Smart Real Estate Management

DEVELOPING A SMART TOOL FOR CAMPUS USER ALIGNMENT

COLOPHON

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PREFACE

This report is the graduation thesis representing the finalization of the master study 'Management in the Built Environment' of the Technical University of Delft, faculty of Architecture. The graduation theme for this report is 'Smart Real Estate Management' (SREM) focussing on the development of Smart Tools to support real estate management.

The objective of this research is to develop a Smart Tool to provide information for the alignment of space demand and supply, for both the user and Corporate Real Estate Management (CREM).

FOREWORD

There are several reasons that led to choosing this research subject. Of course, the notion that we need to move to a more sustainable world is widely spread. Considering the impact of the built environment on the production of CO2, my interest was sparked in finding solutions within my studies. Therefore, in my former graduation research at higher education (HvA) I also chose the subject Smart Building. The research set out to find solutions in primitive architecture to deal with the energy issues of today, mostly focussing on building engineering at the detail level.

In the period between graduating and studying at TU Delft, I had a part time job working as sales and support at an IT startup company. Therefore, I came in contact with web- and mobile-application building and, even though I never developed in my time there, I was engaged in system thinking, workflows and intuitive interfaces for end users.

With the recent hype surrounding the Internet of Things (IoT), I began to think about the implications of IoT for the built environment. Like every smart device is able to provide information on its use, a smart built environment should provide information on buildings and cities. Even more so, it provides an interaction with real estate which, in my opinion is currently absent. This interaction can ultimately possibly lead to a new appreciation for the built environment.

In my travels from Amsterdam to Delft I was already using a mobile app (OV9292) daily, which provided me with information on train departures and transfers, in order to calculate my journey. When arriving on campus or any other building in which I needed to find a place to study, information on the availability and aspects of space was absent. This led to the realisation that there is an absence of a Smart Tool that provides this daily practical information.

The graduation subject 'Smart Real Estate Management' deals exactly with the above described problem, but how it was going to done still needed discovering. Thus, by selecting Smart Real Estate Management as my graduation subject, I was given the opportunity to make this Smart Tool myself, a user of the campus, which I gladly took.

This thesis represents the journey of the development of a smart tool. I hope you will enjoy reading this research report.

Sven ter Veer

ACKNOWLEDGEMENTS

Since September, I have commenced the research for this master thesis in the theme of smart real estate management. This has been the lengthiest and most extensive project I have worked on to date. During the time leading up to this moment, I have had much help from many angles. Therefore, one can argue that this thesis was not the effort of a individual person, but rather a collaborative one. This manifested itself in friends who engaged in thinking actively, mentors who provided guidance or colleagues contributing with valuable insights.

Considering my interests and my expectations of the future, this theme proved to be right up my alley. However, there were still some doubts in the beginning which, fortunately the theme coordinator Monique Arkesteijn was able to steer me through. She had placed me with Alexandra den Heijer, who was very understanding and patient with me from the outset, to make sure I understood everything that was communicated. It also became clear, that other graduation students were researching this subject each having a unique perspective. By getting in contact with them the opportunities that exist in this field were confirmed, which was able to motivate me further. From that point on, I started to gain momentum towards the research proposal.

I had always been interested in doing an internship, and once my research proposal was finished I started to look for an interesting company. Luckily, LoneRooftop was located very close to where I lived which made stopping by less daunting. Once I started conversations with them, it was clear the interests of both parties were there, but a logical collaboration needed to be found. Fortunately, we were able work this out, as retrospectively the internship proved to be very fruitful for the development of my research.

Considering all of this, i would like to thank my friends and fellow students with similar researches who were willing to share information and discuss the topic. I would like to thank everyone of LoneRooftop for taking me under your wing and providing me with a pleasant place to study. I would like to thank Rein for his help with my model and taking the extra time needed to code or explain principles. I would like thank Alexandra for being patient with me and making sure the message got across, even if this meant repeating it multiple times. Finally, I would like to thank my parents for supporting me during my studies, their help has been the backbone of this achievement.

ABSTRACT

Context

Digitalisation enables students to study virtually everywhere. However, demand for study space on the campus remains high and is even increasing. Additionally, students place higher demands on the quality and availability of facilities (Valks, Arkesteijn, den Heijer, & Van de Putte, 2016, p. 15). However, recent research on Dutch campuses (Campus NL,2016) shows several problems were identified regarding the alignment of campus space. (1) The unpredictable nature of demand for campus space makes it difficult to align demand with supply. (2) Another reason for not being able to comply with campus space demand is a result of problems in finding a suitable study space.

Objective

Preference Function Modelling already proved its potential in designing accommodation strategies. Furthermore, there is the need to involve a greater number of stakeholders and a need to improve the usability of the modelling technique. A smart tool presents opportunities to improve the user involvement in the management of design accomodation. As a result of the scientific gap, this thesis will explore these opportunities by developing a smart tool which provides information on study space while simultaneously generating information to support campus management.

Methods

For this thesis an engineering design process is used. Literature research is used in this research to gain understanding of the design problem and its users. With this knowledge, a smart tool will be developed along a iterative sequence of prototype evaluations to support the design process. Design user involvement will be established by two prototype evaluations evaluations with the use of interviews. For the evaluation of the proposed smart tool an assisted approach is utilized. In this evaluation, the data collection methods Task load index and Post-Experience interview are used. A Task Load Index (TLX) measures cognitive workload by assessing how much mental effort a user expends whilst using a prototype or deployed system. While individual Post-Experience interviews are a quick and inexpensive way to obtain subjective feedback from users.

Results

As a result of the first user interviews it was established that users had difficulty with understanding how the system works and which values needed to be entered. Therefore, the primary focus for version 2 was finding ways to improve understandability and usability of the system. One implementation of this, was to improve navigation by having all the input fields on the same tab in excel. Therefore, User forms were used, allowing to have a better overview of the system by preventing the need to switch between tabs. The database structure represent the storage (back end) of information which is needed to operate the proposed Smart Tool. To visualize this an Entity Relationship (ER) model has been constructed in MySQL workbench. The ER model shows all the tables relevant to the proposed Smart Tool. A wireframe model is constructed with use of the program Balsamiq. A wireframe is chosen in this stage of the design because it does not distract users with commenting on stylistic issues (i.e. colour schemes or transitions). Balsamiq allows users to interact with the screens, allowing them to get an idea of the workflow and how to navigate the mobile application.It was made clear that using Preference function modelling is not designed for users on this scale but rather in making complex decisions and by generating alternatives. The purest form of the method is not desired from a user perspective as it was shown users need considerable (mental) effort to determine their preference values. However, if these values only need to be input once the strain on the user is significantly reduced and acceptable. Users clearly showed that once they became familiar with the system they were able to more easily adapt their preferences. This indicates that there is a level of intuitiveness in the use of the smart tool.

Conclusion

It can be argued that hypothesis is confirmed and that the described problem can be solved by providing information about study spaces with the use of smart tools. The findings from the interviews suggest that the proposed smart tool can potentially add much value for both the user and campus management. The users generally reacted very positive to the concept of the smart tool. This shows that the smart tool will have significant value in supporting study space findability when executed correctly. To achieve this, usability of the smart tool is crucial for ultimate use. As this research comprises a design problem, it is important to realize that design problems can be solved in numerous ways, each leading to various results. Therefore, this can be seen as one of the possible ways a smart tool is able to support users in finding a suitable study space.

MANAGEMENT SUMMARY

PART I INTRODUCTION

Introduction

Digitalisation enables students to study virtually everywhere. However, demand for study space on the campus remains high and is even increasing. Additionally, students place higher demands on the quality and availability of facilities (Valks, Arkesteijn, den Heijer, & Van de Putte, 2016, p. 15). However, recent research on Dutch campuses (Campus NL, 2016) shows several problems were identified regarding the alignment of campus space.

(1) The unpredictable nature of demand for campus space makes it difficult to align demand with supply. In Dutch campus management, yearly space demand is derived from the amount of student entries and has always been difficult to predict. Currently, the total number of entries has become even more difficult to predict due to the increasing number of international student entries. Thus, campus managers are faced by the unpredictability of demand on both a yearly basis, making it difficult to align the so-called dynamic demand with supply. This can lead to university campuses having an insufficient amounts of space leading to dissatisfaction.

(2) Other reasons for not being able to comply with campus space demand are problems in finding a suitable study space. A large part of TU Delft students (70%) experience a shortage of study space in the weekend (ORAS, 2017, p. 7). The remaining students (30%) expressed that there was sufficient study space. While the general consensus of the TU Delft campus management is that there was in fact (more than) enough campus space to accommodate its students, but the space was not being used efficiently. It was therefore concluded that this difference in perception is the result of the findability of study spaces (i.e. study spaces need to be found before they can be used). In relation to finding study space, students have different preferences and demands of their study spaces relating to their studysubject. Therefore, it can be argued that students are challenged with finding a study space meeting their specific needs.

Scientific gap

Students have difficulties in finding a suitable study spaces which can lead to the perception that there is insufficient space. Therefore a smart tool providing information about study space to improve the findability is highly desired. Additionally, there is a need to increase alignment through user involvement in designing accomodation. Real estate managers are also missing information about the use of real estate to test and prove the effectiveness of real estate interventions. While the use of a smart tool to provide useful information and the generation of reliable occupancy data has already been explored, the use and strategic purpose of the generated data has not been research. This exposes a scientific gap which this thesis intends to fill.

Preference Function Modelling already proved its potential in designing accommodation strategies However, there is the need to involve a greater number of stakeholders and a need to improve the usability of the modelling technique. A smart tool presents opportunities to improve the user involvement in the design of new spaces. As a result of the scientific gap, this thesis will explore these opportunities by developing a smart tool which provides information on study space while simultaneously generating information to support campus management.

Hypothesis & Research Objective

The hypothesis is that the described problem can be solved by providing information about study spaces with the use of Smart Tools. This results in the research objective of: developing a Smart Tool that provides information to improve the alignment of space demand and supply for both the user and campus management. The research objective is formulated into the following main research question: "How can a Smart Tool provide information to align dynamic user demand more effectively and efficiently with campus space supply on both the long and short term?". The research is conceptualized in image 2.1.

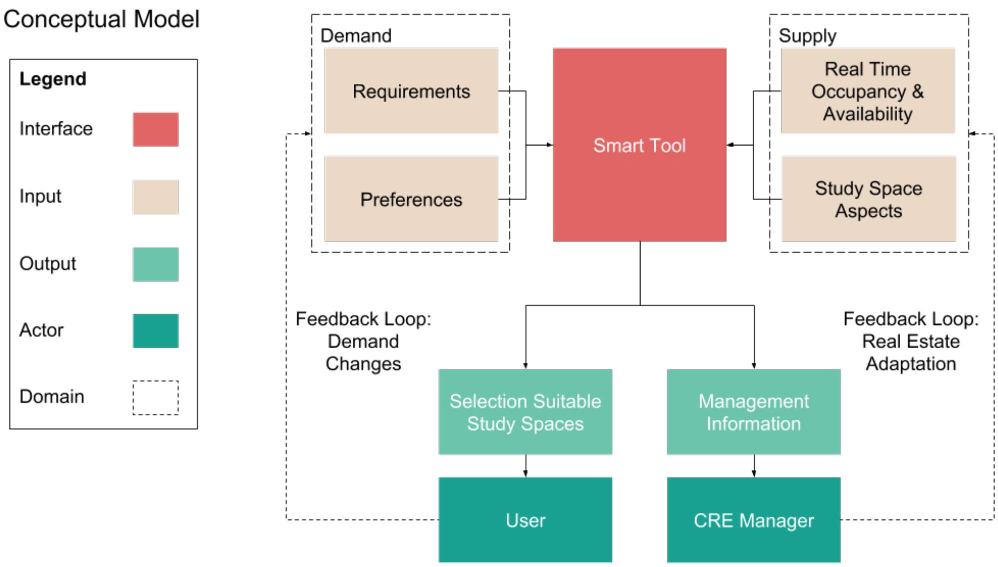


Image 2.1 Conceptual Model (own illustration)

PART II METHODS

The main question of this research can be seen as a design problem, which ultimately leads to the design of an artifact: an artificial, man-made object, thing or device (Dym, Little, & Orwin, 2014, p. 7). Therefore an (engineering) design process is used, resulting in an prescriptive model with five phases. Output of each design phase serves as input to the next design phase linking the five stages of this design process. It starts with the initial problem definition and ends with the documentation of the final design.

Design Process

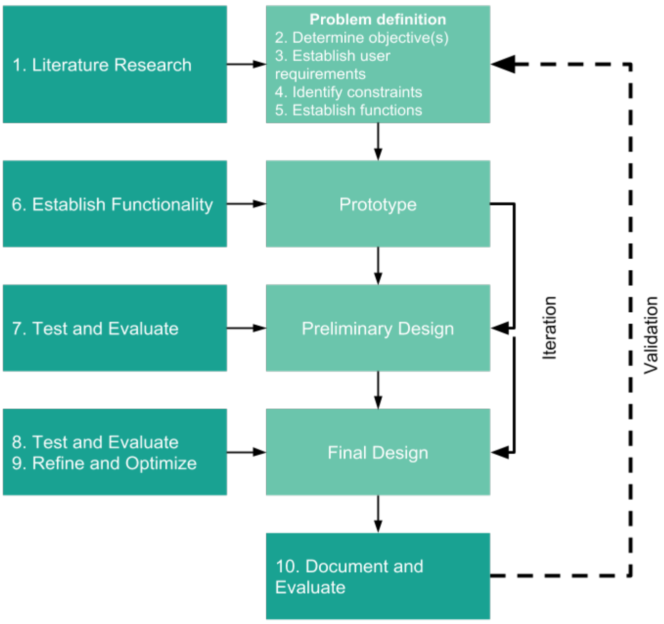


Image 3.3 Design Process (own illustration based based on engineering design (Dym, Little, & Orwin, 2014))

Normally design projects start with a problem needing to be solved for a client, typically inthe form of a verbal problem statement. However, for this research the problem definition will be derived from literature research. Because the problems in current campus management have been extensively researched and documented in 'Managing the University Campus'(2011) and more recently 'Campus NL' (2016), it became possible to get a clear depiction of contemporary Dutch campus management practice. These researches show what the contemporary problems relating to campus management are. Similarly, recently there has been a study concerning 'Smart Campus Tools' (2016 & 2018) in- and outside the Netherlands. This study shows which tools are already available for campuses (and commercial organisations), their functions and what functionality is currently lacking. During the research however, an interview will be held with campus management to enquire about any additional data/information needs.

Another vital subject of this research is learning space preferences (i.e. user requirements). This subject has been extensively studied by a number of researchers, which will serve as a basis for student preferences. After the initial preferences have been used to design the prototype, its functioning will be evaluated by students. Following this, the students are asked about relevant and possible missing preferences, to determine what is important in selecting study space. Thus, by interviewing the client and users the design is developed and new functions can be discovered, making evaluation an integral part of the design process (Dym, Little, & Orwin, 2014, p. 17).

Data collection

Literature research is used in this research to gain understanding of the design problem and its users. Hereafter, Smart Campus Tools for similar problems is researched through literature. Literature research is also needed to support the design process in finding a way to solve the problem. Additionally, researching legal literature will make sure the Smart Tool will comply with contemporary regulations.

The smart tool will be developed along a iterative sequence of prototype evaluations to support the design process. User involvement will be established by two prototype evaluations evaluations with the use of an interview. For the evaluation of the proposed Smart Tool an assisted approach is utilized. The users were asked to input their own preferences into the system and give feedback on the workflow of this and the results. Furthermore, the data collection methods Task load index and Post-Experience interview are used. A Task Load Index (TLX) measures cognitive workload by assessing how much mental effort a user expends whilst using a prototype or deployed system. Individual Post-Experience interviews are a quick and inexpensive way to obtain subjective feedback from users based on their practical experience of a system or product (Maguire, 2001, p. 619).

PART III LITERATURE STUDY

CREM

Real estate management is the continuous process of matching supply (i.e. real estate) with demand, which is derived from organisational objectives and primary processes. Corporate Real Estate Management (CREM) is real estate management by an organisation that both owns and occupies its real estate. The goal of real estate management is to positively contribute to organisational performance or add value to an organisation by making real estate interventions (Den Heijer, 2011, p. 92). This positive influence can occur in four stakeholder perspectives. There 12 ways to add value established and five distinct real estate interventions types.

Relating adding value to organisational performance

The process of adding value through real estate is shown by relating the 12 ways to add value to the four stakeholder perspectives, which is illustrated in image 4.5. This model is based on a more elaborated model of the stakeholders perspectives found in the dissertation of Den Heijer (2011). CREM (i.e. campus management) is placed in the center of the model. From this point CRE managers influence the different perspectives through real estate interventions. These interventions have varying degrees of influence on the perspectives based on the scale of the real estate project. Hence, the indication of the quality ambition, number of users involved, budget and space types of the project.

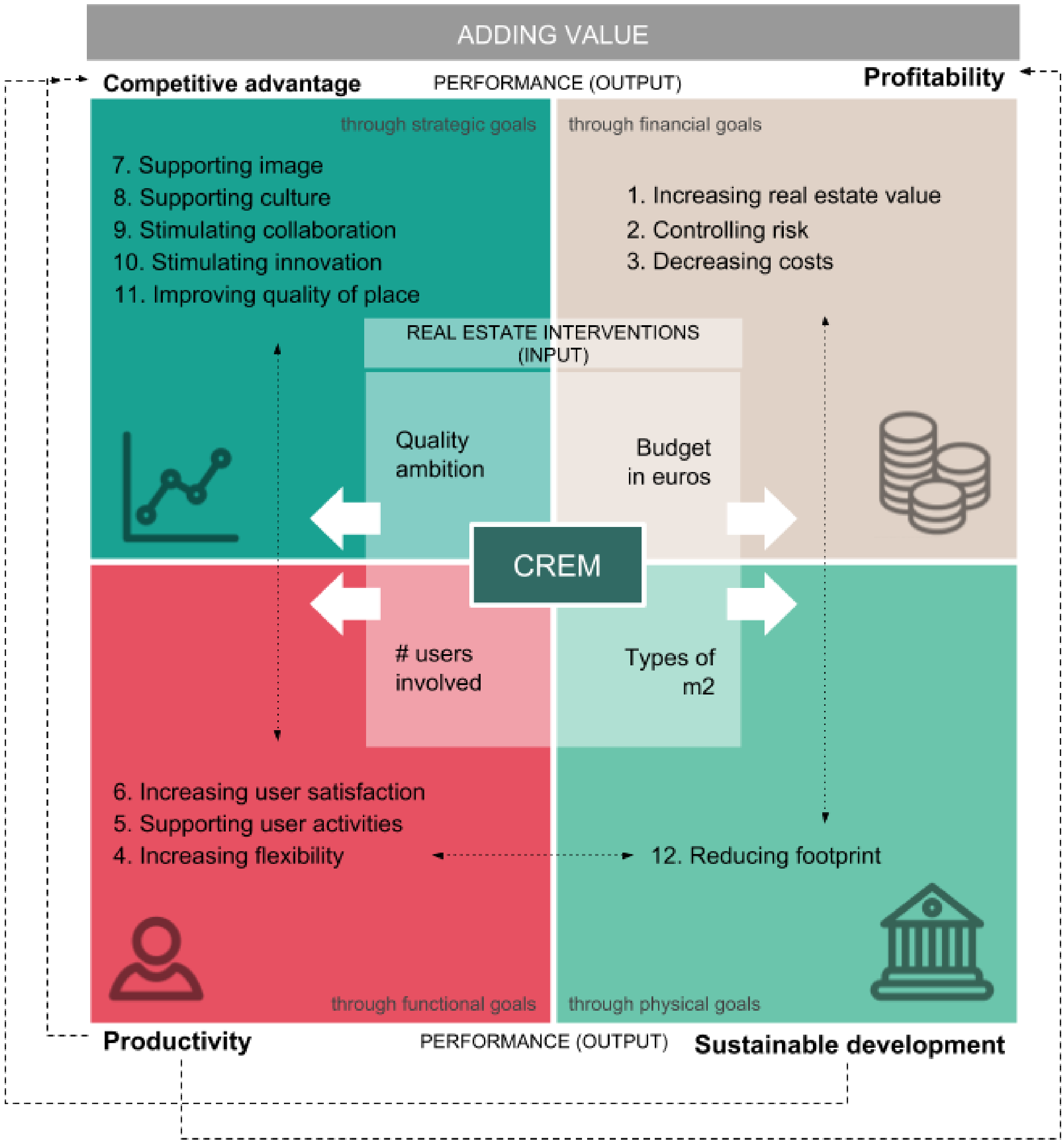


Image 4.5 Adding value related to organisational performance

Current campus management

The current goals for campus managers mostly include making improvements on organisational productivity and competitive advantage. Within campus management processes, differences in organisational structure and approach can be recognized. Campus management processes are generally traditional and based on qualitative information.

Two distinct strategies to CRE alignment are distinguished: involvement-oriented or control-oriented (or bottom-up and top-down). The two approaches to strategy represent the hypothetical extremes of CRE alignment, in practice often a combination of the two described strategies is used and desirable. In general there is a need for more user involvement within decision making. The proposed smart tool offers alternative and supportive ways of communication demand. This can have significant value when involvement oriented strategies are implemented.

A smart tool can be used to solve some of the identified problems in determining demand. Firstly, a smart tool can help improve the communication of dissatisfactory space. Leading to a deceased response time. secondly, the smart tool can see which spaces are utilized more than others which can prove to be valuable in improving the rest of the campus. This can lead to contributions of the organisational objectives. Thirdly, long term utilization data can be used to discover patterns and trends in use, which can improve long term thinking.

With regard to the current smart campus tools, several tools have been identified each having their own purpose. Still, demands exist for smart tools which support user activities, more specifically in finding a study spaces without desktops. The proposed smart tool does this by gathering information on user activity, which has not been covered by another smart tool. Furthermore, for universities using the available infrastructure appears to be most feasible.

Management information

In the past years much more data has already been collected, but there is an additional demand for data on efficiency of real estate (occupancy and frequency rates), user satisfaction, key performance indicators on sustainability issues and any references on effectiveness of certain campus models or campus decisions, in terms of costs and benefits for the university and ways to involve users in decision making.

If a smart tool will gather data passively about the preferences in each situation, it is expected that unconscious behaviour is also gathered. Additionally, when users are put in actual situations they will have a realistic response, which will result in a better representation of demand. Gathering occupancy and frequency information cannot only provide valuable insight of the use of space, but can also be used to inform users for finding available study space. With regard to strategic behaviour, a smart tool can still be susceptible to this type of behaviour. However, it is expected that if a large amount of users will use the smart tool this can be prevented, because more data will lead to a better representation of demand. Strategic behaviour of campus management, can still be an issue however.
If the smart tool is able to give feedback on spaces and a new pilot study is implemented this offers way to see how the changes are received. From this point on, lessons can be learnt and new decisions can be made to make improvements. By giving the option to give feedback on spaces, campus management can be made aware of how users experience the current real estate supply. More specifically this can show which spaces are considered 'below standards'. Additionally, the degree to which spaces are received negatively or positively by its user gives an indication of the overall user satisfaction. If a smart tool includes the preferences of the individual users of the campus, it can indicate that some functions are more frequently needed or more important. Hence, choices can be made to comply with these demands by translating them into different levels of scale. In this sense the user is indirectly involved with decisions.

Generating management information is not a straightforward activity (top-down), and that technologies do not automatically contribute to deriving effective management information (bottom-up), interaction is needed to accomplish the effective management information. Data is firstly extracted from the primary process to see where improvements can be made or present problems can be solved. Additionally, data can be extracted from outside the organisation to see what affect external influences might have (e.g. economic or demographic changes). The data is then transformed into usable information before being provided to the decision making process. Data can be transformed into management information according to four perspectives: data technology, statistical methods, specification methods and information systems.

Development

For the measurement of preference, a scale needs to be constructed to for each criteria and a value for this criteria needs to be assigned on this scale to signify preference. This scale enables the transition of an empirical system (E) to a mathematical system (M).

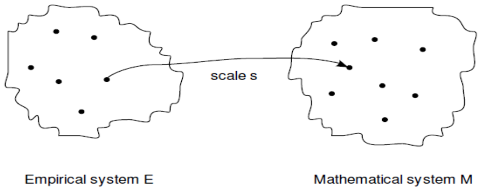


Image 7.1 Transition of an empirical system (E) to a mathematical system (M) through a scale (s)

Using PFM has the following procedure: Initially, a hierarchy of criteria and the identification of the alternatives is needed for the development of PFM. The scores are then elicited by decision makers as preferences for each alternative against each criterion by first establishing reference alternatives. Then, the other alternatives are rated relative to these reference alternatives on the scale established. Thereafter, the decision maker the attaches a weight to each criterion. When finally the PFM algorithm is used to yield an overall preference score to evaluate all the alternatives, it can then be ranked accordingly.

Relating this to the proposed smart tool, it is not needed to determine alternatives as spaces are already existing. Therefore, the preference function modelling procedure needs to be adapted slightly by using the mathematical function on the spaces as alternatives. Thereafter, the results of the algorithm can then be ranked according to the overall preference score.

To determine the relevant criteria to use in preference function modelling the sub question: 'What criteria for study space preferences should be considered in the smart tool?' is answered in the following paragraph.

The typology of learning space preference attributes was be used to evaluate, but more importantly can also to design informal learning spaces. Therefore, space design should encourage users to reflect on their learning preferences and translate these preferences into space selection. As both redevelopment projects and learning spaces research progress, the results can be benchmarked which should ultimately lead to practical and proven designs being implemented. From the attributes and aspects in the former studies, preferences have been selected to use in this research. This will form a basis of criteria used in preference function modelling. The results of the chosen preferences to use as criteria are shown in the table below.

Requirements
Retreat/ Interact
Working Alone/ Collaborate (including nr. students)
Desktop (y/n)
Presentation monitor (y/n)
Preferences
Occupancy levels
Distance to current location
Distance to printers
Distance to catering (clusters)
Layout (open/closed)
Natural light (y/n)

Favourites (determined from record/database)

For the development of the smart tool the processing of information to display is most important. For this, information needs to be stored and extracted. This is done by storing the data in information systems, for which data modelling is required. Data modeling is a structured approach to identify and analyze necessary data components for information systems. A relational database (RDB) is a collective set of multiple data sets organized by tables, records and columns. The two primary areas in which relational databases are used include: operational systems and BI. Operational systems processes transactions and events that occur. For this an Entity Relationship (ER) model needs to be built. This model consists of three building blocks: entities, relationships, and attributes (Sherman, 2015, p. 179-180). An **entity** is a person, place, thing, or event about which the business keeps data. **Relationships** show how the entities are related to one another. Relationships are the logical links between the entities that represent the business rules or constraints. **Attributes** are distinct characteristics of an entity for which data is needed to capture and maintained in order to understand the business. Entities can have a relationship towards each other and identifying the relationship establishes the parent as a way to identify and classify the child.

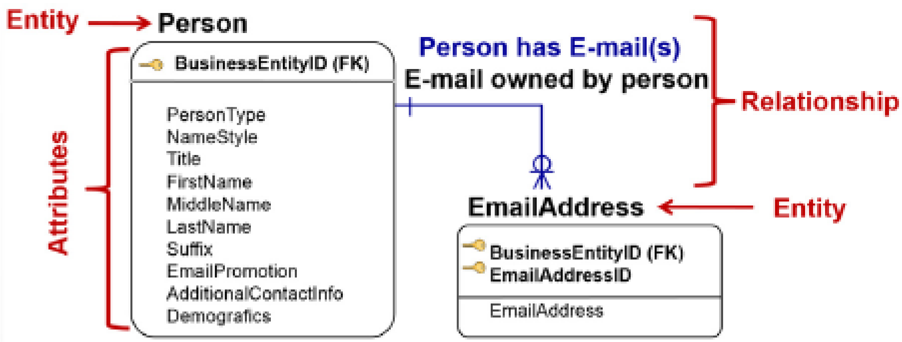


Image 7.6 Illustration of an ER model (Sherman, 2015, p. 180)

Occupancy detection

In network-based positioning base stations (e.g. access points) capture signals transmitted by the mobile devices. A particularly suitable positioning method to use the RSSI is lateration. Lateration uses the distances from a mobile devices to multiple base stations (e.g. APs) in order to calculate an intersection point. In multilateration more than 3 base stations are used to calculate a point of intersection including elevation (z -axis) of a device. Because a higher number of base stations is used, a higher accuracy can also be achieved.

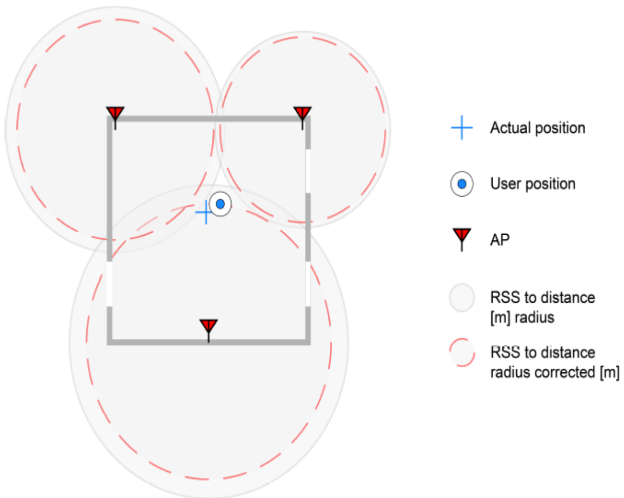


Image 8.4 Principle of trilateration (Braggaar, 2018)

Because he position or location of the device is based on the RSSI value it becomes a very important measurement. By using a mathematical path-loss model signal strength can be translated to a distance estimation. However, in indoor environments the signal is (dynamically) influenced by various objects, human bodies and building elements complicating determination of distance. Therefore, mathematical model needs to take into account all of the different effects on the signal strength.

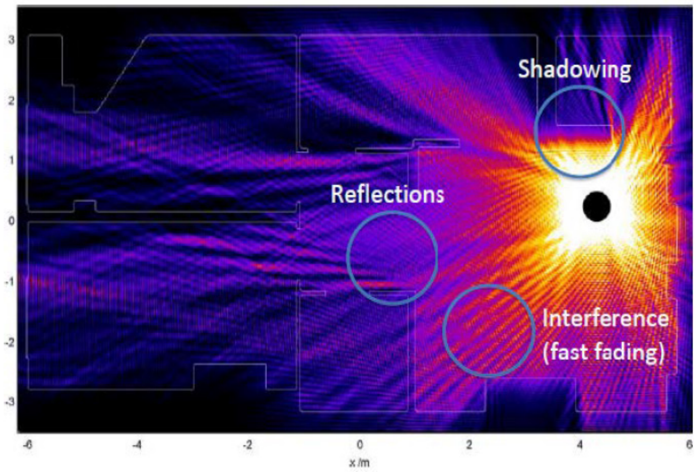


Image 8.6 Influences of radio frequency signals (Callaerts (2016) in Braggaar (2018))

Additionally, the captured data needs to be processed by filtering data to only use the relevant data. The data filtering is a crucial process as it is normal with large data collection that large amounts of unwanted data is also captured.

Privacy

It was determined that detecting occupancy is considered personal information. Therefore, to use this one needs to comply with seven main principles discovered in regulation: Notice, Purpose, Consent, Security, Disclosure, Access and Accountability. To deal with the possible privacy issues relating to the described personal data, the MAC addresses can be depersonalised (anonymized) and encrypted to prevent identification of the associated device. Under the principles 'Notice' and 'Disclosure' the data subjects are also required to be notified of what is being measured, why and by whom.

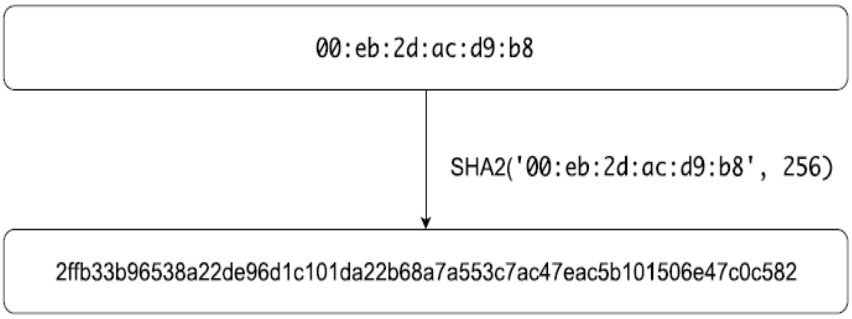


Image 9.1 Encryption algorithm (Braggaar, 2018)

In the use of the smart tool it is not expected that users will object to the gathering of personal information relating to preferences. This is because the values are subjective and can easily be changed. The input values also do not say anything personal except for preference, something that can not be used against users in any way.

PART IV RESULTS

Prototype Version 2

As a result of the first user interviews it was established that users had difficulty with understanding how the system works and which values needed to be entered. Therefore, the primary focus for version 2 was finding ways to improve understandability and usability of the system. One implementation of this, was to improve navigation by having all the input fields on the same tab in excel. Therefore, User forms were used, allowing to have a better overview of the system by preventing the need to switch between tabs, as shown in image 10.8

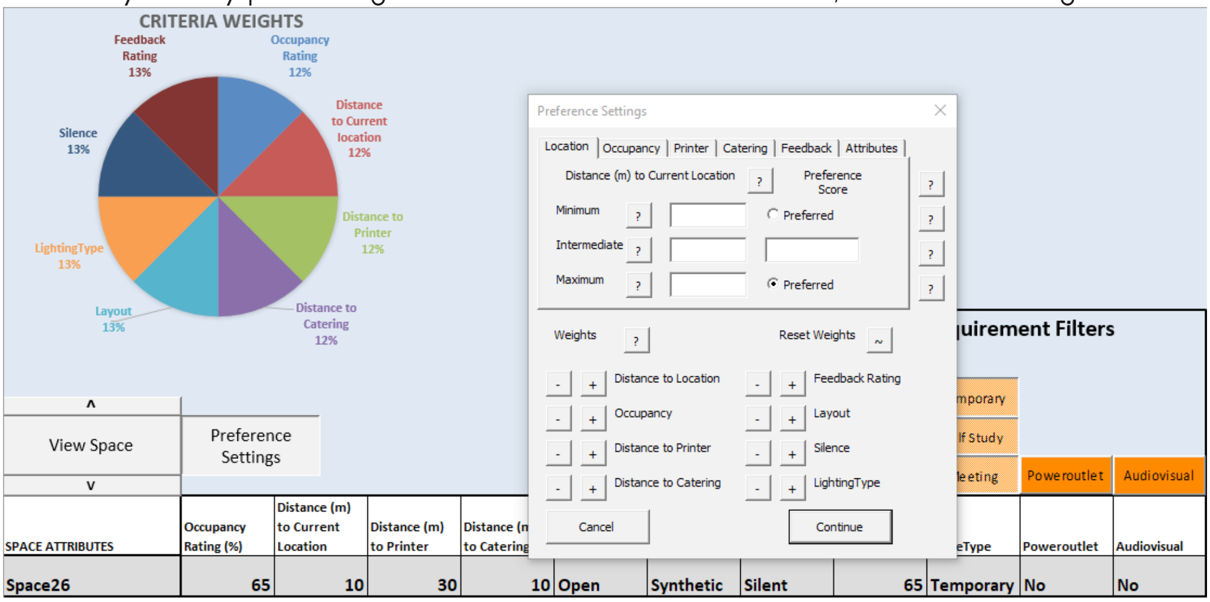


Image 10.8 Start screen after clicking preference settings button (own illustration)

Database structure

The database structure represent the storage (back end) of information which is needed to operate the proposed Smart Tool. To visualize this an Entity Relationship (ER) model has been constructed in MySQL workbench. The ER model shows all the tables relevant to the proposed Smart Tool. For clarification, sections are made clear by using distinguishable colours, blue and red, signifying the geometric data and user settings respectively. An overview of the ER model is shown in image 10.12.

