P2: Predicting the added value of smart technology in a building.

A decision model approach

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Abstract

Purpose – Smart buildings are a relatively new concept introduced in the built environment that have the potential to add value to a building. The implementation of a smart system is a multi-objective problem and much research is done on finding an optimum value based on different quantitative perspectives. However, to date, no model exist that includes both quantitative and qualitative values of all four perspectives of added value: financial, sustainable, strategic and functional. The purpose of this thesis is to provide a model that predicts the overall (quantitative and qualitative) added value of smart buildings based on the preferences of stakeholders. The thesis elaborates on the process of building and testing such a model, including lessons learned.

Design/Methodology/Approach – An appropriate research methodology is that of a mathematical decision model which is part of the operational research field. With Preference Based Design (PBD) all preferences can be scaled and weighted in order to predict the overall preference score. The highest overall preference score is decision that gives the highest added value. In order to quantify all variables a Lagrange curve is used. Other research techniques used that contribute to the research are Tetra SDM and Design of Experiments (DoE).

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Introduction

The uprise of the internet changed the way we look at the built environment. The Internet of Things (IoT) is a suite of technologies and applications that equip devices and locations to generate all kinds of information (Kerjiwal, 2016). The internet is used as a backbone to communicate data about condition, position or other attributes. A relatively new concept that is linked with the IoT is a smart building (Buckman, 2014). An academic view is given by Wang et al. (2012), agreeing that smart buildings are part of the next generation building industry, suggesting that they address both intelligence and sustainability issues by utilising computer and intelligent technologies to achieve an optimal combination. Smart technology also seems to provide a promising solution to gather a lot of information about building operation relevant to building management (Zhao, 2017). A smart system consists of several parts: sensors which capture the data, smart tools which are internet-enabled devices, an integrated open cloud platform and the building installations. However, it's not the sensors, tools or installations that make a building smart, it's the ability to process and learn from all the data those sensors provide (Nouveau, 2017). In the literature part of the thesis the concept of a smart system will be explained in detail.

Smart buildings are part of the innovation of information and communication technology (ICT). In the field of Corporate Real Estate Management (CREM) the impact of innovations in ICT is comparable to the impact of the first industrial revolution (de Jonge et al., 2009). The built environment changed due to these innovations and buildings are increasingly expected to meet higher and potentially more complex levels of performance (Arditi, 2015). CREM responds to these changes by improving and maintaining the value of real estate. Over the years CREM theory elaborated on different stakeholder perspectives distinguishing four main perspectives of adding value: strategic, financial, functional and physical (Den Heijer, 2011). Den Heijer defines this CREM model as the process between demand and supply with the overall goal to optimally attune real estate.

In this thesis the concepts of adding value and smart systems come together. Building owners, investors and developers (decision-makers) are often faced with the challenge of solving the mismatch between demand and their supply by implementing an optimal set of building upgrade measures (Abdallah, 2016). Smart systems offer the opportunity to use resources more efficiently, to support processes in the building and to create new revenue (Kerjiwal, 2016). It has the potential to contribute to all four perspectives of adding value.

Taking advantage of this potential is a complex challenge. Asadi (2012) states that when faced with this challenge of solving the mismatch between demand and supply a multi-objective optimization problem is encountered, characterized by the existence of multiple and competing objectives; a set of feasible solutions that are not predefined but are implicitly defined by a set of parameters and a set of constraints that should be taken into account to reach the best possible solution. Furthermore, as innovative technologies and energy efficiency measures for buildings are well known, the main problem lies in identifying those that will prove to be adding value (Asadi, 2012). It would be too time-consuming to ask a designer to make drawings of every conceivable option that fits the intended purpose and then analyse them by enumeration (Binnekamp, 2014). Secondly, due to the large number of criteria, it is not straightforward for a user to identify the optimal system for a particular application (Mainz, 2012). Binnekamp (2014) states that what we need, therefore, is a design methodology where the design alternatives to be evaluated are not known a priori. This thesis aims at presenting a design methodology to support the decision-making of integrating smart systems to add value in a building.

Problem statement

According to Buckman (2014) it is evident that the design and expected performance of buildings has changed the last few decades and is expected to keep changing. In order for any change to be approached positively it is required that the performance of the building have been met to a higher degree than previously. A higher agree of performance may be reached by implementing new building upgrade measures but the decision making is not straightforward and remains uncertain. Uncertainty negatively effects the efficiency of the market between demand and supply (Evans, 2004). The complexity of the multi-objective problem makes it difficult for the decision maker to predict the performance of a building which could lead to inefficiency in the market.

Much research has been done to provide insight or solutions for the multi-objective problem. This chapter contains a categorisation of previous research regarding multi-objective problems in the built environment. The categorisation is necessary to assess if an appropriate model does exist because if not, an appropriate model must be designed. The table below summarizes three requirements in order to assess previous research: the orientation of the research, if the aim is optimization and the possibility to include all stakeholder perspectives of CREM, both quantitative and qualitative (strategic, financial, sustainable and functional).

The orientation of research can either be empirical or operational. Empirical research is a way of gaining knowledge by observation or experience that is already there and is therefore focussed on the past. Operational research is about problem-solving and uses the knowledge of science, mathematics, logic, economics, and appropriate experience or tacit knowledge to find suitable solutions to a problem (Binnekamp, 2014). The goal of operational research is improvement and the subject is the future. The future is uncertain by definition and research will try to present the future as accurate as possible (Anderson et al., 2015). Operational research focussing on the future often makes use of predictions, simulations and mathematical models. The multi-objective problem that exists during the design process is future-oriented, so useful previous research should have the same orientation.

The categorisation is also made to find a model that supports decision-making to achieve the best possible solution. The aim of achieving the best possible solution is a requirement which is to be followed to the greatest extent possible, either by minimization or maximization (Binnekamp, 2014). Therefor the aim of previous research should be to optimize.

The last requirement of the categorisation is the stakeholder perspective. A multi-objective problem is a trade-off between often competing values and bringing the value of different perspectives into focus (Asadi, 2012). CREM theory distinguished four main perspectives of adding value (Den Heijer, 2011). The perspectives of adding value contain both quantitative and qualitative values. If the best solution is ought to be found, all perspectives need to be taken into account. In other words, the model should be allow the possibility to include quantitative and qualitative values from all perspectives described by Den Heijer (2011).

The subject of this research is smart buildings. The process of making a building 'smart' is the implementation of hard- and software measures in and around the building (Buchman, 2014). It is essentially the upgrade of an existing or new building. A similar process is that of implementing sustainability measures and, according to Arditi (2015), smart buildings can be considered to be part of the sustainability effort.

Appropriate research should be future-oriented, aims to optimize and should focus on all values of CREM. By specifying on relevant interventions such as smart systems, sustainable measures and building retrofit/upgrade, the search can be better targeted. The more the subject of previous research relates to smart buildings, the more appropriate it could be. To find relevant papers four search queries were established applicable in different combinations:

- Predict *OR* Simulate *OR* model*
- Optimization *OR* maximization *OR* minimization *OR* "decision-model*" *OR* "mathematical model*"
- "Added value" *OR* Value *OR* feasibility
- *"Smart building*" OR "smart office*" OR "smart real estate". To expand my search to find other interventions I included later on the search terms "Green architecture" OR "Green building*" OR "green office*" OR "Green real estate" and "Building retrofit" OR "Building renovation" OR "Building upgrade".*

Author	Future- oriented	Optimization	Value	*Quantitative*	*Qualitative*	Intervention
Abdallah & El-rayes (2016)	Yes	Yes	Sustainable Financial	Yes	No	Smart technology
Asadi et al. (2012)	Yes	Yes	Sustainable Financial	Yes	No	Building retrofit
Malidin et al. (2008)	Yes	Yes	Sustainable Financial	Yes	No	Smart technology
Arditi et.al (2015)	No	No	Financial Sustainable Functional Strategic	Yes	Yes	Smart technology
Favoino et al. (2017)	Yes	Yes	Sustainable Strategic	Yes	No	Adaptive insulation
Karatas & El-Rayes (2016)	Yes	Yes	Sustainable Financial	Yes	No	Building retrofit (focussed on sustainable measures).
Kim & Kim (2017)	Yes	Yes	Sustainable Financial	Yes	No	Building retrofit
Moreno et al. (2017)	Yes	Yes	Sustainable Financial	Yes	No	Smart technology
Nguyen & Aiello (2013)	No	No	Sustainable Financial	Yes	No	Smart technology / energy savers
Shaikh et al. (2014)	Yes	Yes	Sustainable Strategic	Yes	No	Smart energy systems
Camporeale et al. (2017)	Yes	Yes	Sustainable Financial	Yes	No	Building retrofit
Michael, et al. (2017)	Yes	Yes	Sustainable Financial	Yes	No	Building retrofit (objective is a green certification)

A sufficient amount of research focusses on the future value of buildings. The future-oriented research often presents a mathematical model to predict or simulate the value of a building in order to support decision-making. Two articles do not make use of prediction or simulating the future. The article of Arditi (2015) and Nguyen & Aiello (2013) try to answer their research question with the use of a survey. The survey is oriented on the past and is part of empirical research. Their research provides valuable information but is not relevant for finding a prediction model.

The aim to optimize values in the built environment is a much bespoken subject. The reason for optimization is problem-solving. Two types of problems are recurring in the literature. Abdallah (2016), Asadi et al. (2012), Karatas & El-Rayes (2016), Camporeale et al. (2017) and Michael et al. (2017) focus on the fact that decision-makers encounter a multi-objective problem during the (re)development of a building and use the help of a model to balance the different objectives. Maladin et al. (2008), Favoino et al. (2017), Kim & Kim (2017), Moreno et al. (2017) and Shaikh (2014) focus on the fact that in the built environment, the performance of buildings is inadequate (inefficient) and that there is potential to add value. All aforementioned research have in common that it is problem-solving by optimizing the value, to include multiple objectives or to improve the efficiency.

The most interesting part of the search query is the inclusion of value. Only the article of Arditi (2015) captures both quantitative and qualitative values of different perspectives. Arditi (2015) focusses on the perceptions of professionals about economic, energy and occupant comfort aspects in smart buildings. The author subdivided these three domains in a wide range of variables which capture all four perspectives in CREM (see appendix 1). However, the study of Arditi (2015) is empirical and oriented to the past.

