12,222	22,04	11,846	20,13	4,35252		
	40%	3	0	8	100	16	0	9	100,00	13	75,00	38,5714		
	15%	450	0	290	50	0	100	209,97	69,03	184,052	74,34	10,4681		
D. 2	35%	20	0	60	80	120	100	22,000	5,27	22,000	5,27	1,84333	27,0995	
	20%	10	0	16	50	25	100	12,222	20,07	11,846	16,80	3,92125		
	35%	2	0	5	100	10	0	9	46,67	13	0,00	14		
	10%	600	0	350	50	0	100	209,97	72,80	184,052	76,62	7,33489		
D. 3	20%	20	0	24	50	35	100	22,000	27,12	22,000	27,12	5,42424	57,7368	
	25%	10	0	15	50	24	100	12,222	24,18	11,846	20,31	5,90718		
	35%	2	0	6	100	14	0	9	100,00	13	34,38	31,7188		
	20%	500	0	300	50	100	100	209,97	72,51	184,052	78,99	14,6866		
														48,6262
D. 4	30%	24	0	60	50	100	100	22,000	0,00	22,000	0,00	0	27,2611	
	25%	10	0	20	50	30	100	12,222	11,11	11,846	9,23	2,71062		
	25%	2	0	5	100	10	0	9	46,67	13	0,00	10		
	20%	450	0	300	50	0	100	209,97	72,01	184,052	77,23	14,5505		
D. 5	25%	10	0	20	50	35	100	22,000	58,40	22,000	58,40	14,6	57,4076	
	30%	10	0	17	50	25	100	12,222	16,50	11,846	13,75	4,83356		
	30%	2	0	9	100	14	0	9	100,00	13	31,43	27,0612		
	15%	450	0	300	50	0	100	209,97	72,01	184,052	77,23	10,9128		
D. 6	35%	12	0	20	50	80	100	22,000	60,91	22,000	60,91	21,3174	64,4468	
	20%	12	0	25	50	50	100	12,222	0,99	11,846	0,00	0,17017		
	30%	2	0	8	100	15	0	9	100,00	13	52,38	27,9592		
	15%	550	0	470	50	0	100	209,97	100,00	184,052	100,00	15		

International students 33,33% (Decision maker weight)

	Weight	X_1	Y_1	X_2	Y_2	X_0	Y_0	Flat X_p	Flat Y_p	Low-rise X_p	Low-rise Y_p	Total
Int. 1	10%	0	0	15	50	25	100	22,000	83,60	22,000	83,60	8,36

WB! Status | InputFinancial | InputPrefShared | Rent shared total | Rent shared specification | Flat | Lowrise | Cashflow Shared | Points shared

Floor	Tenants	Completion year	Completion month	Date value		Uncapped rent per month	Capped rent per month	Maintenance	Operation	Preference rating
Flat - Ground floor (1)	9	2014	3	41699		€ 1.889,73	€ 1.869,57	€ 280,00	€ 254,40	66
Flat - 2nd floor (2)	9	2014	3	41699		€ 1.889,73	€ 1.869,57	€ 280,00	€ 254,40	66
Flat - 3rd floor (3)	9	2014	3	41699		€ 1.889,73	€ 1.869,57	€ 280,00	€ 254,40	66
Flat - 4th floor (4)	9	2014	3	41699		€ 1.889,73	€ 1.869,57	€ 280,00	€ 254,40	66
Flat - 5th floor (5)	9	2014	3	41699		€ 1.889,73	€ 1.869,57	€ 280,00	€ 254,40	66
Flat - 6th floor (6)	9	2014	3	41699		€ 1.889,73	€ 1.869,57	€ 280,00	€ 254,40	66
Flat - 7th floor (7)	9	2014	3	41699		€ 1.889,73	€ 1.869,57	€ 280,00	€ 254,40	66
Flat - 8th floor (8)	9	2014	3	41699		€ 1.889,73	€ 1.869,57	€ 280,00	€ 254,40	66
Flat - 9th floor (9)	9	2014	3	41699		€ 1.889,73	€ 1.869,57	€ 280,00	€ 254,40	66
Flat - 10th floor (10)	9	2014	3	41699		€ 1.889,73	€ 1.869,57	€ 280,00	€ 254,40	66
Flat - 11th floor (11)	9	2014	3	41699		€ 1.889,73	€ 1.869,57	€ 280,00	€ 254,40	66
Flat - 12th floor (12)	9	2014	3	41699		€ 1.889,73	€ 1.869,57	€ 280,00	€ 254,40	66
Lowrise - Ground floor (12)	*13*	*2014*	*3*	*41699*		*€ 4.433,47*	*€ 3.853,08*	*€ 280,00*	*€ 275,60*	
Lowrise - 2nd floor (13)	13	2014	3	41699		€ 2.392,67	€ 2.392,67	€ 280,00	€ 318,00	43
Lowrise - 3rd floor (14)	13	2014	3	41699		€ 2.392,67	€ 2.392,67	€ 280,00	€ 318,00	43
Total	147					€ 31.895,62	€ 31.073,24	€ 4.200,00	€ 3.964,40	62
						€ 31.895,62	€ -			
					Actual rent per month:	€ 31.895,62				