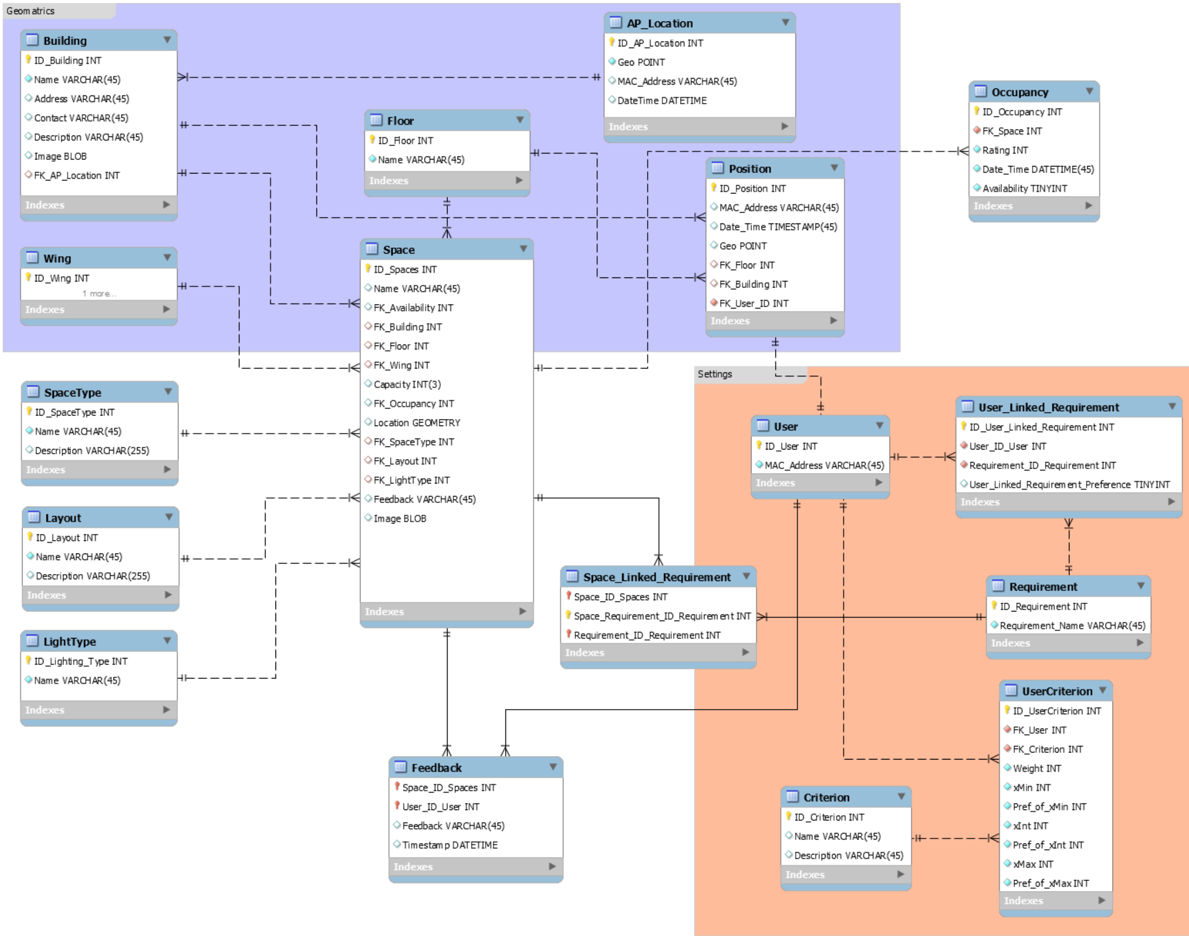


Image 10.12 Overview of the ER model (own illustration)

User interface mock-up

A wireframe model is constructed with use of the program Balsamiq. A wireframe is chosen in this stage of the design because it does not distract users with commenting on stylistic issues (i.e. colour schemes or transitions). Balsamiq allows users to interact with the screens allowing them to get an idea of the workflow and how to navigate the mobile application.

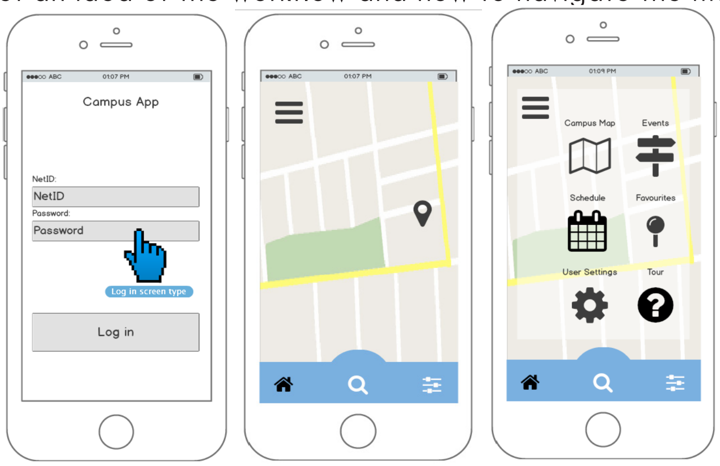


Image 10.15 Starting screens (own illustration)

Lessons from the prototype evaluations

It proved to be fruitful to involve the end-users in the design of the system to determine what works and what doesn't and to make the appropriate changes iteratively. This is for example shown in the system after facilitating use by putting the input fields on one single tab to avoid navigational issues, implementing a userform to focus the users attention and integrate help buttons for guidance. Ultimately, all the students recognized the added value of the tool in finding study spaces, which is able to support them in finding study spaces.

Usability
It was made clear that using Preference function modelling is not designed for users on this scale but rather in making complex decisions and by generating alternatives. The purest form of the method is not desired from a user perspective as it was shown users need considerable (mental) effort to determine their preference values. However, if these values only need to be input once the strain on the user is significantly reduced and acceptable. The users clearly showed that once they became familiar with the system they were able to more easily adapt their preferences. This indicates that there is a level of intuitiveness in the use of the smart tool. However, it has become clear that much needs to be gained in terms of usability, as the students communicated that they are easily frustrated when something does not work accordingly.

Preference criteria
All of the interviewed students indicated that the most important aspects were distance to the current location and the occupancy of available spaces. Considering the criteria which were implemented in the smart tool most were considered important. However, the feedback rating was not understood primarily and since users indicated that they would not actively participate to give feedback to spaces this might not need to be implemented. Furthermore, the weight users assigned to the criteria also had differences. Some students laid more emphasis to a single criteria whereas others had a more balanced division of weights.
The former was mostly the case for the criteria occupancy rating and distance to current location, which unsurprisingly was also stated to be the most important criteria. Overall the functional aspects of spaces are considered most important which confirms the research of Beckers, van der Voordt, & Dewulf (2016).

Results
Considering the results students showed and stated that they would go through a few spaces to review them to decide which of the top (5) ranked meets preference most. The location of the space is something that was considered important and even more so a way to reach that destination, especially in indoor environments.

Missing link between students, CREM and FM
In general students feel like there is a lack for them to communicate their needs and requirements with the ones responsible for the real estate supply.

User satisfaction
In relation to giving feedback ratings of spaces to indicate satisfaction, the users stated that they would not use this functionality very often. They indicated two cases in which they would use it: when a space dramatically underperforms or doesn't meet expectations and when a space performs exceptionally well. While, if a space performed 'ok' or 'as expected' the users would not be incentivized to give feedback. One student stated that he would give feedback about 10% of the cases to indicate the amount he would use giving feedback.

Task Load Index
The Task Load Index (TLX) was used to assess the workload on students while using the system.

PART V CONCLUSIONS
The main research question is answered by developing and designing a smart tool that enables the interaction between users and real estate. The research proposes a smart tool that supports users in finding an appropriate study space based on their preferences. To achieve this this Preference Function Modelling (PFM) is implemented in a smart tool to calculate which of the available spaces correspond most with the user's preferences. This has been realized by constructing an Excel model which enables users to input values for several pref-

erence criteria. Installed on this Excel model is a Lagrange function which processes the preference value input of the user. The Lagrange function is able to output a ranking of spaces according to space attributes and the user's preferences. Additionally, the user is presented options to filter out any spaces which do not comply with any requirements. For example, if a user requires a power outlet there is the option to filter out all the spaces which do not have a power outlet. Ultimately, the user is presented with a ranked list of spaces, informing of which spaces most comply with his/her preferences. Based on the evaluative interviews it is expected that this would be able to inform and support users in making a decision on where to study.

The smart tool simultaneously stores the preference input values users enter into the smart tool for two purposes, representing the short and long term respectively. The input is stored to the user settings to (1) increase usability and prevent the user to fill in his preference values every time. Usability is (very) important as it determines whether a (smart) tool will actually be used or abandoned. It became clear during prototype evaluation that the initial cognitive effort was undesirably high. Therefore, to increase the likelihood the smart tool will actually be used, it is important to store the input values for later use. This allows use of the smart tool without entering the values every single time. While also allowing users to 'tweak' their input values to represent their preferences more accurately.

The smart tool also gathers the input data of user preferences to (2) analyze at a later moment. In the case that a large number of campus users utilize the smart tool to find their preferred study spaces, a large dataset of campus user preferences can be extracted. The stored user data can be analyzed to possibly find new insights on the preferences and behaviour of users. It is expected that this will lead to a more accurate representation of demand. Consequently, this data can be compared to the current campus to see how much supply aligns with this demand. All the uses of campus management for this data are described more extensively in section 8.6, the 'added value of the smart tool'.

In conclusion, it can be argued that hypothesis is confirmed and that the by providing described problem can be solved by providing information about study spaces with the use of smart tools. The findings from the interviews suggest that the proposed smart tool can potentially add much value for both the user and campus management. The users generally reacted very positive to the concept of the smart tool. This shows that the smart tool will have significant value in supporting study space findability when executed correctly. To achieve this, usability of the smart tool is crucial for ultimate use. As this research comprises a design problem, it is important to realize that design problems can be solved in numerous ways, each leading to various results. Therefore, this can be seen as one of the possible ways a smart tool is able to support users in finding a suitable study space. The benefits of using the proposed smart tool is described more specifically in the next section.

Implications to the real estate supply

Since the smart tool is an application to improve the use of real estate, it can also be seen as an extension real estate. Therefore, the smart tool is related to the ways real estate is able to add value to an organisation as described by De Vries (2008) and expanded upon by Den Heijer (2011). The smart tool is related to these ways to add value to use as a structure to clarify the added value of the smart tool. Each of the ways have a symbol beside it indicating the degree to which the effect the smart tool has. The symbols include a "=" representing no significant effect, "-" representing a negative influence and a "+" sign to express positive effects. In the case that the negative or positive effects are great it is indicated by two symbols.

Relating added value to organisational performance

The process of adding value through real estate is shown by relating the 12 ways to add value to the four stakeholder perspectives, which is illustrated in the model below (image 8.1). This model is based on a more elaborated model of the stakeholders perspectives found in the dissertation of Den Heijer (2011). CREM (i.e. campus management) is placed in the center of the model. From this point CRE managers influence the different perspectives through real estate interventions. These interventions have varying degrees of influence on the perspectives based on the scale of the real estate project. Hence, the indication of the quality ambition, number of users involved, budget and space types of the project.

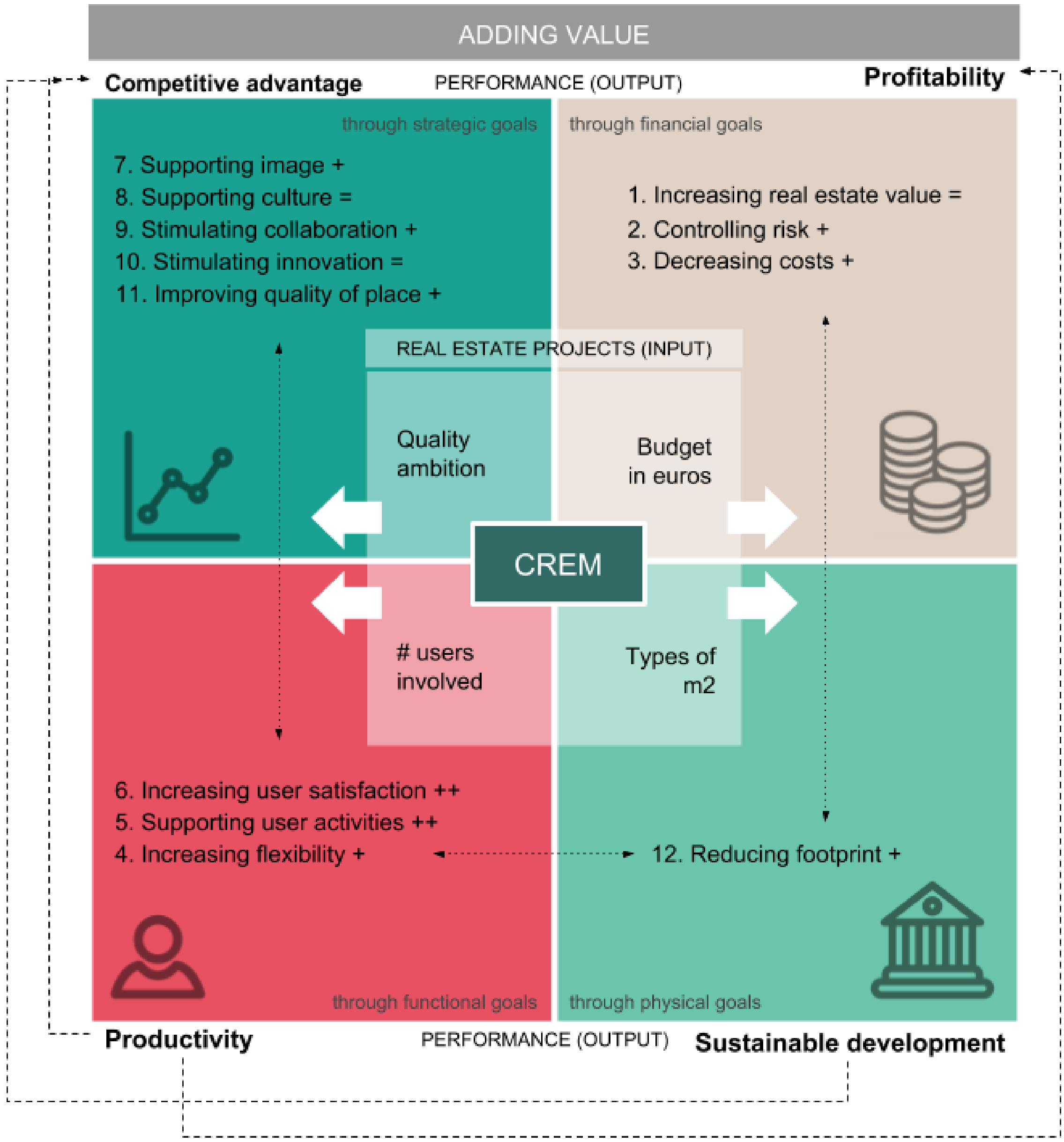


Image 11.1 Adding value related to organisational performance

It can be seen that the smart tool mostly support the added values in the functional perspective, by improving the user satisfaction, supporting user activities and increasing flexibility. The added values of increasing user satisfaction and supporting user activities is also related to some of the added values found in the strategic perspective, which is indicated by the arrow. These include improving quality of place, stimulating collaboration and supporting organisational image. The added value to increase flexibility is also indirectly related to the financial perspective through the of reducing the footprint of the campus.

Surrounding the perspectives is the performance of the organisation with its related key performance indicators. The underlying relations of the key performance indicators are indicated by the arrows. This shows that the functional perspective is related to the productivity dimension. In turn, it can be seen that through the productivity, the competitive advantage and profitability is influenced. While sustainable development is able to influence solely the competitive advantage. Because the smart tool is able to support adding value in multiple perspectives, it can be argued that it is very likely that the smart tool can have significant effect on organisational performance.

Dissemination

Societal relevance

The results of this thesis indicate possibilities for real estate management (and campus management in particular) to develop information sources on user demands through smart tools. The main benefits of this thesis, can be found in the fact that it shows what value the proposed smart tool initially has while also providing value over the long term. Initially it is expected that it will increase user satisfaction by supporting user activities. Simultaneously the smart tool shows ways to generate data to improve the campus. The generated information can prove valuable in supporting decision making with respect to indicating which spaces are underperforming and what functions are most in demand by users. Because, this information is quantified there are also possibilities to analyse the data to make new discoveries about what is expected of future demand. Furthermore, the principle of using smart tools for both supporting users while generating data on their demands can also lead to new developments of similarly useful software.

Scientific relevance

The relevance of this thesis in the scientific field primarily exist in the understanding of the development of software for real estate management. With these insights it has become (more) clear what is possible by using smart tools in both the use of buildings and how to generate data to support decision making. The research also showed how Preference Function Modelling can be used on a greater scale which can also be used for other purposes. Furthermore, it can be concluded that the proposed smart tool has a potential to add significant value to real estate users and management processes. Therefore, it becomes valuable to extend these principles to discover more potential.

Research Position

Position within Smart Real Estate Management

Since the end result of this thesis is a smart tool which firstly supports campus users in their activities it is argued that the smart tool mostly operates in the functional perspective of CREM. More specifically, this thesis mostly focuses on the product side of smart tools, encompassing the needs of end users in the use of such a smart tool. Thus, the research has taken on a user centric approach, while simultaneously generating data to support real estate management decision making. Taking this approach has given insight into what is important for users in using a smart tool, possibilities with the available sensors and the capabilities of software development to support real estate management overall.

Position within Management in the built environment

Since the data generated by the smart tool ultimately focuses on optimizing use of existing structures it is argued that, within the master 'Management in the built environment', this thesis is most applicable to real estate management practice. However, the results also suggest that smart tools can be implemented to a wide variety of other uses within the built environment. This type of smart tool can also be applied to optimize urban development by gathering more data on urban areas for example. Moreover, for project development the lessons learnt from the generated data can also be accumulated over time to integrate it into a new project.

Recommendations

Find ways to increase usability

Though much improvements have been made over the course of this thesis, before the proposed smart tool is implemented it still needs improvement with regard to usability. The continuation of the design for the proposes smart tool needs to balanced with regard to the benefits for the user and the generation of useful data. Researching to which degree both ends of information provision is optimized will be a valuable continuation from this point on.

Increase the accuracy of occupancy detection

By increasing the accuracy of occupancy detection in buildings, users can be supported with this information more effectively. Meaning that occupancy and availability can be determined on a workplace level, rather than that of its surrounding space. Because the main criterias for users are the availability and occupancy of a study space, improving this can lead to a significant value increase.

Research possibilities on the operational level

By integrating the smart tool with facility management software, users are able to give feedback on the operational level on the spaces. It was stated in the interviews that there is a need for a less daunting, more approachable way for users to comment on facilities. Potentially, this could improve the time in which facility management can respond to occuring problems, allowing facility management operate more effectively and efficiently.

Effect of the smart tool on user behavior

As the smart tool is developed to support user activity, it becomes interesting to see how much user behaviour is influenced by use of the smart tool. For example, it is interesting to determine how much users will actually use the smart tool in their study life. This can be done by analyzing how much unique users return use of the smart tool and how frequent. When use of the smart tool decreases or diminishes, users most likely have a good idea of where there preferred spaces are and when they are most likely occupied. Therefore, it is interesting to find how quickly users will cognitively 'learn' campus space. By learning it is meant that over time users will remember from past experience which study spaces comply with their needs and are available at a certain period of time. After the use of the smart tool has declined over a period of time and then unexpectedly starts to peak, one can expect this signifies moments when students have difficulty or want to be supported in finding a space. The reasoning for why that peak in use has occurs can then be analyzed to determine whether it was for example caused by business or a real estate intervention.

Another aspect which is important with regard to user behaviour, is distribution of users among the campus as a result of smart tool use. This is because the distribution of users on the campus can inhibit the reduction of space, which can ultimately constrain cost and footprint reduction.

Applicability to commercial organisations

The smart tool is originally designed for a university campus and considers students in its functioning. This is evident in the criteria and in the argument that the smart tool is very applicable to a university environment because students (usually) do not have an assigned workspaces. Because several authors argued that the university is increasingly operating similar to flexible workspaces it is expected that the proposed smart tool can also be applied to commercial organisations. The same need for individual focus workspaces, group work spaces and conference space exist in both commercial organisations and higher education. Because the need for information on users by real estate management equally exists in commercial organisations, it is interesting to see what the differences are between these organisations and higher education. This can lead to insight in how one should approach applying the findings of this research, to a smart tool for a commercial organisation.

REPORT STRUCTURE

This section will provide an overview of the research structure. The research consists of 5 parts with the following sequence and contents.

Part I forms the introduction to the research. In this part the research subject is introduced and its current problems identified. Following this, the societal and scientific relevance of the research are described. In conclusion the focus of this research is introduced as a continuation. In the second chapter the research framework is described. This includes a concise problem statement following a hypothesis, research objective and its corresponding research questions. Thereafter, the research is conceptualized by illustration of a conceptual model.

In **Part II** the methods of the research are described. This includes the methodology chapter covering the approach to the research and all the methods used in the research. The second half of this chapter includes a research design indicating the structure of the research.

Part III consist of the literature study. The purpose of the part is to form the basis for the model development by answering the specified subquestion. These are arranged beginning from conceptual to more technical in the latter half of this part of the research. The intention of the findings is this part is to gain understanding of the broader concepts, current management processes and software development to ultimately use in the development of the smart tool.

Part IV includes the results from the building of the model and the data collection. Firstly, the process of the Smart Tool development is explained. During this the explanation of the findings from the prototype evaluations are expressed to demonstrate the iterative design approach. In conclusion, the evaluation of the final design is analyzed with use of the methods described earlier.

Part V represents the conclusion. Firstly, general conclusions of the research are made to finalize the research. Following this are the discussion points which are followed by a recommendation for future research. Lastly, the reflection describes the process, methods, positioning within the research subject and ultimate relevance of the research outcomes.

CONTENTS

Image: BKCityGuide 2017/2018

PART I

INTRODUCTION

1. INTRODUCTION

This chapter starts with the (1.1) introduction of the research subject. Thereafter the (1.2) incentive for research is illustrated by describing the identified problems within the field. After this, (1.3) the background is outlined to illustrate the field in which this problem exists. Subsequently, the (1.4) societal and (1.5) scientific relevance is described in more detail. Finally, the (1.6) scientific gap is defined in the last section with implication for the continuation of research.

1.1 Research subject

The graduation subject of this thesis is Smart Real Estate Management. This subject intends to tackle problems existing within the field of real estate management by finding and constructing appropriate smart tools. It includes finding ways of gathering useful information about real estate to support decision making. The ultimate goal is to optimize the use of real estate. Several problems have been identified with regard to the findability of space and alignment of demand with supply for campus management. These problems are described in more detail in the next section signifying the incentive of this research.

1.2 Research Incentive

Digitalisation enables students to study virtually everywhere. However, demand for study space on the campus remains high and is even increasing. Additionally, students place higher demands on the quality and availability of facilities (Valks, Arkesteijn, den Heijer, & Van de Putte, 2016, p. 15). Furthermore, recent research on Dutch campuses (Campus NL, 2016) shows several conclusions were drawn regarding the use of campus space.

"One of the big challenges in corporate real estate management (CREM) is reducing the gap between the high speed of business and the slow speed of real estate, i.e. between the so-called dynamic real estate demand and the relatively static real estate supply." (Arkesteijn, 2016)

The unpredictable nature of demand for campus space makes it difficult to align demand with supply. In Dutch campus management, yearly space demand is derived from the amount of student entries and has always been difficult to predict. Currently, the total number of entries has become even more difficult to predict due to the increasing number of international student entries. In some cases, universities are forced to limit the amount of student entries to keep the demand for space to a manageable level. Further complicating the problem for campus management is the difficulty to determine demand for study space on a day-to-day basis. This so-called dynamic demand is dependant on location, time, amount and differences in preference. If demand for study space is not met it can lead to dissatisfaction with the campus space and its corresponding organisation. This was confirmed by a 2015 article stating that the TU Delft campus was lacking space to accommodate its students. The article stated that '[...]Overflowing lecture rooms, a lack of (quiet) study spaces and even some lectures being held in movie theaters [...]' led to dissatisfaction among students (NOS, 2015). Reportedly, it is the result of a student entry increase in several TU Delft faculties. This illustrates that, when study space demand is not being met, student satisfaction can be severely impacted. In turn, this presents problems for universities to compete in an increasingly competitive environment.

Reasons for not being able to comply with campus space demand is also a result of problems in finding a suitable study space. This is exemplified by research of ORAS (2017), which found that there are several issues regarding study space of the TU Delft campus. One of these issues was that a large part of TU Delft students (70%) experience a shortage of study space in the weekend (ORAS, 2017, p. 7). The remaining students (30%) expressed that there was sufficient study space. While the general consensus of the TU Delft campus management is that there was in fact (more than) enough campus space to accommodate its students, but the space was not being used efficiently. It was therefore concluded that this difference in perception is the result of the findability of study spaces (i.e. study spaces need to be found before they can be used). Furthermore, students have different preferences and demands of their study spaces relating to their study subject (ORAS, 2017, p. 5). For example, silent study spaces are not suitable for students which have group work involved or projects which require developing physical objects which need to be discussed. Therefore, it can be argue that students are challenged with finding a study space meeting their specific needs.

1.3 Background

1.3.1 Context

Since 1995 the government has transferred the ownership of the university real estate to the universities. This gave the universities the freedom to spend their resources according to their own priorities, which greatly improved the speed at which real estate interventions were made (den Heijer, 2012, p. 73). Because real estate is very cost intensive there is a lot of (public) money involved with real estate investment plans. Moreover, real estate costs account for 9 to 16% of the total costs within the researched universities (Algemene Rekenkamer, 2016, p. 34), building on the importance of proper real estate management (REM) for universities. Therefore, formerly REM of universities was primarily focused on the reduction of costs.

However, the transference also presented universities with opportunities to align their real estate to the organisation's primary processes and use real estate for strategic purposes (Algemene Rekenkamer, 2016, p. 16; den Heijer, 2012, p. 73). Therefore, there has been a transition to a more user centric approach in which ways to add value to the organization through real estate are sought (De Vries, 2007, p. 10). Combined, Dutch universities are planning to invest more than 3 billion in their real estate (IvhO, 2016). Reasons for Dutch universities to invest in real estate vary, including the growth of (international) student applications, the need to refurbish outdated buildings and the desire to make their real estate more sustainable are some examples (Algemene Rekenkamer, 2016, p. 16).

1.3.2 CREM

Corporate real estate management (CREM) is the discipline which matches the profile of university campus management (den Heijer, 2011, p. 90). CREM is concerned with developing a long-term strategy for the real estate portfolio. This involves aligning the needs of its users (demand) with the corresponding real estate portfolio (supply) in order to have a well functioning organisation. Study space demand is increasingly dynamic (Valks, Arkesteijn, den Heijer, & Vande Putte, 2016, p. 8) on both a yearly basis (i.e. the number of student entries per faculty) and on a daily basis (i.e. daily activity on the campus is difficult to predict). In contrast, real estate supply is relatively static (i.e. building projects generally take a long time to implement). This requires a profound and up to date understanding of the overall corporate strategy to identify the future demand for property (Jensen & van der Voordt, 2016, p. 336). Presenting CRE managers with the challenge to both align the real estate portfolio to support the organisation's current business activities, while also being adaptable and flexible enough to meet future requirements. This asks the CRE manager to predict or forecast future requirements based on the best knowledge and analysis at that moment in time. For this it is essential to understand the context in which CRE decisions are made (Appel-Meulenbroek & Haynes, 2014, p. 48). Consequentially, it involves investment planning and feasibility studies, for supporting decisions in choosing between alternative options to fulfill future demand (Jensen & van der Voordt, 2016, p. 336).

Real estate investment plans for the university campus are related to the prognosis of the number of student applications, which is important to determine required space and finances. However, estimating the number of student applications has become increasingly difficult due to the increased competitiveness in higher education and more international applications (Algemene Rekenkamer, 2016, p. 21). In order to cope with this, a lot of universities want to increase the flexibility of their real estate to be able to adjust to the before mentioned dynamic space demand. Some of the ways this flexibility can be implemented is through utilization adjustments (i.e. multi-tenant/user concepts or by building modular, phased or adjustable) (Algemene Rekenkamer, 2016, p. 22). However, for knowing how to improve flexibility in existing real estate utilization information is essential.

1.4 Societal Relevance

1.4.1 Utilization Information

As stated before, it remains difficult for campus management to determine demand for study space on a day-to-day basis. This so-called dynamic demand is dependant on location, time, amount and differences in preference. Recent research on higher education (De Vries & den Heijer, 2004; Algemene Rekenkamer, 2016, p. 26; Heywood, Kenley, & Waddell, 2009, p. 10; Beckers, van der Voordt, & Dewulf, 2015, p. 789) shows that campus management still lacks information about the utilization of the campus, including occupancy and frequency ratings (Den Heijer, 2011, p. 111). Furthermore, the link between real estate, its users and primary processes need more attention in general. While demand for study space on the campus remains high and students place higher demands on the quality and availability of facilities (Valks, Arkesteijn, den Heijer, & Van de Putte, 2016, p. 15). Making faculties interested in the degree in which buildings support or disrupt the primary process of the organisation and to which price, relating to the other forms of production: people, capital, technology and information (De Vries & den Heijer, 2004, p. 12). This includes how the spaces add value, how spaces are utilized and how satisfied its users are. Moreover, intangible factors, such as image or employee satisfaction, are becoming increasingly important because higher education is looking for ways to compete (de Vries, de Jonge, & van der Voordt, 2008, p. 210; de Vries, 2007, p. 142). However, universities have little insight of user satisfaction (Algemene Rekenkamer, 2016, p. 27). The mentioned missing information is a missed opportunity for real estate managers to test and prove the effectiveness of real estate interventions (De Vries, 2007, p. 10).

1.4.2 Performance Measurement

In order to determine the added value of real estate interventions, it is important to measure the outcomes and impact of any intervention, ex-post and preferably also ex ante, to use as a business case (Van der Zwart and Van der Voordt, 2015). It is possible to assess how well people or facilities perform in relation to these interventions by using clear performance indicators. These outcomes can then provide inspiration to achieve higher levels of effectiveness, efficiency, quality, and competitiveness (Jensen & van der Voordt, 2016, p. 341). For this it is important to understand and define the cause for a particular performance. Since this will give insight into which changes are needed to improve performance. However, it was concluded that cause-effect relationships are difficult to prove, due to the amount of interrelated factors (Jensen & van der Voordt, 2016, p. 342). De Vries, de Jonge, & van der Voordt (2008, p. 208-209) concluded that measuring the impact of real estate on organisational performance is confronted with three major barriers: Firstly, there is a lack of a standard definition of organisational performance that covers all relevant aspects of organisational performance. Secondly, it is difficult to quantify the effects of real estate interventions. Thirdly, the impact of real estate cannot be isolated from the impact of other variables such as capital, technology, human resources or ICT, and from the external context.

1.4.3 Study Space Findability

Explanations for the inadequacy of study space findability include the fact that human orientation is complicated in indoor spaces as it differs significantly from outdoor space. Several reason for this have been described by Zlatanova, Liu, Sithole, Zhao, & Mortari (2012): The orientation is complicated by the existence of multiple levels, smaller spaces relatively and difficulty to get a clear overview of the entire indoor environment. Furthermore, clues used to orient outdoors (e.g. position of the sun) are missing in indoor environment and indoor spaces also tend to have many obstacles (furniture, columns, podiums, etc.).

In the activity of finding a suitable work/study space indoor orientation is complicated even further by dynamic occupancy. Resulting in situations where it is difficult to determine which space is available and where it is. Normally a user walks through a building looking for a work space to their liking, often somewhere he has worked before and had a good experience. Over time a user probably has different work spaces that have been used which met the user's preferences to various degrees. If the user's preferred work spaces also happens to be popular among other users, these spaces are most likely occupied often. This can result in a frustrated user who either continues to search the building for a work space that does meet his preferences or the user mitigates and chooses a space which does not fully meet his preferences. Ultimately, this leads to a user who is less satisfied with the space supply. His perception can be that there are too few study spaces that meet his preferences or he finds them difficult to find as he does not know where they are. The latter is related to the lack of information about occupancy and aspects of available study spaces.

1.5 Scientific Relevance

1.5.1 Study Space Information

In the research of Smart Tools in university campuses (Valks, Arkesteijn, den Heijer, & Van de Putte, 2016) it was concluded that usable information about study spaces has high priority for student satisfaction. The example was given of a Smart Tool that provides information on the use of study spaces without a desktop. A smart tool that provides information on the work-space level is ideal. But, considering the high costs, it is more realistic for university campuses to provide information on building section or story level (Valks, Arkesteijn, den Heijer, & Vande Putte, 2016). Thus, it can be concluded that it is important to consider level of information the smart tool provides, which can include: time, space or specifics among others.

Furthermore, Harrop & Turpin (2013, p. 26) stated that 'space design should encourage users to reflect on their learning preferences and translate these preferences into space selection'. This suggests that user need to be actively engaged in space selection and involvement of user preferences in designing new spaces. Therefore, it becomes relevant to research the possibilities of using smart tools to improve the user involvement in the design of new spaces. Hence, not only information about study space is highly desired but also information about user preference for the involvement in space design.

1.5.2 Preference-based Accommodation Strategy (PAS)

A Preference-based Accommodation Strategy (PAS) enables CRE managers to actually calculate the added value of real estate strategies (De Jonge et al., 2009). The procedure is based on Preference Function Modelling (PFM). In the evaluation of the pilot study the results confirm that people are able to use the PAS design procedure to design more desired real estate portfolio designs. Additionally, the pilot study has revealed the possibility of combining the PAS design procedure to design a real estate portfolio in combination with scheduling, leading to schedule optimization. After evaluation participants recommended involving more people in the process, especially students and teachers (De Jonge et al., 2009). This implies that there is possible value to be discovered by involving a larger number of people in designing accommodation.

1.5.3 Theses

Tim van Hoek

Tim van Hoek (2016) researched a way to help students find an available study place. With the use of smart tools within the campus portfolio, utilization data enables students to make use of this data to find an available study place. He developed a decision support tool for students who are deciding where to study. This supports the student on the following variables: availability, facilities and preferences (van Hoek, 2016, p. 10). The reason for this was that it should lead to higher user satisfaction and an improved utilization rate (i.e. efficiency).

It was also indicated that the gathered data on study space utilization could give real estate managers better insight in portfolio use. In turn, this information can be used for making better portfolio decisions. However, the thesis mainly focused on supporting users. This indicates a research gap of the practical implications of utilization information and how it is able to add value to real estate.

Hylke de Visser

De Visser (2015) created a model with the possibility to design portfolio alternatives based on preferences. The model enables stakeholders to intuitively design portfolio alternatives by means of selecting a set of locations. It provides insight in the average physical values and accompanying criteria ratings of the portfolio. To provide feedback on the portfolio design in relation to the current portfolio, the model provides the preference rating for the current portfolio and the difference in rating with the alternative. For this Preference-based accommodation strategy (PAS) is used. By combining quantitative data with qualitative assessment a real estate portfolio strategy is suggested by a preference rating. De Visser also states that the model does not present physical values and criterion ratings based on individual locations. (de Visser, 2015, p. 93)

It was concluded that that the developed model and possible application needs to be more user friendly in some respects. For example, 'the model does not provide a visual representation of the locations on a map, something that could have made the design process more insightful for the stakeholders' (de Visser, 2015, p. 93). Indicating the need of to visualize the outcomes to interpret and present the outcomes to stakeholders. Therefore, recommendation for future research included a focus on the way the outcome of the model is made presentable.

Kitty Wu

Kitty Wu (2015) researched a method to determine the state of campus management and the performance of a university. This was done by determining the maturity level in campus management of a university with the use of a maturity model. The basic purpose of a maturity model is to describe a course of action corresponding with a certain maturity stage (Wu, 2015, p. 27). The maturity model is meant to be used by policy makers to understand the current condition of the campus management as well as their performance level (Wu, 2015, p. 97).However, the outcome of the maturity level is a bit constrained which make it harder to use. This is because the five stages of maturity are not mutually exclusive and most organizations exhibit characteristics of multiple stages at the same time (Wu, 2015, p. 101).

Rob Braggaar

Rob Braggaar (2018) research the technical side of live occupancy detection and user flows within in buildings by using a WiFi positioning system (WPS). The research primarily focuses on how to collect building use data for facility management. Therefore, the research is mostly limited to the reliable detection and processing of occupancy and user flow. Because the research concerned a different scientific discipline it did not go into much detail about the strategic purpose and value of the gathered information. This exposed a scientific gap which this thesis intends to fill.

1.6 Scientific Gap

Thus, the importance of having a good alignment of real estate supply with demand has been demonstrated. Campus managers are faced by the unpredictability of demand on both a yearly and day-to-day basis making it difficult to align the so-called dynamic demand with supply. This can lead to university campuses having an insufficient amounts of space leading to dissatisfaction. Real estate managers are also missing information about the use of real estate to test and prove the effectiveness of real estate interventions. Additionally, there is a need to have a greater user involvement in designing space. As smart tools provide opportunities to solve these problems, research of how smart tool can contribute can prove very valuable.

Students have also difficulties in finding a suitable study spaces which can lead to the perception that there is insufficient space. Therefore a smart tool providing information about study space to improve the findability is highly desired. While the use of a smart tool to provide useful information and the generation of reliable occupancy data has already been explored, the use and strategic purpose of the generated data has not been research. This exposes a scientific gap which this thesis intends to fill.

Preference Function Modelling already proved its potential in designing accommodation strategies in the PAS research and the thesis of Hylke De Visser. However, there is the need to involve a greater number of stakeholders and a need to improve the usability of the modelling technique. A smart tool presents opportunities to improve the user involvement in the design of new spaces.

As a result of these findings, this thesis will explore these opportunities by developing a smart tool which provides information on study space while simultaneously generating information to support campus management. This includes both daily practical information and information to support portfolio decision making.

2. RESEARCH FRAMEWORK

In this chapter the research is set up, starting with (2.1) the formulation of a concise problem statement and (2.2) hypothesis followed by (2.3) the research objective. From this (2.4-5) the relevant research questions are formulated and (2.6) conceptual model is constructed to show the essential concepts of the research and how they relate to each other.

2.1 Problem statement

There is a lack of information on demand to support campus management in making campus space decisions. This includes information on the utilization of space and information on user satisfaction. Students also lack information on the availability and aspects of study space which causes problems in finding preferred space to study. This can cause frustration and dissatisfaction of students, which can ultimately negatively influence the productivity and competitive advantage of universities. Therefore, it can be argued that there currently is a lack of a way to provide information to align dynamic space demand with supply on both the long- and short term.

2.2 Hypothesis

The hypothesis is that the described problem can be solved by providing information about study spaces with the use of Smart Tools (Valks, Arkesteijn, den Heijer, & Van de Putte, 2016, p 18). With regard to the use of the university campus or real estate, the objective is to increase both the *effectiveness* of the alignment of supply and demand while optimizing the *efficiency* of space use. To have better grip on the two terms effectiveness and efficiency, they are both defined below.

- *Effectiveness* is defined as the accuracy and completeness with which users achieve their needs. Indicators of effectiveness include match to preferences or quality of solution.
- *Efficiency* is defined as the relation between (1) the accuracy and completeness with which users achieve certain needs and (2) the resources expended in achieving them. Indicators of efficiency include amount of space use at a point in time.