All the other research has a limited focus on value. Abdallah & El-rayes (2016) and Michael, et al. (2017) focus on maximizing the sustainability of a building by measuring emission, pollution water consumption and LEED points while on the other hand minimizing costs. LEED is a certification that uses quantitative sustainable measures such as Sustainable Sites, Water Efficiency, Energy Atmosphere, Materials & Resources, and Indoor Environmental Quality. Asadi et al. (2012), Malidin et.al (2008), Karatas & El-Rayes (2016) and Camporeale et al. (2017) optimize the balance between costs and environmental performance. They only use quantitative variables such as costs, temperature and energy consumption. Moreno et al. (2017), Kim & Kim (2017) and Nguyen & Aiello (2013) include, besides cost and energy performance, occupancy as well. They use quantitative variables such as occupancy rate and energy use per occupant. Favoino et al. (2017) and Shaikh et al. (2014) both aim at finding an optimized balance between minimizing energy and maximizing consumer comfort. Energy is expressed in consumption and consumer comfort in general temperature, air quality and illumination levels.

Plenty of research aims to find an optimized balance for a future situation. When doing so, conflicting values are taken into account such as minimum costs vs. maximum environmental performance or minimum energy use vs. maximum comfort. However, none of the models provide the possibility to include qualitative values. Moreover, functional value (quantitative or qualitative) is hardly ever mentioned. In conclusion, previous research provides models that are capable of predicting the optimized value for conflicting quantitative values but fail to incorporate qualitative values. In the built environment, qualitative values are an important part of the added value of an intervention such as smart systems. Therefor none of the existing models are sufficient in predicting the overall added value.

Wat zijn de gevolgen van het problem!!. Hier benoemen en/of bovenin benoemen.

Research question

The aim of my research is to extend this existing line of research and incorporate the possibility to include both quantitative and qualitative values from all four perspectives of Den Heijer (2011) in a predictive model. The model can be used to predict the added value of the implementation of a smart system in a building. In this thesis, the value of a building is measured using the preference of the stakeholders, which will be explained in detail in the theory and method chapter. The thesis will give an answer to the following research question:

How can a decision model predict the added value of a smart system, based on the preferences of the stakeholders?

The focus of the research is multi-objective and takes all stakeholders representing all four perspectives of CREM into account. The model is going to be designed to support the decision-maker in the effort to design an optimal smart building. The requirement to answer this question is to integrate the preferences of the stakeholders and the weight of each preference.

The answer to the research question will both be technical and strategical. The technical answers will focus on the product; how the decision model and smart system work. The strategic answer focusses on the process; how the decision model is created and how the prediction of the added value comes about.

To derive at an answer, the critical elements of my research are the composition of the decision model, the selection of design alternatives (smart systems) and the preferences of the stakeholders. The critical elements can be divided in demand and supply. The demand side consists of the variables, preferences and weights of the stakeholders which make up the parameters of the model. The supply side are the design alternatives. The following sub-questions should gain insight into the critical elements of this research:

1. *Demand: Which parameters (variables, preferences and weight) need to be present in the decision-model?*
2. *Supply: Which relevant design alternatives can be made based on existing smart technologies?*

The term 'relevance' is of importance and needs to be elaborated on before answering the second question. The supply side consists of a comprehensive amount of options. An inventory of smart systems will give insight into the supply of smart systems. Subsequently, the list of interventions needs to be narrowed down based on the aim of the redevelopment. To do so, additional sub-questions are added:

   2.1 What smart systems are present today?
   2.2 *What smart systems suit the aim organisation?*

Scientific relevance

Scientific theory that is applicable when a set of multiple design alternatives are presented is called 'design space'. Design space is a mental construct of an intellectual space that envelops or incorporates all of the potential solutions to a design problem (Dym & Little, 2004). A mental construct that is used within this domain is simulation. Simulation using a mathematical decision model is a scientific approach to predict your optimum. It must be noted that most of the authors concluded that such models are never 100% accurate. The primary concern during simulation is that the modeller is never sure if calibration is presenting an accurate evaluation of model uncertainty (Kim & Kim, 2017). Researches such as Asadi (2012), Kim & Kim (2017) and Abdallah (2016) - who all developed a mathematical model to support decision making - state that their model is a simplified version of reality based on limited information and that it is subject of uncertainty. Therefore, an important part of the research is the process of building an accurate model and the lessons learned on the use, evaluation and validation of the decision model.

The second scientific contribution of this research is the process of matching demand and supply in the field of CREM. In the built environment demand changes constantly while at the other hand the supply side is also subject to deterioration (de Jonge et al., 2009). In the field of CREM, extensive literature is written about strategies, methods and models to support the process of matching demand and supply. In practise, decision-makers develop an intelligent combination of methods and instruments available in order to create the best possible solution (de Jonge, 2009). Even so, this research also is a combination of methods. The aim of the research is to provide a model and a process that could be used for a wide range of building intervention problems.

Societal relevance

The improved economic conditions in the Netherlands have stimulated the real estate market. Due to the well performing market, as well as the trend to transform offices into other use, the vacancy of the office market strongly decreased (JLL, 2017). In quantitative terms, the amount of real estate in the Netherlands offers enough space until 2030 but in qualitative terms the supply is lacking (CPB, 2017). CPB also concludes that in the recent years a limited amount of new supply has been added to the market and a large number of existing buildings fails to meet the changing demands. Simultaneously, the user requirements of real estate have changed towards smart and sustainable buildings; buildings that with the use of innovative technology provide higher performance (Kejriwal, 2017). We already see a lot of smart solutions in buildings today and it is expected to play an increasing important part in society. The research could serve as a reference for the upscaling of smart systems in the built environment.

Theory

The research question can be divided into four parts: smart buildings, added value, decision model and stakeholders.

Smart building

What is a smart building?
Although there is an increasing amount of academic, popular and business literature addressing Smart Buildings as a concept, it's is still a relatively new implementation to the real estate sector (Buckman, 2014). The concept is still evolving and so are the many definitions of smart tools and smart buildings. Valks et al. (2016: p.11), in his PhD research at the TU Delft, describes a smart tool as the following:

"A service or product which collects (real-time) information to improve the use on the current building on the one hand, whilst supporting decision making on the future use on the other hand".

Buckman, (2014: p.98) described the definition of smart systems in relation to real estate:

"Smart Buildings are buildings which integrate and account for intelligence, enterprise, control, and materials and construction as an entire building system, with adaptability, not reactivity, at the core, in order to meet the drivers for building progression: energy and efficiency, longevity, and comfort and satisfaction. The increased amount of information available from this wider range of sources will allow these systems to become adaptable, and enable a Smart Building to prepare itself for context and change over all timescales".

Arditi, (2015: p.554) describes a smart building as:

"*A building that involves the usage of design solutions and technology to develop facilities that is comfortable for their occupants while at the same time economical for their owners"*.

Every definition has its own terminology but they all agree on certain points. (1) Smart buildings collect and aggregate information. (2) The smart system is capable of adapting the performance of the building for current and future use. (3) Smart building performance is a multi-actor or multi-objective issue.

Horizontal and vertical differentiation of a smart building
The PhD research of Valks (2016) is the study of smart systems present at Universities in the Netherlands today. To categorise all available applications he provided an inventory of smart systems. Valks (2016) made a distinction between four smart studies that are present in the science of today (p.85). The distinction between the studies is the horizontal differentiation:

A. Study of energy efficiency based on the use in buildings.
B. Study to support facility management by localizing and tracking users
C. Study of crowds to get a better insight in the flow of people
D. Study of space in order to improve building facilities

However, Buckman (2014) and Kejriwal (2017), both smart system experts, state that there is also vertical differentiation. Vertical differentiation can be seen as the smartness of a building. The earlier smart solutions where typically to install a system on a piecemeal basis to automate individual tasks (Kejriwal, 2017). An example of this is a sensor placed in lighting so that the light only switches on when someone is detected in the room. Buchman (2014) describes this state as an intelligent building which is in the lower bound of smart buildings and is reactive by nature.

On a smarter level the building is seen as being capable of adaption by aggregating intelligence. The smart system utilises information gathered internally from a range of sources to adapt the building for a particular event when the event is going to happen, which is fundamentally different to being reactive (Buchman, 2014). These systems are more integrated, require less manual intervention, and enable faster decision making (Kejriwal, 2017). Buchman (2014) describes this as a smart building with adaptability, not reactivity, at its core, in order to meet the drivers for building progression.

On the highest level of smartness, the Internet of Things (IoT) enables smart systems to integrate with a deep customer and data focus (Kejriwal, 2017). IoT is an ideal emerging technology to influence this domain by providing new evolving data (Gubbi, 2013). Gubbi defines IoT as the interconnection of sensing and actuating devices providing the ability to share information across platforms through a unified framework, developing a common operating picture for enabling innovative applications. The information is gathered using every available database. Buchman (2014) defines this level as the upper bound and is as a 'thinking building' which is predictive by nature. Figure 1 integrates the research of Kejriwal (2017) and Buchman (2014).

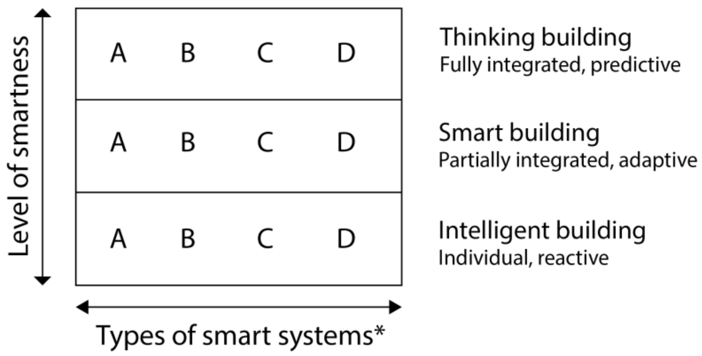


*Figure 1. Horizontal and vertical differentiation of smart. *see the distinction of Valks (2016).*

Smart buildings in practice

One thing is the wide amount of definitions regarding smart technology and smart buildings, the second is how this is comes about in practice. The research focusses on the most recent design innovations being applied in buildings: integrated smart systems. These systems which are in the upper bound of a smart building utilise four different technologies:

- Sensors
- An integrated platform
- Building facilities
- Internet-enabled devices.

In a smart building, different information such as temperature, humidity, air flow, light and sound can be collected from sensors and transferred to the building control system (Arditi, 2015). Many sensors exist such as Infrared, camera's, Bluetooth, Wi-Fi, Ultra-wideband, Radio-frequency identification (RFID), CO2, security gateways, utility meters, thermostats, smoke and pressure sensors (Valks, 2016 & Kerjiwal, 2016). They are placed throughout the building, connected with each other in a grid and linked to the integrated platform.