WB! Status | InputFinancial | InputPrefShared | **Rent shared total** | Rent shared specification | Flat | Lowrise | Cashflow Shared | Points shared

General

Floor	Flat (12 floors)		
Bedrooms (#)	9		
Central heated shared areas (GFA m²)	35,73	Shared area p.p.	4,0
Central heated shared kitchen (GFA m²)	13,73		
Kitchens (#)	1		
Private kitchens (#)	0		
Toilets (#)	2	Toilet p.p.	4,5
Toilets (GFA m²)	5,18		
Bathrooms (#)	2	Bathroom p.p.	4,5
Washingrooms (#)	3	Washing room p.p.	3,0
Bathrooms (GFA m²)	18,04		
Shared outdoor areas (GFA m²)	10,76		
Shared bicycle storage	0		
Corridors (GFA m²)	36,05		

Per room

Room nr.	Room type	Points	Uncapped rent price	Capped rent price		GFA (m²)	GFA private kitchen	Central heating	Gas heating	Thermostat control	Private toilet	Private bathroom	Private sink	priv. outdoor areas	Private bicycle storage	Deduction points
F 1	Living room	0	€ -	€ -		22	0	1	0	0	0	0	0	0	0	0
F 2	Bedroom	100	€ 196,46	€ 196,46		11	0	1	0	0	0	0	0	0	0	0
F 3	Bedroom	100	€ 196,46	€ 196,46		11	0	1	0	0	0	0	0	0	0	0
F 4	Bedroom	100	€ 196,46	€ 196,46		11	0	1	0	0	0	0	0	0	0	0
F 5	Bedroom	100	€ 196,46	€ 196,46		11	0	1	0	0	0	0	0	0	0	0
F 6	Bedroom	100	€ 196,46	€ 196,46		11	0	1	0	0	0	0	0	0	0	0
F 7	Bedroom	100	€ 196,46	€ 196,46		11	0	1	0	0	0	0	0	0	0	0
F 8	Bedroom	100	€ 196,46	€ 196,46		11	0	1	0	0	0	0	0	0	0	0
F 9	Bedroom	100	€ 196,46	€ 196,46		11	0	1	0	0	0	0	0	0	0	0
F 10	Bedroom	163	€ 320,17	€ 300,00		22	0	1	0	0	0	0	0	0	0	0
F 11	-	0	€ -	€ -		0	0	1	0	0	0	0	0	0	0	0
F 12	-	0	€ -	€ -		0	0	1	0	0	0	0	0	0	0	0
			€ 1.891,85	€ 1.871,68	*Bedrooms (m²)*	110										
					Living rooms (m²)	22										
	Flat total		€ 22.702,20	€ 22.460,16	Total (m²)	132										
					Total (m²) available	132										

General

Floor	Lowrise (2 floors)		
Bedrooms (#)	13		
Central heated shared areas (GFA m²)	33,25	Shared area p.p.	2,6
Central heated shared kitchen (GFA m²)	11,25		
Kitchens (#)	1		
Private kitchens (#)	0		
Toilets (#)	3	Toilet p.p.	4,3
Toilets (GFA m²)	4,04		
Bathrooms (#)	3	Bathroom p.p.	4,3
Washingrooms (#)	4	Washing room p.p.	3,3
Bathrooms (GFA m²)	19,67		
Shared outdoor areas (GFA m²)	4,48		
Shared bicycle storage	0		
Corridors (GFA m²)	65,9		