Ultimately by having a more effective alignment of users and real estate supply, by taking preferences into account, a higher user satisfaction can be achieved (Valks, et al., 2016, p. 20). Satisfaction, being the users' comfort with and positive attitudes towards the use of the real estate supply. It is assumed that this can be done by implementing a preference function modelling method on which the user inputs its preferences after a Smart Tool is able to calculate a selection of available work spaces based on match with preference. Additionally, if users are confronted with their demands and its costs they might be incentivized to alter demand to give a better representation of the actual demand. This can be seen as a feedback loop that changes user demand to each particular situation. Simultaneously this can generate information for campus management to align supply to demand leading to a more effective use of real estate in the long term.

Furthermore, since campus space is rather unique in the number of flexible space types it provides opportunities to improve space use efficiency through flexibility and increasing density. Thus, providing an ideal working ground for space sharing with both internal and external partners. However, space sharing is only possible if the different work cultures are able to coexist (Valks, et al., 2016, p. 20).

2.3 Research Objective

This results in the research objective of developing a Smart Tool that provides information to improve the alignment of space demand and supply for both the user and campus management. The principle is illustrated in image 2.1.

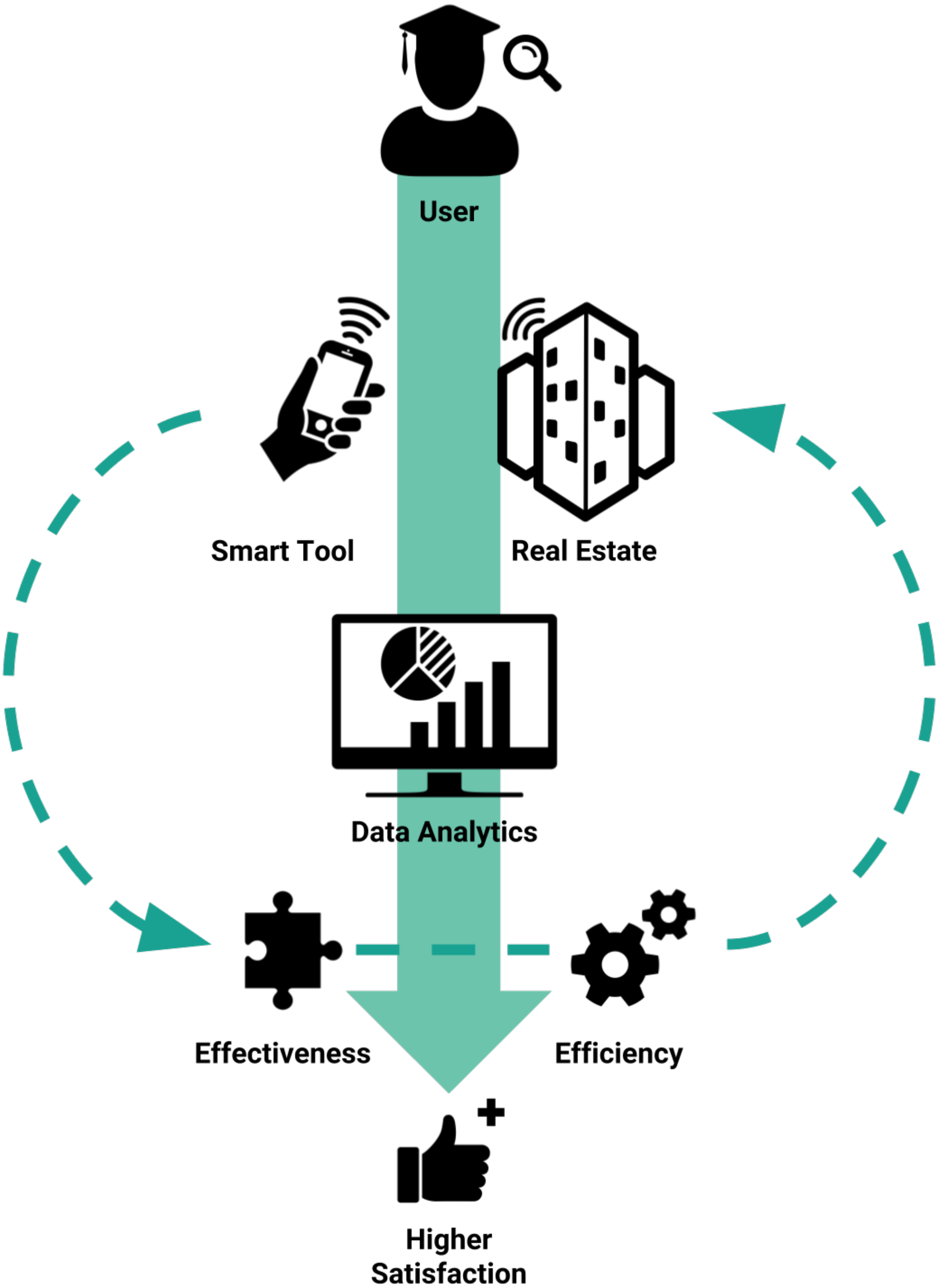


Image 2.1 Principle of the Smart tool (own illustration)

2.4 Main Research Question

The research objective is formulated into the following main research question:

"How can a Smart Tool provide information *to align dynamic user demand more effectively and efficiently with campus space supply on both the long and short term?"*

2.5 Subquestions

This main research question is divided into several sub questions to tackle the relevant aspects of the research. These sub questions are each linked to the chapters of this thesis.

2.5.1 Context

- What is CREM?
- What is the current state of university campus management practice?
- What Smart Campus Tools currently exist?

2.5.2 Management Information

- What management information is needed to improve campus management decision making?
- How is management information generated?

2.5.3 (Design) Problem definition

- How can one develop a Smart Tool to enable the interaction of real estate and users to enable the generation of usable management information?
- What criteria for study space preferences should be considered in the smart tool?

2.5.4 Occupancy detection

- How is occupancy detected through an existing WiFi infrastructure?
- What are the privacy issues concerning gathering use data?

2.6 Conceptual Model

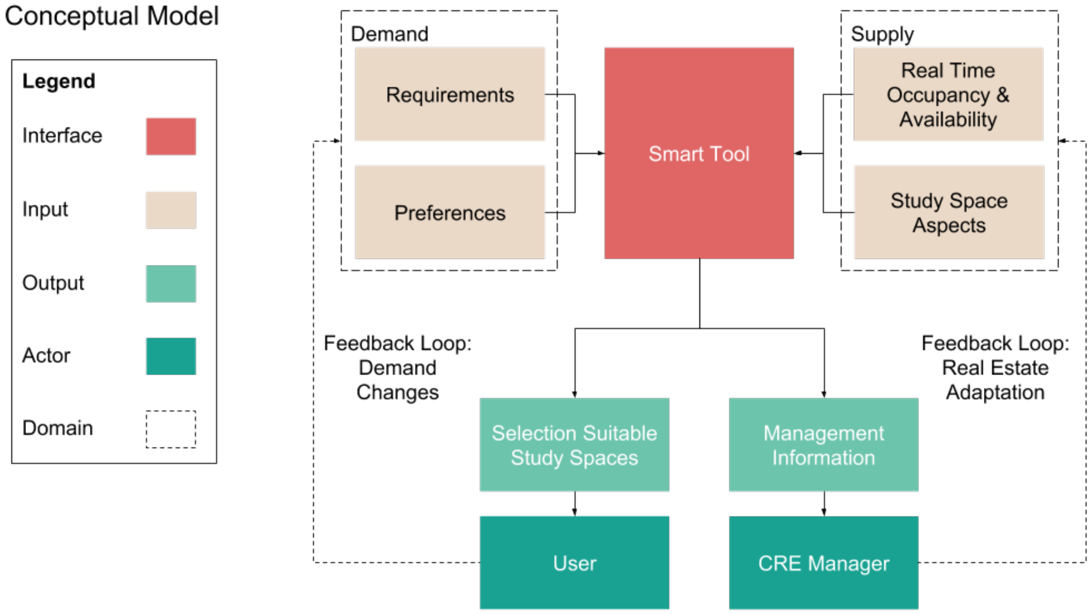


Image 2.2 Conceptual Model (own illustration)

In order to help understand the different concepts and their relation to each other, the concepts are translated into the conceptual model in Image 2.2. First the Smart Tool at the center of it all enables the interaction between the Real Estate (Supply) and User (Demand). By using the Smart Tool users are supported in finding an appropriate study space according to their preference by showing a selection of suitable study spaces. If the user is not satisfied with the results of the selection, he is able to make changes to his demand and choose his input accordingly. This signifies the feedback loop in which the demand is changed leading to a more effective alignment of the user to the real estate supply at that point in time. Simultaneously, through this interaction data is generated which is stored into the Real Estate Intelligence System (REIS) as Management Data. This Data serves the purpose to quantify the dynamic demand of the Users which can be analyzed over the long (or short) term by the CRE Manager. With this data the actual demand is made explicit on which the CRE Manager can make decisions which can make its Real Estate more efficient by making changes to maximize the utilization. Also the data can be used to increase the effectiveness of the Real Estate by making changes to optimally accommodate its Users while considering its preferences. Hence, this feedback loop signifies the changes made to the Supply on the basis of the generated data leading to improved Efficiency and Effectiveness. Ultimately, this should lead to higher satisfaction of the Users.

Image: BKCityGuide 2017/2018

PART II

METHODS

3. METHODOLOGY

In this chapter the research methodology is explained. The various steps and decisions taken in the research are exposed, in order for the reader to evaluate the research on logic and validity. This chapter will start with (3.1) the explanation of the research strategy, to describe the approach to the research. Secondly, (3.2) the research design is described by explanation the process of the research and the specific steps that will be taken. Thirdly, (3.3) the of data collection methods are described in more detail. Lastly, (3.4) this chapter will be concluded with a list of expected deliverables.

3.1 Research strategy

3.1.1 Deductive

It is important to state what the research strategy is as this will describe the research approach more systematically. The relation to theory in this research is deductive, as shown in image 3.1. In this research a hypothesis is formed from the existing theory. The hypothesis is used as a clear statement which is analyzed on truthfulness. To confirm or reject the hypothesis, the data necessary for analysation of the hypothesis is collected. With an outcome on the hypothesis, the underlying reasoning for this outcome will be analysed. Finally, the outcome and reasoning is related to existing theory and some form of revision or addition to theory will conclude the research. Therefore, the last step involves taking on a inductive approach to theory (Bryman, 2012, p.24).

Image 3.1 Deductive theory (Bryman, 2012)

3.1.2 Qualitative

Because the research requires the involvement of clients and users to really understand their needs, it becomes important to discover the underlying motivations and needs. For those reasons a qualitative approach is chosen. The qualitative approach to research is concerned with subjective assessment of attitudes, opinions and behaviour (Kothari, 2004, p. 4).

3.2 Research Design

The research design is the structure for the execution of the research. It shows the various methods for the collection, measurement and analysis of data. The design includes an outline of what specific steps are taken, including writing the hypothesis to its operational implications, concluding with the final analysis of data. The function of the research design is to provide the method for collecting relevant evidence with minimal expenditure of effort, time and money (Kothari, 2004, p. 14).

3.2.1 Operations Research

Within the research the most important aspect is the development of the smart tool which will be used to test the hypothesis. Therefore, the research is considered an applied operations research. Operations research refers to the application of mathematical, logical and analytical techniques for the solution of business problems (also called optimisation problems) (Kothari, 2004, p. 6). Operations research aims at finding a solution for an immediate problem facing a society or an organisation (Kothari, 2004, p. 3).

3.2.2 Engineering design

The main question of this research can be seen as a design problem, which ultimately leads to the design of an artifact: an artificial, man-made object, thing or device (Dym, Little, & Orwin, 2014, p. 7). Therefore to find a solution for the problem a (engineering) design process should be followed. Dym, Little, & Orwin define **Engineering design** as: *'a systematic, intelligent process in which engineers generate, evaluate, and specify solutions for devices, systems, or processes whose form(s) and function(s) achieve clients' objectives and users' needs while satisfying a specified set of constraints'* (2014, p. 7).

Roles

In a design process three "roles" are distinguished with each having their own responsibilities: the *client*, the *designer*, and the *user*. The roles are illustrated as a designer-client-user triangle (Image 3.2) which forces to recognize that interests of the three players might diverge. These possible consequences of multiple interests can create conflicting obligations, making design problems complex (Dym, Little, & Orwin, 2014, p. 6).

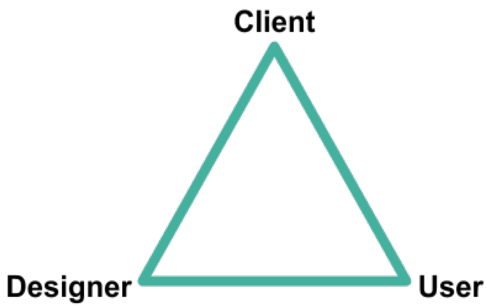


Image 3.2 designer-client-user triangle (own illustration based on Dym, Little, & Orwin, 2014)

- The **client** is a person, group or company that wants a design conceived. It is typically the client who motivates and presents the starting point for design. Often the client speaks to the designer on behalf of the intended users.
- **Users** are a key player in the design effort because they employ or operate whatever is being designed.
- **Designers** solve the client's problem in a way that meets the user's needs. A designer's first task is to to clarify what the client wants and translate it into a form that is useful as an engineer. Designers have obligations not only to clients and users, but also to their profession and to the public at large (Dym, Little, & Orwin, 2014, p. 7).

Within this research campus management is considered as the client, the users of the campus are the users and researcher is the designer. However, in some cases several roles can be played by the same person(s) (Dym, Little, & Orwin, 2014, p. 4). This is one of those cases, as for this thesis the researcher is also a user, enabling greater empathy during the design process.

3.2.3 Design Process

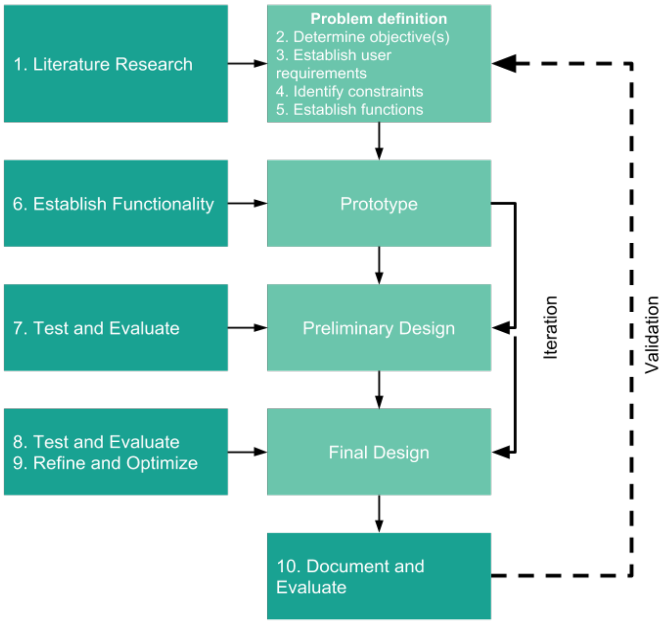


Image 3.3 Design Process (based on engineering design (Dym, Little, & Orwin, 2014))

For the design process an extensive prescriptive model with five phases will be used based on the engineering design process described by Dym, Little, & Orwin (2014, p. 20). Output of each design phase serves as input to the next design phase linking the five stages of this design process. It starts with the initial problem definition and ends with the documentation of the final design. For the use of the model it is important to not lose sight of the original objectives, constraints, and functions, giving importance to regular feedback and iteration (Dym, Little, & Orwin, 2014, p. 23). Thus, the model is displayed as a linear model to show normal sequence of the five phases but does involve iteration.

Following the Literature Research the problem is defined along with the objectives, constraints, functions and user requirements. Afterwards, a first design is made in the form of a prototype in order to establish functionality. In turn, this functionality can be evaluated by the end users. Following two evaluative steps to involve the client and user in the Preliminary- and Final Design. When the Design is finalized the design is documented. The steps of the design process are described in more detail in the following sections.

3.2.4 Problem definition

Normally design projects start with a problem needing to be solved for the client, typically in the form of a verbal problem statement. However, for this research the problem definition will be derived from literature research. Because the problems in current campus management have been extensively researched and documented in 'Managing the University Campus'(2011) and more recently 'Campus NL' (2016), it became possible to get a clear depiction of contemporary Dutch campus management practice. These researches show what the contemporary problems relating to campus management are. Similarly, recently there has been a study concerning 'Smart Campus Tools' (2016 & 2018) in- and outside the Netherlands. This study shows which tools are already available for campuses (and commercial organisations), their functions and what functionality is currently lacking. During the research however, an interview will be held with campus management to enquire about any additional data/information needs.

Another vital subject of this research is learning space preferences (i.e. user requirements). This subject has been extensively studied by a number of researchers, which will serve as a basis for student preferences. After the initial preferences have been used to design the prototype, its functioning will be evaluated by students. Following this, the students are asked about relevant and possible missing preferences, to determine what is important in selecting study space. Thus, by interviewing the client and users the design is developed and new functions can be discovered, making evaluation an integral part of the design process (Dym, Little, & Orwin, 2014, p. 17). How this is done exactly is explained in section 3.3.

Since this is a thesis, the time available is one of the main constraints for this research. So, in order to keep the research feasible within the timeframe the functionality of the smart tool will be limited. However, some research will be done on the requested functions for the smart tool from students and campus management. But since execution of these functions is not feasible within the time restriction they will be recommended to be researched hereafter or developed later by another design team. The functionalities of the smart tool is made explicit in the Research Scope.

3.2.5 Functions

Understanding the functionality of a design is essential to design successfully (Dym, Little, & Orwin, 2014, p. 71). To help understand the functionality designers can take a systems view and relate functions to **transforming** an **input** to an **output,** also called a functional analysis. Functions can be categorized as either basic or secondary. A basic function is the specific, overall function that must be performed, and secondary functions are functions needed to perform the basic function or result from doing the basic function. Secondary functions can be categorized as either required or unwanted (Dym, Little, & Orwin, 2014, p. 73).

Functional analysis

In this research a **black-to-glass box** functional analysis will be performed. A **black box** is a graphic of the system or object being designed, showing inputs entering the box and outputs leaving it. All identified inputs and outputs should be specified, even undesirable byproducts (Dym, Little, & Orwin, 2014, p. 73). While describing the different input and output it is desired to use the same level of detail. In relation to this research the transformation of input to output by using the smart tool only involves data. Therefore it is most important to look at information flows. Information flows include the transfer of data transmitted over the internet or by wireless connections and can be stored in databases or -warehouses (Dym, Little, & Orwin, 2014, p. 72).

Within this thesis the conceptual model (2.4) is considered the black box of the smart tool. Over the course of this research the objective was to make this black box transparent to show how input is transformed to output, in the level that is needed for the main functionality of smart tool. Graphically, the **glass box** displays several new boxes within the original (black) box, each representing a subfunction that must be performed to support the overall functionality (Dym, Little, & Orwin, 2014, p. 75). Ways to do this include constructing a Entity-Relational model as described later in this report.

3.3 Data collection

The several ways for acquiring design knowledge which will be described in this next section, comprising of literature study and interviews. All the forms of data collection have been included in table 3.1.

3.3.1 Literature Research

Literature research is used in this research to gain understanding of the design problem and its users. Existing Smart Campus Tools solving similar problems are also analyzed in literature. Literature research is also needed to support the design process for developing a smart tool. Additionally, researching legal literature will make sure the Smart Tool will comply with contemporary regulations.The subjects of the literature research are listed in table 3.1.

3.3.2 Interviews

The smart tool will be developed along a iterative sequence of prototype evaluations to support the design process. User involvement will be established by two prototype evaluations evaluations with the use of an interview. The first interview acts as evaluation of the prototype and determines requests for the functionality, whereas the second interview is to gauge how much the requests have been met. As a result of the results from the interview the design is finalized. The process within the interview will be described in more detail in section 3.3.3.

Literature study	Interviews
The role and needs of CREM	User prototype evaluation (and the establishment of (additional) needs) x2
Current campus management practice	CRE managers (for the establishment of (additional) needs)
Existing smart campus tools	
Business intelligence	
Privacy concerns	
(WiFi) occupancy detection	
Learning space preferences	

Table 3.1. Overview of the data collection

3.3.3 Usability Evaluation for Iterative User Involvement

Poorly designed systems, which users find difficult to learn or complicated to operate, are likely to be underused or abandoned altogether by frustrated users. Users will then return to their current working methods, rendering the system useless (Maguire, 2001, p. 587). This stresses the importance to consider usability and involve the end-user in the design process. Therefore, usability is now widely recognized as critical for the success of an interactive system or product (Shackel, 1981, 1984; Eason, 1984; Whiteside, Bennett & Holtzblatt, 1988; Fowler, 1991; Shackel, 1991; Nielsen, 1994; ISO, 1997b).

Design solutions develop out of logical progression from previous designs, thus going through iterative development as they progress. Iteration is defined as "the repeated application of a common method or technique at different points in a design process" (Dym & Little, 2004, p. 26). With the involvement of users in the design process of the proposed Smart Tool the usability will be evaluated at various stages to stimulate iterative development. For this 'methods to support human-centered design', as described by Maguire (2001), are used.

Prototype Evaluation

Mock-ups and simulations of systems are necessary to support an iterative design lifecycle. A method to do this is described as prototyping. Prototyping helps to ensure that the product will both be usable and will meet the functional needs of the users. Furthemore, this helps to avoid the costly process of correcting design faults in the later stages of the development cycle (Maguire, 2001, p. 604). Prototypes can be divided into:

- • Low fidelity prototypes (e.g. mock-up or scripted demonstration) and;
- • High fidelity prototypes (working simulation or operational system).

In the case of developing software prototypes, computer simulations are utilized to provide a more realistic mock-up of the system under development. Furthermore, end-users are able to interact with the prototype to accomplish set tasks and any problems which arise are noted (Maguire, 2001, p. 609).

Evaluating is a very important activity within the system development life cycle. Initially this will most likely be done using low fidelity prototypes, following by more sophisticated prototypes. During each evaluation session user interactions and comments can be recorded on audio- or videotape for later analysis. This can confirm how far user and organizational objectives have been met as well as provide further information for refining the usability of designs throughout its development. More importantly, critical incidents can be identified which are events that represent significant failures of a design. Ultimately, the output of a usability evaluation is documented describing the process of testing that was carried out, the results obtained, and recommendations for system improvement (Maguire, 2001, p. 615).

Usability evaluation can be distinguished into three levels of formality (Maguire, 2001, p. 614): *participative* (least formal), *assisted* (intermediate) and *controlled* evaluation (most formal). A **participatory** approach includes asking the user for their impressions of a set of screen designs, what they think different elements may do, and what they expect the result of their next action to be. The user may also be asked to suggest how individual elements could be improved. For the **assisted** approach the user is requested to perform tasks without help and is asked to talk aloud, if the user gets stuck the evaluator is able to intervene. The objective is to obtain the maximum feedback from the user while trying to maintain as realistic an operational environment as possible. In the presence of a fully working system a **controlled** user test is applied, replicating the real world in the test environment as closely as possible. This also limits the amount of help a user might get in the real world situation (e.g. possibly a manual or a help line). The controlled user test can be used to evaluate whether usability requirements have been achieved, for example via the following measures (Maguire, 2001, p. 614):

- • Effectiveness: the degree of success with which users achieve their task goals.
- • Efficiency: the time it takes to complete tasks.
- • Satisfaction: user comfort and acceptability.

For the evaluation of the proposed Smart Tool the assisted approach is utilized. This approach was chosen because of the complexity of the input, and the likelihood that users will not understand this initially. Similar to a search engine the system will output a list of results based on the highest preference rating. The users were asked to input their own preferences into the system and give feedback on the workflow of this and the results.

Assessing Cognitive Workload

Measuring cognitive workload involves assessing how much mental effort a user expends whilst using a prototype or deployed system. This can be obtained from questionnaires such as the Task Load Index (TLX). The TLX has six scales (mental, physical, temporal, performance, effort and frustration) to measure the individual's perception of what a task has asked of them (Maguire, 2001, p. 618).

Post-Experience Interviews

Individual Post-Experience interviews are a quick and inexpensive way to obtain subjective feedback from users based on their practical experience of a system or product (Maguire, 2001, p. 619). As a semi structured interview the user has the freedom to express additional views that they feel are important.

3.4 Deliverables

As described by Sherman (2015, p. 56) it is important to classify the determined requirements in the following categories: Must-have, Should-have, Nice-to-have, Forget about it. For this research the same approach will be used with regard to the functionality of the Smart Tool. Resulting in the following deliverables in table 3.2 below.

Must-have	Should-have
Selection model based on preferences, requirements (& availability)	Net-id integration (Single sign-on)
Preference match selection	Campus integration (2 or more faculties in the database)
Dashboard for data visualisation	UI design for mobile app
User-bound preferences (saved)	
Nice-to-have	Forget-about-it
Live link for occupancy determination	Events
Determination availability studyplace level	Way-finding
Brightspace schedule integration	3D model
Favourites	Mobile app
Booking system	Safety

Table 3.2 Deliverables

Must-have
Within the must-have category it is most important to have a model that is able to make a selection of all the spaces based on requirements and availability (i.e. by filtering out the spaces which did not met these criteria) firstly. And secondly a selection of the spaces based on what the particular user finds most important (i.e. having the highest match with preferences). As the user will not likely want to fill in his preferences every time he uses the smart tool it is desirable to store these preferences for later use. Hence the user-bound preferences to signify this. This function also has another function, by storing the input of users for analysation the demands of users can be determined and analyzed. As this data needs to be analyzed a dashboard will help with translating the data to useful information by visualizing data.

Should-have
In the should-have category a Net-ID integration as used in TU Delft will help to sign into the app more easily. This allows to decrease the threshold users to start using the smart tool as it requires less effort to log in. Campus integration implies that the multiple or all buildings of the TU Delft are in the database of the Smart Tool. This allows users to decide to travel to a different faculty building for a study space if it meets their specific needs better. Lastly, a user interface(UI) design which is able to simulate how the users interact with the smart tool and what is important for them to ultimately use it.

Nice-to-Have
In the Nice-to-Have category a live link to determine occupancy is actually inherently important for the functioning of the smart tool. However, since this is not available and implementation will take too long it will likely not be included in the research. A derivative of occupancy determination is the availability of study spaces also depending on this same technology. A Brightspace integration will be able to show students their schedule and with some additional functionality students can be supported in finding the classrooms. Favourites implies storing the most liked spaces in their personal account or settings, which allows users to easily check if theses spaces are available. Finally, a booking system will help teachers to reserve spaces for meetings etc.

Forget-about-it
Lastly, the forget-about-it category are welcome additions which are simply not feasible or of less importance for the smart tool. The first is Events which can show users which events are available on campus. Wayfinding will guide users across campus and within buildings to their selected spaces. While very useful, it is not feasible within the research. Similar to this

a 3D map of the campus and buildings will most likely navigating the campus but is too technically difficult to achieve at this point. Similarly, a working mobile application is desired but not feasible. Finally, functionalities to improve the safety of can prove valuable but are not important within this research.

Image: BKCityGuide 2017/2018

PART III

LITERATURE STUDY

4. CREM

In this chapter the key theory relating to the field of (corporate) real estate management is described in order to answer the first subquestion: 'What is CREM?'. In the first section (4.1) the definition and objectives of Corporate Real Estate Management (CREM) are explained. The next section (4.2) clarifies the objectives more specifically by defining organisational performance. In the third section (4.3), performance measurement is defined and described. Thereafter, (4.4) the different stakeholders and their perspectives are described.. The fifth section (4.5) defines the ways to add value and relates them to organisational performance and its different perspectives. and includes the generation of management information to support decision making. Then, (4.6) the process of real estate management and accommodation strategy design is explained alongside the DAS frame. Finally, (4.7) the subquestion will be answered.

4.1 Corporate Real Estate Management (CREM)

Real estate management is the continuous process of matching supply (i.e. real estate) with demand, which is derived from organisational objectives and primary processes (Den Heijer, 2011, p. 104). Primary processes of organisations demand a certain quality and quantity of real estate (Den Heijer, 2011, p. 103). It is crucial for an organisation to align their real estate to support these primary processes while considering the financial consequences and changes in time. The expensive nature of real estate makes it important to have a good real estate alignment to optimize organisational operation while minimizing costs.

Corporate Real Estate Management (CREM) is real estate management by an organisation that both owns and occupies its real estate (Den Heijer, 2011, p. 104). Therefore, CREM is closely related to the processes, the people, the organisation's culture and the organisational objectives (De Jonge et al., 2009, p. 21). CREM operates between business and real estate, connecting the strategic- and operational level (De Jonge, 1994, p.15). It focuses on the performance of the organisation (benefits) in relation to the resources that are spent on real estate (costs) (Den Heijer, 2011, p. 104). In CREM decision making it is important to take the interrelationship of resources into account. In a (rapidly) changing context a continuous matching process is required to match the dynamic demand and the static supply (De Jonge et al., 2009, p. 23). Currently, due to the increasing importance of economic goals and the growing dependency on private funding in universities, CREM theory is most applicable to university campus management (Den Heijer, 2011, p. 104).

4.2 Organisational performance

The goal of real estate management is to positively contribute to organisational performance or add value to an organisation by making real estate interventions (Den Heijer, 2011, p. 92). Following management theory, an organisation produces a desired output with a certain input. The input consists of the following five resources: human resources, technology, information and capital, with the addition of real estate. The output is affected by the available resources and organisational characteristics such as the organisation's culture, structure, leadership or objectives. Management is responsible for making choices concerning the resources to produce the desired output (de Vries, de Jonge, & van der Voordt, 2008, p. 210). In relation to organisational performance, real estate interventions make changes to real estate (input) which influences performance (output) (Den Heijer, 2011, p. 243).

Three performance indicators have been identified which are related to different stakeholders. The performance indicators include: Productivity, profitability, competitive advantage and sustainable development. To specify, profitability is defined as the difference between benefits and costs. Competitive advantage has been defined as the (developments in) market share, and productivity as the ratio of output/input. Of the performance indicators, productivity is the most difficult to quantify, especially if the organisation concerned is a centre of expertise, a service provider or an educational institute (de Vries, de Jonge, & van der Voordt, 2008, p. 210). The input - process - output principle and organisational performance are combined in image 4.1. Thus, it is assumed that real estate interventions impact performance which should show in changes of the performance indicators.

Additionally, multiple levels of performance can also be distinguished: the input side consists of the levels: areas (city- region), portfolio (campus), buildings and places, while the output side of: organizational, individual and societal, adding to the complexity of real estate decisions.

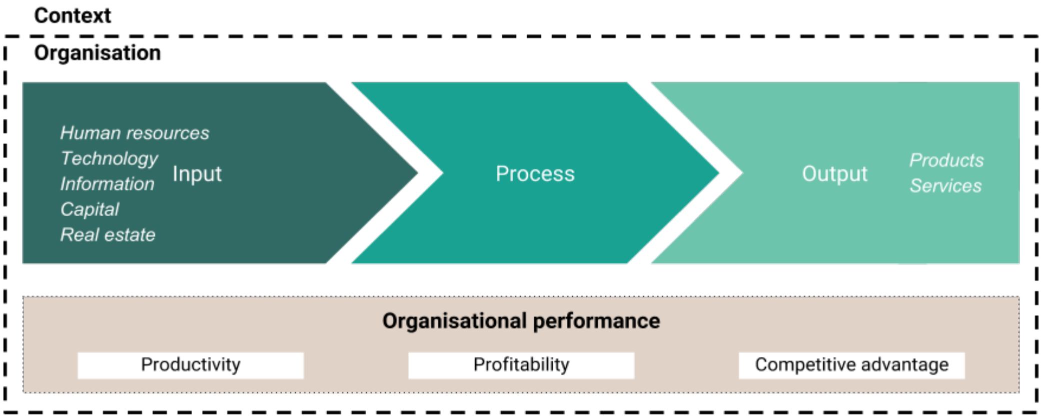


Image 4.1 Conceptual model of the input - process - output in relation to organisationalp erformance (own illustration based on de Vries, de Jonge, & van der Voordt, 2008, p. 211)

4.3 Performance Measurement

Performance measurement is defined as the process of translating the strategy of an organisation into concrete objectives to evaluate the achievement of those objectives (Lindholm, 2008, p. 24). It focuses on communicating, guiding and controlling objectives of the primary processes to focus efforts towards achieving the established objectives. Performance measurement is described by Neely et al. (1995 in Lindholm, 2008, p. 24) as the process of quantifying action, where measurement is the process of quantification and action correlates with performance. Consequently, the performance of the action is related to a certain efficiency and effectiveness. Performance measures are the means for determining the status of a success factor, for which multiple measures can be used to assess a single success factor. A performance measurement system (PMS) represents a set of strategically important performance measures.

For performance measurement a distinction between measures and indicators is made by Ho et al. (2000, in Lindholm, 2008, p. 24). While measures represent the (internal) scale of the organisation, (key performance) indicators represent figures to enable comparison between (external) organisations. Performance measurements are directly measurable items, (e.g. total expenses or real estate particulars, such as occupancy costs, gross floor area, etc.), while performance indicators are data obtained by measuring expenses of real estate particulars against certain metrics (e.g. occupancy cost per employee, occupancy cost per square feet, ratio of gross floor area, etc.) (Lindholm, 2008, p. 24). Measurements of the key performance indicators can then be used to quantitatively assess whether real estate decisions are having the desired effect on the (financial) success of the organisation (Lindholm, 2008, p. 50).

4.3.1 Management information

Thus, as KPIs can be used to measure the performance at different moments in time (e.g. past and current) the outcome and impact of any intervention can be determined, ex-post. This forms the basis for generating management information which are needed to support real estate investment decision making (Image 4.2). Meaning, performance measurement can also be used to determine expected impact on performance ex ante, to use as a business case (Van der Zwart and Van der Voordt, 2015). Data on performance variables on the output side and data on real estate variables on the input side needs to be collected to generate KPIs. The main sources of data are simultaneously the processes that are being supported by the management information, making the process of generating management information cyclic.

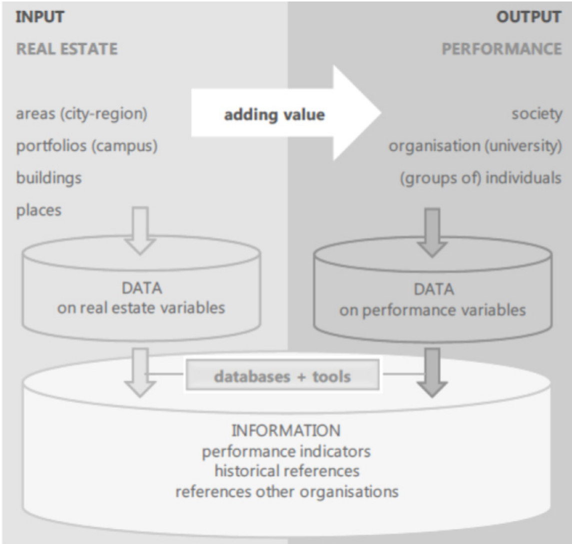


Image 4.2 Process of adding value to performance as the basis for generating manage ment information (Den Heijer, 2011, p. 113)

Following the changes of KPIs over time, patterns and relations can be discovered which can not only help management practice, but also management theory (Den Heijer, 2011, p. 101-102). KPI's can also be used to measure performance in relation to other organisation (i.e. benchmark studies). This requires comparative reference information of other organisations on the selected KPI's (Den Heijer, 2011, p. 101).

However, effects of equal real estate interventions on performance are hard to determine. This is because of the uniqueness of organisations and real estate, and the many direct and indirect influences of real estate on performance resulting in a complex set of interrelationships. Therefore, real estate intervention effects rarely yield the same results and are difficult to isolate from other factors that might influence performance (Den Heijer, 2011, p. 99). If an organisation does not take into account the complexity of these interrelations, it can lead to (negative) side effects (Vries, 2007, p. 325).

Thus, the management information can be used to make business cases for real estate interventions, but it remains difficult to predict what its effects will be on performance.

4.4 Stakeholders

Within real estate management four stakeholders have been determined, being (1) Policy makers, (2) users, (3) controllers, and (4) technical managers, (Den Heijer, 2008). CREM requires real estate decision making by incorporating the interests of the different stakeholders involved. These interests are weighed with the consideration of time, as a result of the ever changing demand (accommodation requirements) and obsolescence of supply (existing accommodation). Ultimately the costs and benefits are weighed to make decisions. Furthermore, CREM is required to involve these stakeholders in various steps of the decision making process, by informing them (passive) or making them participate (active).

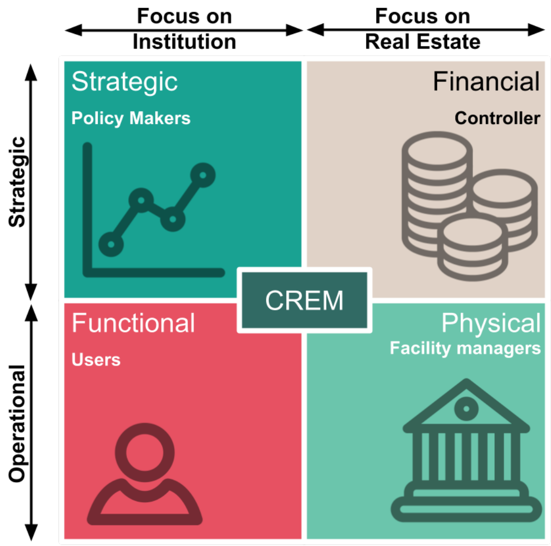


Image 4.3 The different perspectives of stakeholders, distinguished in four quarters (own illustration based on Den Heijer (2011)

In image 4.3, the different perspectives of stakeholders are distinguished in four quarters. The perspectives are connected to a certain focus shown above and beside the quarters. The horizontal axis focuses on the institution (demand) or real estate (supply) perspectives. On the vertical axis the focus is either on the strategic or operational level (Den Heijer, 2011, p. 106).