The main body of the grid is the integrated platform where all the data is stored. Structured and unstructured data from different internal and external sensors can then be aggregated through a common platform. Additionally, information can also be gathered from external sources such as weather or traffic forecasts. The aggregated information can be analysed with different analytical tools and approaches (Kerjiwal, 2016). Without this process, the sensors would be useless. It is the ability to process, analyse and learn from all the data that make a building smart (Nouveau, 2017). This can be seen as the brain of the smart system.

The building consists of a variety of installations controlling things such as the indoor climate, facade, space, lighting, entry/exit points etc. The information from the integrated platform can be used to change the operation of these installations on the three levels of smartness (Buchman, 2014). On the lower level of smartness, information is used to change the operation of the building installations (reactive). On a higher level of smartness building operations is defined with the use of the data (adaptive). On the upper bound of smartness, building operation is defined based on predicting the future operation.

The internet-enabled devices are tools to connect with the integrated platform via applications installable on the device. It is a tool for input in order to change building operations and output in order to request information from the database. The use of these applications also generates a new set of information. An example of such applications is that of the test case of the Rijksgebouwendienst (Rijksoverheid, 2016). They developed a smart building application accessible by any internet-enabled device in which you can adjust the indoor climate in order to increase the quality of space (input), but also to request information about occupancy (output). Furthermore, all information is stored so it can be analysed to further improve the building and predict maintenance.

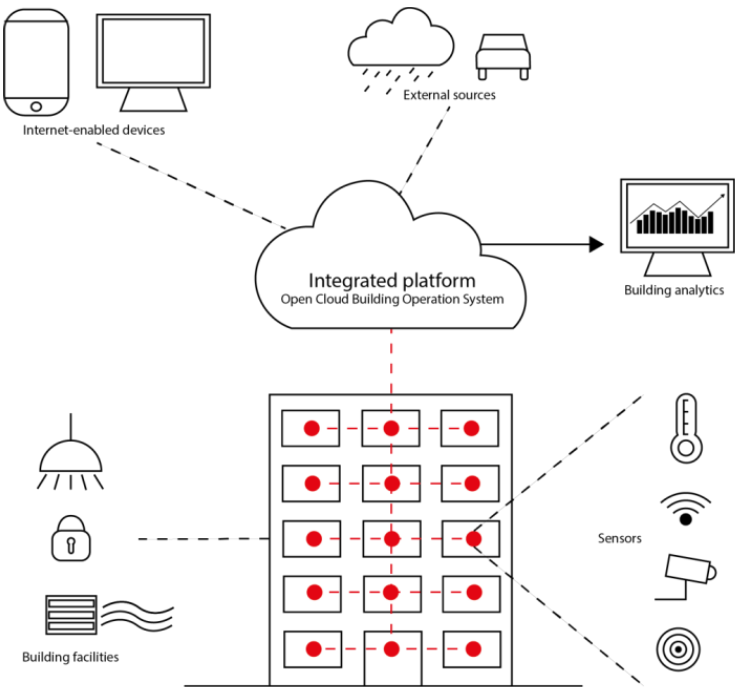


Figure 2. Integrated smart building

Added value

The second part of the definition is the added value or the preference of a smart building. Preference and added value have similar but not identical definitions. Arkesteijn et al. (2017: p.244) describes added value and preference as following:

"We note that to decide is to choose. We choose the alternative that we prefer, and prefer the alternative that adds value. This means that value can be measured by measuring preference, that is, evaluating/judging the alternatives as to the value they add, and in this context, value and preference are equivalent".

De Vries (2007) and Den Heijer (2011) defined the added value of real estate as the contribution of real estate to organisational performance and the attainment of organisational objectives from a point of view of different stakeholders. In her dissertation 'Managing the university campus' Den Heijer (2011) linked a number of values to four perspectives and twelve types of value: policy makers (strategic value), controllers (financial value), technical managers (sustainability) and the end users (functional value). Note that the model of Den Heijer functions as a reference to understand the different perspectives of added value. It does not necessarily mean that all (12) values are acknowledged by the stakeholders. The preference of each person are unique and still need to be established.

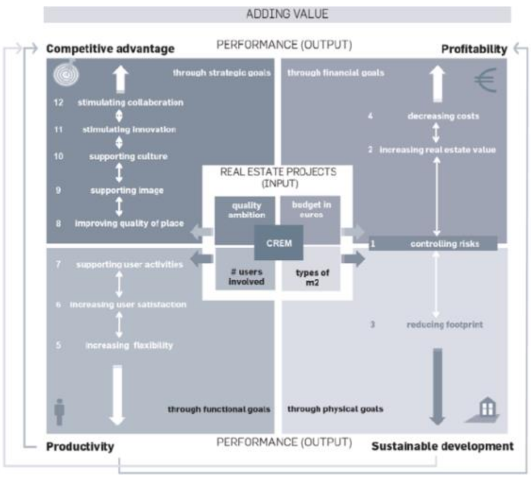


Figure 3. Four perpectives of adding value in CREM (Jensen, van der Voordt & Coenen, 2013)

Kerjiwal (2016), a smart technology expert at Deloitte, also describes the value of smart systems by naming three objectives in the Corporate Real Estate (CRE) theory: efficiency, differentiation and new revenue opportunities.

Efficiency is mostly researched with the aim to reduce energy use, repair and maintenance and Real Estate costs. The continuous monitoring and predicting capability is a tool for building managers to take appropriate corrective action which can result in lower asset risk and enhanced portfolio management capabilities (Kerjiwal, 2016) . For example, tracking the flow of people can be used to analyse occupant behaviour. It can then be used to better align space and activities based on this information. Note that the objectives described by Kejriwal (2016) are present in the different perspectives of Den Heijer (2011). For example, the financial controller aims at energy efficiency to achieve lower costs while the end user wants to efficiently perform their tasks.

The second objective described by Kerjiwal is the opportunity to differentiate by using the information to identify unmet consumer demands, provide more sophisticated services to their tenants and transform tenant and user experience (Kejriwal, 2016). It can support daily working activities of the users of the building. An example given by the Kejriwal is use of data about the movement of individuals through open spaces to help tenants boost the productivity of workers by better designing tasks and breaks to facilitate collaboration and even socializing between employees (Kerjiwal, 2016). Secondly, it can give competitive advantage to the tenant and the owner. Both the tenant and the owner operate in a market with competition and changing patterns in consumption and work. This forces companies to revaluate their CRE space usage as they look for innovative ways to stay ahead of competition (Kejriwal, 2016). Smart systems are an intervention that gives them competitive advantage in the market.

The last objective of a smart system described by Kerjiwal (2016) is that of creating value through new revenue sources. Companies applying smart systems can perhaps offer analytics-as-a-service. The data present in the integrated platform and the analysed information could be sold to other interested parties. For example, the flow of people through a public building can be sold to advertisers or urban planners and building performance data can be used to support investors in their decision-making. Because it is not related to the design of alternatives it is not part of the research. However in a later stage, after the smart system is optimally attuned, it may become a relevant objective for the building owner or CRE manager.

Mautz (2012), assessed the features of all technologies capable of indoor positioning and match them with the user requirements. They state that it is a crucial element for any initiative to design an indoor positioning system is a thorough study of the user requirements and specific application descriptions in order to justify the research and development in this field. Indoor positioning is an element of smart systems and therefore this study provides useful insight. He developed a model of 16 general user requirements that illustrates the complexity and multi-dimensionality of the optimization problem (see figure below) (Mautz, 2012). The requirements can be translated into preferences. It can be used as another reference to define the preferences of the stakeholders.

Figure 4. User requirements for indoor positioning systems (Mautz, 2012).

Decision-model

The third definition for this research is that of a decision model and its relation to added value described above. Decision making is the term generally associated with the problem-solving process. Problem solving can be defined as the process of identifying a difference between the actual and the desired state of affairs and then taking action to resolve the difference (Anderson et al., 2016). Anderson (2016) identifies that decision-making is the first five steps of problem solving:

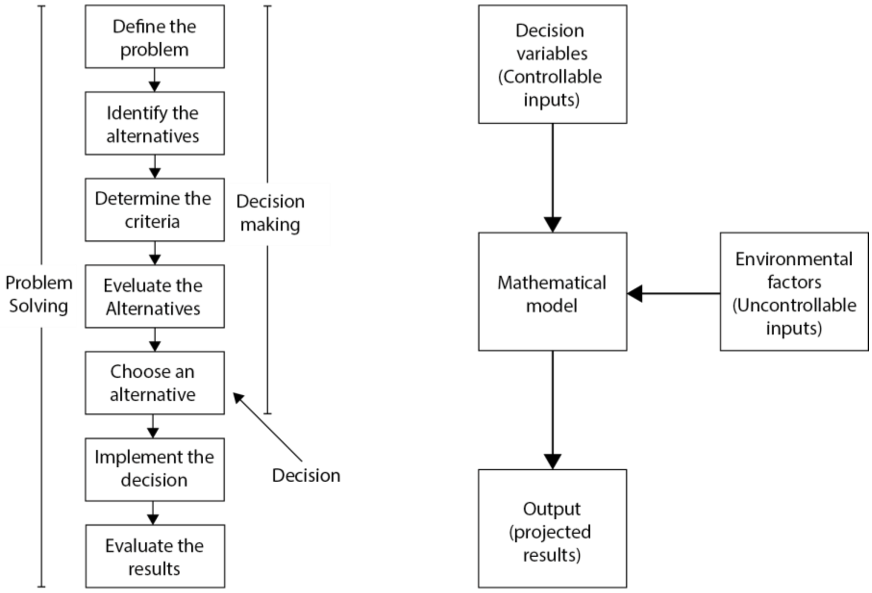


Figure 5. Problem solving and Decision making (Left) and flowchart of the process of transforming model inputs into output (right) (Anderson et al., 2016)

Once the problem has been structured, the decision-making process may take two basic forms: qualitative and quantitative. Qualitative analysis is based primarily on the decision maker's judgment and experience. With the quantitative approach, the decision maker will concentrate on the quantitative facts or data associated with the problem and develop mathematical expressions that describe the objectives, constraints, and other relationships that exist in the problem. In the field of science, mathematical models are a critical part of any quantitative approach to decision making (Anderson et al., 2016). The process of a mathematical model is transforming model inputs into output. The input consists of decision variables which are controlled by the decision maker. Inputs that are not controlled by the decision maker are environmental factors. Once all input is specified, the objective function and constraints can be evaluated and the output of the model is determined. The output of the model is simply the projection of what would happen when those variables occur in a real situation (Anderson, et al. 2016). Often, the problem definition leads to a specific output, such as maximization or minimization.