Per room

Room nr.	Room type	Points	Uncapped rent price	Capped rent price		GFA (m²) adjusted	GFA private kitchen	Central heating	Gas heating	Thermostat control	Private toilet	Private bathroom	Private sink	priv. outdoor areas	Private bicycle storage	Deduction points
L 1	Living room	0	€ -	€ -		22	0	1	0	0	0	0	0	0	0	0
L 2	Bedroom	89	€ 174,83	€ 174,83		11	0	1	0	0	0	0	0	0	0	0
L 3	Bedroom	89	€ 174,83	€ 174,83		11	0	1	0	0	0	0	0	0	0	0
L 4	Bedroom	89	€ 174,83	€ 174,83		11	0	1	0	0	0	0	0	0	0	0
L 5	Bedroom	89	€ 174,83	€ 174,83		11	0	1	0	0	0	0	0	0	0	0
L 6	Bedroom	89	€ 174,83	€ 174,83		11	0	1	0	0	0	0	0	0	0	0
L 7	Bedroom	89	€ 174,83	€ 174,83		11	0	1	0	0	0	0	0	0	0	0
L 8	Bedroom	89	€ 174,83	€ 174,83		11	0	1	0	0	0	0	0	0	0	0
L 9	Bedroom	89	€ 174,83	€ 174,83		11	0	1	0	0	0	0	0	0	0	0
L 10	Bedroom	89	€ 174,83	€ 174,83		11	0	1	0	0	0	0	0	0	0	0
L 11	Bedroom	89	€ 174,83	€ 174,83		11	0	1	0	0	0	0	0	0	0	0
L 12	Bedroom	89	€ 174,83	€ 174,83		11	0	1	0	0	0	0	0	0	0	0
L 13	Bedroom	89	€ 174,83	€ 174,83		11	0	1	0	0	0	0	0	0	0	0
L 14	Bedroom	152	€ 298,58	€ 298,58		22	0	1	0	0	0	0	0	0	0	0
L 15	-	0	€ -	€ -		0	0	1	0	0	0	0	0	0	0	0
L 16	-	0	€ -	€ -		0	0	1	0	0	0	0	0	0	0	0
			€ 2.396,54	€ 2.396,54	*Bedrooms (m²)*	154										
					Living rooms (m²)	22										
	Low-rise total		€ 4.793,08	€ 4.793,08	Total (m²)	176										
					Total (m²) available	176										

WB! Status | InputFinancial | InputPrefShared | Rent shared total | **Rent shared specification** | Flat | Lowrise | Cashflow Shared | Points shared

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1																				
2				A_LIV	A_BEDR	N_BEDR_11	N_BEDR_22	N_BEDR_33	N_BEDR_44	N_BEDR_TOT										
3				22	110	8	1	0	0	9										
4	Bedroom points					63	127	190	253											
5	Shared living room points					20	20	20	20											
6	Other facilities points					17	17	17	17											
7	Total points per room					100	163	227	290											
8	Uncapped rent price per room type					196,20	320,17	431,27	540,06			**Total rent per month:**								
9	Total uncapped rent price per room type					1569,57	320,17	0,00	0,00			1889,734								
10																				
11	Capped rent price per room type					196,20	300,00	300,00	300,00			**Total capped rent per month:**								
12	Total capped rent price per room type					1569,57	300,00	0,00	0,00			1869,57								
13																				
14	Preference score living room	35%	60,91									**Total preference rating:**								
15	Preference score bedrooms	20%	0,41			-4,53	39,92	72,61	93,54			66,40								
16	Preference score housemates	30%	100,00																	
17	Preference score capped rent price	15%	100,00			100,00	100,00	100,00	100,00											
18	Preference score uncapped rent price	15%	100,00			100,00	100,00	69,87	6,87											
19																				
20	Area total			1	1							132	=	132						
21	Nr of bedrooms					-1	-1	-1	-1	1		0	=	0						
22	Area bedrooms				-1	11	22	33	44			0	=	0		Room size:				
23	Liv. Min			1								22	>=	11		11	2	22	=	22
24	Liv. Max			1								22	<=	44						
25																				
26																				
27	**Alternative**	**Conf. Nr.**	**Group pref.**				**Configuration**													
28																				
29	Alternative 1 (**actual** dutch shared - 100/2)	1	**25**	22	110	8	1	0	0	9										
30	Alternative 1 (**actual** dutch shared - 100/3)	1	**33**	22	110	8	1	0	0	9										
31																				
32	Alternative 2 (**actual** international shared - 100/2)	2	**29**	22	110	10	0	0	0	10										
33	Alternative 2 (**actual** international shared - 100/3)	2	**34**	22	110	10	0	0	0	10										
34																				
35	Alternative 3 (IRR maximizing)	3	**75**	11	121	11	0	0	0	11										
36																				