Different aspects are relevant for the perspectives in the decision making process. The most important aspects per perspective are (Den Heijer, 2011, p. 107):
• Physical perspective: the quantity and quality of current and future campus, including location characteristics, types of spaces condition and age of the buildings
• Functional perspective: the number and types of users that have to be accommodated, the satisfaction about the current campus, occupancy and frequency rates.
• Financial perspective: cost of campus investments, resources that are spent on real estate and the value the campus represents
• Strategic perspective: The extent that institutional goals on education, research, human resources and valuation of knowledge supported, achieved or obstructed in the current real estate portfolio

Because different stakeholders have different objectives, they each have their own set of KPIs. Interestingly, Den Heijer added a fourth performance indicator to the physical perspective, sustainable development. Sustainable development indicates the footprint on the environment in terms of CO2 emission and amount of space. A list showing the different KPIs for each of the stakeholder perspectives of universities is shown in image 4.4.

Key performance indicators (KPIs) to measure a university's performance			
productivity	profitability	competitive advantage	sustainable development
• publications per academic fte • output per m² • students per m² • employees per m² • energy costs per m² • total costs of ownership as % of total costs (or turnover) • etc.	• revenue minus costs • solvency • liquidity • environmental goals • position on innovation index • citation score • (economic) value of alumni • increased real estate value	• international rankings • market share of students • quality of alumni • student satisfaction • alumni satisfaction • employee satisfaction	• energy use per m² • energy use per user • CO_2 emission per m² • CO_2 emission per user • energy labels of buildings • footprint in m² per user

Image 4.4 Key Performance Indicators (KPIs) for university performance (Den Heijer, 2011)

4.5 Adding Value

De Vries (2007) distinguished ten ways in which real estate can contribute to performance, elaborating on the 'seven ways of adding value in former CREM theory by De Jonge (1994). Thereafter, this has been expanded upon by Den Heijer (2011) to twelve ways of adding value. The twelve interrelated ways of adding value can also be called real estate goals or objectives. In theory, every corporate real estate decision can be related to at least one of these goals (Den Heijer, 2011, p. 98). Furthermore, the hierarchy of the twelve ways to add value can be used as a tool to support the process of making a decision in relation to the objectives of the organisation (Den Heijer, 2011, p. 244). The twelve ways to add value through real estate are listed in table 4.2.

12 ways to add value through real estate	
1. Increasing real estate value	7. Supporting image
2. Controlling risk	8. Supporting culture
3. Decreasing costs	9. Stimulating collaboration
4. Increasing flexibility	10. Stimulating innovation
5. Supporting user activities	11. Improving quality of place
6. Increasing user satisfaction	12. Reducing footprint

Table 4.1 twelve ways to add value

4.5.1 Real Estate Interventions

By combining the results of several scientific studies considering real estate interventions, five distinct real estate intervention types were established. These are included in table 4.2. In turn these can have influence on organisational performance through the twelve ways to add value (table 4.1), as described in the next previous section.

Types of real estate interventions		
Maintenance	Functional adjustment	Reshuffling
(partial) Renovation	New building	

Table 4.2 five real estate intervention types

4.5.2 Relating adding value to organisational performance

The process of adding value through real estate is shown by relating the 12 ways to add value to the four stakeholder perspectives, which is illustrated in the model below (image 4.5). This model is based on a more elaborated model of the stakeholders perspectives found in the dissertation of Den Heijer (2011). CREM (i.e. campus management) is placed in the center of the model. From this point CRE managers influence the different perspectives through real estate interventions. These interventions have varying degrees of influence on the perspectives based on the scale of the real estate project. Hence, the indication of the quality ambition, number of users involved, budget and space types of the project.

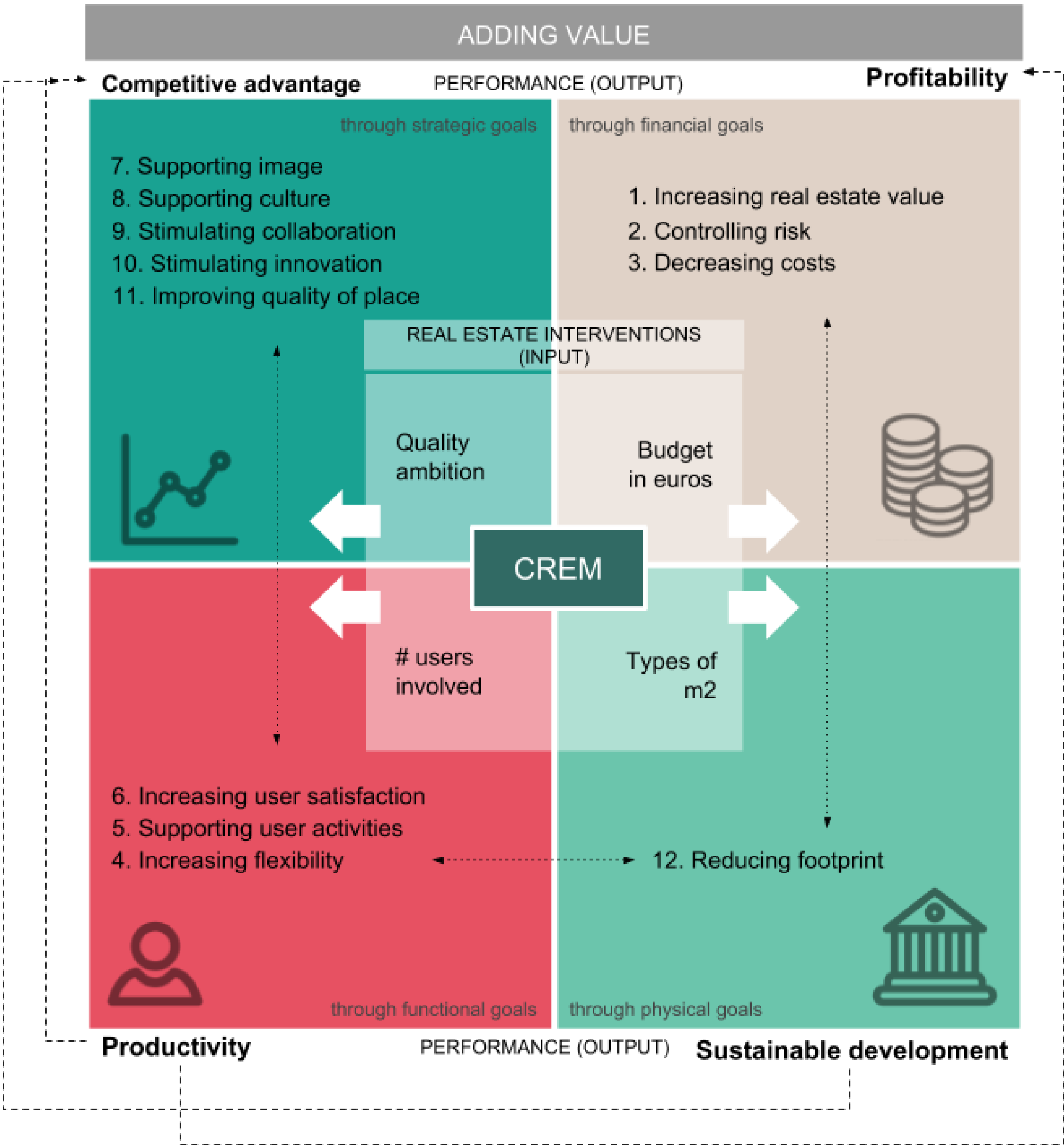


Image 4.5 Adding value to organisational performance (own illustration based on (Den Heijer, 2011))

The added values of increasing user satisfaction and supporting user activities is also related to some of the added values found in the strategic perspective, which is indicated by the arrow. These include improving quality of place, stimulating collaboration and supporting organisational image. The added value to increase flexibility is also indirectly related to the financial perspective through the added value of reducing the footprint of the campus.

Surrounding the perspectives are the performance of the organisation with its related key performance indicators. The underlying relations of the key performance indicators are indicated by the arrows. This shows that the functional perspective is related to the productivity dimension. In turn, it can be seen that through the productivity, the competitive advantage and profitability is influenced. While sustainable development is able to influence solely the competitive advantage.

4.6 DAS Frame

The Designing an Accommodation Strategy (DAS) framework is an abstract model that describes demand, supply and match (De Jonge et al., 2009, p. 98). The framework provides a structure and clarifies the process for designing accommodation strategies for real estate. As a result of using the framework, time should be reduced and quality of the designed strategy should be increased. Key issues in the framework are four main steering events (De Jonge et al., 2009, p. 36):

1. **Assessing current supply**: determine the mismatch between current demand and current supply;
2. **Exploring changing demand**: determine the mismatch between future demand and current supply;
3. **Generating future models**: design, evaluate and select solutions for the mismatch;
4. **Defining projects to transform**: planning the transformation of current supply into selected future supply.

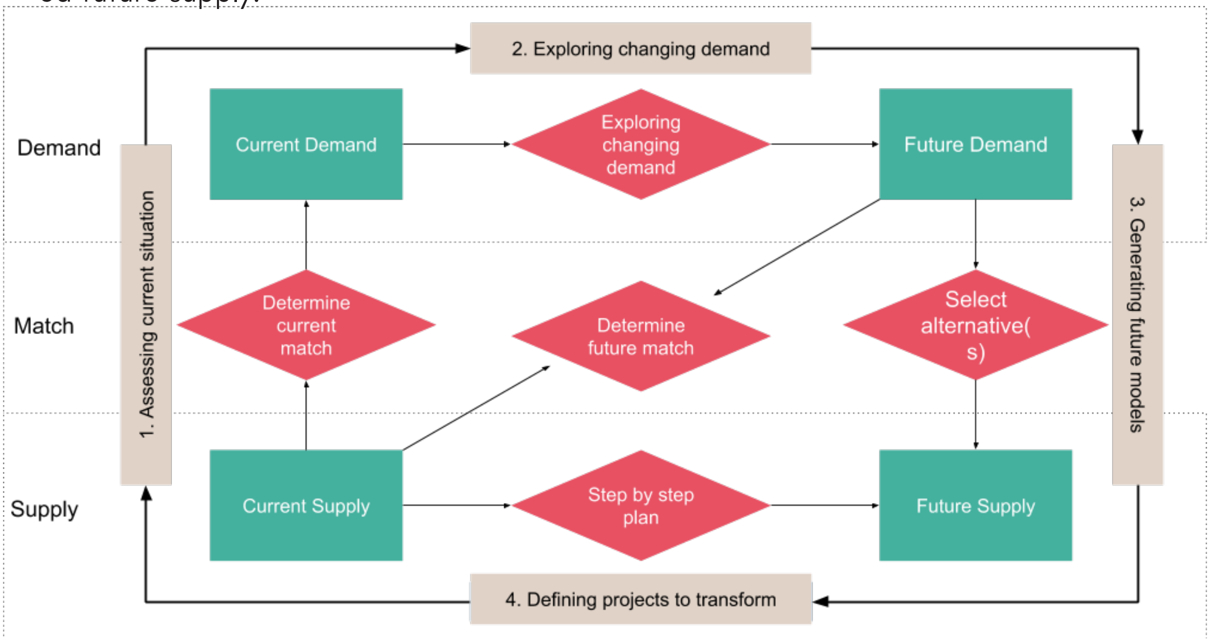


Image 4.6 DAS Frame (own illustration based on (De Jonge et al., 2009))

Designing accommodation strategies is a response to organisational demand in relation to the current real estate supply. Because each real estate object is unique within a certain context it is hard to make procedures for each situation. Therefore the information forms the basis for problem analysis which, in turn, is converted to workable solutions. Implying that strategy design, in other words the transition from problem to solution, takes place in a black box (De Jonge et al., 2009, p. 87).

The design process is iterative by nature: it involves a succession of analysis and synthesis, aiming to find a match between demand and supply (De Jonge et al., 2009, p. 37). In the case that there is a mismatch one might search for solutions that can be applied to the supply or adjustments can be applied to demand. The actual accommodation strategy is defined at the end of this process (Dewulf, Den Heijer et al. 1999).

An accommodation strategy can be developed at different levels of scale within different time frames and faced with different contexts. There can be chosen to target an entire real estate portfolio or a single building (De Jonge et al., 2009, p. 37).

1. Assessing current situation

In the first phase the alignment of current demand & current supply is determined.

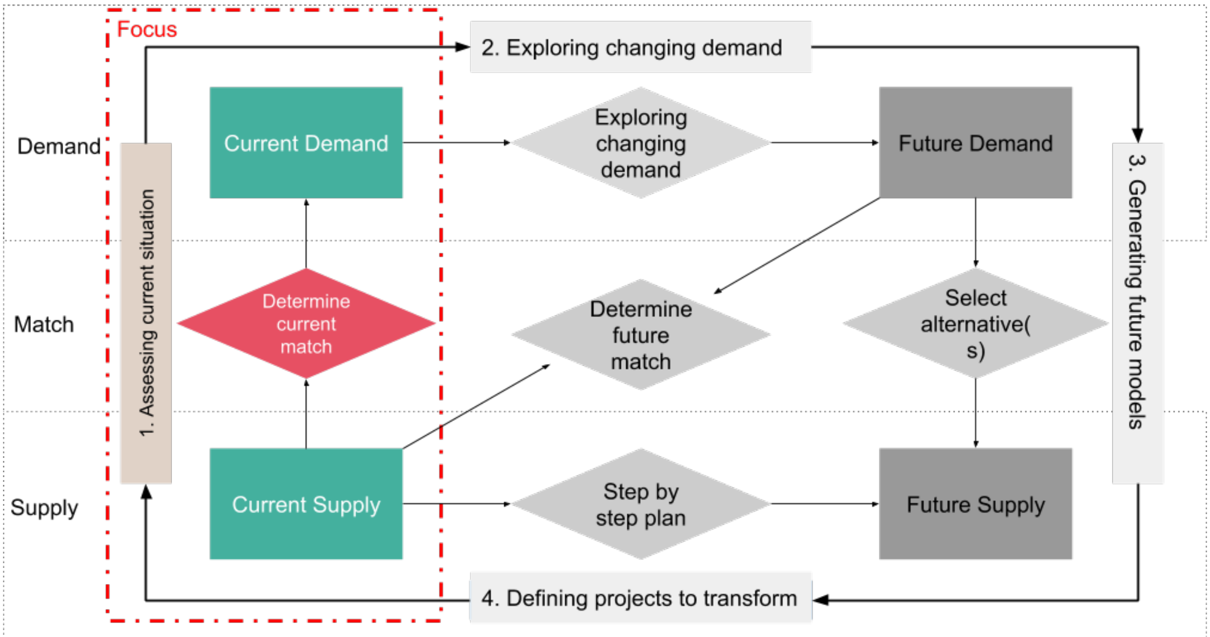


Image 4.7 DAS Frame (own illustration based on (De Jonge et al., 2009))

The following steps lead to the determination of alignment:
a. Inventorying current space need and use (current demand);
b. Quality and quantity of the current supply at building and portfolio level (current supply);
c. Comparing current supply and demand to determine alignment.

a. Inventorying current space need and use (current demand)

The phase is started by making an inventory of the stakeholder problems in the current situation (a subjective analysis). The result of this step is a compact overview of all relevant stakeholders and their problem(s) with respect to real estate. This helps the CRE manager to become aware of the overall problems per object as well as the problems on the different aspects, like quality, quantity and costs. After thorough analysis, the CRE manager becomes fully aware of the organisation and its real estate (De Jonge et al., 2009, p. 39).

b. Quality and quantity of the current supply

Describing current supply can result in a very detailed analysis of all kinds of aspects: technical state, m2, capacity, qualities, location, available services etc (De Jonge et al., 2009, p. 39). Descriptions of quantities are supported by stating the added values to the accommodation.

c. Mismatch (if applicable) as a problem statement

After the same type of data on both demand and supply side is collected, it becomes possible to compare the data and draw objective conclusions. It is essential to use standards for some subjects (space use, occupancy cost etc.) to judge whether a price and/or space use is relatively high or low. To establish standards a benchmark study is usually applied.

2. Exploring changing demand

The next phase compares the estimated future requirements (demand) with the current supply. Changes in an organisation's ambitions or space requirements are caused by internal and external developments. An analysis of these changes leads to a qualitative and quantitative description of the organisation's future space requirements. These requirements are often expressed in ranges (minimum-maximum) and require a modular and flexible solution (supply) to deal with uncertainty of the future. Not only uncertainty of the future, but also the difference in time frames of organisations (3 to 5 years) and real estate (10 to 50 years) complicates real estate decision making (De Jonge et al., 2009, p. 40). The phase is concluded with a problem analysis in which the future accommodation mismatch is estimated in the case that supply is kept at its current state.

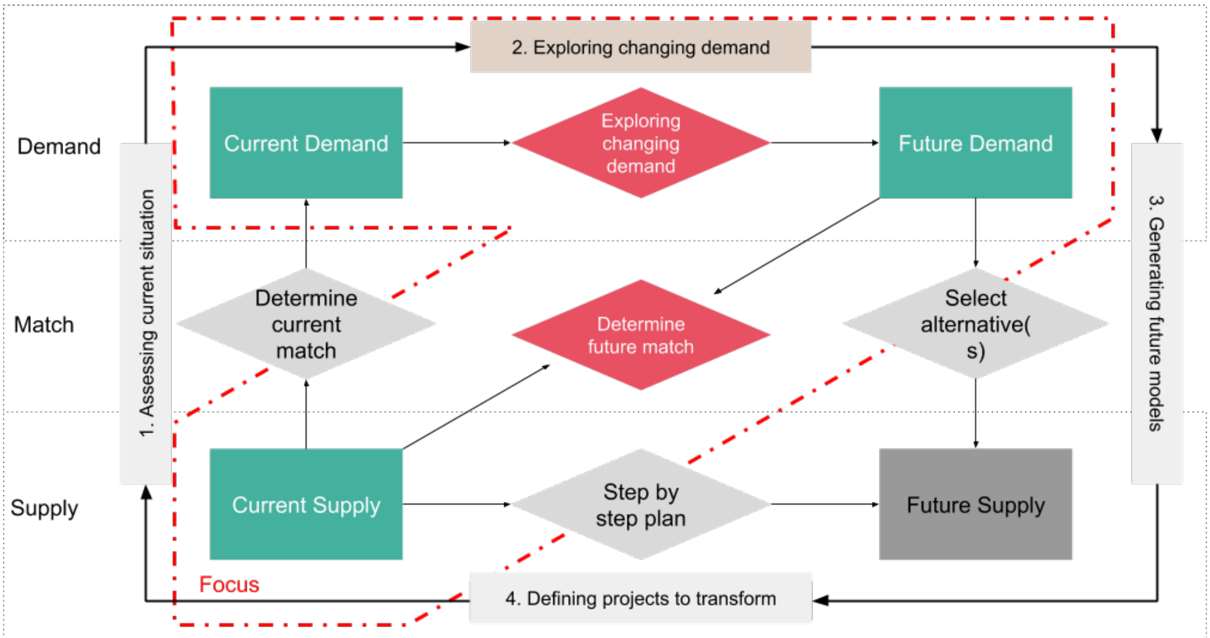


Image 4.8 DAS Frame (own illustration based on (De Jonge et al., 2009))

a. Changes in space demand and strategic choice

In order to translate the organisational objectives into changing space demand, the strategic choices need to be made more specific by using performance criteria. In other words, the impact of the developments on amount of square meters, finances, users and objectives from both the supply and demand side, is specified. Not only do the various kinds of developments need to be evaluated on impact, the possibility to influence the developments also needs to be considered. From these considerations strategic choices are made for the real estate portfolio, either by making a custom strategy or choosing a standard strategy. Tools for making these strategic choices include scenario variables from 'Scenario Planning' (Dewulf, Den Heijer et al. 1999: 49).

b. Strategic vision in key words

A strategic vision is the best accommodation the visionary can wish for, often mostly based on intuition. To develop this vision an analysis of comparable organization can be used as a starting point. The strategic vision can applied to different scales: the whole portfolio or an individual building.

c. Future demands create a solution space

A strategic vision usually has an abstract, qualitative character. However, it is important to translate this into quantitative data, even if it requires to make a lot of assumptions. Current demand can be used as a starting point, from there the future demand is assumed to be more or less than(including amount) or the same as the demand previously defined.

d. Future mismatch (if applicable) as a problem statement

Possible developments and problems are analysed following the comparison of future demand with current supply. Hereafter, the analysis is translated into a problem statement.

3. Generating future models

In the third phase alternatives are designed and related to the corresponding strategic choices. Following the former phase of defining the future supply to match the future demand with, alternatives for the future supply are designed and evaluated. When designing the alternatives it is important to consider relevant possibilities and involve stakeholders. During this process stakeholders might rethink their objectives by returning and altering the previous phase. If an alternative is selected, considering all costs, benefits and risks it can be specified and implemented in the following phase.

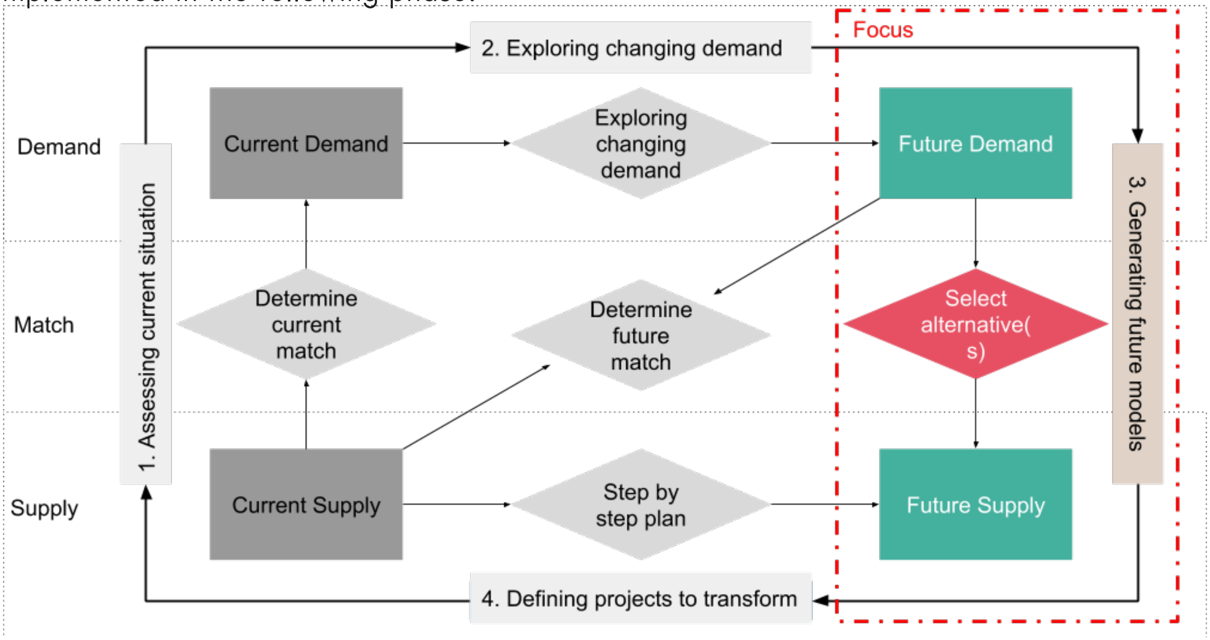


Image 4.9 DAS Frame (own illustration based on (De Jonge et al., 2009))

a. Exploring possible solutions

Subsequent to the problem analysis, alternative solutions are designed. Each alternative should be assessed in terms of costs and benefits as well as contribution to its primary objective. This includes weighing added values of alternatives to organisational or societal objectives, using reason and intuition. Uncertainties associated with changing demand complicates the selection of possible solutions.

b. Evaluation by all stakeholders

The objective of the assessment process is to design the most optimal future supply considering all stakeholders in the long term. The criteria to assess the solution are set when the stakeholders' demands are defined, making the possibility to define a generic set of criteria impossible.

4. Defining projects to transform

The final phase deals primarily with implementing the selected solution of the former phase while considering specifications in time and resources. When considering resources it is possible for the CREM to reconsider the solution and generate a better solution.
The transition of the current supply to the future supply is then specified in a step by step plan. This plan describes the main changes to the portfolio and to the different buildings and is supported by a time schedule and a financial plan.

During implementation, developments or sudden events can change demand, supply, objectives and/or the financial context. In order to deal with these sudden changes the organisation should always be prepared to change its accommodation strategy at any given time. Therefore the planning cycle is iterative and can require repeated use of the DAS framework to align the accommodation strategy to its context. With a more dynamic strategic context, the accommodation strategy can be and is often less specified. Furthermore, the design process takes more or less time depending on available data, size of real estate portfolio, number of constraints and dynamics of future demand (De Jonge et al., 2009, p. 44).

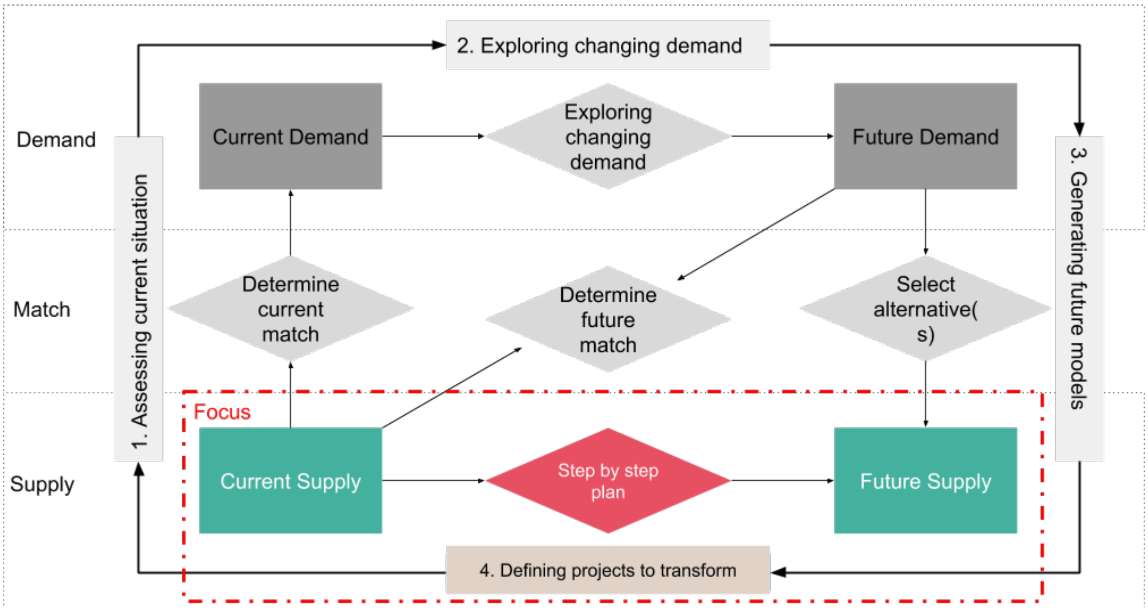


Image 4.10 DAS Frame (own illustration based on (De Jonge et al., 2009))

4.7 Conclusion

On the basis of the findings is can be concluded on "What is CREM?". Real estate management is the continuous process of matching supply (i.e. real estate) with demand, which is derived from organisational objectives and primary processes. Corporate Real Estate Management (CREM) is real estate management by an organisation that both owns and occupies its real estate. The goal of real estate management is to positively contribute to organisational performance or add value to an organisation by making real estate interventions (Den Heijer, 2011, p. 92). This positive influence can occur in four stakeholder perspectives. There 12 ways to add value established and five distinct real estate interventions types.

The models and findings in this chapter can be used to structure the added value of the smart tool, as the smart tool can be seen as form of real estate intervention. Furthermore, the DAS frame can serve as structure to see how the smart tool can provide benefits within real estate management processes. For this, the processes specific to (corporate) real estate management of the university campus are specified in the next chapter.

5. CURRENT CAMPUS MANAGEMENT

This chapter will continue the literature study by explaining the findings related to current campus management. The objective of this chapter is to answer the sub questions: 'What is the current state of university campus management practice?' & 'What Smart Campus Tools currently exist?'. The first section will start by (5.1) describing the main university goals among universities. Thereafter, the (5.2) processes are explored to see which approaches are possible. After this, the third section (5.3) will describe the processes of campus management in more detail by using the structure of the DAS frame. The fourth section (5.4) explores the existing smart campus tools. Lastly, (5.5) in the conclusion the findings are described and sub questions answered.

5.1 University Campus Goals

In this section the most prevalent ways campus management seeks to contribute to organisational performance are explored. Den Heijer (2002) research the hierarchy of organisational goals for the (Dutch) campus. To determine this a qualitative framework was used involving a series of questionnaires. A list of goals (shown in image 5.1) varying from goals that focus on efficiency (bottom) to goals that focus on effectiveness (top) was formed. The goals include technical, financial and functional aspects besides organisational aspects (Den Heijer, 2011, p. 132).

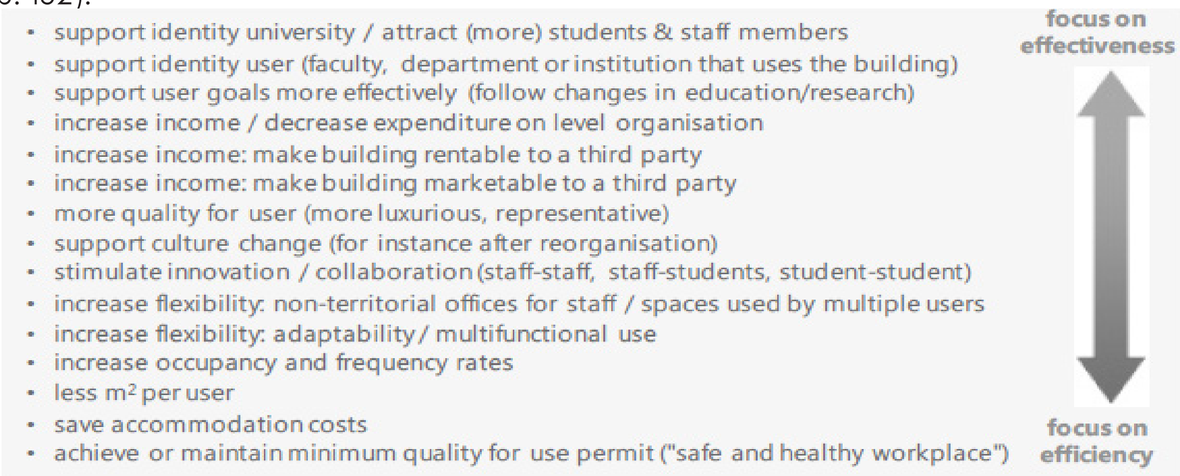


Image 5.1 Goals for University campuses (Den Heijer, 2011, p. 132)

This list was presented to Dutch Campus Managers to determine what the campus goals were and which priority they had. Goals scoring the highest, thus on average having the highest priority were (Den Heijer, 2011, p. 144):

1. Support user goals more effectively
2. Support identity university/ attract more students & staff members
3. Achieve minimum quality for use permit
4. Accommodating growth
5. Increase occupancy and frequency rates

When these goals were related to the performance of the organisation it demonstrated that campus strategies aimed at 'improving productivity' first and 'competitive advantage' second. These goals were also linked to the ten ways of adding value. While 'supporting user activities' and 'supporting image' had the highest scores they were also related and influenced by the other means to add value e.g. 'stimulating innovation' and 'increasing user satisfaction'. These finding can provide valuable insight for the added value of the tool as the implementation of the smart tool is considered a real estate intervention.

5.2 Approaches to CRE alignment

Within the process of CRE alignment different approaches to management have been distinguished by Beckers & van der Voordt (2014) including different ways to deal with communication and decision making in higher education.

5.2.1 Organisational Structure

Relating to the four stakeholder perspectives, a distinction of four categories of internal stakeholders has been made in Dutch higher education :

- • Top management: consisting of the executive board;
- • Middle management: academy directors, institute directors, program directors;
- • Teachers and staff;
- • Students.

Top and middle management are called clients and customers respectively, while students, teachers and staff are considered the end-users. Since CRE managers are able to get into contact with management functions or teachers and staff more easily, it can be more straightforward to specify their requirements. Contrastingly, because the student population is large and considered increasingly divers it can be harder to determine the needs from this category. Students make up the majority of the internal stakeholders in higher education (91.5%), while the other categories represent just 8.5% of the stakeholders (Beckers & van der Voordt, 2014, p. 5).

Additionally, it is also important to take into account the size of the organisation for the alignment of real estate. In smaller organisations the difference between the operational and strategic level is much narrower in relation to bigger organisation. Alignment of maintenance and the functional adaptations following demand changes are less impactful for smaller organisations. Moreover, stakeholders and crucial considerations in smaller organisations are less divers, making the effects of taken actions more clear, ultimately leading to an easier alignment. Contrastingly, in larger organisations it becomes especially important to consider the (side) effects of decisions, for all involved. For this, it becomes necessary to become aware of the performance of real estate interventions on both the strategic and operational level (Vries, 2007, p. 339).

5.2.2 Stakeholder Involvement Processes

Stakeholders are involved by managing cooperation and communication between stakeholders of the demand and supply side for appropriate CRE alignment. Several activities, including accommodation management, large projects and maintenance were explained by relating them to the involved stakeholders, what type of analysis is used to explicate demands and with what frequency this occurs (Beckers & van der Voordt, 2014, p. 8). An overview of the processes to determine demand is shown in table x. It was made clear that demand is analysed by asking, surveying satisfaction (ex post) real estate interventions and occasional conversations with clients, customers or end-users to check for e.g. complaints. Satisfaction surveys can be done by using e.g. instruments as WODI (werkomgevingdiagnose-instrument). WODI enables the evaluation of satisfaction in relation to real estate aspects as: the indoor climate, quality and availability of self study space, educational space and facilities (Vries, 2007, p. 346). However, it was concluded that stakeholder involvement concerning the CRE alignment process lacks structure and that communication between demand and supply side is mainly based on traditional approaches (Beckers & van der Voordt, 2014, p. 9).

Activity	Involved (internal) stakeholders	Demand analysis	Frequency
Accommodation management	Executive board and middle management	Account management meetings	Occasionally (when needed)
Accommodation management	End users	Surveying satisfaction	Annually
Projects (large renovations or construction projects)	Large representation (internal) stakeholders, students less involved	Project teams/focus groups	Structural during the project
Maintenance	Executive board	Budget meetings	Annually

Table 5.1 Types of stakeholder involvement

5.2.3 Determining Demand

Regarding collecting information for the determination of needs and requirements (demand) in higher education three main aspects have been distinguished. Firstly, stakeholders have difficulty to think of or formulate what it is they want but can easily describe what they don't want. This relates to with the what Sundstrum (1986) described as dissatisfiers. Sundstrom (1986 in Vries, 2007, p. 86) distinguished two types of factors which influence employees satisfaction: satisfiers and dissatisfiers. The physical environment is acknowledged as a dissatisfying factor. Meaning that if no problems are apparent it is experienced as positive, while when it doesn't meet requirements it can strongly decrease performance and cause dissatisfaction (Vries, 2007, p. 340). As a result requirements are often derived from dissatisfaction with the current situation. Secondly, since dissatisfaction often leads to formulating requirements in operational solutions, while ways to improve performance to enable contribution to organisational objectives get less attention. Thirdly, demand is mostly determined for the short term and lack focus on future needs. It was stated that while CREM requires long term thinking, it is difficult to align real estate with the dynamics in education (Beckers & van der Voordt, 2014, p. 7).

A smart tool can be used to solve some of the identified problems. In relation to the first aspect, a smart tool can help improve the communication of dissatisfactory space. Leading to a deceased response time. Regarding the second aspect, the smart tool can see which spaces are utilized more than others which can prove to be valuable in improving the rest of the campus. This can lead to contributions of the organisational objectives. Considering the last aspect, a smart tool can provide long term utilization data. This can be used to discover patterns and trends in use, which can improve long term thinking.

5.2.4 Power distribution and Resource Allocation

Considering decision making, a factor which strongly influences the way organisation and CRE manager make decisions is related to the power distribution between various stakeholders involved in the CRE alignment process. For this two opposite approaches to decision making have been recognized: Advisory or directive. A CRE department can take on a advisory approach by consulting the client for the translation of demands into CRE operating solutions, while keeping the client as the ultimate decision maker. The benefit of this approach is that it allows CRE solutions to derive from the primary processes, leading to a greater focus on performance.Contrastingly, the CRE department can also take the directive approach in which customers can request changes to the accommodation. In turn the CRE department considers the requests with support of the client and can decide whether that request will be granted. The benefit of this is that it enables to consider projects more in terms of organisational contribution over the long term.

The advisory or directive approach also translates to the allocation of finances, for which two different approaches showed: Finances allocated a by the executive board or by the CRE executive or the transfer of finances to lower organizational levels (e.g. managers of academies, faculties, course directors). The first approach mostly uses standards or norms for space use to benchmark the allocation of financial resources while the second approach requires organisational units to pay for use of their accommodation with commissioned finances.

5.2.5 Control- vs involvement

Generally, the above described approaches result in two distinct strategies to CRE alignment: involvement-oriented or control-oriented (Beckers & van der Voordt, 2014, p. 12). The two approaches to strategy represent the hypothetical extremes of CRE alignment, in practice often a combination of the two described strategies is used.

The control oriented strategy can be described as a top down approach in which responsibilities, power and often also the financial resources are allocated to the strategic CREM level. The CRE strategy directly derives from the corporate strategy after which the implementations are translated to the operational level. There is clear hierarchy in this strategy as communication between demand and supply is mainly organized at the strategic level. This means that middle management is responsible for analyzing and presenting demand for the primary processes to the executive board.