Van der Voordt (2016) expressed that in the literature of added value, the operationalisations of parameters for a decision model is researched by making each value measurable and manageable, to explore which building characteristics and facilities may contribute to it and how a changing context may influence the most appropriate interventions. Especially measurability is critical because of qualitative values. The success of the mathematical model and quantitative approach will depend heavily on how accurately the variables can be expressed in terms of mathematical equations or relationships (Anderson et al., 2016). Secondly, the model should be capable of incorporating changing contexts, such as a changing economic environment. Appropriate methods exist for both challenges, the Lagrange curve and Design of Experiments (DoE) respectively, which will be explained in detail in the Research techniques paragraph. When all preferences can be quantified, a decision-model is capable of giving the added value of each design alternative and to find an optimum.

Stakeholders

The aim of this research is to include all stakeholders. Stakeholders are people with an interest in the project. The decision-maker is a person that approves or disapproves the selection from available options and may be limited to only one stakeholder. In this research, a decision-maker is a stakeholder but not every stakeholder is a decision-maker. Relevant stakeholders in this research are the owner, developer, building manager, tenant, users and asset manager. A secondary stakeholder is the government. In this chapter, the general characteristics of relevant stakeholders will be discussed, in order to get an understanding of their perspective. The elaboration below is a reference of possible stakeholders in the redevelopment of an office building.

The owner (also referred to as investor) has four motives to invest in real estate (Brueggeman et al., 1997). First, building owners anticipate the market demands and try to produce a net income and secondly, after holding on to it for some period of time, they may sell the building for a profit. A third reason for investing in real estate is to achieve diversification. This means a variety of investment types in order to reduce the overall risk. The last reason is potential tax benefit. The motives postulated by Brueggeman (1997) indicate the owner is mostly interested in the financial perspective: creating value, reducing costs and reducing risk.

The developer strive to create value for the owner/market by creating an attractive and successful building (Adams, 2012). Strategic values such as image, stimulating collaboration and quality of space are goals to create an attractive building. Additionally, real estate developers have to take regulations into account. They see buildings in terms of rents per square foot, planning or zoning regulations, and height limitations (Adams, 2012).

The third stakeholder is the building manager. Maintenance activities have become more and more important given the amount of installations in a building and the high volume of building activities. The planning and implementation of maintenance are crucial for the efficiency of the building and business (Lind, 2012). The facility manager is interested in the (in)efficiency regarding consumption, that will result from the implementation of smart systems.

A company can have three perspectives: tenant, user and asset manager (Evans, et. al., 2011). As a tenant it can stimulate the competitive advantage of the company, expressed in strategic values. A building can also express special meaning, corporate identity and cultural values (van der Voordt & Wegen, 2005). Having a building that is in line with the business and strategy of the company can contribute to the competitive advantage of the company.

From the perspective of the employees (user), it provides space in which they can operate. The requirements of the employees are expressed in the functional values described by Den Heijer (2011). According to Nouveau (2017), a smart building expert from Microsoft, the link between building users and Smart systems has a lot of potential. Smart systems provide the opportunity to support and improve the processes of people in the building (Nouveau, 2017). For example, Microsoft developed a 'user timeline', putting the activities of the end-user central in order to get better insight in where and when a smart system can provide support.

The third role of property for a company is as a financial asset. For modern businesses there may be compelling reasons to procure corporate real estate by freehold, leasehold or a mixture of the two, within an occupational portfolio (Haynes & Nunnington, 2010). Both freehold and leasehold have a number of financial advantages and disadvantages. Which option is best depends on the market and the situation of the company. The asset manager is an important decision-maker in the buy, sell, hold or redevelopment process of a building.

Each project will have a different focus but it is likely to find the four perspectives of Den Heijer (2011) when all stakeholders are taken into account. The involvement of all four perspectives makes the process of decision-making operational by being able to discuss and compare the costs and benefits with all stakeholders.

Conceptual model

The core of the conceptual model consists of four parts, which are the key elements of the research: preference of the stakeholders, (smart) building, overall preference score and the added value. First, the parameters of the decision model are established by the stakeholders by using the Preference Measurement Methodology. Preference Measurement is the process of measurement of preference and selection of the optimal solution. This box is indicated in grey as it contains a process within. This will be explained in detail in the research method chapter. Secondly, the design process consists of the current building without any interventions and the design alternative which is the building including a smart system. Third, to assess what the added value is, it is necessary to determine both the value of the existing building as well as the value of the proposed alternatives. This is expressed in the overall preferences scores. Finally, the overall preference score of the alternatives will be compared with the current overall preference score to derive at the added value of each alternative. The building that has the highest overall preference score, i.e. adds the most value to the stakeholders, is suggested as the building that optimally aligns the supply and demand (Arkesteijn et al., 2017).

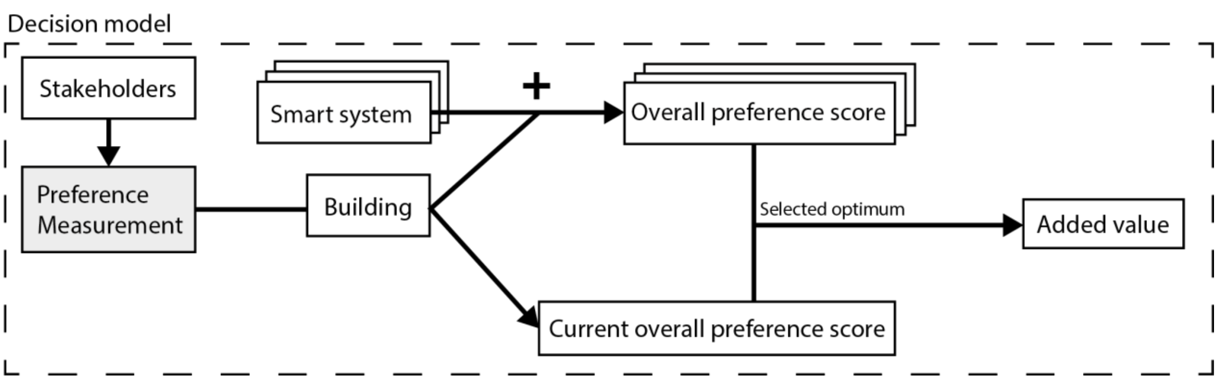


Figure 6. Conceptual model

Research method

The main question describes a design problem and is aimed at making operation related solutions towards the future. As discussed in the problem statement there is a distinction between empirical and operational research (see figure below). The problem statement and research question imply that this thesis is future oriented, aimed to improve by creating an artefact and changing a situation. Therefor an appropriate research methodology is that of operational research.

	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

Figure 7. Distinctions between operational and empirical research (Binnekamp, 2014: p.1)

Operations Research, nowadays also called Management Science, is a discipline dealing with the application of analytical methods to aid decision-making and solve design problems (Arkesteijn et al., 2017). In the built environment a small set of problem types have been identified which account of most of the problems. Because of the frequent reoccurrence of certain problems, several standard analytical methods do already exist (Binnekamp, 2014). In the table below I summarized the description by Binnekamp (2014) of common applications in the field of operational research:

Method	**Problem**	**Description**
Optimization analysis with Linear Programming (LP)	The general linear optimization problem	The mathematical modelling technique of LP helps finding an optimal solution given an objective function and a set of constraints
Choice analysis with Preference Measurement	The general preference measurement problem	A mathematical model for the measurement of preference and for the selection of the most preferred/optimal solution.
(In)dependency analysis with Regression Analysis	The general linear regression problem	Statistical processes to find an average and for estimating the relationships among variables.
Cost Quality analysis with Financial Feasibility and Discounting	The general cost vs. benefit problem	Analysis focusses on the financial aspect of optimization problems
Spatial Allocation analysis with Geometric Modelling.	The limited distribution problem	Mathematical method for negotiations on the spatial dimension of resources.
Network Planning and Mitigations	The general sequencing and coordination problem	LP programming method based on the principles of construction planning to efficiently plan activities.

The description indicates that Optimization Analysis and Preference Measurement have common ground with the research problem and question. With Optimization Analysis it is possible to optimize the implementation of design alternatives in a building if the input is based on constraints and a single objective function. When an optimal solution has to be chosen based on multiple preferences and weights, Preference Measurement is most suitable. Regression analysis is not applicable as it seeks to find an average and not an optimum. Cost Quality Analysis, Spatial Allocation Analysis and Network Planning and Mitigations focus on other interests in the built environment and are not applicable for this thesis.

Study of Optimization Analysis and Preference Measurement

Delft University of Technology offers for both Optimization Analysis and Preference Measurement a computer program: Excel What's Best and Tetra Single Decision Maker (SDM). Both computer programs are explained and tested in order to find out which method is most useful for my research.

A convenient way of creating models to solve linear programming problems is to use the What's Best add-in for Microsoft Excel (Binnekamp, 2014). It is an excel format which leaves you free to predefine the amount of design alternatives and constraints. It gives an optimal objective function by either maximizing or minimizing. When performing an investigative study, by creating a fictional case, I encounter a couple of problems with the What's Best Model. The design alternatives are interdependent and the optimum outcome is the accumulative of all alternatives. In order to comply with the constraints, the alternatives average each other out. In the figure below this is illustrated.

The floor height of the office is 310 cm and each of the smart systems needs a certain height in order to work efficiently. Smart system A needs 320 cm and system B and C need 300 cm. Smart system A would be impossible to install but due to the interdependent character it seeks an average between the three systems and gives smart system A score of 20. Secondly, not all preferences may be of equal importance and weights may need to be attached to the preferences. This is not possible in What's Best. Therefor the model does not have the intended purpose for this research.

Endogenous variables	Smart system A	Smart system B	Smart system C		Totaal			
Outcome (%)	20	71	8		100			
Floor height (cm)	320	300	300			304,0782123	<=	310

Figure 8. Excel What's Best outcome

The second decision model is based on the theory of Preference Measurement. The main results of this theory are the construction of measurement scales to which linear algebra and calculus are applicable (Binnekamp, 2014). A Preference Function Modelling (PFM) software tool that is capable of solving linear programming problems is Tetra SDM. The Tetra model is making a comparative assessment of the design alternatives considering the users (or users') criteria weights and alternatives' ratings. The solution is a score between 100 (maximum) and 0 (minimum). The highest score, in this case 87, is the best option and the closer to 100 the more it suits with the preferences of the stakeholders (see figure below). Based on the investigative study, the Tetra model, or more general speaking: Preference Measurement, is suitable for my research.