WBI Status | InputFinancial | InputPrefShared | Rent shared total | Rent shared specification | **Flat** | Lowrise | Cashflow Shared | Points shared

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1																			
2				A_LIV	A_BEDR	N_BEDR_11	N_BEDR_22	N_BEDR_33	N_BEDR_TOT										
3				22	154	12	1	0	13										
4	Bedroom points					63	127	190											
5	Shared living room points					13	13	13											
6	Other facilities points					13	13	13											
7	Total points per room					89	152	216											
8	Uncapped rent price per room type					174,52	298,49	412,25			**Total rent per month:**								
9	Total uncapped rent price per room type					2094,18	298,49	0,00			2392,67								
10																			
11	Capped rent price per room type					174,52	298,49	300,00			**Total capped rent per month:**								
12	Total capped rent price per room type					2094,18	298,49	0,00			2392,67								
13																			
14	Preference score living room	20%	60,91								**Total preference rating:**								
15	Preference score bedrooms	35%	3,07			0,00	39,92	72,61			43,97								
16	Preference score housemates	30%	52,38																
17	Preference score capped rent price	15%	100,00			100,00	100,00	100,00											
18	Preference score uncapped rent price	15%	100,00			100,00	100,00	78,59											
19																			
20	Area total			1	1						176	=	176						
21	Nr of bedrooms					-1	-1	-1	1		0	=	0						
22	Area bedrooms				-1	11	22	33			0	=	0		Room size:				
23	Liv. Min			1							22	>=	11		11	2	22	=	22
24	Liv. Max			1							22	<=	99						
25																			
26																			
27	**Alternative**	**Conf. Nr.**	**Group pref.**	**Configuration**															
28																			
29	Alternative 1 (actual dutch shared - 100/2)	1	**25**	22	154	12	1	0	13										
30	Alternative 1 (actual dutch shared - 100/3)	1	**33**	22	154	12	1	0	13										
31																			
32	Alternative 2 (actual international shared - 100/2)	2	**29**	22	154	14	0	0	14										
33	Alternative 2 (actual international shared - 100/3)	2	**34**	22	154	14	0	0	14										
34																			
35	Alternative 3 (IRR maximizing)	3	**75**	11	165	15	0	0	15										
36																			

WB! Status | InputFinancial | InputPrefShared | Rent shared total | Rent shared specification | Flat | **Lowrise** | Cashflow Shared | Points shared