In involvement oriented strategies a bottom-up approach is used where responsibilities, power and often also the financial resources are allocated to lower levels in the organization. In this approach real estate interventions are a direct consequence of the primary processes and activities. Since stakeholders have more power it becomes more important to organize and arrange communication with the involved stakeholders to steer towards organisational objectives. The proposed smart tool offers alternative and supportive ways of communication to how demand is organized. This can have significant value when these involvement oriented strategies are implemented.

5.3 Current Campus Management Practice

This next section will explore current university campus management with the use of the previously described steps of the DAS frame. With each step the current approach to decision making is described including some of the challenges that occur during the processes involved. In general, it is noted that decision makers need management information for the various steps in this process, while continuously considering the four stakeholder perspectives: strategic, financial, functional and physical and relating to their key performance indicators (KPIs) (Den Heijer, 2011).

The DAS frame prescribes a certain sequence of steps, yet practice shows that campus management processes often start with the fourth step of defining projects. This is often the result of demands becoming apparent (e.g. a building becomes outdated and needs to be renovated, a faculty needing more space to accomodate students or new campus facilities are required to enter international research challenges). Despite this, most campus managers have acknowledged that it is favorable to follow the sequence of the DAS frame, defining projects as a result of step 2 assessing changing demand and step 3 of developing a strategy for the campus (Den Heijer, 2011).

5.3.1 Assessing the current situation

For assessing the current situation information is needed to determine whether demands for real estate supply are being met. For this assessment it is important to consider the demands of all four stakeholder perspectives as previously described. To do this information is gathered internally to see how much alignment is achieved, but also by benchmarking the real estate supply with comparable organisations to determine performance of real estate. The history that led up to how campus management currently assesses the current situation is explained in the following paragraphs.

Before the transfer of campus ownership to universities in 1995, campus management was mainly responsible for maintenance of the campus and satisfying the campus users with the appropriate mix of campus functions. Important tools during that time were condition based monitoring and maintenance planning, focusing on the technical perspective (de Jonge et al., 2000). This approach of condition based monitoring compared the actual condition with the minimum required condition, this then resulted in the objective to eliminate or reduce the observed difference in condition.

The transfer of ownership of the campus in 1995 gave universities full responsibility of their campuses. While all universities needed the same type of management information, the transfer of ownership was not accompanied with sharing information and knowledge for mutual benefits. Therefore, universities built customized databases and administrations for campus data. From the organisational perspective policy makers and controllers were looking for ways to add value and to do this they needed references of other universities (i.e. benchmarks). However, these customized administrations made it very hard to compare data, although the required management information was practically the same for every university. Furthermore, for communicating with different stakeholders, universities needed more transparency in administration and more objective standards as references.

From 2005 on Dutch campus managers acknowledged the value of collectively measuring, combining and comparing campus data. To enable this, Dutch campus managers agreed on the definition of four types of stakeholders leading to four types of perspective to combine for campus decisions (Den Heijer 2005). Benchmarking was done by comparing the values of key performance indicators for the different perspectives. However, it was concluded that campus managers lacked comparable information on variables to make functional, financial and organisational assessments.

Therefore, the challenge was to create uniform information to enable benchmark between university campuses with at least three variables essential for campus performance measurement: m2, costs and benefits. With a format to measure CREM variables, in 2007 a comparative analysis of the current campus was made with participation of all Dutch Universities. Leading to the creation of a campus database which included fourteen campus profiles of Dutch universities with technical, functional, financial and organisational information able to connect all four CREM stakeholder perspectives. Ultimately, the competence level of campus managers has increased as a result of the use of this comparative management information (Den Heijer, 2011, p. 128).

Implications for a smart tool

Considering the results that the proposed smart tool yields, which is a better representation of campus user demand, campus management is able to compare this representation with the physical campus to determine how much the real estate supply matches with demand from the functional perspective. In the case that certain criteria or spatial aspects appear to be more important in campus study spaces than is currently present, campus management can see this is in the data and subsequently focus on meeting this to achieve a higher satisfaction. Moreover, by giving the option to give feedback on spaces, campus management can be made aware of how users experience the current real estate supply and more specifically which spaces are especially considered below demand. This can signal the need for and prioritize real estate interventions but can also give an indication of user satisfaction by seeing how much of the campus space is perceived as below standards or obstructing primary processes. A more in depth analysis can thereafter be directed to these specific spaces to see where improvements can be made.

5.3.2 Exploring changing demand

For exploring changing demand is is essential to generate information about how relevant developments influence the campus. Different approaches to exploring changing demand are recognized: reactive or proactive. A reactive approach bears risks as this usually leads to mismatches between supply and demand. Due to the relatively long implementation time of accommodation changes this mismatch can remain for many years, ultimately leading to hindrance of primary processes ultimately decreasing performance. Additionally a reactive approach might mean investing in projects that end up unnecessary or dysfunctional in time (Den Heijer, 2011, p. 155). While a proactive approach intends to anticipate on future developments by expressing them in manageable variables. The content of this management task is highly dependant on the quality of the information about the current developments and trends. However, practice has often showed that lack of information on future demand forces campus managers to be reactive instead of proactive (Den Heijer, 2011, p. 154). This emphasizes the importance of putting effort in generating the required management information (Den Heijer, 2011, p. 155).

For exploring changing demand many tools are able to explore trends and developments of the future campus on the basis of qualitative information. However, it is important for campus managers to generate quantitative data to support the identification of trends and developments affecting the organisational, financial, functional and technical requirements. These developments can be expressed as programmatic requirements in terms of m2, required qualities, function mix and available budget (Den Heijer, 2011, p. 166). Ultimately, leading to a list of programmatic requirements(demand) that can be compared or matched with the current campus (supply) to determine both the current and future match (Den Heijer, 2011, p. 153). This quantitative data forms the basis for making campus strategies, project decisions and investment programmes. Nonetheless, for making valid comparison with the future demand and current supply it is crucial to use the same variables (Den Heijer, 2011, p. 150). Because of the lack of quantitative data on trends and developments campus managers can fall back on e.g. forecasting student numbers on an approximated percentile increase or using outdated space use standards, based on past campuses.

Exploring changing demand starts with a base analysis of various developments that influence the physical campus directly or influences internal or external demand. *Internal* demand signifies user demand for quantity and quality of real estate. While *external* demand signifies the demand to share with other parties to sell or let some of the campus to generate income. One qualitative tool to explore these developments is scenario planning. The scenario planning process can be performed by brainstorming in groups of experts, by sending questionnaires or conducting interviews. This is able to set the framework for real estate strategies, identify the strategic choices and other developments that are part of scenarios for future accommodation (Den Heijer, 2011, p. 158).

Implications for a smart tool

Since the proposed smart tool is able to give a better representation of campus user demand and this data is being generated passively it is possible to analyse the accumulated data over a periods of months or years to see whether patterns or trends can be recognized. After this recognition campus management can be informed of developing trends and have quantified means to support decision making. This can be done by mining or analyzing the data to find long term patterns which can be translated into the future. Thus, these patterns can be translated into expected future demand after which the supply can be adapted accordingly.

5.3.3 Generating future models

The objective of 'Generating future models' is finding a satisfying match between future demand and future supply. The generated future models (supply) should match with the changing organisational demands determined in the previous step (exploring changing demand). For a university, future models can be determined for four different physical scales relating to four different organisational levels. On the supply side this includes future models for the (knowledge) city, campus, building and places or functions within a building (workplaces, lecture halls and libraries). On the demand side these models need to align with the changing goals of the municipality, university, faculty and individual users of the campus: students and (academic) staff members (Den Heijer, 2011, p. 175).

Future models
Future models can be composed by designing alternatives for the division of space types. In universities ten different space types are defined for building future campus models as shown in table 5.1.

Space Types	
Studio space	Retail leisures and public space
Office space	Storage space
Lecture halls	Conference rooms
Library space	Restaurants
Laboratories	Other educational facilities

Table 5.1. Ten different space types

Since sharing spaces between different organisational groups can reduce the total amount of required space, it becomes important to consider what space can be used collectively and what can only be used by a certain group or individual. Therefore, the first step in composing future campus models is to decide what to share and on what level, relating to the physical scales and organisational levels as described above. Because these levels are able to influence the campus functionally and financially all CREM stakeholder perspectives are involved (Den Heijer, 2011, p. 195).

Evaluating Existing Models
Because many future models can already be found in current practice, analyzing recent projects and new concepts enables real estate managers to learn from successful concepts while preventing copying less successful concepts (Den Heijer, 2011, p. 196). The future campus is shaped by looking at the future as well as learning from the past. Many of the future models can be derived from experimental and innovative projects. Evaluating these projects provide useful references for CREM decisions. This emphasizes the importance of evaluating future models and pleads for databases of new projects (Den Heijer, 2011, p. 198). However, beside the increasing availability of past and future models, it is essential to express the models in measurable and comparable variables to support CREM decisions. Preferably the models should be expressed in: floor area, space type, organisational goals and effect on financial resources (Den Heijer, 2011, p. 177).

Implications for a smart tool
With regards to this step the outcomes of the data analysation can provide inherent suggestions for adaptations to the real estate on the basis of the demands of the individual users of the campus, primarily consisting of students. These demands can inherently suggest models for the supply on the campus, building and functional level. For example, the demands can show a higher demand for a certain study space (e.g. collaborative spaces) after which the future model can include more of these studyspaces, leading to a more effective alignment. These demands can then be translated to the amount this type of space is implemented on a building or campus-wide level. Hence, choices can be made to comply with these demand by translating them into different levels of scale. Similarly, the weight users give to certain criteria can be translated into the building or campus models to reflect this. Furthermore, pilots and innovative projects can act as experimentations and the use data can show what the results of these projects are in relation to the former situation.

5.3.4 Defining projects to transform
In the fourth step of the DAS frame, projects are defined to transform the current campus into the future campus. When new projects are defined campus managers make business cases

by specifying the project in terms of input and output of resources. This requires specific input in CREM variables, but also comparable data of other projects to generate management information. It is important to remember that defining projects requires the assessment of its contribution to the future campus. Therefore, the presumed contribution is to the university's performance (ex ante) and evaluate decisions over time (ex post) is made explicit.

Similarly to what was described in the step 'exploring changing demand' defining projects to transform is distinguished into two types: *proactively* and *reactively* defining projects. *Proactively* defining projects follows the result of the first three phases of the DAS frame.
While *reactively* defining projects reacts on occurring problems in the current real estate supply. The proactive approach is considered to be more favourable. However, without (comparable) data of the current campus and future campus (as a result of steps 2&3), the proactive approach of defining projects is difficult to achieve due to lacking management information (Den Heijer, 2011, p. 204). Therefore, in current practice most projects still start from the reactive approach (Den Heijer, 2007b).

Since new projects can contain essential management information about the campus of the future, information about the contribution of these projects is stored. Currently, campus managers have professionalized their administrations to enable the generation of this information. This includes storing information on campus projects on different levels of scale (i.e. city-campus, campus-building and building-function level). Data of these projects can implicitly include components of future models, contain new insights and innovative concepts for the campus (or real estate in general) (Den Heijer, 2011, p. 205). Ultimately, this includes e.g. project comparisons of space use in relation to investment levels and contribution to organisational performance. This is highly requested management information for Dutch campus managers. (Den Heijer, 2011, p. 204). Therefore, universities are eager to test and evaluate new concepts in practice to gain knowledge.

Therefore, in 2009 39 projects were added to a collective database of campus projects to serve as a source of management information. This enabled the comparison of data for similar projects within Dutch campuses but also the assessment of space use in office buildings. However, there are still disadvantages of using benchmarks caused by the fact that campuses and buildings are heterogeneous, which make it hard to determine how a project will perform in advance (Den Heijer, 2011, p. 208).

Implications for a smart tool

There are several ways the more accurate representation of demands through generating data can support the definition of projects. Similarly to the first step of the DAS frame the spaces with the most problems or least popularity can be recognized to focus attention to improve these spaces. Likewise, when the demands of users show a highly recurring demand for a particular function or spatial aspect it can be seen as highly important. As a result, the priority to implement these demands into projects can become higher. This means a particular project might be implemented before another on the basis of a higher demand. Thus, by gaining more information on what the actual demand of the users are choices can be made regarding the planning of the projects. It is therefore argued that the proposed smart tool enables prioritization of different projects based on occurrence of a particular demand.

5.4 Existing smart campus tools

On the basis of a literature study It was intended to discover and assess the existing smart campus tools. There are several reasons for considering existing solutions: Because design problems are open-ended they typically have several acceptable solutions. Thus, by **reverse engineering** or analysing the working of available systems and recognizing their functionality we are able to look for an alternative (better) way to reach the same objective. Furthermore, it can lead to **contiguous solutions** meaning adjacent ideas which take advantage of natural connections between ideas, concepts, and artifacts. Contiguous solutions are distinguished from similar solutions by the fact they solve different problems. Considering existing solutions is also a good way to evaluate the functionality and behavior of similar systems available to set the goal for a better system (i.e. **benchmarking)** (Dym, Little, & Orwin, 2014, p. 75-76).

Several universities have already developed smart tools to deal align demand and supply of university space more effectively. In a second part of the research on Dutch campuses the use of smart tools in Dutch universities is explored. Currently 26 different smart tools have been recognized on Dutch campuses. In addition to the 26 different smart tools, approximately half of the universities are working on the further development of their smart tools. This is done in different ways: by developing existing tools further, by starting pilot projects with market players or by developing new tools themselves.

To obtain the objectives of the stakeholders smart tools are used to obtain data on space use. Space use is measured on multiple levels also called 'resolutions'. The different resolutions to measure space are frequency, occupancy, identity and activity as shown in image 5.2.

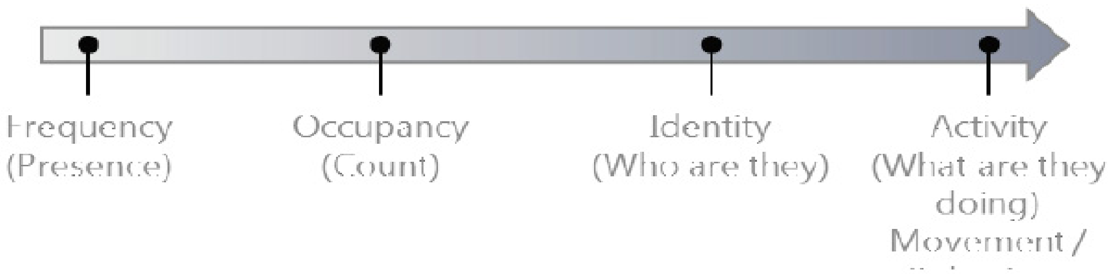


Image 5.2 Resolutions in space use (Valks et al. , 2016, p. 13)

In all of the current smart tools explored, data is collected on the resolution of frequency and/or occupancy. Frequency represents the use of space in relation to the time it is available or open. While occupancy represents the use of space in relation to its capacity(seats or workplaces) of a space. There is no case in which information is collected on the resolution of identity or activity. The reason for this is the privacy issues concerning data gathering. Furthermore a distinction has also been made between actual use and scheduled use resulting in a total of 4 space use 'resolutions' as shown in image 5.3.

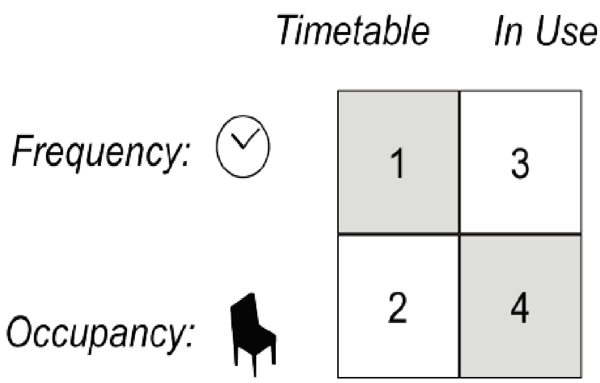


Image 5.3 Space use information types (Valks et al. , 2016, p. 14)

The objectives of the universities are primarily to facilitate the student, in self-study and collaboration with fellow students. Currently the available smart tools are primarily focused on using the campus more effectively through reservation of space. The additional demand for smart tools is to use space more efficiently (Valks, Arkesteijn, den Heijer, & Vande Putte, 2016).It is effective to learn from existing smart tools therefore some tools have been highlighted and explored.

- • **Boekit** (Avans) combines both the demand for user tools (effective space use) and the demand for space use data (efficient space use). This is a combination that is not yet existent at the universities.

- • **Seated** (Fontys) is an example of an interactive self-booking system. In this app, the act of making or deleting a booking is determined by the vicinity of the user to the space he/she wants to reserve.
- • **Spacefinder** (Cambridge University) shows an alternative for offering users information regarding the availability of spaces – instead, it displays information on the location of study places on campus in combination with information about the properties of the study place. This makes it possible for students to find a study place based on their requirements: e.g. daylight, atmosphere, noise levels, vicinity to coffee.

More recent research (2018) has shown that several tools exist which support the different perspectives in various ways. This is shown in the image 5.4

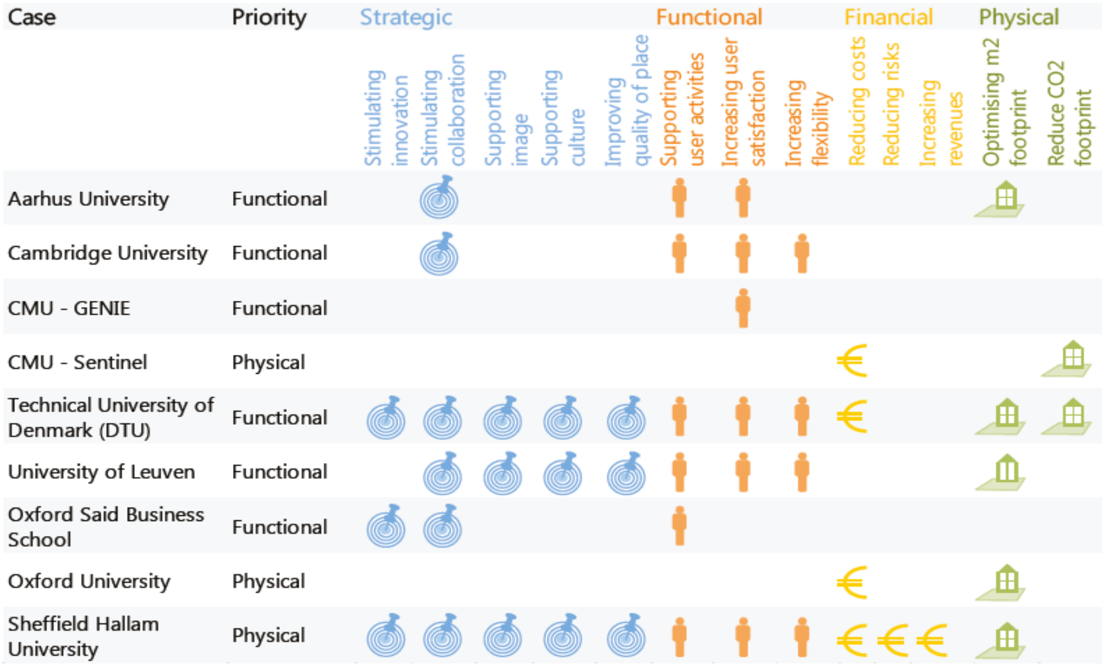


Image 5.4 Smart tools of universities which support the different perspectives (Valks 2018)

Compared to universities, smart tools at commercial organisations are much more focused on increasing efficient space use, leading to a reduction in cost. For example: Shell has developed its own smart tool, which is used to determine which locations have high and low occupancy levels, which is used to make investment or divestment decisions.

5.4.1 Demand for Additional Smart Tools

Several recommendations followed as a result of the research on smart tools in campuses.

- • There is a high need for more information on study space to increase user satisfaction. For study space the highest need for information is on spaces without desktops. What is important to consider on what resolution this data gathering need to occur: time, space or detail level.
- • More effective use of available systems has a good cost-benefits ratio. Especially concerning the option to change the function of the space at a later stage.

Thus, it can be concluded that several smart tools have been identified, each having their own purpose. However, there is still is demand for additional smart tools which are able to support user activities and support making real estate decisions. The proposed does so by gathering information on user activity, which has not been covered by another smart tool.

5.5 Conclusions

The objective of this chapter is to to explain the findings and answer the sub questions: 'What is the current state of university campus management practice?' & 'What Smart Campus Tools currently exist?'. The goals of the campus are found to mostly focus on the improvement of productivity and competitive advantage. Within campus management processes, differences in organisational structure and approach can be recognized. Campus management processes are generally traditional and based on qualitative information.

Two distinct strategies to CRE alignment are distinguished: involvement-oriented or control-oriented (or bottom-up and top-down). The two approaches to strategy represent the hypothetical extremes of CRE alignment, in practice often a combination of the two described strategies is used and desirable. In general there is a need for more user involvement within decision making. The proposed smart tool offers alternative and supportive ways of communication demand. This can have significant value when involvement oriented strategies are implemented.

For example, a smart tool can be used to solve some of the identified problems in determining demand. Firstly, a smart tool can help improve the communication of dissatisfactory space. Leading to a deceased response time. secondly, the smart tool can see which spaces are utilized more than others which can prove to be valuable in improving the rest of the campus. This can lead to contributions of the organisational objectives. Thirdly, long term utilization data can be used to discover patterns and trends in use, which can improve long term thinking.

With regard to the current smart campus tools, several tools have been identified each having their own purpose. Still there exist a high need for smart tools which support user activities, more specifically in finding a study spaces without desktops. The proposed does so by gathering information on user activity, which has not been covered by another smart tool. For universities using the available infrastructure appears to be most feasible.

6. MANAGEMENT INFORMATION

In this chapter the relevant aspects of related to management information are described. This goal of this chapter is to answer the sub questions: 'What management information is needed to improve campus management decision making?' and 'How is management information generated?'. In the first section (6.1), the demand for additional management information by campus management is specified. Thereafter, (6.2) the process of generating management information is made explicit. Finally, the (6.3) findings are concluded and the sub questions answered.

6.1 Demand for Management information

As stated in chapter 4, management information should support the decision-making process to add value to the primary processes and the performance of an organisation. Input for this management information is data consisting of facts and figures that elaborate on the possible consequences of decisions ex ante (before they are taken). The following sections will describe where management information is currently lacking and therefore improvements on these aspects are demanded.

6.1.1 Data Reliability

Improving reliability of data is still an important issue. For making portfolio decisions campus managers require management information to be reliable and convincing. Lohman (1999, p. argues that poor quality data can have a substantial effect on the effectiveness of the decision making process and ultimately on the performance of an organisation.The gathered inaccurate or incorrect data might still be transformed into management information which can ultimately lead to wrong decisions being taken due to incorrect data. Therefore the quality of data determines the quality of management information. There are several reasons discovered why the quality of information, in particular subjective information, can be of lesser quality. These reasons are:

- • Unconscious behaviour
- • Strategic behavior

Unconscious behaviour

User behaviour is not always conscious, which can result in differences between the stated demands and their *actual* demands. First and foremost preference is subjective and each individual has their own desires and frame of reference. Subjects in question can find it hard to determine their demands because this might relate to the situation they are in, leading to different demands depending on the situation. For uncovering this type of subconscious behaviour, questionnaires alone are often insufficient. Campus managers think that influences on student and employee satisfaction are therefore preferably found with a combination of questionnaires and observing behaviour (Den Heijer 2002c).

Strategic Behavior

When dealing with qualitative aspects subjectivity still plays a significant role, therefore stated information can be vulnerable to strategic behaviour of stakeholders. A discrepancy between the actual and stated reality can also occur when the questioned individual is aware of the consequences the answer may have. Information manipulation problems exist when information is considered not 'neutral', meaning the information might influence outcome. Lohman (1999, p. 31) stated that 'strategic manipulation of the employees' was labeled as one of the major reasons for the existence of inaccurate data. An example was given of employees which manipulated data with the knowledge that the information gave a representation of their functioning, hence they supplied management with information suggesting high productivity and effectiveness (Lohman, 1999, p. 31).

Not only employees are susceptible to strategic behavior, but also managers could use information to improve their personal position instead of bothering about organizational contribution (Lohman, 1999, p. 66). Despite negative impact on organizational performance, managers can withhold information or decide to not undertake any action. A plausible reason might be that using the information could result in a negative impact on them personally and their personal interests outweigh the organization's interest (Lohman, 1999, p. 7).

In the assessment of the current campus, data on physical aspects are often reliable and reliability of financial data can be derived from sources related to annual financial reports. However, in dealing with qualitative aspects, subjectivity still plays a significant role. By building a collective set of references, more management information can be generated on space standards, ultimately enabling the comparison of space standards to office space and educational space (Den Heijer, 2011, p. 232).

Implications for the smart tool

If a smart tool will gather data passively about the preferences in each situation, it is expected that unconscious behaviour is also gathered. Additionally, when users are put in actual situations they will have a realistic response, which will result in a better representation of demand.

With regard to strategic behaviour, a smart tool can still be susceptible to this type of behaviour. For example, if users collectively give a space a bad feedback rating, others are less likely to choose the space through the smart tool. This can be exploited to 'keep the space for themselves'. However, it is expected that if a large amount of users will use the smart tool this can be prevented because more data will lead to a better representation of demand. Strategic behaviour of campus management, can still be an issue however.

6.1.2 Utilization Data

The number of users of the building is still harder to determine than the number of users on campus level. An indication of the expected numbers of students and staff members is stated in the brief, but reality often differs from these numbers, reflecting one of the problems campus managers have: a lack of information on occupancy and frequency rates. Occupancy and frequency rates signify indicators for utilization: capacity in relation to use and use related to the time available respectively. Reliable data about the number of users can generate much management information, for instance about the current space standards (users per m2, types of m2 per types of user). A solution for this could be collecting data on capacity of space, to generate design standards for office and study workplaces, in m2 per unit. Furthermore, this data can also be used as input for tools to calculate future space demand, by identifying long-term patterns in spaces use to explore changing (dynamic) demand (Den Heijer, 2011, p. 232).

Implications for the smart tool

Gathering occupancy and frequency information cannot only provide valuable insight of the use of space, but can also be used to inform users for finding available study space. The way this data is gathered is explained in chapter 8.

6.1.3 Performance of Innovative concepts and Pilot studies

The demand for management information described in several steps in the DAS frame can be generated by analysing innovative concepts and pilot studies (Den Heijer, 2011, p. 171). Therefore, it can be worthwhile to pay more attention to the evaluation of new projects to determine the added value and contribution to (organisational) performance. New concepts come with different space demands, but the impact on space use is hard to predict (Den Heijer, 2011, p. 169). Making a business case at the start of a project (ex ante) and evaluating the project periodically afterwards (ex post) is be highly recommended, based on the reactions of campus managers on the project database (Den Heijer, 2011, p. 232). By measuring performance indicators before and after implementation, the effectiveness of these projects on productivity, competitive advantage, profitability and sustainable development can be assessed (Den Heijer, 2011, p. 220). Thus, real cases that supply management information with an estimation of added value are very valuable for CREM (including the universities and campus managers) (Den Heijer, 2011, p. 171).

Implications for the smart tool
If the smart tool is able to give feedback on spaces and a new pilot study is implemented this offers way to see how the changes are received. When these projects have been implemented the increase in user satisfaction can be measured by analyzing any changes in use after implementation. If this is facilitated more users are more likely to give feedback, leading to a better representation of the performance of the pilot study. This can show a satisfactory increase in use of the newly adapted space or a staggering and disappointing use of the space. From this point on, lessons can be learnt and new decisions can be made to make improvements.

6.1.4 User Satisfaction

In general it is stated that for higher education it became evident that it is important to gain more insight into the satisfaction of users in relation to the quality and availability of the real estate supply. This relates to the objectives of improving productivity and competitive advantage associated with students, employees and the workfield (Vries, 2007, p. 334). Realisation of objectives are dependent on the consistency between the real estate intervention, organisational culture and its policy (Vries, 2007, p. 328). Therefore, it is best to use indicators deriving from the objectives, which enable indicators to be related to the organisational objectives.

With testing of pilot studies, additional information on satisfaction of new projects and the judgement of policy makers is especially important. This includes evaluating the original intention of the concept and the actual result. Apart from new projects, Dutch campus managers also plead for adding evaluations to the projects that are already in the campus database, to determine if the goals been achieved, how the building is used, satisfaction of policy makers on effectiveness and efficiency and user satisfaction (Den Heijer, 2011, p. 232). However, there is still no uniform method to assess user (student or employee) satisfaction of real estate (or the current campus) for the comparison of user satisfaction as a key performance indicator (Den Heijer, 2011, p. 130).

For the assessment of user satisfaction, it is important to consider the previously described *unconscious* behaviour. Because the psychology of user behaviour is not always conscious, there can be differences between stated and revealed preferences. For uncovering this type of subconscious behaviour, questionnaires alone are often insufficient. Campus managers think that influences on student and employee satisfaction are therefore preferably found with a combination of questionnaires and observing behaviour (Den Heijer, 2011, p. 102). Hence, there is also demand for tools that not only measures user satisfaction in absolute terms, but also relatively. This means the user is asked to choose between alternatives to specify their preferences. This is a way to confront users with the costs of their demands (Den Heijer, 2011, p. 148).

Implications for the smart tool
By giving the option to give feedback on spaces, campus management can be made aware of how users experience the current real estate supply. More specifically this can show which spaces are considered 'below standards'. When a space is can repeatedly badly rated, it indicates the need for real estate interventions and perhaps prioritizes them. Additionally, the degree to which spaces are received negatively or positively by its user gives an indication of the overall user satisfaction. In any case, when space is frequently considered as 'below standards' campus management is able to more specifically analyze why the space is underperforming and how improvements can be made.

6.1.5 Stakeholder Involvement

Multi layered organisations are very common, however universities are extra complex in terms of decision making. With many different stakeholders involved, decision making can become very complex and campus management processes can become very slow. This demonstrates the need to make these layers more explicit and generate sufficient management information to support these considerations (Den Heijer, 2011, p. 248). From this need to bring the educational demand side and the CRE professionals closer together, approaches to CRE alignment need to be more involvement-oriented. This requires a more advisory role of the CRE department and increases involvement of the customer and end user for co-creation and collaborative design (Beckers & van der Voordt, 2014, p. 12).

However, prior research (Den Heijer and de Vries 2004b) showed that campus managers did not have appropriate tools to analyse and integrate stakeholder interests in the decision making process or to make these stakeholders more aware of the consequences of their demands (Den Heijer, 2011, p. 36). When stakeholders express their demands for future models each stakeholder should be confronted with the consequences of their requirements and choices. (Den Heijer, 2011, p. 197). This will make the decision making process more transparent and can make different stakeholders more aware of other stakeholders goals and the considerations of campus managers to weigh these different goals, usually in terms of costs and benefits (Den Heijer, 2011, p. 250).

An integrated approach to CREM implies involving more stakeholders for each real estate decision, leading to more information to collect and more key performance indicators (KPIs) to consider and weigh. The integrated and more complex approach to campus management is reflected in the process of generating management information: information needs to be generated in a form that can be interpreted by the different stakeholders (Den Heijer, 2011, p. 249). Therefore, there is a demand for tools that brings structure to the management information and supports the process to operationalise and integrate different stakeholder perspectives. These tools should supply multi-stakeholder information, connecting KPIs of the strategic, financial, functional and physical perspectives in order to reflect the complexity of campus decisions to each of the stakeholders involved (Den Heijer, 2011, p. 250). Ultimately, this should support CREM to discuss financial implications of user demands or new concepts with user groups.

Thus, stakeholders should also play a more central role in forming real estate information systems. It was stated that: *'It is essential to invest in the development of a common language between demand and supply side, and to develop new ways to recovering the educational needs and requirements and to translate these needs into future-proof accommodation solutions' (Beckers & van der Voordt, 2014, p. 12).*This is because a user (e.g. a faculty) is mostly interested in the degree to which real estate contributes or interrupts its primary processes and at which price, relating to the other means of production: people, capital, technology and information. Additionally, since "supporting user activities" and "increasing user satisfaction" were two of the main CRE objectives for universities, the relevance of end-user involvement in formulating CRE operating solutions also showed. It was recommended to further research the alignment processes between demand and supply to improve understanding of which CRE operating solutions support end-user needs in terms of efficiency, effectiveness and satisfaction. (Beckers, van der Voordt, & Dewulf, 2015, p. 789).

Contested information

It is also Important to consider that much crucial information is 'contested' at the time of decision making, meaning that information will be criticized by stakeholders of a project on its validity (Bruijn, 2004, p. 85). If the information is of poor quality it becomes difficult to use as argument for or against. This can lead to stakeholders conducting their own research to confirm their personal interest, habits or experiences (Bruijn, 2004, p. 91). One way to mitigate this is to agree on certain information and the way the data is obtained, leading to 'negotiated knowledge'. In this way the ones involved have to accept the outcomes of the research.

Implications for the smart tool

If a smart tool includes the preferences of the individual users of the campus, it can indicate that some functions are more frequently needed or more important. These preferences can inherently suggest models for the supply on the campus, building and functional level. For example, the demands can show a higher demand for a certain study space (e.g. collaborative spaces) after which the future model can include more of these studyspaces, leading to a more effective alignment. These demands can then be translated to the amount this type of space is implemented on a building or campus-wide level. Hence, choices can be made to comply with these demands by translating them into different levels of scale. In this sense the user is indirectly involved with decisions.

6.2 Effectiveness of Management Information

This section describes how management information is generated what is important for the effectiveness of management information. It also describes the different perspectives one can take relating to management information.

Management information is defined as a subclass of information intended to be used to support decision-making processes in order to contribute to the performance of the organization (Lohman, 1999, p. 43). The importance of good, accurate and timely (management) information was already relevant at the time of the dissertation of Lohman in 1999. Reasons for this were: intensification of competition, emergence of new markets, and an increasing number of customer requirements. Information technology (IT) provides ways to meet these information demands in order to improve the effectiveness or efficiency of management (Lohman, 1999, p. 57). However, upgrading IT to generate management information is often a costly endeavor. This is because besides developing the technology (which is already costly) it also requires analysis of information requirements and possibly conversion of the existing data beforehand, while at later stage employees must for example be retrained. If these steps are not taken correctly the chances are greater that proposed IT solution will not improve organizational performance, as this is not guaranteed (Lohman, 1999, p.2). Making sure the provided management information is effective and thus usable is therefore important and described in this next section.

6.2.1 The process of generating of management information

In image 6.1 a framework describing the generation of management information is shown. It is important to notice that the framework also contains the decision-making process that should subsequently use the information. From the primary process data can be extracted to see where improvements can be made or possibly solve presented problems. Additionally, data can be extracted from outside the organisation to see what affect external influences might have e.g. economic or demographic changes. The data is then transformed into usable information before being provided for the decision making process. The decision-making process in its turn might lead to a possible action, which will result in some sort of adaptation within the primary processes. After this adaptation has been made the extracted data from the primary process can be analysed to see what influence the decision/action was able to make. To determine what information is required the process is followed in reverse, starting with seeing what information is provided and what is requested. Thereafter the information requirements are specified the data needs are analyzed. Finally the primary process is studied to see how the data can be retrieved.

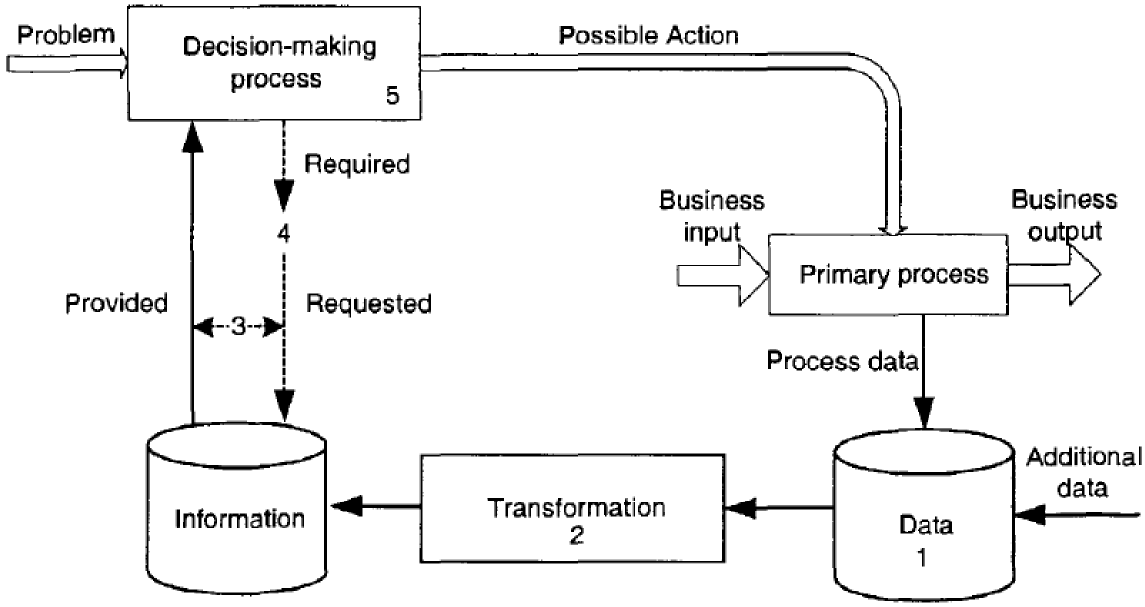


Image 6.1 The process of generating management information (Lohman, 1999)

5.5.2 Bottlenecks for the effectiveness of management information

However there are several problems, issues and difficulties that could directly or indirectly obstruct the effectiveness of management information to organizational performance. A collection of these is clustered into five bottlenecks:

1. Quality of data does not meet the specified requirements

There are several reasons why the quality of data renders it useless. Some examples of why the data quality is not good enough are: that data is incomplete, incorrect, missing, inaccurate or inaccessible.