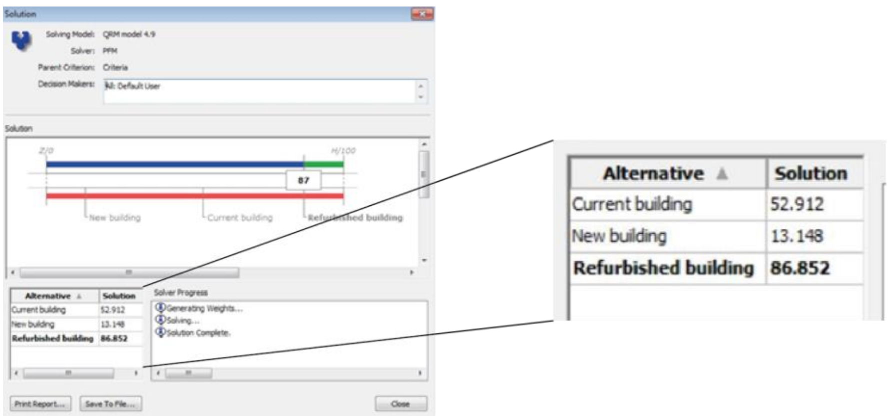


Figure 9. Tetra outcome

Within Preference Management theory there is a subtle difference in two types of research. Preference Function Modelling (PFM) and Preference Based Design (PBD). PFM is an evaluation methodology, helping decision makers to choose the most preferred design alternative from a set of predefined alternatives. When the design alternatives are not know a priori, PBD is used to generate design alternatives based on preferences and weights. (Binnekamp, 2010).

Research techniques

Based on the conclusion that Preference Management is most suitable for this thesis, several previous research techniques regarding Preference Measurement will be analysed. The analysis will be used to develop a workflow for building and executing Preference Measurement.

Tetra

As aforementioned a model that seems to suit my research is Tetra SDM. The process of using Tetra to make a decision consists of six steps (Binnekamp, 2014):

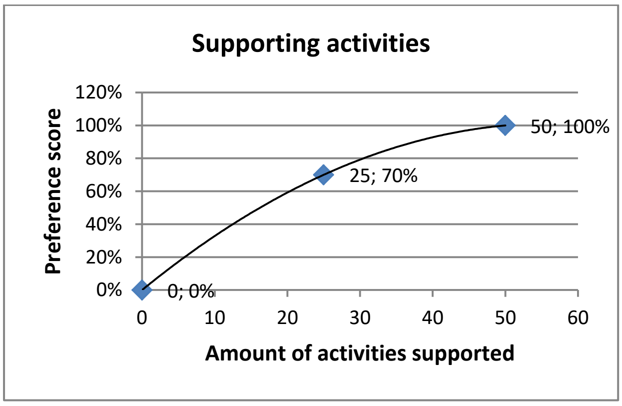
1. Define the decision makers who will be involved in the process
2. Define the alternatives to be considered in making the decision.
3. Define the criteria upon which the decision will be based. These criteria may be defined in a tree like structure, using main criteria, sub-criteria, sub-sub-criteria and so on.
4. Define the weights for all the criteria. These are defined relatively, specifying how important each criterion is in relation to others. The weights are defined in each node of the criteria tree.
5. The decision makers enter their ratings for each alternative with respect to each criterion.
6. Solve the model that has been created by the previous steps to compute the overall scores and get a numerical rating of the alternatives that corresponds to the combined ratings of all of the decision makers.

As aforementioned Tetra is based on PFM, whereby the alternatives are known a priori. For many CRE design processes the alternatives are not known a priori and a design methodology is necessary. In this research the alternatives are not known priori. Secondly the steps of Tetra do not provide a process to assess the score and weight of the criteria. In the field of CRE many criteria are based on qualitative values and first need to be translated in quantitative values. Therefor a research technique capable of designing alternatives and scaling qualitative values is necessary.

Preference Based Design (PBD)

A research approach that uses PBD instead of PFM is that of Binnekamp (2010) and Arkesteijn et al. (2017). The research offers a Preference-based Accommodation Strategy (PAS) design procedure that enables CRE managers to design a real estate portfolio, makes use of scales for direct measurement of added value/preference, and allows the aggregation of individual ratings into an overall performance rating. Their methodology is an iterative process in which the model could be adjusted in accordance with the results of the evaluation of intermediate solutions. The PAS model is created as an add-on for existing CRE alignment models and the approach of PAS is generic and can be used for a wide range of problems in real estate portfolios (Arkesteijn, et al., 2017). The research is a design process in which the alternatives are not known a priori. With the use of a mathematical model the decision-makers are able to design an optimum design alternative based on their preferences.

Arkesteijn et al., (2017) uses the Lagrange curve to scale a the preference of a quantitative or qualitative variable with a undefined number of options. For example, the preferred distance of a food facility. Distance gives an unlimited amount of options and the Lagrange curve can be used to find the preference for each distance. The Lagrange curve is a polynomial P(x) of degree ≤ (n = 1) that passes through n points [x1, y1 = f (x1)], [x2, y2 =f (x2)], [xn, yn = f (xn)] (Arkesteijn et al., 2015). In other words, the curved line goes through three points predefined by the decision-maker. This is done by letting the decision maker determine a bottom reference, top reference and intermediate reference. The X-axis is the value, the Y-axis is the preference score rating from 0 to 100. For each value of X the preference score can be found on the curve. The figure below illustrates an example of the Lagrange curve.



The X-axis is the amount of activities that are supported by the smart system. The bottom reference, zero activities supported is determined by the decision-maker with a preference of 0. The maximum amount of preferred activities supported is 50 and therefor rated with 100 (top reference). The intermediate reference set on 25 activities is rated by the decision-maker with 70. This gives the model a curve on which each smart system can be rated. If for example a smart system supports 20 activities the preference score is approximately 60.

The preference score can be calculated using the following formula:

$$P(x) = ((x - x1)(x - x2)/(x0 - x1)(x0 - x2)) * y0 + ((x - x0)(x - x2)/(x1 - x0)(x1 - x2)) * y1 + ((x - x0)(x - x1)/(x2 - x0)(x2 - x1)) * y2 \ldots$$

An important part of the research of Arkesteijn et al. (2017) is the iterative process. During the test of the PAS approach the model was evaluated. In workshops the participants were asked to design the alternatives, which gave them a better understanding of the model and their preference. In interviews the participants were able to alter their input. Iteration made it possible for them to formulate the variables as they intended and improve the model (Arkesteijn, 2017). It was perceived as positive by both the researcher and the participants and should be included in this research.

Van Alphen (2016), a graduation student of the Delft University of Technology, also used the PBD technique. The aim of her research was to establish the most suitable dwelling for home seekers. By using the PBD and a decision model she was able to support the decision-making of finding the optimal home. Van Alpen (2016) encountered difficult variables such as aesthetics. She was unable to quantify the variable in order to make a Lagrange curve. To solve the problem she limited the amount of options and constructed a series of images or illustrations for each variable (see appendix

2). The decision-maker was asked to choose the most and least preferred option and rate them respectively 100 and 0. Subsequently the decision-maker had to rate all other options between 0 and 100. This resulted in a preference scale which could be used to establish the preferences of the design alternatives. This method is a secondary measure when there is only a limited amount of options or when the researcher is unable to establish an X-axis for the Lagrange curve.

Based on the researches above the Preference Measurement box in my conceptual model can be 'opened up'. The figure below is the process within the grey box. The stakeholder decides which criteria he/she is interested in. Each of the criteria is then given a preference scale and weight by the stakeholders. The stakeholders, building and data also specify the constraints such as budget (stakeholder constraint), floor height (building constraint) and privacy (data constraint). The preference score and weight are the two factors that in combination with the design alternatives formulate the overall preference score.

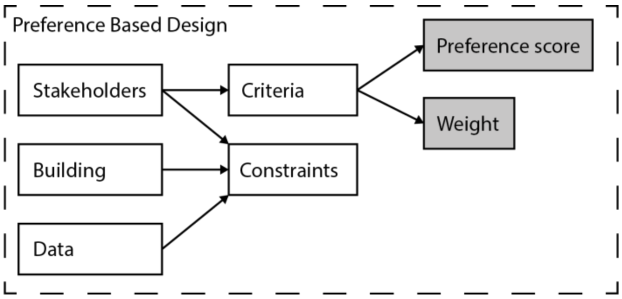


Figure 10. Preference Based Design

Data analysis
Kim & Kim (2017) performed a case study to measure the performance improvement potentials of Energy Conservation Measures (ECM's). The simulation-based case study compared a base energy model against simulated data using a decision model. The research provided lessons learned about analysing variables and the outcome of a decision model. Design of Experiments (DoE) was recommended to analyse interactions among variables, for establishing or maintaining quality control and to simulate different situations (Kim & Kim, 2017). Design of Experiments (DoE) is a designed experiment in which some purposeful changes are made to the input variables of a process or system so that we may observe and identify the reasons for changes in the output response (Montegomery, 1991).

Shun (2016) provided two DoE techniques for financial and mathematical models; sensitivity and scenario analysis. A sensitivity analysis determines the robustness of an optimal decision by identifying critical variables underlying projections or forecasts. Each variable is tested in isolation to identify the impact of the variable. Note that resulting outputs can be misleading as they tend to exaggerate outcomes because counter movements are not factored in (Shun, 2016). The second analysis is a scenario analysis which examines a combination of variable changes. The scenarios are based on possible futures to see how the model responds in different scenarios. The obtained information from the analysis can then be used to adapt the variables.