	A	B	C	D	E	F	G	H	I
1	Month	12	1	2	3	4	5	6	7
2	Year	1	2	2	2	2	2	2	2
3		dec-13	jan-14	feb-14	mrt-14	apr-14	mei-14	jun-14	jul-14
4		0	0	0	1	2	3	4	5
5	**Revenue**								
6	Maximum possible rental income Zusterflat	€ -	€ -	€ -	€ 32.693,01	€ 32.693,01	€ 32.693,01	€ 32.693,01	€ 32.693,01
7	Actual rental income Zusterflat	€ -	€ -	€ -	€ 32.693,01	€ 32.693,01	€ 32.693,01	€ 32.693,01	€ 32.693,01
8									
9	**Expenses**								
10	Start-up costs	€ -	€ -	€ -	€ 1.289.626,29	€ -	€ -	€ -	€ -
11									
12	Lease costs	€ 50.000,00	€ -	€ -	€ -	€ -	€ -	€ -	€ -
13									
14	Taxes	€ 31.887,00	€ 32.524,74	€ -	€ -	€ -	€ -	€ -	€ -
15									
16	Maintenance costs	€ -	€ -	€ -	€ 4.284,00	€ 4.284,00	€ 4.284,00	€ 4.284,00	€ 4.284,00
17									
18	Operation costs	€ -	€ -	€ -	€ 4.043,69	€ 4.043,69	€ 4.043,69	€ 4.043,69	€ 4.043,69
19									
20	**Net Value**	**€ -81.887,00**	**€ -32.524,74**	€ -	**€ -1.265.260,97**	**€ 24.365,32**	**€ 24.365,32**	**€ 24.365,32**	**€ 24.365,32**
21	Net Present Value	€ -78.360,77	€ -31.010,20	€ -	€ -1.197.525,44	€ 22.976,49	€ 22.892,37	€ 22.808,55	€ 22.725,04
22	Cummulative NPV		€ -31.010,20	€ -31.010,20	€ -1.228.535,64	€ -1.205.559,15	€ -1.182.666,78	€ -1.159.858,23	€ -1.137.133,19

	A	J	K	L	M	N	O	P	Q
1	Month	8	9	10	11	12	1	2	3
2	Year	2	2	2	2	2	3	3	3
3		aug-14	sep-14	okt-14	nov-14	dec-14	jan-15	feb-15	mrt-15
4		6	7	8	9	10	11	12	13
5	**Revenue**								
6	Maximum possible rental income Zusterflat	€ 32.693,01	€ 32.693,01	€ 32.693,01	€ 32.693,01	€ 32.693,01	€ 33.510,33	€ 33.510,33	€ 33.510,33
7	Actual rental income Zusterflat	€ 32.693,01	€ 32.693,01	€ 32.693,01	€ 32.693,01	€ 32.693,01	€ 33.510,33	€ 33.510,33	€ 33.510,33
8									
9	**Expenses**								
10	Start-up costs	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
11									
12	Lease costs	€ -	€ -	€ -	€ -	€ 50.000,00	€ -	€ -	€ -
13									
14	Taxes	€ -	€ -	€ -	€ -	€ -	€ 33.175,23	€ -	€ -
15									
16	Maintenance costs	€ 4.284,00	€ 4.284,00	€ 4.284,00	€ 4.284,00	€ 4.284,00	€ 4.369,68	€ 4.369,68	€ 4.369,68
17									
18	Operation costs	€ 4.043,69	€ 4.043,69	€ 4.043,69	€ 4.043,69	€ 4.043,69	€ 4.124,56	€ 4.124,56	€ 4.124,56
19									
20	**Net Value**	**€ 24.365,32**	**€ 24.365,32**	**€ 24.365,32**	**€ 24.365,32**	**€ -25.634,68**	**€ -8.159,14**	**€ 25.016,09**	**€ 25.016,09**
21	Net Present Value	€ 22.641,84	€ 22.558,94	€ 22.476,34	€ 22.394,05	€ -23.474,44	€ -7.444,22	€ 22.740,54	€ 22.657,28
22	Cummulative NPV	€ -1.114.491,35	€ -1.091.932,41	€ -1.069.456,07	€ -1.047.062,03	€ -1.070.536,47	€ -1.077.980,69	€ -1.055.240,14	€ -1.032.582,86

WBI Status | InputFinancial | InputPrefShared | Rent shared total | Rent shared specification | Flat | Lowrise | **Cashflow Shared** | Points shared

Points	Rent price (from July 2013)
0	0
1	2,01
2	3,96
3	5,94
4	7,91
5	9,86
6	11,84
7	13,81
8	15,78
9	17,75
10	19,71
11	21,64
12	23,61
13	25,58
14	27,55
15	29,52
16	31,47
17	33,44
18	35,42
19	37,38
20	39,34
21	41,29
22	43,24
23	45,23
24	47,17
25	49,15
26	51,1
27	53,09
28	55,05
29	57,01
30	58,97
31	60,93
32	62,9
33	64,85
34	66,81

WB! Status | InputFinancial | InputPrefShared | Rent shared total | Rent shared specification | Flat | Lowrise | Cashflow Shared | **Points shared**