- Incomplete; some data are available, some data are not
- Incorrect; the data is faulty
- Missing; Part is unavailable
- Inaccurate; the accuracy of the data is lacking
- Inaccessible; data exists, it is however not accessible

As data quality is dependent on the reliability of those who enter the data and if they don't gain value they might feel less motivated to enter accurate data (Alsyne et al., 1995 in Lohman, 1999, p. 31). This can be prevented by motivating the ones who enter data through stating the purpose of the data. Furthermore, Orr (1998, in Lohman, 1999, p. 31) showed that a way to increase data quality is to increase its usage, meaning that not only the managers should use these data, but also the people within the primary processes.

Another reason for data inaccuracy lies in the fact that the generated data is seen as an instrument of power. When data is not considered to be neutral but which can influence this can lead to 'strategic manipulation' of the data. Lohman (1999) gave the example of a case in which information given by employees on their workload supply was substantially lower than their actual workload supply to suggest productivity. In this case it was seen as one of the major reasons for the existence of inaccurate data (Lohman, 1999, p. 31).

2. Data cannot be transformed into requested information

Some data, such as qualitative or complex data can simply not be transformed. Therefore the abstraction/transformation of existing data to information cannot be accomplished.

3. Provided and requested information are unrelated

The main reason for the missing link between provided and requested information is separation of the information system developers and the end-users during development. This bottleneck can also be caused by the 'information overload' phenomenon. Meaning the quantity of the provided information is too great to be analyzed, making it hard for the manager to distinguish relevant from irrelevant information (Lohman, 1999, p. 5).

4. Discrepancy between the information requested and required

This can actually be caused by managers themselves if they do not know what information they need, making them ask for 'everything' to be sure nothing is missing.

5. Information use does not contribute to organizational performance

Ultimately, it is the decision-making process carried out by management that is responsible for the contribution of management information. If using the information could result in a negative impact on them personally and their personal interests seem to be more important than the organization's interests, this might lead to the decision not to undertake action or withhold information. Secondly, unstructured execution of the decision-making processes can also lead to an inability to adequately take action according the information (Lohman, 1999, p. 7).

5.5.3 Four perspectives for generating management information

The methods, systems and technologies that are closely related to the generation of management information were explored and evaluated by Lohman (1999). To further explain the relationship between data and information a model for this is shown in in image 6.2.

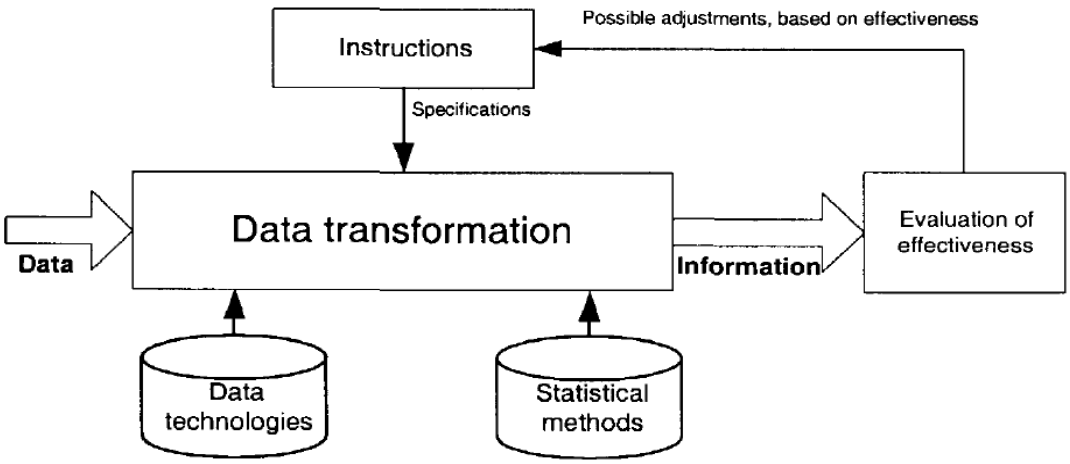


Image 6.2 The relationship between data and information (Lohman, 1999)

The theory was structured according to four perspectives: data technology, statistical methods, specification methods and information systems. The perspectives and their methods are shown in table 5.2. Their strengths and weaknesses are explained in more detail below.

Data Technologies:	**Statistical methods:**
Data visualization	Regression analysis
Data warehousing	Clustering
OLAP	Data mining
Query tools	Bootstrapping
Drill-down technologies	Rule induction
Specification methods:	**Information Systems:**
Critical Success Factors	Executive Information systems
Balanced Scorecard	Expert Systems
Strategic Business Objectives	Decision Support systems
Business Systems Planning	Management Information Systems
Ends-means analysis	Executive Support Systems
Interviews	

Table 5.2 Four perspectives on the relationship between data and information including the in

volved methods (Lohman, 1999)

Data Technologies

The primary objective of data technologies is to make the data accessible for management and provide information to support their decision-making processes. These technologies offer methods to compress or aggregate figures to describe and understand data. These methods include calculation of the sum, average or standard deviation of a data set, but also visualisations that transform data to understandable information (Lohman, 1999, p. 43).

However, several issues with data technologies exist, which stem from the usual linear way of working. This way of working, implies that the information and those who have to use this information are being seen as independent. Resulting in less attention paid to the requirements of management and an absence to evaluate the effectiveness of the information. Furthermore, organisation have to deal with dynamic changes and they should therefore constantly adapt themselves. This approach lacks opportunities to adapt design objectives (Lohman, 1999, p. 46).

Statistical methods

Statistical methods offer ways to analyze data. The objective of this analysis is to find relationships or patterns within the data that could be used to the advantage of the decision-maker (Lohman, 1999, p. 47). An example of a statistical method is data mining. Data mining can be used to discover new insight from data, which can be used in the decision making process. In essence, data mining consists of performing several analyses on the available data to find unknown patterns, which is done automatically. Data mining techniques are designed to search for possible relationships between data elements and to select the most interesting relationships (Lohman, 1999, p. 48-49).

Issues relating to statistical methods are also present. These include translating the data mining results into appropriate actions. It is also difficult to determine the added value before data mining sessions takes place. Limitations include the domain statistical methods can be applied to, which is often applied to market analysis. Furthermore, statistical methods often also involve a linear approach, resulting in the same issues as described above (Lohman, 1999, p. 50-51).

Specification methods

At the starting point of management information is the determination of what is needed. Specification methods are methods that are used to determine management information requirements (Lohman, 1999, p. 52). Lohman identified four general categories to classify information requirement specification methods, which are described in more detail below.

1. Asking

This method is fully dependent of the quality and analytical capabilities of the manager. Nevertheless, managers could be led by their personal interest, habits or experiences without fully evaluating the need from an organizational perspective.

2. Deriving from an existing information system

Information requirements can be determined by analyzing existing information systems.

3. Discovering from experimentation i.e prototyping

Prototyping specifies an initial set of requirements afterwhich a prototype system is built. By an interaction of the end-user with the system, requirements are added or changed until the user is satisfied. Lohman (1999) Criticizes prototyping with two arguments. Firstly, prototyping can only be useful if a thorough analysis has been carried out before the prototyping stage. Without such an analysis, there is no assurance that the information requirements will lead to a contribution towards the organizational performance (Schaik, 1988 in Lohman, 1999, p. 53). Secondly, prototyping is mostly focused on individual specifications rather than the organizational needs (Frolick and Robichaux, 1995 in Lohman, 1999, p. 53).

4. Synthesis from characteristics of the utilizing system

Popular methods for this include the methods Critical Success Factors (CSF) and Balance

Score Card (BSC). However, some conclusions were made after analysing this method (Lohman, 1999, p. 56). First, these methods still heavily depend on interviews held with the managers, as this is the primary instrument to derive information requirements. Secondly, most methods only identify and specify straightforward performance indicators which can also easily be derived by using techniques related to descriptive statistics. Thirdly, the methods do not require an exhaustive analysis of the primary processes within the organization. While understanding these processes (including its actions and their effects) is crucial to derive valuable information requirements.

Information systems

Information systems are designed to improve the effectiveness or efficiency of management by using supportive technology. These include ways to report data and decision support for narrow or semi-structured problems. Considering the other perspectives there are clear overlaps, although the different information systems still form their own domain in the area of management information.

This also means that the issues within the similar perspectives apply. Additional issues include that the systems only partly support the decision-making processes based on the intelligence, design, choice division of decision-making processes by Simon (1960, in Lohman, 1999, p. 59). This lack of support towards the other stages could, seriously affect the total effectiveness of the system.

Conclusions

All the perspective showed an inability to link the added value of the information with the characteristics and decision-making processes of the organization. No attention is paid to modeling or describing the different processes within the organization for deriving management information. *'[...] Determining information requirements is not a straightforward activity (top-down), and that technologies do not automatically contribute to deriving effective management information (bottom-up), interaction is needed to accomplish the desired goals.'* (Lohman, 1999, p. 61). This is however not supported in a linear approach is used, as desired information is usually generated without feedback.

6.3 Conclusions

This goal of this chapter is to answer the sub questions: 'What management information is needed to improve campus management decision making?' and 'How is management information generated?'. The following findings will answer these questions.

In the past years much more data has already been collected, but there is an additional demand for data on efficiency of real estate (occupancy and frequency rates), user satisfaction, key performance indicators on sustainability issues and any references on effectiveness of certain campus models or campus decisions, in terms of costs and benefits for the university and ways to involve users in decision making.
If a smart tool will gather data passively about the preferences in each situation, it is expected that unconscious behaviour is also gathered. Additionally, when users are put in actual situations they will have a realistic response, which will result in a better representation of demand.
Gathering occupancy and frequency information cannot only provide valuable insight of the use of space, but can also be used to inform users for finding available study space. With regard to strategic behaviour, a smart tool can still be susceptible to this type of behaviour. However, it is expected that if a large amount of users will use the smart tool this can be prevented, because more data will lead to a better representation of demand. Strategic behaviour of campus management, can still be an issue however.
If the smart tool is able to give feedback on spaces and a new pilot study is implemented this offers way to see how the changes are received. From this point on, lessons can be learnt and new decisions can be made to make improvements.
By giving the option to give feedback on spaces, campus management can be made aware

of how users experience the current real estate supply. More specifically this can show which spaces are considered 'below standards'. Additionally, the degree to which spaces are received negatively or positively by its user gives an indication of the overall user satisfaction. If a smart tool includes the preferences of the individual users of the campus, it can indicate that some functions are more frequently needed or more important. Hence, choices can be made to comply with these demands by translating them into different levels of scale. In this sense the user is indirectly involved with decisions.

The sub question: 'How is management information generated?' will be answered in this paragraph. Generating management information is not a straightforward activity (top-down), and that technologies do not automatically contribute to deriving effective management information (bottom-up), interaction is needed to accomplish the effective management information. Data is firstly extracted from the primary process to see where improvements can be made or present problems can be solved. Additionally, data can be extracted from outside the organisation to see what affect external influences might have e.g. economic or demographic changes. The data is then transformed into usable information before being provided to the decision making process. Data can be transformed into management information according to four perspectives: data technology, statistical methods, specification methods and information systems.

7. SMART TOOL DEVELOPMENT

This section consists of literature on several diverse topics to form the foundation to answer the question: 'How can one develop a Smart Tool to enable the interaction of real estate and users to enable the generation of usable management information?'. This will be done by first (7.1) explaining the principles of preference function modelling. Thereafter, the (7.2) the preference criteria needed to implement in preference function modelling are described. This will answer the sub question: 'What criteria for study space preferences should be considered in the smart tool?'. In the next section (7.3) methods of developing the back end of the smart tool to are specified by explaining business intelligence and database structure. The chapter will end with the (7.4) conclusions on the findings to answer the sub questions.

7.1 Preference Function Modelling

The Smart Tool needs to be able to make a selection of spaces based on the preferences of a particular user, to support finding a suitable study space. A way to establish this selection is by determining the users preferences whereafter it can be matched with the aspects of the spaces. On the basis of the selection shown, the user is able to make a *decision* on where to study or work. Therefore, the Smart Tool can be seen as a decision support tool and decision theory can be applied. Decision theory is concerned with the problems of identifying the best choice to take. Its practical application is called decision analysis, which aims at finding tools, methodologies and software to help people make better choices (Binnekamp, 2010, p. 1).

7.1.1 Finding a Study Space

In the case of looking for a suitable study space the user needs to be able to consider spaces on their aspects, subsequently the user can select a space that matches with their personal preferences and requirements. These preferences and requirements can be described as criterias and constraints respectively while the aspects of a space can be defined as attributes. Thus, for the Smart Tool to support this process multiple criteria and constraints need to be matched with the attributes of the space leading to a selection that the Smart Tool will ultimately display to the user. To determine this match the attributes, criteria and constraints need to be known. Since the attributes of a space are physical they can be determined by observation. However, a users preferences are subjective making them more difficult to determine. Additionally, for the individual finding a suitable space some criteria might be more important than others, while constraints signify necessities. The spaces, on the other hand, have multiple attributes which independently meet the user's criterias and constraints to various degrees. If all of this is measurable, it can be used for mathematical functions, for example calculating which space has the highest match to the users preferences. However, these measurements need to be justified to enable mathematical operations as described later in this chapter. This makes it important to find an acceptable way to determine what the user's criteria and constraints are, in other words measuring preference.

7.1.2 Preference Measurement

Decision making is founded on preference measurement as preference is the only property of relevance for the mathematical foundations of decision theory. This makes the correctness of the decision analysis methodology dependent on the correctness of the preference measurements (Binnekamp, 2010, p. 2). However, it can be difficult to determine someone's preference while also making it usable for mathematical operations. E.g. simply asking for the preference on, say a likert scale, gives an indication of the preference of an individual, but is unfit for mathematical operations. This is because a likert scale is an ordinal scale which signifies ranking and since the difference between the rankings remains unknown it cannot be applied for addition and multiplication (Barzilai, 2010, p. 23). Demonstrating the purpose of measurement, (i.e. representing variables by scales) to enable the application of mathematical operations to these scale values. Scales are mappings from empirical objects to

mathematical objects that reflect specific empirical operations which characterize a given property to corresponding operations in the mathematical system (Binnekamp, 2010, p. 2).
To clarify the considered 'mathematical system of measurement' some concepts relating to the framework is required. An empirical system E signifies a set of empirical objects together with operations (i.e. functions) and possibly the relation of order which characterize the property under measurement. The purpose of modeling E by M is to enable the application of mathematical operations on the elements of the mathematical system M, as shown in image 7.1. For this, a scale s is required to transfer the objects in E as objects in M to reflect the structure of E into M (Barzilai, 2010, p. 18; Binnekamp, 2010, p. 24).

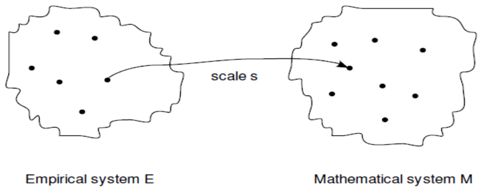


Image 7.1 Transition of an empirical system (E) to a mathematical system (M) through a scale (s)

The mathematical foundation of preference measurement therefore initially needs to be evaluated on the scales used for measuring preference (Binnekamp, 2010, p. 29). Barzilai (2005) therefore classifies measurement scales by the mathematical operations that are enabled on the resultant scales and scale values. He distinguishes scales to which mathematical operations are applicable as proper scales, while all other scales are defined as weak.

7.1.3 Constructing scales

For the constructed scales to be proper the underlying field must be ordered and homogenous. The order is established by indicating what is more preferable to determine the direction (on a straight line) (Barzilai, 2010, p. 20). The scales are homogenized by constructing a one-dimensional vector space where the elements of the field serve as the set of scalars in the vector space. To homogenize its additive identity as well, points are combined with the vectors and scalars to construct a one-dimensional affine space, which is a homogeneous field, over the previously constructed vector space (Barzilai, 2010, p. 19). In other words, a particular scale needs to be constructed for the criteria and preference for this criteria needs to be assigned on this scale.

Thus, in order for the operations of addition and multiplication to be applicable on preference scale values the mathematical system must be a one-dimensional affine space (Binnekamp, 2010, p. 28). In an affine space, the difference of two points is a vector and no other operations are defined on points. In particular, the ratio of two points as well as the sum of two points are undefined. In the one-dimensional affine space, the ratio of a vector divided by another non-zero vector is a scalar (Barzilai, 2010, p. 19). Leading to the expression $(a-b) / (c-d) = k$ where a, b, c, d are points on an affine straight line and k is a scalar is used in the construction of proper scales. The number of points in the left hand side of this expression can be reduced from four to three (e.g. if $b = d$) but it cannot be reduced to two (Barzilai, 2010, p. 21).

7.1.4 Multiple Criteria Decision Analysis

After the mathematical system has been modeled there has to be found a way to make a selection of the alternatives based on these measurements, for which a rather suitable approach is Multiple Criteria Decision Analysis (MCDA). MCDA is described by Belton and Stewart (2003, p. 2) as 'a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter'. Within the context of of this thesis the main objective to solve with MCDA is: supporting the selection of a study space according to the user's interests, taking into account the space's attributes. Because decision makers have difficulties judging the performance of an alternative as a whole, different attributes of the alternatives are taken into account, termed criteria. Therefore the (available) spaces represent the alternatives to choose from and for finding out which alternative is preferred over the other the alternatives need to be rated on performance. The relative importance of criteria are incorporated using weights. The overall preference rating (performance) of an alternative is then determined by an algorithm that takes into account each alternative's performance on each criterion and its weight (Binnekamp, 2010, p. 31). The above is summarized in the following generic formal procedure:

1. Specify the alternatives.
2. Specify the decision maker's criteria tree.
3. Rate the decision maker's preferences for each alternative against each leaf criterion.
4. To each leaf criterion assign the decision maker's weight.
5. Use an algorithm to yield an overall preference scale.

7.1.5 Value Measurement Methodologies

Different methodologies are possible for MCDA of which value measurement methodologies are most eligible for the described objective. Value measurement methodologies help decision makers to choose the most preferred (design) alternative from a set of already existing alternatives and are therefore classified as evaluation methodologies (Binnekamp, 2010, p. 54). Value function methods evaluate assessments of the performance of alternatives against individual criteria, together with inter-criteria information reflecting the relative importance of the different criteria, to give an overall evaluation of each alternative indicative of the decision makers' preferences (Belton and Stewart, 2003, p. 119).These methods are based on evaluating alternatives in terms of an additive preference function. After the model has been structured and a set of alternatives for evaluation have been identified, the next step is to elicit the required information. There are two types of information, intra-criterion information and inter-criterion information, which also be referred to as scores and weights (Belton and Stewart, 2003, p. 121). The overall evaluation of an alternative is determined by its value score on each bottom-level criterion and by the cumulative weight of that criterion (Binnekamp, 2010, p. 37).

7.1.6 Preference Function Modelling (PFM)

According to Barzilai (2005) the value methodology developed by himself called Preference Function Modeling (PFM) has a mathematical sound foundation allowing the operations of addition and multiplication on the scales it generates. According to the new theory of measurement, PFM is the only decision theoretical methodology that has a solid mathematical foundation (Binnekamp, 2010, p. 54). Therefore, PFM offers the (only) correct model for the measurement of preference and for the selection of the most preferred alternative. Using PFM has the following procedure: Initially, a hierarchy of criteria and the identification of the alternatives is needed for the development of PFM. The scores are then elicited by decision maker's as preferences for each alternative against each criterion by first establishing reference alternatives:

• A 'bottom' reference alternative which is rated at 0
• A 'top' reference alternative which is rated at 100

Then, the other alternatives are rated relative to these reference alternatives on the scale established. Thereafter, the decision maker the attaches a weight to each criterion. When finally the PFM algorithm is used to yield an overall preference score to evaluate all the alternatives which can then be ranked accordingly.

The results of the algorithm can then be ranked according to the overall preference score. An example of this can be seen in image 7.2, where the alternatives can be found left under Alt. and the different decision variables are shown as letters while the left of the table the preference scores are indicated (Binnekamp, 2010, p. 132). On the right side of image 7.2 information of the highest ranking alternative is shown in more detail.

Alt.	Decision variable i	t	d	f	Pref.
396	20	0.5	31.40	10	80.144
1430	22.56	0.5	40	10	79.969
385	20	0.5	29.43	10	79.281
1419	22.56	0.5	36.58	10	78.677
374	20	0.5	27.75	10	78.318
1429	22.56	0.5	40	9.73	78.255
1551	22.56	0.55	40	10	78.151
1408	22.56	0.5	33.74	10	77.852
363	20	0.5	26.25	10	77.157
1397	22.56	0.5	31.40	10	77.083

Decision variable	Value	Rating
Investment i [$ billion]	20.00	20.000
Travel time t [hours]	0.50	100.000
Distance d [km]	31.40	75.190
Flight movements f [×100k]	10.00	100.000
Overall preference rating		80.144

Image 7.2 (left) Ranking of highest scoring alternative according to preference rating, (right) Decision variable values and preference ratings for the highest rated alternative (Binnekamp, 2010, p. 118)

7.1.7 Conclusion

For the measurement of preference, a scale needs to be constructed to for each criteria and a value for this criteria needs to be assigned on this scale to signify preference. This scale enables the transition of an empirical system (E) to a mathematical system (M).

Using PFM has the following procedure: Initially, a hierarchy of criteria and the identification of the alternatives is needed for the development of PFM. The scores are then elicited by decision makers as preferences for each alternative against each criterion by first establishing reference alternatives:
• A 'bottom' reference alternative which is rated at 0
• A 'top' reference alternative which is rated at 100
Then, the other alternatives are rated relative to these reference alternatives on the scale established. Thereafter, the decision maker the attaches a weight to each criterion. When finally the PFM algorithm is used to yield an overall preference score to evaluate all the alternatives, it can then be ranked accordingly.

Relating this to the proposed smart tool, it is not needed to determine alternatives as spaces are already existing. Therefore, the preference function modelling procedure needs to be adapted slightly by using the mathementical function on the spaces as alternatives. Thereafter, the results of the algorithm can then be ranked according to the overall preference score.

7.2 Learning space preferences

Several studies related to learning space preferences have been conducted, two of the most relevant will be discussed in this next section to provide the basis for the study space preferences in this research. Thus, a selection will be made of the most relevant distinguished preferences for study space aspects.

7.2.1 Space Attributes

In an empirical research on learning space preference a typology of informal learning space attributes have been determined (Harrop & Turpin, 2013). For this research the term informal learning spaces is defined as: 'non-discipline specific spaces used by both staff and students for self directed learning activities'. These spaces can be on campus, but also outside the campus space. The research starts off with an analysis of the relevant scientific body, concluding that informal learning space design is primarily drawn from three distinct disciplines: *learning theory*, *placemaking* and *architecture*. *Learning theory* refers to understanding of how people learn and the recognition of differences in learning preferences. *Placemaking* is about users and their experiences whilst occupying a space, leading to mental associations. *Architecture* refers to the physical tangible in- and outside of a space. Including material, design, furnishings, lighting, ventilation and acoustics, and facilities (Jamieson, 2006; Kennedy, 2003; George, Erwin and Barnes, 2009).

The research is a reaction on a study of Boys (2010, p. 160 from Harrop & Turpin, 2013, p. 2) who concludes, *'almost no data exists to help assess the effectiveness of the new and adapted buildings currently being constructed across universities and colleges'*. Recognizing that spaces must continue to develop to ensure alignment to its users, and that decisions must be evidence based.

Nine Space Attributes

A typology of informal learning spaces has been determined by distinguishing nine learning space preference attributes. The typology was constructed using data from observational sweeps alongside coordinate and photographic mapping exercises (Harrop & Turpin, 2013, p. 7). The typology is not designed to be hierarchical but rather to inform evaluation and decision making activities related to informal learning space design (Harrop & Turpin, 2013, p. 10). The nine attributes are shown in Table 7.1:

Attribute	Aspect	
Destination	Proximity	Favourites
Identity(ambience)	studious,relaxed and informal'	'buzz and activity'
Conversation	talk, share ideas,	discuss and debate.
Community	Social interactions, sitting close to peers/friends	Sense of common purpose, shared learning environment
Retreat	Quiet /Silent	Privacy
Timely	On demand/ time slots	Fit in with schedule(quick tasks & longer study periods)
Human factors	Large work spaces	(Natural) light
Resources	Printers/ internet/ power availability	Presentation screens
Refreshment	Food & Drinks	Proximity to catering outlets

Table 7.1 Nine Learning Space Attributes

The research noted the importance to consider all nine attributes for the evaluation of informal learning space. Another important consideration is the fact that evaluations usually primarily involve the macro level (i.e. building or campus level), while attributes may be discarded at a micro level based on localised factors (Harrop & Turpin, 2013, p. 26). Furthermore, some attributes can be measured and/or are absolute, while others are subjective. For example, the identity and use of a space can be interpreted differently and contrasting among users. On-demand access to spaces and their resources are also particularly important on a typical day for a student, making timely quite an important attribute. This is at the same time most difficult to predict because of the dynamic nature of this demand

Conclusion

The typology of learning space preference attributes can be used to evaluate, but more importantly to design informal learning spaces. Therefore, space design should encourage users to reflect on their learning preferences and translate these preferences into space selection (Harrop & Turpin, 2013, p. 26). However, the study has been less revealing with regard to understanding selection and use of space by students. Relating to the assessments undertaken, it has not revealed inter-relationships in the form of response patterns; meaning which behaviours, attitudes and preferences are typically associated with each other.

Finally, the typology must be viewed as an evolving entity, drawing upon existing datasets for the progression of informal learning space design. As both redevelopment projects and learning spaces research progress, the results can be benchmarked which should ultimately lead to practical and proven designs being implemented.

7.2.3 Learning space preference in higher education

A more in-depth empirical study is part of the dissertation of Beckers (2016) aimed to find learning space preferences in higher education learning. It did this by dividing learning into two basic activities: *individual* activities, requiring concentration and self-regulation or *collaborative* activities, requiring communication and interaction. Furthermore, within the learning space preferences two dimensions are defined, the *physical* and *social* dimension. The *physical* dimension is operationalized with four characteristics: the perceived importance of comfort, aesthetics, ICT facilities, and layout. For the *social* dimension, degree of interaction, privacy, and autonomy is used for operationalization. Finally, the socio demographic aspects of the students were taken into consideration. All of which is visualized in the conceptual model in image 7.3.

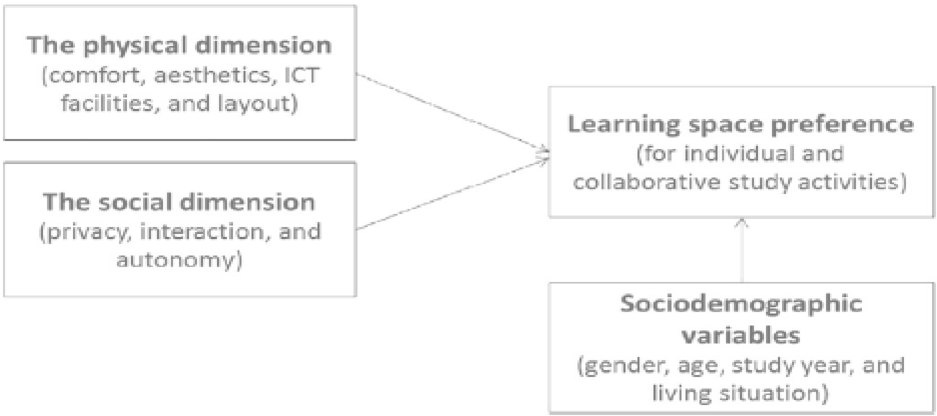


Image 7.3 Conceptual model showing the different dimensions taken into consideration (Beckers, van der Voordt, & Dewulf, 2016, p. 245)

Functional aspects of space

The following table is an overview of the distinguished functional aspects for learning spaces, derived from the physical and social dimension. The type in table 7.2 signifies a certain aspect type while aspects are the specific features.

Type	Aspect			
Comfort	Natural light	Size working surface	Comfortable furniture	Temperature
ICT Facilities	Desktops	Printers		
Layout	Open	Closed		
Aesthetics	Plants	Finish	Decoration	

Table 7.2 Functional space aspects (own table based on (Beckers, van der Voordt, & Dewulf, 2016)

Space types

Furthermore, different space types have been determined and related to the layout, this is shown in table 7.3. It can be seen that catering areas, cafés, entrances and corridors represent Open areas while project rooms and personal cockpits represent closed areas.

Preferred learning spaces.	Busy, open area	Quiet, closed area
	$\alpha = 0.76$	$\alpha = 0.69$
A catering area.	**0.82**	0.02
A café.	**0.82**	0.05
The entrance area.	**0.73**	−0.14
The corridors.	**0.66**	0.04
A project room.	0.02	**0.89**
A personal cockpit.	−0.03	**0.87**

Table 7.3 Layout related to space type (Beckers, van der Voordt, & Dewulf, 2016, p. 247)

Results

An important finding was that students are mostly focused on the functional aspects of a learning space. This demonstrates that students' preferences regarding learning spaces are mostly influenced by their perceived effectiveness, for conducting the appropriate study activities. These can be highly autonomous activities needing appropriate ICT facilities, sufficient comfort, and being able to working alone in a quiet environment or in groups (Beckers, van der Voordt, & Dewulf, 2016, p. 248). This, simultaneously implies that aesthetical aspects of the physical dimension are not greatly important to most students.

"[…] students appeared to be most concerned about the functional aspects of space. They presented themselves as not overly concerned about aesthetics […]".

An interesting result in relation to research of Harrop & Turpin (2013) was that privacy was not as important as implied in that research, rather quietness seemed to be the key reason for preferencing places that support the possibility to retreat. This result confirmed the findings in the study by Price et al. which stated that quiet areas are one of the most relevant study facilities of universities. Moreover, it was stated that regardless of the study activity, students highly favor closed areas (project rooms or individual cockpits). Thus, whatever study activities students work on, students do not prefer busy, open learning spaces in a university building. However, the importance of these preference depend significantly on whether individual or collaborative activities are required. Another important finding in the research was the fact that there was no significant correlation between learning space preferences and socio demographic aspects of students.

7.2.4 Existing Data Structure

It was attempted to collect data that was already available. Therefore the CREM firm FMVG was approached to see which datasets can be used for the set up of the Smart Tool. There was available data resulting from an inventorisation concerning space aspects in 2014. The dataset is show in image 7.4.

Eigenschappen													Faciliteiten					
Soort plek A/B/C	*Totaal aantal studieplekken*	*Aantal tafels*	*Aantal stoelen per tafel*	Verstelbare stoel	Vaste stoel	Overige plek	Waarvan te gebruiken als individuele studieplek	mate van werkplek	Stilte	Reserveren	Licht	WCD	Wifi	Ethernet	Vaste PC	Overige faciliteiten	Afstand tot coffeecorner/ automaat	Afstand tot printer
C	24	4	6		24		4	1	nee	nee	daglicht	nee	ja	nee	nee		0-25m	0-25m
B	4	2	2		4		2	1	nee	nee	daglicht	nee	ja	nee	nee		0-25m	0-25m
B	104	104	1		104		104	1	nee	nee	daglicht	nee	ja	nee	nee		0-25m	0-25m
B	36	36	1		36		36	1	nee	nee	daglicht	nee	ja	nee	nee		25-50m	25-50m
A	88	11	8	88			88	1	nee	nee	daglicht	ja	ja	ja	nee		0-25m	0-25m
C	16	4	4		16		4	5	nee	nee	kunstmati	nee	ja	nee	nee		0-25m	0-25m
C	48	12	4		48		12	5	nee	nee	daglicht	nee	ja	nee	nee		0-25m	0-25m
A	7	1	7	7			7	1	ja	nee	daglicht	ja	ja	ja	ja		0-25m	0-25m
C	10	3	3			10	0	1	ja	nee	kunstmati	nee	ja	nee	nee		0-25m	0-25m
B	12	1	12		12		12	1	ja	nee	daglicht	nee	ja	nee	nee		0-25m	0-25m
A	16	2	8	16			16	1	ja	nee	kunstmati	ja	ja	nee	nee		0-25m	0-25m
A	20	1	20	20			20	1	ja	nee	daglicht	ja	ja	ja	nee		0-25m	0-25m
A	24	3	8	24			24	1	ja	nee	daglicht	ja	ja	nee	ja		0-25m	0-25m
A	12	1	12	12			12	1	ja	nee	kunstmati	nee	ja	nee	nee		0-25m	0-25m
C	8					8	0	1	ja	nee	daglicht	nee	ja	nee	nee		0-25m	0-25m
B	24	8	3		24		24	1	nee	nee	kunstmati	nee	ja	nee	ja		0-25m	0-25m
C	40	4	10		40		12	5	nee	nee	kunstmati	nee	ja	nee	nee		0-25m	25-50m
C	40	5	8			40	15	5	nee	nee	kunstmati	nee	ja	nee	nee		0-25m	25-50m
C	80	10	8			80	20	5	nee	nee	kunstmati	nee	ja	nee	nee		0-25m	25-50m
C	48	18			23	15	24	5	nee	nee	kunstmati	nee	ja	nee	nee		0-25m	25-50m

Image 7.4 Dataset Room aspect inventorisation 2014 (Faculty of Architecture, FMVG)

Several room aspects have been determined: Space Type, Nr. or studyplaces, nr. of tables, nr. Of Chairs per table, adjustable chairs, regular chairs, Miscellaneous place, individual studyplace, degree of studyspace, silence (y/n), ability to book (y/n), Light type (natural/

artificial), Power Outlet, Wifi, Ethernet, Desktops, Distance to coffee-corner/-machine and Distance to printer.

7.2.5 Selection Preferences

From the attributes and aspect in the former studies above, preferences have been selected to use in this research. This will form a basis from which a prototype is made. The student preferences are shown in table 7.4 and the room aspects in table 7.5.

Requirements
Retreat/ Interact
Working Alone/ Collaborate (including nr. students)
Desktop (y/n)
Presentation monitor (y/n)
Preferences
Occupancy levels
Distance to current location
Distance to printers
Distance to catering (clusters)
Layout (open/closed)
Natural light (y/n)
Favourites (determined from record/database)

Table 7.4 List of student preferences

Space Attributes
Name
Location (measured for determining proximity to student location)
Building
Size (sqm)
Capacity (nr. of study spaces)
Occupancy
Availability (y/n)
Distance to printer
Distance to catering (clusters)
Presentation monitor (y/n)
Layout (open/closed)
Natural light (y/n)

Table 7.5 Space attributes

Several optional aspects have also been determined which are more difficult to determine or less interesting to students. However these aspects can prove to be more important over time. These aspects are shown in table 7.6.

Aspects	Range
Size working surface	regular/large
Ability to Eat and/or Drink	y/n
Light levels	Lux
Noise levels	Decibel (Db)
Aesthetics	
Plants	y/n
Finish level	high/low

Table 7.6 Space attributes out of the scope of the smart tool

7.3 Business Intelligence

Organisations need information to understand their operations, customers, competitors, suppliers, partners, employees, and stockholders. Information is gained by gathering and processing data. However, due to the expansion of internal and external data sources relating to the organisations, this led to massive amounts of data. Therefore, a system is needed to process these large amounts of data into usable information. Business Intelligence (BI) does just that, it turns data into 'usable' information to support decision making and gain knowledge concerning the business (Sherman, 2015, p. 10). BI is a data visualisation tool decision makers use, usually in the form of dashboards (Sherman, 2015, p. 14). As shown in the image below the process of converting data to BI: Data integration makes the gathered data from multiple sources uniform, data warehousing stores the data, and BI presents it to decision-makers in an understandable way (Sherman, 2015, p. 3).

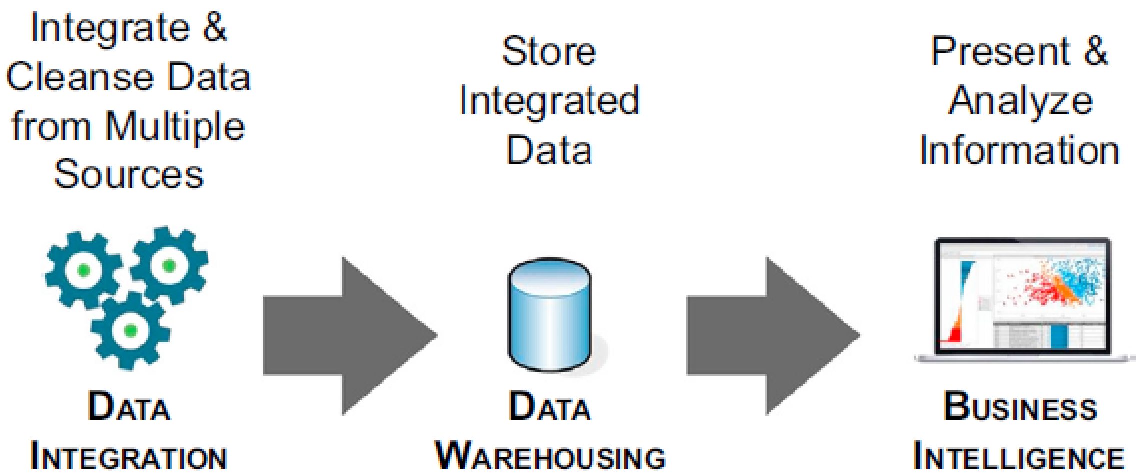


Image 7.5 Process of converting data to usable information (Sherman, 2015, p. 15)

Organisations cannot solely function on business intelligence, organisations still need leaders and decision-makers with intuition. However to support their decision making they depend on data to validate their intuitions. Thus, data becomes a strategic tool that helps decision makers to see patterns which are otherwise difficult to notice (Sherman, 2015, p. 7).