Workflow

Based on the PAS approach of Arkesteijn and Binnekamp (2017) the following workflow is developed:

1. Select the stakeholders. Subsequently, define the decision-maker. The decision-maker is the person that will approve the implementation of the smart system.
2. Each stakeholder specifies the decision variable he/she is interested in.
3. Each stakeholder defines the preferences (also called criteria). Each stakeholder rates his/her preference for each decision variable. Either the Lagrange method of Arkesteijn (2017) or the method of van Alphen (2016) is used to define the preferences.
4. Each stakeholder defines the weights for each of his/hers criteria. These are defined relatively, specifying how important each criterion is in relation to others.
5. Determine and define the constraints the stakeholders are interested in.
6. Design the alternatives. From the starting point, the current situation, the decision-maker can choose an intervention from the inventory. After the decision maker has chosen a set of interventions a design alternative is generated. The decision maker generates several design alternatives to search for the highest possible overall preference (Arkesteijn, 2017).
7. Deriving to a solution. The objective is to achieve the highest overall preference score, the optimal decision. It is compared with the current preference in order to assess the added value.
8. Evaluation. Both Kim & Kim (2017) and Arkesteijn et al. (2015) concluded their research with the fact that is was generally found difficult to quantify subjective measures. Arkesteijn et al. (2017) derived to a solution of using an iterative process to adjust and improve the assigning of preferences. By evaluating the criteria, weights, constraints, design alternatives and the outcome, the stakeholder will be able to better define their input.
9. Design of Experiments. Make purposeful changes to the input variables of the model so to observe and identify the reasons for changes in the output response. The purposeful changes are based on likely futures and situations.
10. The last step is the writing of the report including a recommendation for the decision maker. A concern during optimization is that the modeller is never sure if the model is presenting an accurate prediction due to uncertainty in the model. The major contention of the decision-support under uncertainty is to render the simulation result as a probability distribution function (Kim & Kim, 2017 and Shun, 2016). For example, "the probability of an ECM consuming less than 80% of the baseline energy would be 60%", rather than "This ECM would consume less than 80% of the baseline energy" (Kim & Kim, 2017).

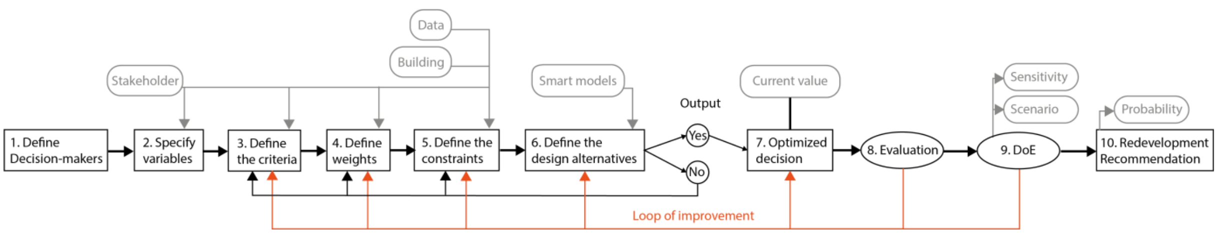


Figure 11. Own workflow based on Arkesteijn et al. (2017) and Kim & Kim (2017).

Data collection

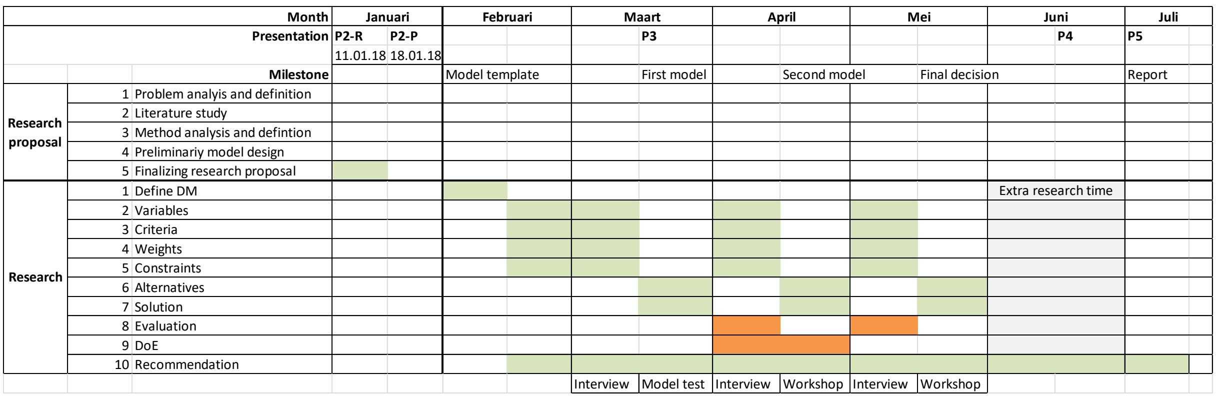
In case of operational research the collection and analysis of data form the basis of the model parameters. The first issue with data collection is limitation. Best practises require detailed measured data. Due to on-site access limitations, budget, and/or project timelines, all high resolution data may not be entirely available (Kim & Kim, 2017). Due to the limitations the research is focussed on a single case.

Based on the research of Arkesteijn et al. (2015) interviews are a good data collection technique to obtain all necessary information for step 1 to 5. In several interviews the variables, criteria, weights and constraints will be discussed. When all information is collected the first mathematical model can be built. After, the interviewees participate in a workshop to find an optimum by designing alternatives. The self-design workshop method from Arkesteijn et al. (2017) shows that it helps the participants to better understand their input and improve if necessary. By doing so the preferences of the model better depicts the actual situation. The data collection is an iterative process of interviews and workshops until a satisfied result is achieved.

Other information, such as information about the building or smart systems, is based on existing data. Data such as budget, building use, contracts, specifications and regulation should be acquired at the organisation or the internet. This is done by examining documents in the form of facility and operational reports, building and system information documents, financial records, organisational databases, literature databases and market research.

Planning

The figure below is a general planning. In the spring semester of 2018 the research will be executed according to the workflow. A non-repetitive workflow would go from step 1 to 10 in the usual order. This research shows an iterative process in which step 2 to 5 and step 6 & 7 are repeated. This is done so that the model can be adjusted in accordance with the results of the evaluation.



Introducing the pilot study (Schiphol CBD)

The Preference model is going to be tested on the real estate portfolio of Schiphol. Schiphol Group is an airport operator and owner of Amsterdam Airport Schiphol, Rotterdam The Hague Airport and Lelystad Airport. The most important airport is Amsterdam Airport Schiphol and this is where Schiphol Central Business District (CBD) is located. Schiphol Real Estate (SRE), a 100% subsidiary of Schiphol Group is responsible for the development, investment, maintenance and asset management of all the commercial properties in the Schiphol CBD. Schiphol CBD is a prime office centre with more than 500 companies and 65.000 employees. Schiphol is located in the municipality the Haarlemmermeer and the CBD is located next to the passenger hall. All the land of the CBD is privately owned by Schiphol Group.

SRE is constantly (re)developing commercial property in order to create and maintain an effective and attractive business location. Recently SRE stated that their vision is to transform Schiphol CBD into a smart area by integrating smart systems not only on building level but also on area level. Willem van der Ven (2017), project developer at SRE, elaborates on the envisioned roadmap of Schiphol. The smart building implementation starts with the Microsoft office building: The Outlook. Secondly they want to expand by redeveloping other buildings to smart. The third step is to connect buildings, public space and parking with each other. SRE expressed the desire to involve the stakeholders in the process of determining which interventions add the most value. The vision of SRE is summarized in the presentation slide of Ven (2017) (see appendix 3). In short: the CBD should optimally support the business of our tenants and visitors SRE has four focus points: Flex, Sustainable & Health, Connect and Smart (Ven, 2017). Smart is the overall concept addressing to all focus points.

Currently none of the buildings are smart and some of the buildings do not fit their intended market purpose anymore. This incited SRE to rethink their vision of Schiphol CBD. The exact requirements are not clear but SRE, the initiator, desires the CBD to be a smart area. The upcoming years SRE will research, test and implement smart systems in the CBD. Recently SRE initiated the development by collaborating with Microsoft, tenant of a large office in the CBD, to upgrade the Outlook building into a smart building. The lease of Microsoft ends in 2018 and they are willing to extend for another 10 years if the building is going to be upgraded to a state of the art smart building. Currently plans are being made to develop the building. Parallel to this development SRE is researching how to extend the smart concept on a larger scale.

SRE presents two research development assignments. The development of the Outlook building and the development of Schiphol Smart Area. The research approach can be applied to both cases. The pilot study will focus on the development of the Outlook building.

Try-out of the model

Based on the study of Preference Measurement, PBD is most suitable. Before using the workflow in the Schiphol Case a try-out should reveal if it works appropriately. The input is fictional so the results are not of importance. The chapter will mainly discuss the process and usefulness.

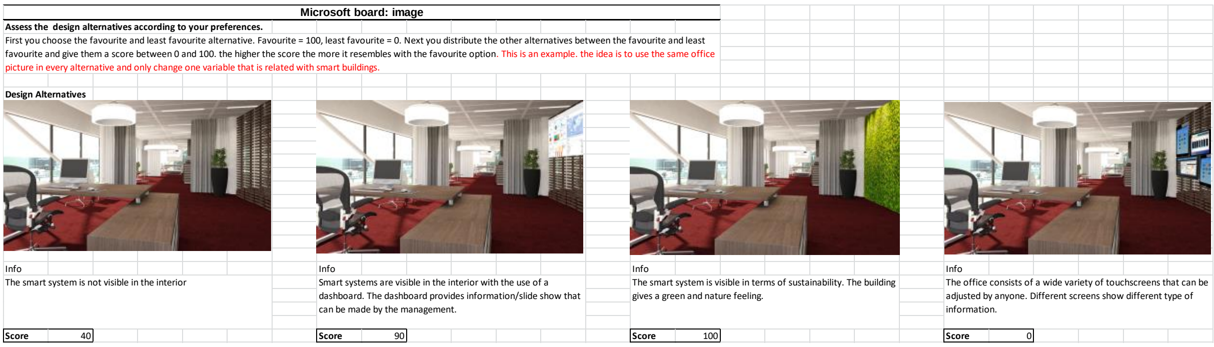
Step 1 + 2: Define stakeholders and specify their variables

The first two steps need to be established in collaboration with the company. For now, the stakeholders are fictional and defined by the literature aforementioned. The interest of the stakeholders is unknown and the variables cannot be specified. The user requirements of Mainz (2012) can be used as reference to specify general variables. Mainz, 2012 also provided useful quantitative units for the variables. Three variables will be used to test all steps: number of activities that are supported, occupancy rate and image.