7.3.1 Data

It is important to recognize there is a (big) difference between data and information. Data is raw, random, and unorganized. While information is data that has been organized, structured, and processed (Sherman, 2015, p. 8-9). Once necessary (raw) data is located and evaluated, it often needs to be turned into a clean, consistent, and comprehensive set of information ready to be analyzed (Sherman, 2015, p. 10). Thus, it is essential to consider the quality of data, or when data exhibits the "five Cs": clean, consistent, conformed, current, and comprehensive (Sherman, 2015, p. 17).

In the current climate data is increasing in *volume*, *velocity* and *variety*. **Volume** is defined as the amount of data. Amounts of data become more difficult to process as they increase in size. **Velocity** is related to the speed data is gathered. Because much of the data need is time sensitive there is greater pressure to decrease the time between when it is gathered and processed as information. **Variety** relates to the different sources of data. As variety increases, multiple data sources producing data in different formats create difficulties for data integration. Data integration is aligning or relating the same or similar data in the same format (Sherman, 2015, p. 4-5).

As implied in *variety*, sources of data continue to expand. Smartphones, tablets, and a wide variety of mobile devices have become a new source of data (to analyze). With the expansion of technology platforms on the internet and mobile devices, businesses and consumers are expanding the use of networked devices that monitor, measure, and transmit data related to all types of human and machine activities. This has been labeled the Internet of Things (IoT) and is considered the latest technology platform evolution that will significantly impact data (Sherman, 2015, p. 145).

7.3.2 Analytics

Ultimately, data has no value unless you can understand what you have, analyze it, and then act on the insights from the analysis (Sherman, 2015, p. 6). Analytics is the examination of information to uncover insights to help the decision maker to gain knowledge for making informed decisions. Currently, analytics is not just growing in volume but is also growing more complex. Therefore, advanced analytics is expanding to include data visualization and predictive analytics (Sherman, 2015, p. 7). **Data visualization** presents data in a visual way, e.g. with graphs and charts (Sherman, 2015, p. 17). By **Data mining** large quantities of data are analyzed to find patterns and relationships (Sherman, 2015, p. 17). With predictive analysis one hopes to see patterns that help predict the direction of the future. Thus, there is significant value of analyzing the amount of information and then acting on that analysis (Sherman, 2015, p. 10).

7.3.3 Data Sources

There is an important difference between operational systems and BI. Operational systems are used to capture data and act as a data source for BI. Capturing data means converting or translating data to a digital form. Operational systems are focused on the present and therefore lack many key attributes to support all the necessary analysis (Sherman, 2015, p. 12). Therefore an additional system, BI, is the application used for reporting, querying, and analytics. This also includes data warehousing, which is the database backbone to support BI applications (Sherman, 2015, p. 11). A common BI tool used to present information is a dashboard. A **dashboard** displays numeric and graphical informations on a single display, making it easy for decision makers to gain information from different data sources (Sherman, 2015, p. 17).

7.3.4 Data modeling

A **data model** specifies data structures, providing a method to visually communicate the data that is needed, collected, and used by an organization (Sherman, 2015, p. 173). The primary objective of a data model is to support the data design for an IT application (Sherman, 2015, p. 174). It is used as a communication tool for discussions between developers, database analysts, and business analysts during design and application development. Thus, data modeling is a structured approach to identify and analyze necessary data components for information systems (Sherman, 2015, p. 174).

7.3.5 Relational databases

A relational database (RDB) is a collective set of multiple data sets organized by tables, records and columns. RDBs establish a well-defined relationship between database tables which communicate facilitating data searchability, organization and reporting. RDBs use Structured Query Language (SQL), which is a standard user application that provides an easy programming interface for database interaction (https://www.techopedia.com/definition/1234/relational-database-rdb).

Data models are a key component of relational databases (Sherman, 2015, p. 178). The two primary areas in which relational databases are used include: operational systems and BI. **Operational systems** processes transactions and events that occur in a business. E.g. a customer places an order. **BI applications** are used for reporting, querying, and analytics. This category also includes data warehousing, which is the database backbone to support BI applications.

7.3.6 Entity-Relationship (ER) modeling

Enitity relationship (ER) modeling is a logical design modeling technique mostly used for operational systems. It minimizes data redundancy and ensures data integrity, but because of this, can become rather large and complex. Because of its complexity, a structured approach and technique is critical to eliminate data redundancy (Sherman, 2015, p. 179). Ultimately, understanding ER modeling helps dimensional modeling, because the entity, relationship, and attributes are all building blocks for the dimensional model (Sherman, 2015, p. 195).

ER models are built up of three building blocks: entities, relationships, and attributes (Sherman, 2015, p. 179-180). An example of these building blocks is shown in image 7.6.

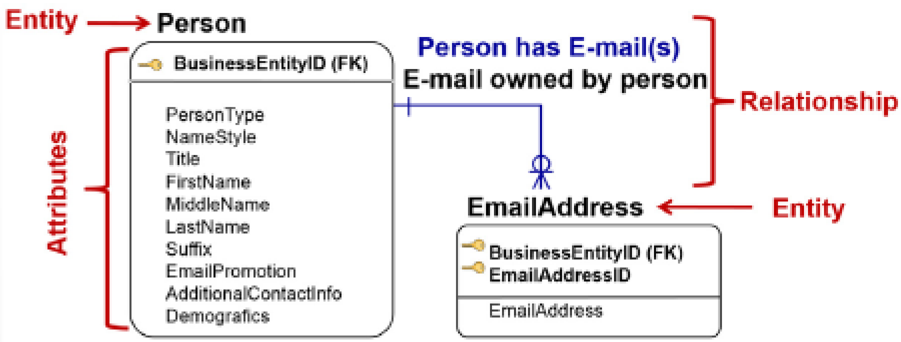


Image 7.6 Developing a Data model (Sherman, 2015, p. 180)

• An **entity** is a person, place, thing, or event about which the business keeps data.
• **Relationships** show how the entities are related to one another. Relationships are the logical links between the entities that represent the business rules or constraints.
• **Attributes** are distinct characteristics of an entity for which data is needed to capture and maintained in order to understand the business.

Thus, entities can have a relationship towards each other and identifying the relationship establishes the parent as a way to identify and classify the child (Sherman, 2015, p. 181). This leads to two types of entities, independent and dependent:
• Independent entities: can survive on their own and does not need any children.
• Dependent entities: are child records that need a parent record to exist.

Relationships

An entity-relationship model has four basic types of **relationships**: identifying, non-identifying (either optional or mandatory), and many-to-many relationships. Cardinality imposes itself on these various relationships. The different forms are shown in Image 5.9.

Identifying relationships establishes the parent as a way to identify and classify the child. In this type of relationship, the primary key from the parent migrates through the relationship to become part of the primary key, or identity, of the child. The child entity is dependent upon the parent for its identification or classification, and it cannot exist without the parent.

In **non-identifying mandatory** relationships the parent entity's primary key migrates as a non-key attribute to the child but does not identify the child. The non-key attribute is a foreign key pointing back to the parent entity, but it is not used as primary key. Because the child cannot exist without a parent, but is independent of the parent for its identification, the relationship becomes mandatory.

In a **non-identifying optional** relationship, the parent entity has a primary key that migrates, as a non-key attribute, to the child but does not identify the child. In other words, the child is independent of its parents for its identification.

Many-to-many relationship has a nonspecific relationship in which primary keys do not migrate as foreign keys. The relationship is many-to-many, representing a relationship for both the parent and child sides. In describing the relationship it is required to state from the perspective of first the parent to the child and then the child to the parent (Sherman, 2015, p. 184).

A **recursive** relationship is also referred to as a self-referencing relationship. It is a non mandatory relationship in which the same entity is both the parent and the child. Each migrating primary key attribute must be given a role name to clarify the attribute's foreign key role (Sherman, 2015, p. 185).

Cardinality

Cardinality is defined as the number of relationships an entity has with another entity. It defines, on both the parent and child side, how many occurrences can take place between these entities. There are four options, as described in the Table below: *one-to-one*, *one-to-many*, *many-to-one, and many-to-many*. In addition to these four types of cardinality, relationships can also be recursive. With recursive, or self-referencing relationships, the same entity can be in both ends of the relationship. In other words, there may be more than one relationship between entities (Sherman, 2015, p. 181).

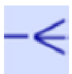
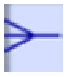
Type	Crow's Foot Notation
One-to-one—One instance of the first entity, the parent, corresponds to only one instance of the child or the second entity. If you have one, you have to have the other. For example, one employee has one employee ID number.	
One-to-many—The example in Figure 8.5 shows the relationship between an order header item and an order detail item. The parent is *SalesOrderHeader*: there is only one of them. The children are *SalesOrderDetail*: there can be many of them.	
Many-to-one—There is more than one instance of the first entity, the parent, but it corresponds to only one instance of the second entity. For example, there can be many survey responses to one question. Or there are multiple reasons why a person buys one product. The difference between one-to-many and many-to-one depends on what side of the relationship you are looking at. For example, one department has many employees (one-to-many), but many employees work in one department (many-to-one).	
Many-to-many—The most complex is the many-to-many relationship. There is more than one instance of the first entity corresponding to more than one instance of the second entity. The classic example of this is a sick patient visiting the doctor. The patient can have many symptoms and diagnoses. There can be many procedures that apply to each of those diagnosis. These are the most complex relationships to implement in a relational database. But there are techniques, covered later under dimensional modeling, that show how to handle them.	

Image 7.8 Cardinality (Sherman, 2015, p. 182)

b. Keys

An entity can also have different kinds of attributes **key** or **non-key**. To build a physical data model, it is important to decide which attributes are used for keys. Key attributes serve to uniquely identify an attribute (Sherman, 2015, p. 180). There are four types of keys: candidate, primary, alternate, and foreign.

- The **candidate key (CK)** is the attribute or group of attributes that can uniquely identify each instance of an entity.
- The **primary key (PK)** is the attribute or group of attributes that is chosen to uniquely identify each instance of an entity. If there is a list of candidate keys, then one needs to be designated as the PK.
- The **alternate key (AK)** is the attribute or group of attributes that is not chosen as a primary key to uniquely identify each instance of an entity.
- The **foreign key (FK)** is a primary key of a parent entity that is contributed to a child entity across a relationship.

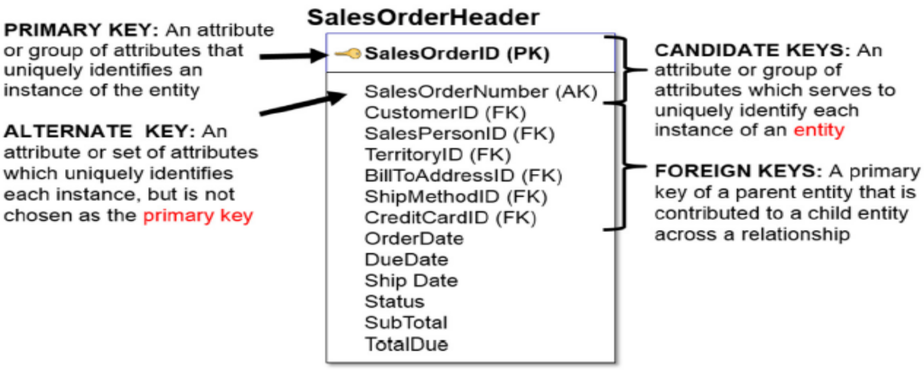


Image 7.9 Key Types(Sherman, 2015, p. 182)

Normalization

The goal of **normalization** is to create the cleanest entity relationship model possible in order to eliminate or minimize redundancy. In normalized model the entities only have attributes related to the entities themselves, while allowing the establishment of relationships between other entities. Therefore it becomes easier to maintain, not only because of the lack of redundancy, but also because the entities, the attributes, and the relationships are clearly defined (Sherman, 2015, p. 195). An example of this is: rather than fully typing the building name and adding the address and phone number of the building to the row of each room, you create an unique identifier for the building e.g. building '1' or 'A' in a separate table which has all the information related to the building which you are still able to find. Normalization, however, leads to very complex data structures. With this increased complexity it becomes harder to understand. Furthermore with large models querying can become difficult when many tables need to be joined.

7.4 Conclusions

The findings of this chapter will now be described to answer the question: 'How can one develop a Smart Tool to enable the interaction of real estate and users to enable the generation of usable management information?'.

For the measurement of preference, a scale needs to be constructed to for each criteria and a value for this criteria needs to be assigned on this scale to signify preference. This scale enables the transition of an empirical system (E) to a mathematical system (M).

Using PFM has the following procedure: Initially, a hierarchy of criteria and the identification of the alternatives is needed for the development of PFM. The scores are then elicited by decision makers as preferences for each alternative against each criterion by first establishing reference alternatives. Then, the other alternatives are rated relative to these reference alternatives on the scale established. Thereafter, the decision maker the attaches a weight to each criterion. When finally the PFM algorithm is used to yield an overall preference score to evaluate all the alternatives, it can then be ranked accordingly.

Relating this to the proposed smart tool, it is not needed to determine alternatives as spaces are already existing. Therefore, the preference function modelling procedure needs to be adapted slightly by using the mathementical function on the spaces as alternatives. Thereafter, the results of the algorithm can then be ranked according to the overall preference score.

To determine the relevant criteria to use in preference function modelling the sub question: 'What criteria for study space preferences should be considered in the smart tool?' is answered in the following paragraph.

The typology of learning space preference attributes was be used to evaluate, but more importantly can also to design informal learning spaces. Therefore, space design should encourage users to reflect on their learning preferences and translate these preferences into space selection. As both redevelopment projects and learning spaces research progress, the results can be benchmarked which should ultimately lead to practical and proven designs being implemented. From the attributes and aspects in the former studies, preferences have been selected to use in this research. This will form a basis of criteria used in preference function modelling. The results of the chosen preferences to use as criteria are shown in the table below.

Requirements
Retreat/ Interact
Working Alone/ Collaborate (including nr. students)
Desktop (y/n)
Presentation monitor (y/n)
Preferences
Occupancy levels
Distance to current location
Distance to printers
Distance to catering (clusters)
Layout (open/closed)
Natural light (y/n)
Favourites (determined from record/database)

For the development of the smart tool the processing of information to display is most important. For this, information needs to be stored and extracted. This is done by storing the data in information systems, for which data modelling is required. Data modeling is a structured approach to identify and analyze necessary data components for information systems. A relational database (RDB) is a collective set of multiple data sets organized by tables, records and columns. The two primary areas in which relational databases are used include: operational systems and BI. Operational systems processes transactions and events that occur. For this an Entity Relationship (ER) model needs to be built. This model consists of three building blocks: entities, relationships, and attributes (Sherman, 2015, p. 179-180). An **entity** is a person, place, thing, or event about which the business keeps data. **Relationships** show how the entities are related to one another. Relationships are the logical links between the entities that represent the business rules or constraints. **Attributes** are distinct characteristics of an entity for which data is needed to capture and maintained in order to understand the business. Entities can have a relationship towards each other and identifying the relationship establishes the parent as a way to identify and classify the child.

The findings have shown how the information in relation to preference is processed and what information is relevant (i.e. criteria) to use. These results will form the building blocks on which the smart tool prototype will be built. The process of making the relevant structure for prototype evaluation is described in chapter 10.

8. OCCUPANCY DETECTION

The following findings are described to answer the sub question: 'How is occupancy detected through an existing WiFi infrastructure?' In the first section, (8.1) the principle of detecting occupancy through wifi is described and what is important in processing the raw. The second section (8.2) concludes on the findings through summarisation.

8.1 WiFi Occupancy Detection

For acquiring data to measure occupancy in buildings Wi-Fi is very interesting because the main infrastructure is often already present in buildings. Additionally, standard Wi-Fi devices do not need any modifications, which limits the amount of preparation needed. Moreover, many contemporary electronic products have Wi-Fi capabilities built in, including portable devices such as smartphones, tablets, smart watches and music players (Braggaar, 2018, p. 12). This classifies Wi-Fi as a major opportunity for measuring occupancy, especially for application in a university setting (Valks et al., 2016).

For example, the TU Delft campus already has a Wi-Fi network infrastructure that covers the whole (indoor) campus consisting of Cisco Aironet access points (see image 8.1). By using these access points costly investments in additional hardware can be avoided. However, limitations include that visitors or users that are connected over a LAN cannot be recorded, as well as limited data accessibility and latency of data acquirement (Braggaar, 2018 p. 37).

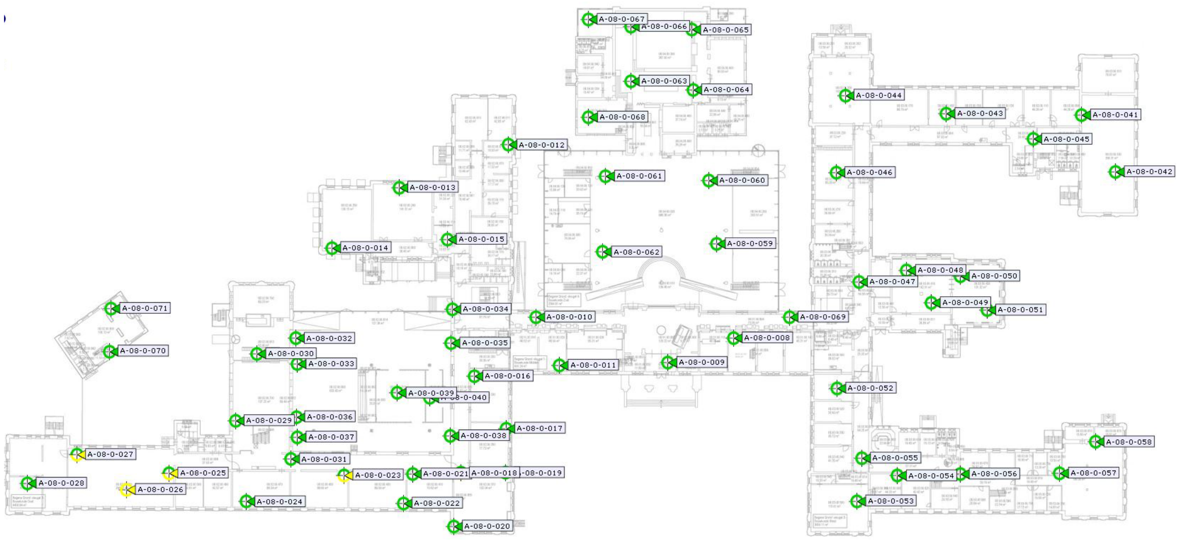


Image 8.1 Existing Wi-Fi (Access Points) infrastructure in the Faculty of Architecture, TU Delft

8.1.1 Network based positioning

Performing positioning centrally is advantageous as is doesn't require active user involvement and allows large scale data collection and aggregation. Therefore it is beneficial to use a network-based positioning to determine position from the network or server side, instead of the mobile side (Mautz, 2012). In network-based positioning base stations (e.g. access points) capture signals transmitted by the mobile devices. Access Points (AP) are Wi-Fi base stations that expand the local network by providing access to a Wireless Local Area Network (WLAN). This enables a wireless connection between APs and mobile devices allowing communication between the two components.

In order for this to occur the (wireless) network must first be discovered also called the network discovery process. For this two distinct processes have been identified passive or active network discovery. Passive network discovery happens when the mobile device receives a signal sent out by APs on a regular interval (in the left illustration of image 8.2), to establish a connection. In active network discovery the mobile device initiates the process by sending out a blind request (i.e. probe) to be recognized by surrounding networks enabling the establishment of a connection (shown in the right illustration of image 8.2). Device users have no control over the amount of probe requests that devices send out with the exception of turning off Wi-Fi (Braggaar, 2018 p. 13).

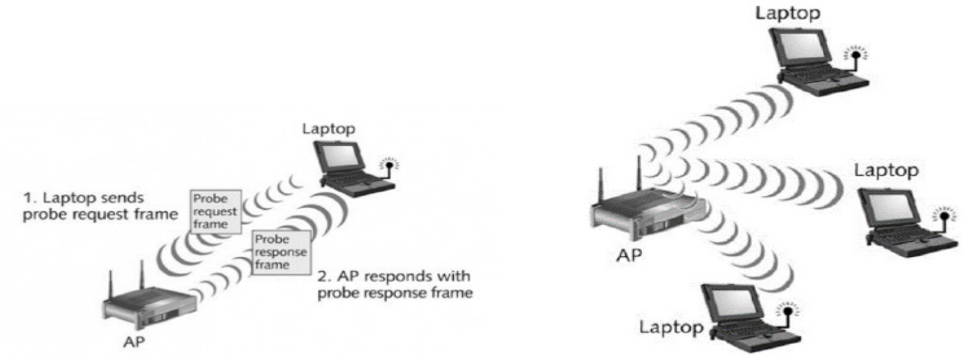


Image 8.2 In the left illustration the probe request and response of the access point and in the right illustration a broadcasted signal from an access point reaching several devices. (Braggaar, 2018)

8.1.2 Metadata

When these probe requests are captured their metadata (information which describes the request) can provide useful insight that can be used for indoor positioning. The following metadata can be retrieved from the probe requests (Braggaar, 2018, p.15):

- Timestamp: the time at which the probe request arrives at the Wi-Fi base station
- MAC address: the Media Control Address or unique identifier of the device on the network
- RSSI: an indicator for signal strength (amount of RadioFrequency-energy in Dbm)
- SSID: the name of the network the client is currently connected to
- (optional) Requested SSID: the name of the network the client station wants to connect to
- Vendor: the manufacturer info of the device's chipset (If included by the manufacturer)

8.1.3 (WiFi) Positioning

Position is defined as an exact point in a space expressed in (x, y) coordinates and can be either absolute or relative, depending on the used reference frame as shown on the right in image 8.3. Indoor location, however is referred to by Sithole and Zlatanova (2016, p. 92) as the smallest space physically defined (i.e. by walls) space in a building (e.g. room or corridor) as shown on the left in image 8.3. However, spaces can also be defined as sub-space by campus management in cases that it spaces are large and sections are clearly identifiable.

For determination of the exact position of a mobile device in a space the accuracy of Wi-Fi is not accurate enough. However, exact positions of users is not of interest to campus management, but accuracy on location (as described earlier) is sufficient to determine utilization of spaces.

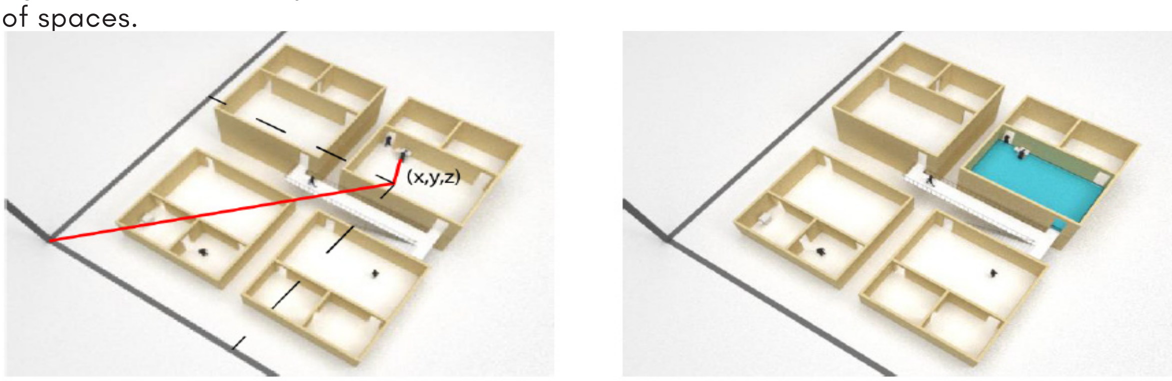


Image 8.3 The left image shows an absolute position with coordinates, the right image high lights a location, a room in this case (Braggaar, 2018)

Techniques to determine position through Wi-Fi can be based on time, angle or signal strength. The techniques based on signal strength (RSSI) are most commonly used because they require no hardware adaptations and are not prone to clock errors which some of the other techniques have (Braggaar, 2018, p. 15) A particularly suitable positioning method to use the RSSI is lateration. Lateration uses the distances from a mobile devices to multiple base stations (e.g. APs) in order to calculate an intersection point. The RSSI values can be used to determine distance between APs and mobile devices for Wi-Fi lateration as described in the next section (13.5.4).

Tri/Multilateration for Position Determination

By combining the RSSI values from more network base stations the accuracy can be increased and elevation can be determined. For trilateration a device' RSSI values to three base stations is used, which is can give meter accuracy. However, the accuracy and reliability is usually severely decreased due to environmental factors (Oguejiofor et al., 2013 in Braggaar, 2018, p. 47). The principle of localisation by trilateration is shown in image 13.6, which shows different radii for each base station determined from the RSSI value, by combining these radii the intersection can discovered to determine the location of a device. Similarly, for multilateration more than 3 base stations and their respective RSSI values are used to calculate a point of intersection including elevation (z -axis) of a device. Furthermore, because a higher number of base stations is used, a higher accuracy can also be achieved.

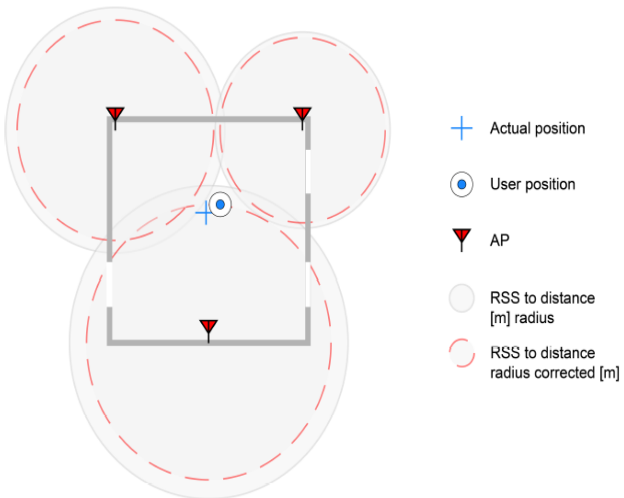


Image 8.4 Principle of trilateration (Braggaar, 2018)

Elevation Determination

The main benefit of multilateration is that by combining the RSSI values from multiple bases station on multiple floors it is able to determine the vertical plain (i.e. a floor) a device is located on. For this at least the input values form 4 bases stations are needed and by combining the average values of multiple values and grouping them per the floor a total average per floor can be calculated (Braggaar, 2018, p. 47). Ultimately leading to the determination of the floor the device is on.

Occupancy Detection

By processing the results of the positioning within a vector polygon (defined area) stored in the database, the occupancy of each area can be calculating comparing the capacity and number of devices of each area. Image 8.5 shows a valid closed polygon which contains 5 points (start and endpoint overlap) able to determine the occupancy as a combination of the detected devices, inside the spatial points of the polygon within a given timeframe (Braggaar, 2018, p. 47).

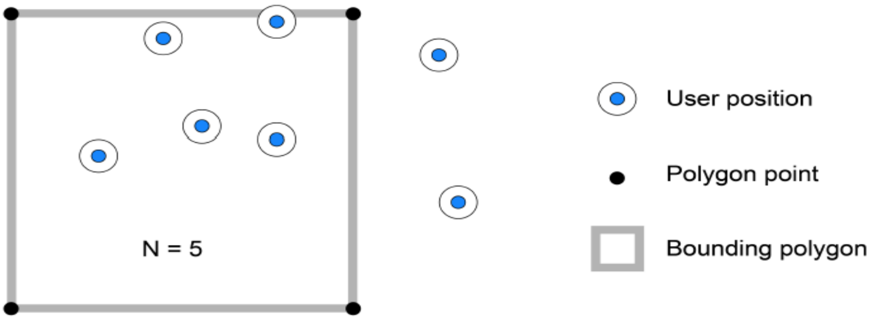


Image 8.5 Defined area with a vector polygon (Braggaar, 2018)

8.1.4 Signal Strength

Because he position or location of the device is based on the RSSI value it becomes a very important measurement. In an outdoor situation signal strength normally degrades quadratically over distance. By using a mathematical path-loss model signal strength can be translated to a distance estimation. However, in indoor environments the signal is (dynamically) influenced by various objects, human bodies and building elements complicating determination of distance. Radio frequency signals and some identified influences in indoor environments can be seen in the visualization of image 8.6. The influences are described in more detail in the next section.

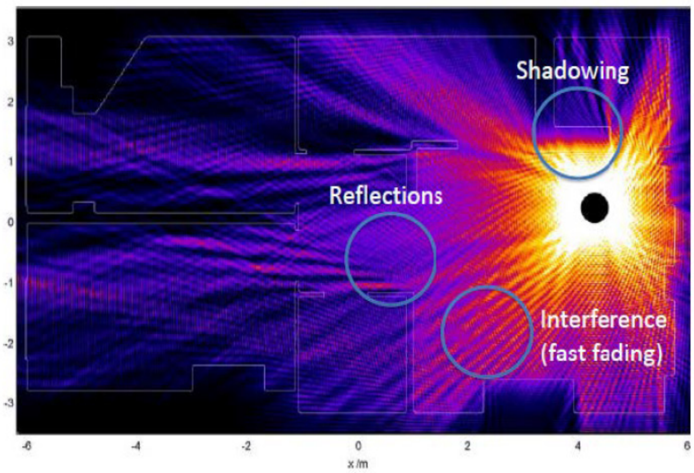


Image 8.6 Influences of radio frequency signals (Callaerts (2016) in Braggaar (2018))

Indoor Influences on Signal Strength

As the radio frequency signal of a device is transmitted in an indoor environment it comes into contact with and travels through various materials and objects. Each of these materials have different properties and as a result causing different amount of reflection, absorption and penetration making the calculation of the path loss of the signal much more complex. A distinction of 6 main effects that can have an influence on the signal path loss calculation in indoor environments have been distinguished by Seybold (2005):

Multipath reflection

This means that due to reflection of the signal multiple versions of the same signal, arrive at different times. Signals travel at different lengths as result of reflection ultimately leading to different signal strengths. For example, metallic surfaces are especially known to reflect Wi-Fi signals.

Absorption

The different types materials and obstacles can also partially absorb the signal, leading to a decrease of signal strength. For example, the human body consists for a large part of water which can strongly reduce the strength by absorption. The decrease in signal strength caused by objects in the path is called shadow fading or slow fading.

Refraction
: When a signal goes through different materials or objects, (e.g. glass and thin air) it refracts. During transition through a material the angle of the signal is changed by th a certain degree which can be predicted or calculated.

Scattering
: When a signal collides with an object it is able to scatter the signal in multiple unpredictable directions.

Diffraction
: A signal is also able to curve or bend around an obstacles' edges, causing changes in direction. This phenomenon is called diffraction.

Depolarisation
: Polarisation (wavelength vibrations) can change upon impact with the surface for certain types of waves.

8.1.5 Data Filtering

The captured data needs to be processed by filtering data to produce usable input data needed to calculate distances. The data filtering is a crucial process as it is normal with large data collection that large amounts of unwanted data is also captured. For example, users which are not in the defined space e.g. outside the building (i.e. outliers) shouldn't be added to the occupancy rating of the building. To deal with this Braggaar (2018, p. 40) determined three different types of filtering to apply to his data for his thesis: redundancy filtering, outlier and threshold filtering and user type filtering. Within the user type filtering three sub categories are recognized.

1. Redundancy filter
2. Outliers and thresholds
3. Actor type filtering:
   (a) Static devices
   (b) Anonymised traffic
   (c) One-hit traffic

8.2 Conclusions

By relating these findings to the development of the smart tool more known about the process of gathering data on building use. Since the occupancy detection is essential in the functioning of the smart tool, the most relevant findings are explained to answer the sub question: 'How is occupancy detected through an existing WiFi infrastructure?'

In network-based positioning base stations (e.g. access points) capture signals transmitted by the mobile devices. A particularly suitable positioning method to use the RSSI is lateration. Lateration uses the distances from a mobile devices to multiple base stations (e.g. APs) in order to calculate an intersection point. In multilateration more than 3 base stations are used to calculate a point of intersection including elevation (z -axis) of a device. Because a higher number of base stations is used, a higher accuracy can also be achieved.

Because he position or location of the device is based on the RSSI value it becomes a very important measurement. By using a mathematical path-loss model signal strength can be translated to a distance estimation. However, in indoor environments the signal is (dynamically) influenced by various objects, human bodies and building elements complicating determination of distance. Therefore, mathematical model needs to take into account all of the different effects on the signal strength.

Additionally, the captured data needs to be processed by filtering data to only use the relevant data. The data filtering is a crucial process as it is normal with large data collection that large amounts of unwanted data is also captured.

9. PRIVACY AND DATA PROTECTION

The purpose of this chapter is to answer the sub question: 'What are the privacy issues concerning gathering use data?'. The first section (9.1) will explain the regulations concerning the gathering and storing of data about building use. Finally, the (9.2) findings are explained and implications for the smart tool described.

9.1 Definition and Regulation

Gathering data on occupancy involves determining the number of individual people on a certain location at a certain time. This data can ultimately be led back to a person making it personal privacy sensitive information. In order to comply with privacy legislation several aspects need to be covered which will be described in this section.

The described way to determine occupancy in a (space within a) building involves MAC-addresses. A MAC-address (Media Access Control address) is a unique string (set of characters) to identify a device, making it possible for devices to communicate with each other over ethernet. MAC-addresses are prescribed to devices by their manufacturer and in principle unique. When the Wifi is active on a device it will (nearly) constantly send out a signal with this MAC address to detect and/or connect to Wifi networks. A device's MAC address can be led back to a person with additional information. Because the described data gathering involves information about the date and time of a particular device (e.g. smartphone), the behaviour of the device's user can be exposed leading to possible privacy infringement. This has been confirmed by a study in 2011 which concluded that a MAC address is considered personal data because it is a unique number which be used for the identification of person (Kranenborg and Verhey, 2011 in Braggaar, 2018).

The European Union (EU) establishes regulation or directives regarding privacy and data protection which its members need to comply. Furthermore, each member is obliged to set up a supervisory body to maintain compliance with the regulation, which for the Netherlands is the authority of personal data. In 1995 the EU established the Data Protection Directive which deals with the protection of individuals with regard to the processing of personal data. This directive consists of seven main principles:

1. Notice: data subjects need to be notified when their data is being collected
2. Purpose: The purpose of the data collection needs to be stated and cannot be used for any other purposes.
3. Consent: data should not be published without consent of the data subject
4. Security: the storage of the collected data needs to be secure from any potential abuses
5. Disclosure: it should be clear for data subjects who is collecting their data
6. Access: data subjects should be allowed to access their data and make corrections to any inaccurate data
7. Accountability: data subjects should be able to hold data collectors accountable for not following the any of the stated principles.

9.2 Anonymizing Data

To deal with the possible privacy issues relating to the described personal data, the MAC addresses can be depersonalised (anonymized) and encrypted to prevent identification of the associated device. A way to anonymize the MAC addresses is by hashing the character string. A hashing algorithm produces a different set of characters following the input as shown in image 9.1 The result is dependent on the input and therefore produces the same result. This makes tracking users is still possible, despite the fact that the MAC address is not directly known (Braggaar, 2018, p. 54). Furthermore, if an existing MAC address is known the hash can be recalculated. However, this can be solved easily by restricting access to the data (Autoriteit Persoonsgegevens, 2016, p. 5).

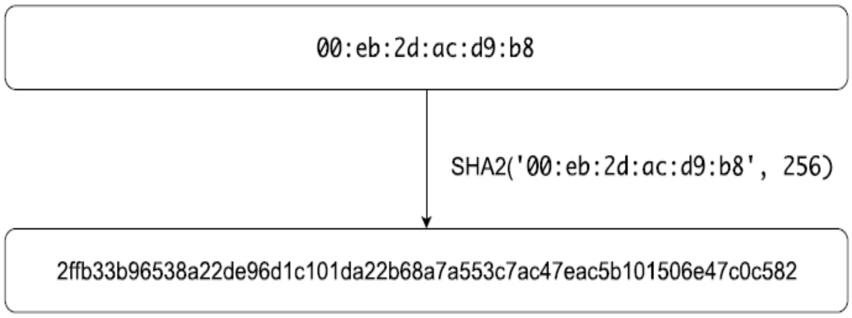


Image 9.1 Encryption algorithm (Braggaar, 2018)

In a test to use WiFi to determine user flows in the London Metro (Weinstein, 2017) the irreversible encryption method included a 'salt'. This was added to enhance security by adding an unknown character string to each MAC address before encryption. Making it is impossible for the original MAC address to be identified without knowing the salt, even if a MAC address and the encryption mechanism is known. Reducing both the possibility of a single known MAC being identified in the data, and a look-up table of all possible MAC addresses being created and joined to the data. By working this way the data can be considered anonymous and unable to identify any specific device (Weinstein, 2017, p. 22).

9.3 Data Storing

Because occupancy requires storing information on the detected MAC addresses it also becomes possible to unintentionally store data outside the area of interest. This happens when a device comes within the range of the access point to detect it, while being outside the building. All the data which have been determined to be outside the area of interest need to be filtered and cannot be stored (Autoriteit Persoonsgegevens, 2016, p. 11). Furthermore, access to the data needs to be restricted to a particular team which are designated to use the data for its intended purpose. These individuals need to go through privacy and data protection training. Finally, the collected data collected can never be shared with any third parties (Weinstein, 2017, p. 22). Personal data can be stored no longer than is necessary for the intended purpose according to article 10 of the Wbp (Wet Bescherming Persoonsgegevens). Meaning that organisations can store personal data in an archive if it is intended for historical, statistical or scientific purposes.

9.4 Transparency

Under the principles 'Notice' and 'Disclosure' the data subjects are required to be notified of what is being measured, why and by whom. This can be accomplished by giving information step by step. Meaning that when data is gathered, the company responsible needs to be stated, the purpose of the data collection and additional information on how the data is processed is made explicit. An example of this can be a clearly visible sign or sticker which data subjects are able to read before entering the space where the data is being collected. This, gives individuals the possibility stop entering the area or switch off their wifi to make sure their device is excluded from detection (Autoriteit Persoonsgegevens, 2016, p. 15.).