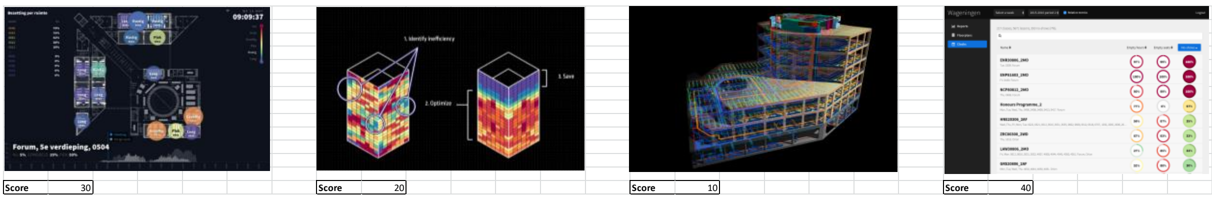
Step 3: Define the preferences

In order to define the preferences several methods are applied. I will explain the process of assessing the preferences with two examples: occupancy rate and image. The criteria focusses on the vacancy rate. Vacancy rate is a quantified unit for the X-axis. Secondly the Preference Score (Y-axis) needs to be established. To do so, the stakeholder should rate the bottom, top and an intermediate reference. For now, this is fictional. The fictional tenant gives a preference score of 0 when 20% is vacant. The reasoning is that this amount of vacant space means that the space is not used effectively. When the vacancy is at 5% the space is used effectively and the tenant scores this with 100. The intermediate is set at 10% vacancy with a score of 40. The Lagrange curve is shown below:

The second illustration is the criteria ‘image’. The criteria means that the tenant wants to show that they occupy a smart building. There is no quantitative scale to represent the X-axis. Therefor the solution of Van Alphen (2016) is used. By using images with only one variable the participant is asked to first rate the most favourite (top) and least favourite (bottom) with respectively 100 and 0 and subsequently rate the others in between. The method is shown below:



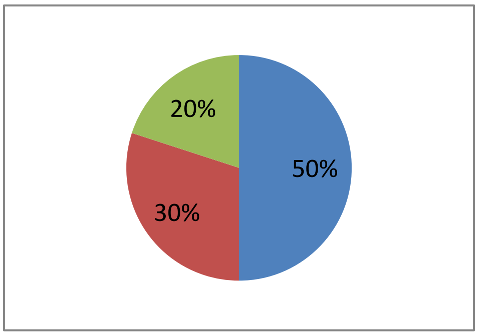
The third illustration below shows a slightly different use of the method of van Alphen (2016). This method is used when the one option does not exclude the other option. A design alternative can be one or a combination of the options below. The participant is asked to divide 100 points between the options. The preference score of the design alternative depends the accumulation of the options it includes.



4. Define weights
The stakeholders assign the weights to each variable that they have specified. In this try-out I assigned the weights for the Microsoft Board (tenant).

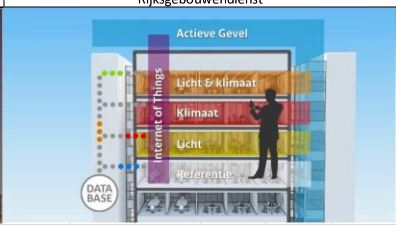
Weight of the variables

Microsoft board	weight
Supporting activities	50%
occupancy rate	30%
Image	20%
Total	100%



5. Determine the constraints
Some of the objectives the stakeholders have are not preferences but constraints. The objective then contains a minimum, maximum or both and when a design alternative does not comply it is not suitable. The same accounts for the building and data constraints.

6. Design the Alternatives
The list of interventions has not yet been established. Due to time limitations the design alternatives are already set. The fictional process has the character of a PFM instead of PBD. This will not be the case in the research. The three options are listed below.

Bgrid	Rijksgebouwendienst	KPN smart building
		

For each of the alternatives the preference score can be calculated using the Lagrange formula. As an example the preference score of the 'criteria supporting' activities is shown below. This will be done for each criteria.

	Supported activities	Interpolated preference score
KPN	15	27,41
RGD	25	51,85
Bgrid	18	35,05

7. Solution
Based on the decision-maker's input the model calculates the design alternative with the highest overall preference score. In the try-out the model shows the overall preference scores and the highest is selected as optimum. The formula used to derive at the overall preference score is:

*Preference 1 * Weight 1 + Preference 2 * Weight 2 + …*

The highest overall preference score is Bgrid. It can be compared with the current situation to assess the added value:

	Current	KPN	RGD	Bgrid	Weight
Supporting activities	20	27,41	51,85	35,05	50%
Occupancy rate	0	3,20	0,00	72,80	30%
Image	30	70,00	50,00	30,00	20%
Overall preference score	**16,00**	**28,66**	**35,93**	**45,37**	

The successful try-out of all relevant steps proves that the model works. Note that step 8, 9 and 10 are not yet applicable but does not influence the usage of the model. It can therefore be left out of the try-out. For future research the model will be used accordingly, except that the design alternatives are not yet given.

Limitation

The LaGrange curve contains one problem. It can give negative preference scores or scores above the maximum (often 100). This problem presents itself when the intermediate is far from the linear between the top and bottom reference. When this happens the Lagrange curve is not suitable for establishing preference scores. The example below illustrates the problem. On the left a linear line is created because the intermediate (30,25) is exactly on the y = -ax + b formula. In the middle graph, the intermediate (30,40) moves slightly away from the linear and a curve is created. In the right graph, the intermediate (30,75) moves further away from the linear and the Lagrange problem occurs. The curve goes above the maximum of 100 which is unacceptable in the research. Thus, it seems that the further the intermediate is from the linear, the more likely it becomes that the Lagrange problem occurs and the preference score cannot be established.

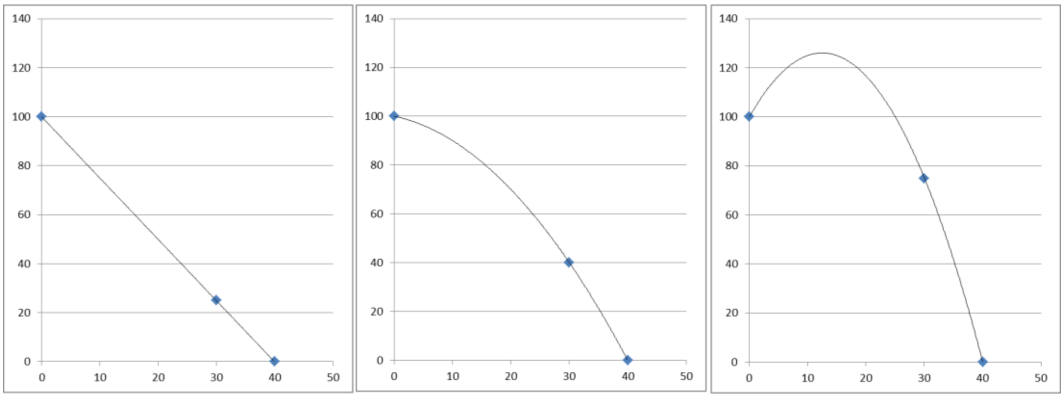


Figure 12. Lagrange curves

Ruud Binnekamp (2010) recommends in his dissertation a Bezíer Curve to exclude this problem. First the stakeholder has to decide on the coordinate of the top and bottom reference. The stakeholder then uses two intermediate control points to shape the curve until its slope corresponds to how the stakeholder relates decision variable values to preference ratings (see figure below). However this method is more difficult for both researcher and participants.

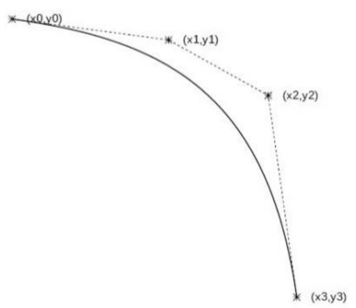


Figure 13. Bezíer Curve (Binnekamp, 2010)

Another solution in the field of mathematics is Piecewise Cubic Interpolation (PCI). The curve is made out of pieces. For each curve between two points the slope changes. In other words, the individual segments have different coefficients (Erasmus, 2007). The figure below is an example of PCI. The main advantage is that no interpolated function values outside the range of data (negative or above maximum). The downside is that the graph is not very smooth.

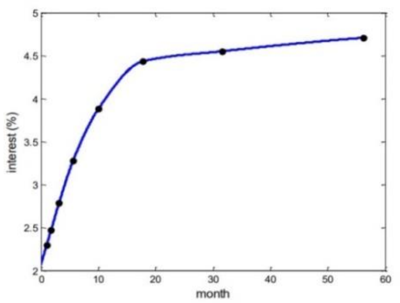


Figure 14. Piecewise Cubic Interpolation (PCI) (Erasmus, 2007)

The last mathematical formula that could replace the Lagrange curve is Spline. 3D models make use of splines to create smooth surfaces. For that reason it is used a lot in 3D modelling. The downside is that in extreme situations the function can overshoot data (Erasmus, 2007). Secondly the ability to make smooth curves results in the example below in a upwards opening parabola between the last two points. This may not be in line with the preferences and the use of smooth curves may not be relevant for this research.

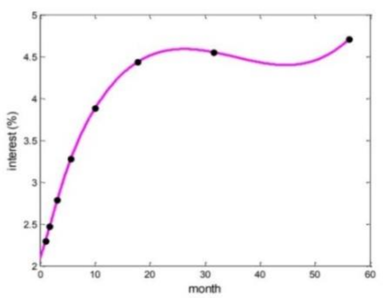


Figure 15. Spline (Erasmus, 2007)

In the upcoming research the available formulas can be examined and the most favourable formula can be used to determine the preference scores.

Goals and objectives

The generic objective of this research is to contribute to the need of a decision-making model for the prediction of smart systems in real estate and offer an approach in which decision-makers are able to select an optimum intervention. The scientific purpose is to provide lessons learned in how to develop such a model and to contribute to the general study of CREM.

The model specific objective is to provide a solution to the stakeholders in which the highest overall preference score is reached. In other words, a solution with the highest added value.

Deliverables

The outcome of my research is a complete, reliable and valuable research thesis. The report should include sufficient literature and market research, a working mathematical model and appropriate analysis models. The research should deliver an optimum solution that could be implemented by the organisation which was subject of this research.

Dissemination and audiences

The research will be disseminated in the repository of Delft Technical University and could hopefully contribute to the field of Real Estate Management and operational research within Management of the Built Environment.

Personal study targets

My personal study target is to familiarise myself with new innovative technology within the built environment. I agree with the phrase ‘smart is the new green’ as stated by many experts in the field. Not only research but also the market is strongly interested in what smart has to offer. This way I can connect with practise and step into the market with a relevant piece of knowledge.

During my studies I became very interested in operational research and my personal aim is to become an expert in the design and use of decision models. This could be an excellent first step in doing so.

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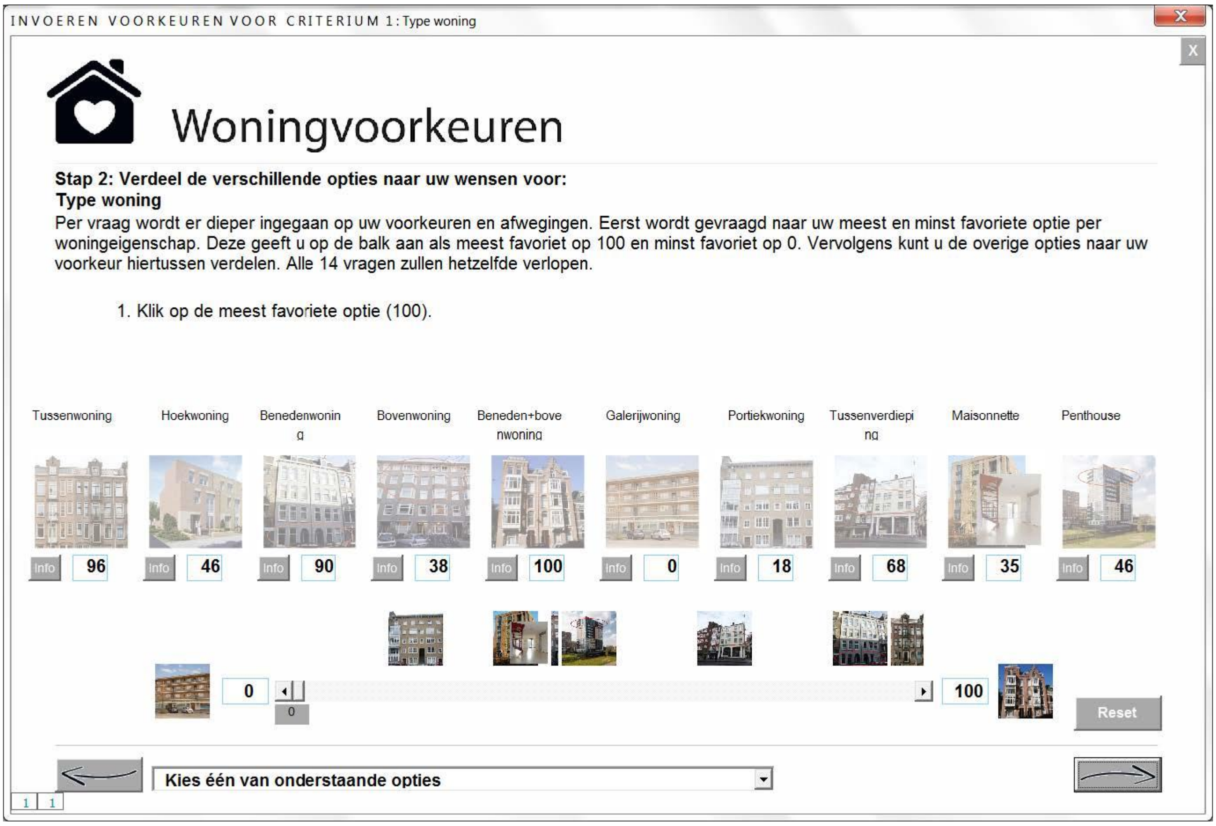
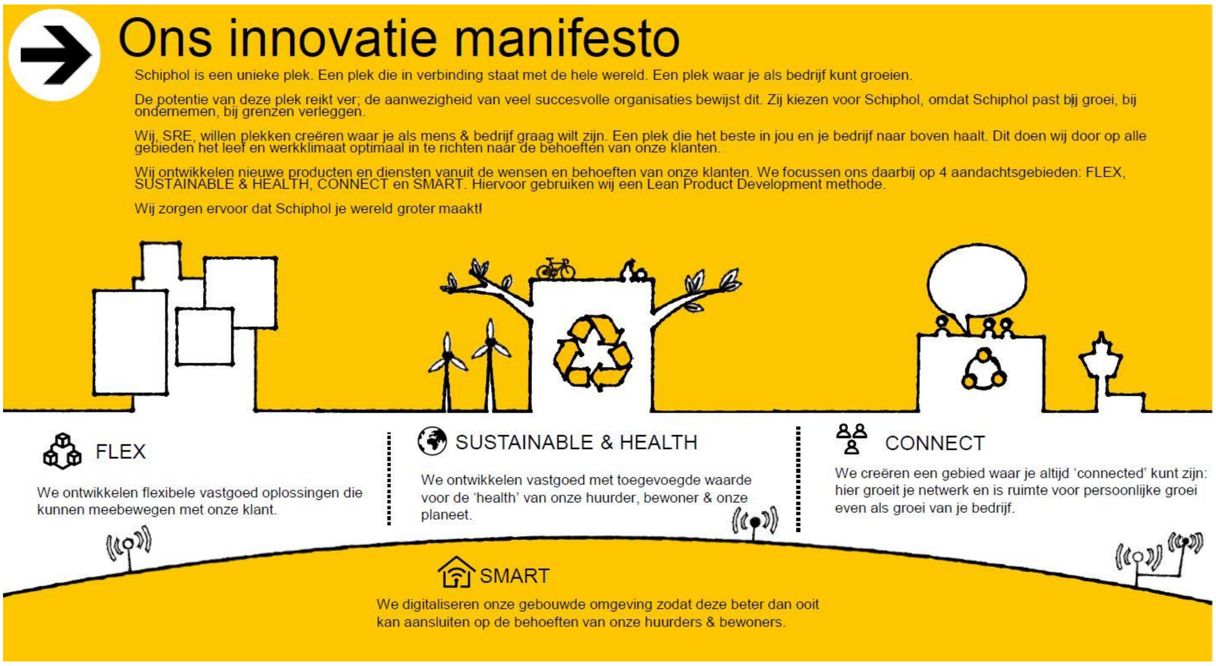
Appendix 1

Tools	Domains	Variables	Sources
Communication network, automation technologies and materials/equipment	Economic issues	Planning and design costs	Alwaer and Clements-Croome (2010), Brown and Southworth (2008)
		Construction costs	Alwaer and Clements-Croome (2010)
Financial		Operation and maintenance costs	Kolokotsa *et al.* (2011), Wong *et al.* (2008), Alwaer and Clements-Croome (2010)
		Sustainability costs	Wang *et al.* (2012a, 2012b), Kolokotsa *et al.* (2011)
	Energy issues	Heating systems	Wu and Noy (2010), Wong *et al.* (2008), Kolokotsa *et al.* (2011), Chwieduk (2003), LEED (2008)
		Cooling systems	Wu and Noy (2010), Kolokotsa *et al.* (2011)
Sustainable		Lighting systems	Wu and Noy (2010), Wang *et al.* (2012a, 2012b), Eang and Priyadarsini (2008), Wong *et al.* (2008), Wong and Jan (2003), LEED (2008)
		Water systems	Chwieduk (2003), Kleissl and Agarwal (2010)
	Occupant comfort	Temperature	Doukas *et al.* (2007), Wang *et al.* (2012a, 2012b), Eang and Priyadarsini (2008)
		Humidity	Doukas *et al.* (2007)
Strategic		Air quality	Doukas *et al.* (2007), Wang *et al.* (2012a, 2012b), Eang and Priyadarsini (2008), Wong and Jan (2003)
		Acoustic comfort	Wong and Jan (2003)
		Functionality	Yang and Peng (2001)
		Psychological aspects	Morsy (2007)
		Security	Doukas *et al.* (2007), Wong *et al.* (2008), Kleissl and Agarwal (2010)
Functional		Fire protection	Doukas *et al.* (2007), Wong *et al.* (2008)

Appendix 2


INVOEREN VOORKEUREN VOOR CRITERIUM 1: Type woning
Woningvoorkeuren
Stap 2: Verdeel de verschillende opties naar uw wensen voor:
Type woning
Per vraag wordt er dieper ingegaan op uw voorkeuren en afwegingen. Eerst wordt gevraagd naar uw meest en minst favoriete optie per woningeigenschap. Deze geeft u op de balk aan als meest favoriet op 100 en minst favoriet op 0. Vervolgens kunt u de overige opties naar uw voorkeur hiertussen verdelen. Alle 14 vragen zullen hetzelfde verlopen.
1. Klik op de meest favoriete optie (100).
Tussenwoning
Hoekwoning
Benedenwoning
Bovenwoning
Beneden+bovenwoning
Galerijwoning
Portiekwoning
Tussenverdieping
Maisonnette
Penthouse
Info 96
Info 46
Info 90
Info 38
Info 100
Info 0
Info 18
Info 68
Info 35
Info 46
0
100
Reset
Kies één van onderstaande opties

Appendix 3



The vision of Schiphol Real Estate (SRE) is to create places where people and business want to be. The CBD should optimally support the business of our tenants and visitors. SRE has four focus points: Flex, Sustainable & Health, Connect and Smart (Ven, 2017).

- FLEX: SRE develops flexible real estate solutions that are able to adapt with the changing demands of the tenants.
- SUSTAINABLE & HEALTH: the existing stock is in the process of sustainable improvement. New developments are in line with the advanced sustainable requirements. The offices have an excellent indoor climate to support the health of the users and visitors.
- CONNECT: The CBD is an area where people can meet, interact and built a network. It is place where people and business can grow.
- SMART: SRE digitalises the built environment in order to meet the demands of users and visitors. Smart is the over-arching concept for the other three focus points.

By building a platform spaces can be shared in the area which offers greater flexibility. The data will also be analysed so that inefficient space use can be detected. This information can be used to support asset management, such as more efficient occupancy.

Personalized apps and constant monitoring of the indoor climate and occupancy could lower the energy use and better align the temperature, lighting and air quality to the user's requirements. Apps allow people to adapt the indoor climate of their working space. The sensoring of temperature and light could also prevent unnecessary energy use. The analysis of the data could be used for preventive maintenance and improvement of the installations.

The smart system allows interaction between different companies by sharing spaces and information. The smart area connects people with people or spaces. It could be possible that a smart system tells you where the best working place is (based on your preferences) where your meeting could take place, or where your colleague is.

The greatest challenge with Schiphol Smart Area is the wide range of tenants. The CBD consists of large multinationals and medium to small sized companies in different working fields. Additional the tenants in the CBD are constantly changing. The model should take all the different preferences and the changing character into account in order to achieve well balanced optimum.