9.5 Conclusions

Since occupancy detection is essential in the functioning of the smart tool, the most relevant findings are explained to answer the sub question: What are the privacy issues concerning gathering use data?'.

It was determined that detecting occupancy is considered personal information. Therefore, to use this one needs to comply with seven main principles discovered in regulation:

1. Notice: data subjects need to be notified when their data is being collected
2. Purpose: The purpose of the data collection needs to be stated and cannot be used for any other purposes.
3. Consent: data should not be published without consent of the data subject
4. Security: the storage of the collected data needs to be secure from any potential abuses
5. Disclosure: it should be clear for data subjects who is collecting their data
6. Access: data subjects should be allowed to access their data and make corrections to any inaccurate data
7. Accountability: data subjects should be able to hold data collectors accountable for not following the any of the stated principles.

To deal with the possible privacy issues relating to the described personal data, the MAC addresses can be depersonalised (anonymized) and encrypted to prevent identification of the associated device. Under the principles 'Notice' and 'Disclosure' the data subjects are also required to be notified of what is being measured, why and by whom.

In the use of the smart tool it is not expected that users will object to the gathering of personal information relating to preferences. This is because the values are subjective and can easily be changed. The input values also do not say anything personal except for preference, something that can not be used against users in any way.

Image: BKCityGuide 2017/2018

PART IV

RESULTS

10. DESIGN PROCESS SMART TOOL

This chapter will illustrate the process of designing the proposed Smart Tool and its functionalities by describing the construction and outcomes of several aspects. Firstly, (10.1) the objectives set out for the functionality of the Smart Tool is clarified signifying the (design) objectives. Thereafter, the (10.2) required technology to achieve these functionalities are explored. Consequentially, the execution of the proposed smart tool is clarified by making several models. Beginning with, (10.3-4) two prototypes which were used to test Preference Function Modelling on users of the campus. Then, (10.5) a database structure which illustrates the back-end of the smart tool needed to store the generated data is described. After this, a (10.6) mock-up of a mobile application is described which is tested on users to show workflow in order to improve usability. Lastly, the (10.7) findings in these evaluation interviews are described using the predetermined method of the Task Load Index.

10.1 Objectives

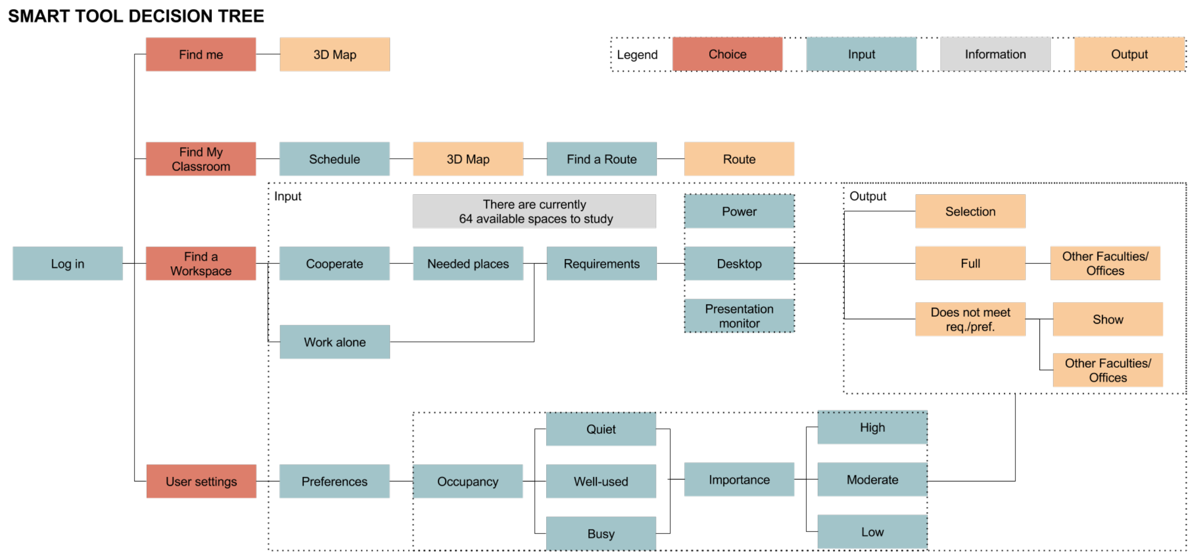


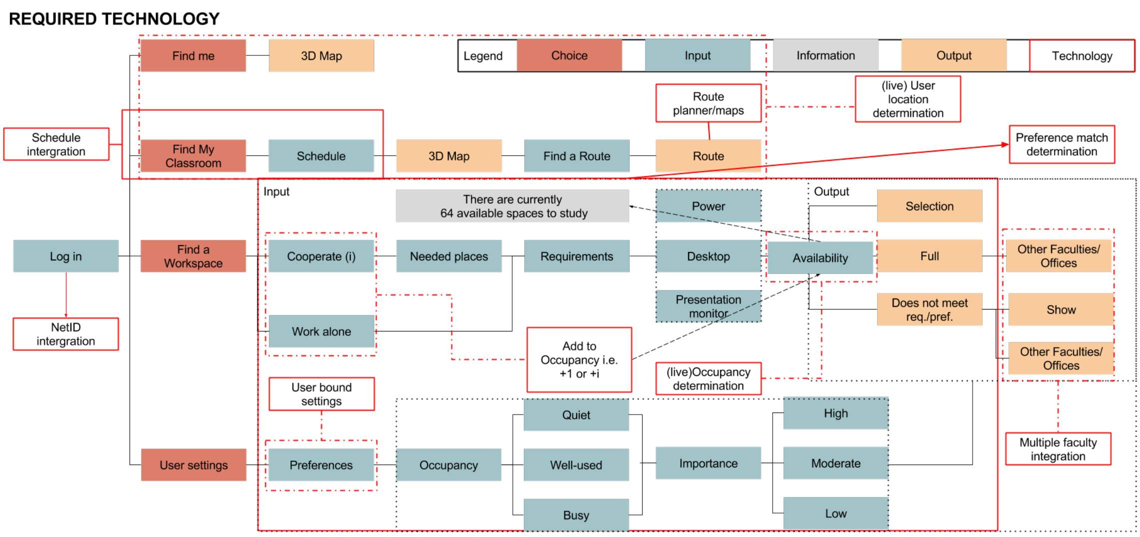
Image 10.1 Workflow Smart Tool (own illustration)

Image 10.1 is a representation of the proposed smart tool that is able to help students with finding a study space meeting their personal preferences and requirements. This was one of the first ideas about the functionality of the smart tool which has been developed throughout the research. The Smart tool is represented as a decision tree to indicate the choices a user needs to make to enable a selection of the study spaces according to preferences. Firstly, it is important to be able to use an smart tool on a smartphone while approaching the building. In this manner wayfinding is delayed the least (or not at all) by gaining information about the supply of available study spaces. Such an smart tool would work for each individual student who is able to set up their own preferences. Preferences are by indicating the preferred degree of occupation, natural light/window view, closeness to facilities etc. of spaces. Thereafter of each of these criteria is weighed by the user, to indicate importance. This ultimately allows the app to show a selection of spaces that has the highest match with the user's preferences.

In the first screen of the smart tool three options are given: "Find Me", "Find My Classroom" And "Find A Study/workspace". After selecting, each option shows different results. When "Find me" is selected a 3D map of the faculty/office building is shown while the location of the user is indicated. This will enable the user to navigate the building and offers a better alternative to the traditional paper building map. If "Find my classroom" is selected the schedule of the individual student is shown through an integration of Brightspace. After the class is selected a 3D map is shown indicating both the student and the room linked to the selected class. Using the 3D map the student can navigate himself to the classroom or choose the option to "Find a route" showing the fastest route to the room and estimating the time needed to reach the location.

When a user is looking for a study/work space the "Find a study/workspace" can be selected. Subsequently the smart tool shows the number of available spaces and asks the user if it is going to 'Work Alone' or 'Cooperate'. In the case that the user is cooperating the number of needed spaces is requested up to a total of 10. Afterwhich the requirements for the space are requested giving the options of: Power outlets, Presentation monitor, etc.. When this is completed a selection is made of the available study/workspaces the users is able to choose. After one of the options is chosen the user is directed to the space(s) through a 3D map. In the case that there are no study spaces available that meet the requirements or preferences of the user or there are no more study spaces left available, two options are show. The option to 'Show' the study spaces which did not meet the requirements anyway or the option to 'Find a space on a different faculty'. This makes it possible for the user to either adapt his requirements/preferences or move to a different faculty. When 'Show' is chosen the study spaces are which did not meet the requirements are shown with indication what requirements were not met. The users are then still able to choose these spaces making them mitigate/easing up on their requirements or preferences. The reason for showing the selection of study spaces on other faculties is to use the unique ability of student to use multiple faculties to meet their needs. This should lead to a more effective use of the campus as a whole.

Image 10.2 Required Technology Smart Tool (own illustration)



10.2 Required Technology

In image 10.2 the required technology is linked to the decision tree of the proposed smart tool to show which technology is needed for which function. To start, a student must be able to log in to his personal account, for which a Single Sign-on Net ID integration is most desired as this reduces the time to log in. To enable the functionality of finding a classroom in relation to the students schedule an integration of the Brightspace is most likely needed or the schedule can be extracted from the underlying scheduling system. To guide a user to a classroom the location of the user needs to be determined. What is also important in this regard is determining the location of the user, from which a route can be calculated. Which leads to the next technology wayfinding which is the technology for calculating routes.

Determination of a users location is also important with regard of the distance a user is willing to travel to a space. This distance is stored in the user bound settings which holds all of the values for the preferences of the user. When a selection of spaces is shown according to the users preferences it has to be available, otherwise it is of no use. Therefore the technology of occupancy detection is needed. Furthermore, occupancy is another aspect which is of influence of users preferences which adds to the importance of this technology of the proposed smart tool. Additionally, to reduce the time to build the smart tool it is expected that some integrations with existing systems need to be established, include a (3D) systems for maps for example.

10.3 Prototype Version 1

To test the proposed Smart Tool a space preference function model was constructed in excel. This was chosen for its ease of use with regard to input information, its ability to add backend functions in Visual Basic where e.g. the lagrange function was implemented and the fact that most people have been exposed to excel before. In the first version of the model the step-by-step process of PFM was used, each tab representing a different step.

Step 1. Firstly the criteria was shown which formed the basis for the PFM rating. This also allowed to ask users which criteria are important to them, which could be deleted and which were missing (shown in Image 10.3).

Criteria	Unit
Needed Spaces	nr.
Occupancy Rating	%
Distance to Current location	meter
Distance to Printer	meter
Distance to Catering	meter
SpaceType	Meeting/SelfStudy/Temporary/All
Layout	Open/Closed
LightingType	Natural/Synthetic
Poweroutlet	y/n
Audiovisual	y/n
Silence	y/n
Feedback Rating	%

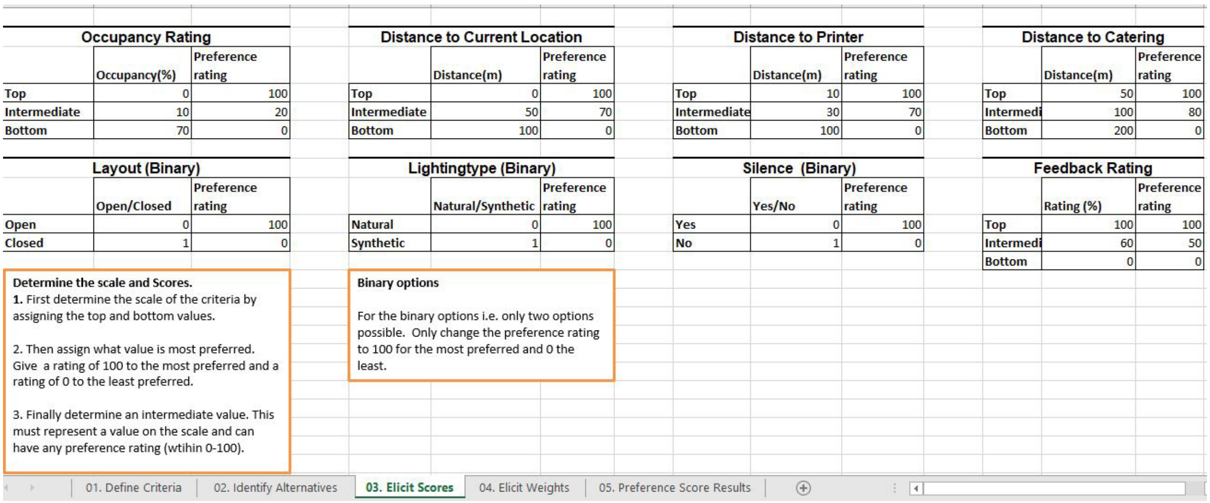
Image 10.3 Criteria (own illustration)

Step 2. The following step was "Identify Alternatives", which included a list of spaces with different value for each of the criteria. The values that were input was random to allow the calculation to function.

	Criteria										
Alternatives	Occupancy Rating	Distance to Current location	Distance to Printer	Distance to Catering	Layout	LightingType	Silence	SpaceType	Poweroutlet	Audiovisual	Feedback Rating
Space1	30	5	15	20	0	1	1	Temporary	Yes	No	60
Space2	20	15	10	10	1	0	0	SelfStudy	Yes	Yes	75
Space3	25	10	25	15	1	1	0	SelfStudy	Yes	No	80
Space4	15	50	100	35	0	1	1	SelfStudy	Yes	No	90
Space5	50	25	10	15	0	1	0	Temporary	Yes	Yes	30
Space6	65	30	5	10	0	0	1	Temporary	Yes	No	85
Space7	75	10	50	25	1	1	1	Meeting	Yes	No	90

Image 10.4 Alternatives in the model (own illustration)

Step 3. The step thereafter was "Elicit Scores" in which the values of the users preferences were asked. This was expected to be the least comprehensible step as it could easily be too abstract for users which values were asked. Therefore additional guidance was implemented in the form of text boxes. This however still required the users to read the text boxes and showed to still be insufficient to make users understand which values needed to be filled in, as shown in the interviews (Appendix 2).



Occupancy Rating	Occupancy(%)	Preference rating
Top	0	100
Intermediate	10	20
Bottom	70	0

Distance to Current Location	Distance(m)	Preference rating
Top	0	100
Intermediate	50	70
Bottom	100	0

Distance to Printer	Distance(m)	Preference rating
Top	10	100
Intermediate	30	70
Bottom	100	0

Distance to Catering	Distance(m)	Preference rating
Top	50	100
Intermedi	100	80
Bottom	200	0

Layout (Binary)	Open/Closed	Preference rating
Open	0	100
Closed	1	0

Lightingtype (Binary)	Natural/Synthetic	Preference rating
Natural	0	100
Synthetic	1	0

Silence (Binary)	Yes/No	Preference rating
Yes	0	100
No	1	0

Feedback Rating	Rating (%)	Preference rating
Top	100	100
Intermedi	60	50
Bottom	0	0

Determine the scale and Scores.
1. First determine the scale of the criteria by assigning the top and bottom values.

2. Then assign what value is most preferred. Give a rating of 100 to the most preferred and a rating of 0 to the least preferred.

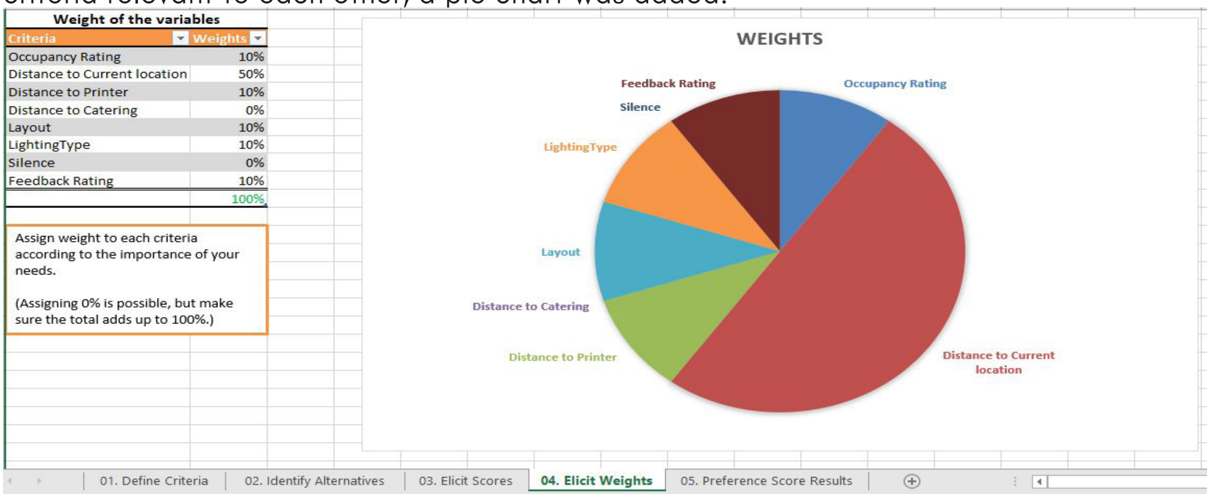
3. Finally determine an intermediate value. This must represent a value on the scale and can have any preference rating (wtihin 0-100).

Binary options

For the binary options i.e. only two options possible. Only change the preference rating to 100 for the most preferred and 0 the least.

Image 10.5 Elicit Scores tab (own illustration)

Step 4 required users to input the importance or weight of each of the criteria. To explain what is asked of the user a text box was included. For the mathematical function to work the percentage needs to be 100%. Therefore conditional formatting was used to show whether the total percentage of 100% (which then turned green), or did not meet this requirement (making the percentage turn red). Enabling users guidance for filling in the appropriate weights. Additionally, to help users to get an understanding of the weight differences of the criteria relevant to each other, a pie chart was added.



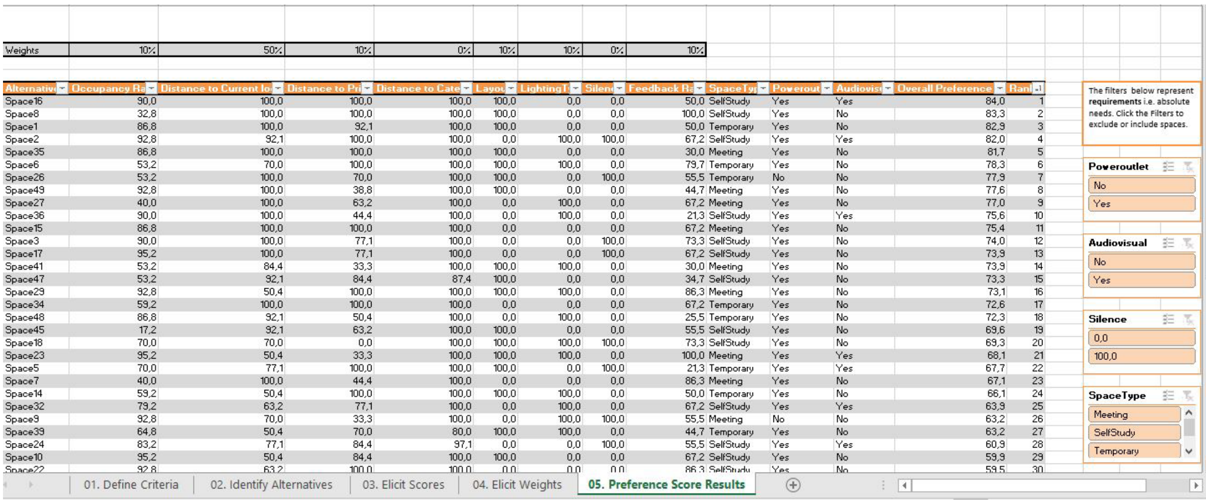
Weight of the variables	
Criteria	Weights
Occupancy Rating	10%
Distance to Current location	50%
Distance to Printer	10%
Distance to Catering	0%
Layout	10%
LightingType	10%
Silence	0%
Feedback Rating	10%
	100%

Assign weight to each criteria according to the importance of your needs.

(Assigning 0% is possible, but make sure the total adds up to 100%.)

Image 10.6 Changing weights (own illustration)

Step 5. Included the results of the mathematical calculations showing a preference score of 0-100 for each criteria. The overall preference score and ranking was shown in the right hand side as shown in image 7.7 For the "binary" criteria, the results showed a score of either 100, indicating they matched completely or 0 indicating that the criteria wasn't met at all. This allowed the system to still show spaces which did not met this particular aspect, while the space itself might have a high overall preference score. Contrastingly, one could also opt for a "requirement" meaning an absolute need which filters the results based on this attribute. This was shown on the far right allowing the user to filter the requirements on Silent spaces, Meeting-, Temporary Work- and Self Study Spaces. Also users were able to filter spaces on whether it contained a Power Outlet or Audiovisual support. To make the input values insightful, weights relating to each criteria were indicated above the results. This was to stimulate users to iteratively change their input to support them in calculating the desired results.



Alternative	Occupancy Ra	Distance to Current lo	Distance to Pri	Distance to Cate	Layou	LightingT	Silen	Feedback Ra	SpaceTyp	Powerout	Audiovis	Overall Preference	Rank
Weights	10%	50%	10%	0%	10%	10%	0%	10%					
Space16	90,0	100,0	100,0	100,0	100,0	0,0	0,0	50,0	SelfStudy	Yes	Yes	84,0	1
Space8	32,8	100,0	100,0	100,0	100,0	0,0	0,0	100,0	SelfStudy	Yes	No	83,3	2
Space1	86,8	100,0	92,1	100,0	100,0	0,0	0,0	50,0	Temporary	Yes	No	82,9	3
Space2	92,8	92,1	100,0	100,0	0,0	100,0	100,0	67,2	SelfStudy	Yes	Yes	82,0	4
Space35	86,8	100,0	100,0	100,0	100,0	0,0	0,0	30,0	Meeting	Yes	No	81,7	5
Space6	53,2	70,0	100,0	100,0	100,0	100,0	0,0	79,7	Temporary	Yes	No	78,3	6
Space26	53,2	100,0	70,0	100,0	100,0	0,0	100,0	55,5	Temporary	No	No	77,9	7
Space49	92,8	100,0	38,8	100,0	100,0	0,0	0,0	44,7	Meeting	Yes	No	77,6	8
Space27	40,0	100,0	63,2	100,0	0,0	100,0	0,0	67,2	Meeting	Yes	No	77,0	9
Space36	90,0	100,0	44,4	100,0	0,0	100,0	0,0	21,3	SelfStudy	Yes	Yes	75,6	10
Space15	86,8	100,0	100,0	100,0	0,0	0,0	0,0	67,2	Meeting	Yes	No	75,4	11
Space3	90,0	100,0	77,1	100,0	0,0	0,0	100,0	73,3	SelfStudy	Yes	No	74,0	12
Space17	95,2	100,0	77,1	100,0	0,0	0,0	100,0	67,2	SelfStudy	Yes	No	73,9	13
Space41	53,2	84,4	33,3	100,0	100,0	100,0	0,0	30,0	Meeting	Yes	No	73,9	14
Space47	53,2	92,1	84,4	87,4	100,0	0,0	0,0	34,7	SelfStudy	Yes	No	73,3	15
Space29	92,8	50,4	100,0	100,0	100,0	100,0	0,0	86,3	Meeting	Yes	No	73,1	16
Space34	59,2	100,0	100,0	100,0	0,0	0,0	0,0	67,2	Temporary	Yes	No	72,6	17
Space48	86,8	92,1	50,4	100,0	0,0	100,0	0,0	25,5	Temporary	Yes	No	72,3	18
Space45	17,2	92,1	63,2	100,0	100,0	0,0	0,0	55,5	SelfStudy	Yes	No	69,6	19
Space18	70,0	70,0	0,0	100,0	100,0	100,0	100,0	73,3	SelfStudy	Yes	No	69,3	20
Space23	95,2	50,4	33,3	100,0	100,0	100,0	0,0	100,0	Meeting	Yes	Yes	68,1	21
Space5	70,0	77,1	100,0	100,0	100,0	0,0	100,0	21,3	Temporary	Yes	Yes	67,7	22
Space7	40,0	100,0	44,4	100,0	0,0	0,0	0,0	86,3	Meeting	Yes	No	67,1	23
Space14	59,2	50,4	100,0	100,0	100,0	100,0	0,0	50,0	Temporary	Yes	No	66,1	24
Space32	79,2	63,2	77,1	100,0	0,0	100,0	0,0	67,2	SelfStudy	Yes	Yes	63,9	25
Space9	92,8	70,0	33,3	100,0	0,0	100,0	100,0	55,5	Meeting	No	No	63,2	26
Space39	64,8	50,4	70,0	80,0	100,0	100,0	0,0	44,7	Temporary	Yes	No	63,2	27
Space24	83,2	77,1	84,4	97,1	0,0	0,0	100,0	55,5	SelfStudy	Yes	Yes	60,9	28
Space10	95,2	50,4	84,4	100,0	100,0	0,0	0,0	67,2	SelfStudy	Yes	No	59,9	29
Space22	92,8	63,2	100,0	100,0	0,0	0,0	0,0	86,3	SelfStudy	Yes	No	59,5	30

The filters below represent **requirements** i.e. absolute needs. Click the Filters to exclude or include spaces.

Poweroutlet: No, Yes

Audiovisual: No, Yes

Silence: 0,0, 100,0

SpaceType: Meeting, SelfStudy, Temporary

01. Define Criteria | 02. Identify Alternatives | 03. Elicit Scores | 04. Elicit Weights | 05. Preference Score Results

Image 10.7 Preference Score Results tab (own illustration)

Conclusion

The test showed that the system still had a lot to gain in terms of usability. In particular, Step 3. Elicit weights demand much effort from users as it was unclear which value needed to be filled in where, what the values meant and what they did for the score. Therefore, much verbal guidance was needed. Furthermore, users were overall very meticulous with filling in their values which led to a lengthy input time of 10-15 minutes. In daily use, this would be far too great as users will most likely abandoned the Smart Tool because of the cognitive effort demanded to use it. However, it was shown that when users 'got the hang of it' they were able to input values at a much higher rate. Users also intuitively understood that they were able to change the values to get other results (see Appendix 2.).

Relating to the preference input values of users for "Distance to current location" were interestingly much higher than the values of the mock-up data. Reasons for this were they indicated that they imagined they would use it from home which was situated a couple of kilometers from the campus. In the results however, this showed that the "Distance to current location" mostly resulted in high preference score values for every space, making this criteria significantly less impactful for the preference score results.

Concerning the output of the system, the results did not show the attribute values of the actual spaces, but only the preference scores. Requiring users to go to a different tab to evaluate the results, which in terms of workflow, is considered to be demanding.

10.4 Prototype Version 2

As a result of the first user interviews it was established that users had difficulty with understanding how the system works and which values needed to be entered. Therefore, the primary focus of for version 2 was finding ways to improve understandability and usability of the system. One implementation of this was to improve navigation by having all the input fields on the same tab in excel to have better overview of the system by preventing the need to switch between tabs. However, if all the input fields had been put in one tab the understandability would most likely decrease dramatically instead of improve. Therefore, User forms were used, which are input windows which display after clicking a button, as shown in image 10.8

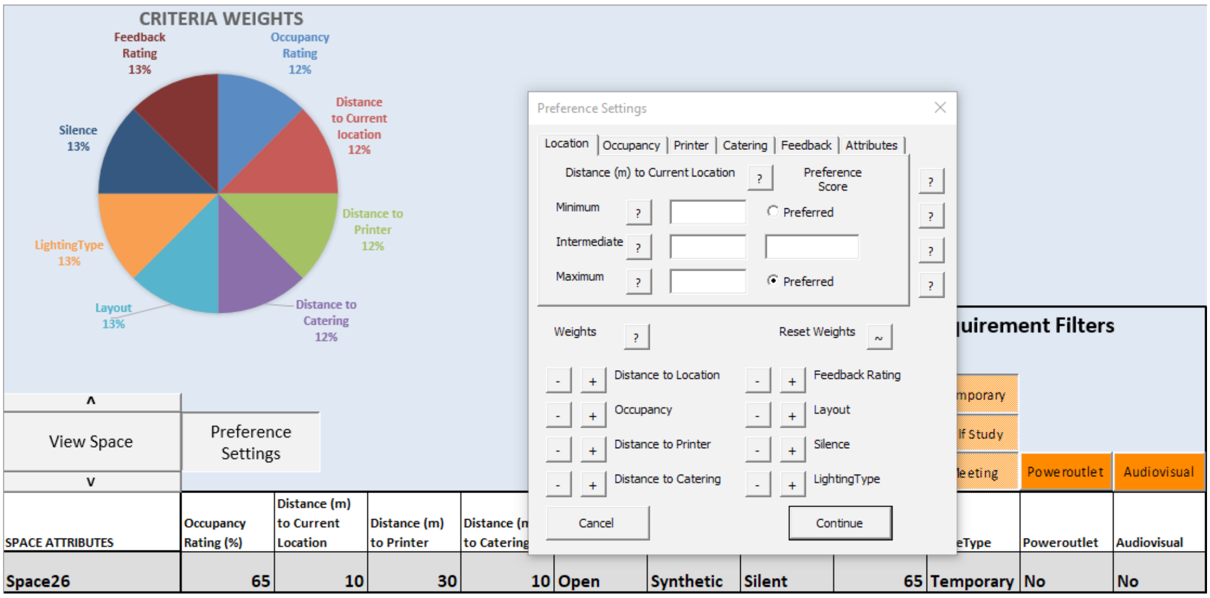


Image 10.8 Start screen after clicking preference settings button (own illustration)

Userform ares able to show users where to input data in the many fields it required without leaving the tab. The userform consisted of two sections: a top where the scales for preference modelling function are determined and a bottom where weight to the criteria can be given. The top was most intricate and therefore displayed above. Because the fields of each criteria are the same tabs are used in the user form itself which helps the user to focus on one set of criteria preferences at a time. Furthermore, users are able to learn fairly quickly that the criteria require a similar set of preference values, which is able to increase understandability. Throughout the whole userform many help buttons are placed to help the users in each of the task in the case he might get stuck. Furthermore, options buttons of which value is most preferred lessen the strain on users by allowing them to click instead of typing out the value, improving usability.

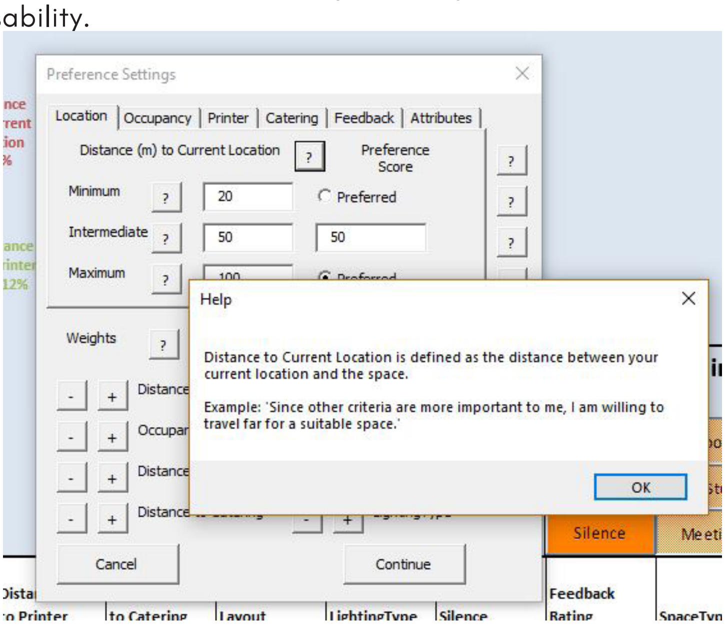


Image 10.9 Help button for distance to current location (own illustration)

In the bottom section of the user form a the criteria are shown with a set of buttons to increase or decrease the weight of the criteria. The buttons are set to increase the weight with increments of 5 on a scale of 0 to 100. The result of this is shown in a pie chart which displays the weights of criteria relative to each other in percentages.

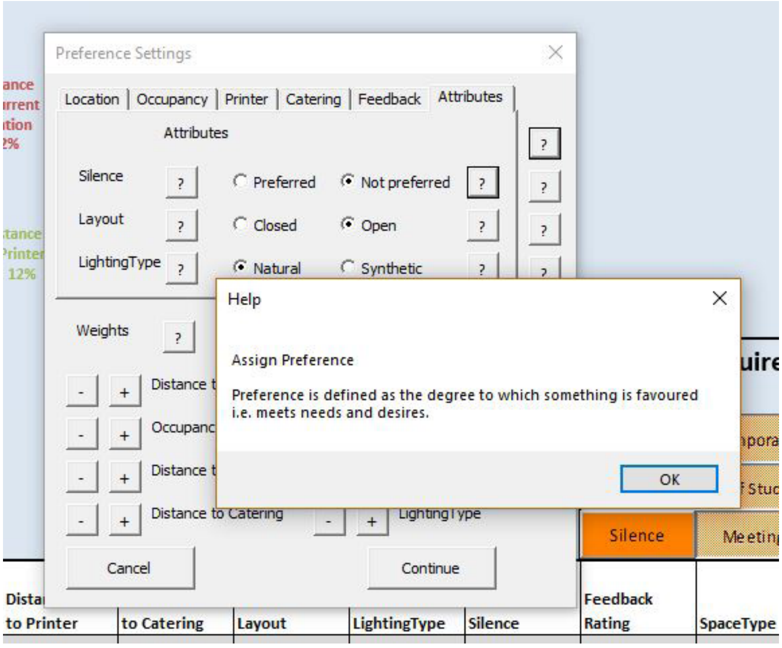


Image 10.10 Help message for assigning preference (own illustration)

When the preference values have been filled in by the user the preference scores are calculated by clicking on the continue button, automatically set up to select the highest ranked space. The results are shown in a table with all the spaces with every preference scores for each criteria and ranked according to overall preference score. To improve understandability of the results the preference scores are formatted conditionally. This shows the values of the preference scores of 0 to 100 with a gradient from green to red respectively. Other scores are shown with a progress bar indicating perceived distance.

^

View Space

v

Requirement Filters

Temporary | Self Study | Silence | Meeting | Poweroutlet | Audiovisual

Results

SPACE ATTRIBUTES	Occupancy Rating (%)	Distance (m) to Current Location	Distance (m) to Printer	Distance (m) to Catering	Layout	LightingType	Silence	Feedback Rating	SpaceType	Poweroutlet	Audiovisual
Space26	**65**	**10**	**30**	**10**	**Open**	**Synthetic**	**Silent**	**65**	**Temporary**	**No**	**No**

Preference Scores	Occupancy Rating	Distance to Current Location	Distance to Printer	Distance to Catering	Layout	LightingType	Silence	Feedback Rating	SpaceType	Poweroutlet	Audiovisual	Overall Preference Score	Rank
Space26	24,1	100,0	100,0	100,0	100,0	100,0	100,0	72,9	Temporary	No	No	87,1	1
Space38	69,1	46,4	100,0	90,3	100,0	100,0	100,0	86,3	SelfStudy	Yes	No	86,5	2
Space13	51,6	70,8	95,1	99,0	100,0	100,0	100,0	72,9	SelfStudy	Yes	Yes	86,2	3
Space3	89,1	100,0	100,0	100,0	0,0	100,0	100,0	91,7	SelfStudy	Yes	No	85,1	4
Space5	43,8	89,7	100,0	100,0	100,0	100,0	100,0	46,7	Temporary	Yes	Yes	85,0	5
Space30	100,0	32,9	100,0	100,0	100,0	100,0	100,0	46,7	SelfStudy	Yes	No	84,9	6
Space46	6,6	80,0	96,6	100,0	100,0	100,0	100,0	91,7	SelfStudy	Yes	No	84,3	7
Space17	100,0	100,0	100,0	100,0	0,0	100,0	100,0	72,9	SelfStudy	Yes	No	84,1	8
Space33	51,6	54,0	95,1	100,0	100,0	100,0	100,0	56,3	SelfStudy	Yes	Yes	82,1	9
Space31	69,1	0,0	100,0	100,0	100,0	100,0	100,0	80,0	SelfStudy	Yes	No	81,1	10
Space1	78,8	100,0	100,0	100,0	100,0	100,0	0,0	36,3	Temporary	Yes	No	76,9	11
Space24	69,1	89,7	100,0	99,0	0,0	100,0	100,0	46,7	SelfStudy	Yes	Yes	75,6	12
Space49	100,0	100,0	99,5	100,0	100,0	100,0	0,0	0,0	Meeting	Yes	No	74,9	13
Space16	89,1	100,0	100,0	100,0	100,0	100,0	0,0	0,0	SelfStudy	Yes	Yes	73,6	14
Space35	78,8	100,0	100,0	100,0	100,0	100,0	0,0	0,0	Meeting	Yes	No	72,3	15

Image 10.11 Results (own illustration)

A set of requirement filter buttons are added to give users the opportunity to specify their absolute needs. In the case that no results show or the user is unhappy with the results he is able to deselect the filter to show more results. This is able to either make a better representation of these demands or confront users with their demands.

Since the criteria preference scores show how much the (dynamic) attributes of space relate with the users preferences, it can give too little information about the actual attributes of the space. Therefore a row has been added which shows the attribute values of the space by clicking on the space name. This enables users to review the results and choose between the spaces regardless of preference score.

10.5 Database Structure

The database structure represent the storage (back end) of information which is needed to operate the proposed Smart Tool. To visualize this an Entity Relationship (ER) model has been constructed in MySQL workbench, which has been transferred to Access to demonstrate the principle of obtaining the right combination of data to display to the user as usable information. The ER model shows all the tables relevant to the proposed Smart Tool. For clarification, sections are made clear by using distinguishable colours, blue and red, signifying the geometric data and user settings respectively. An overview of the ER model is shown in image 10.12 below.

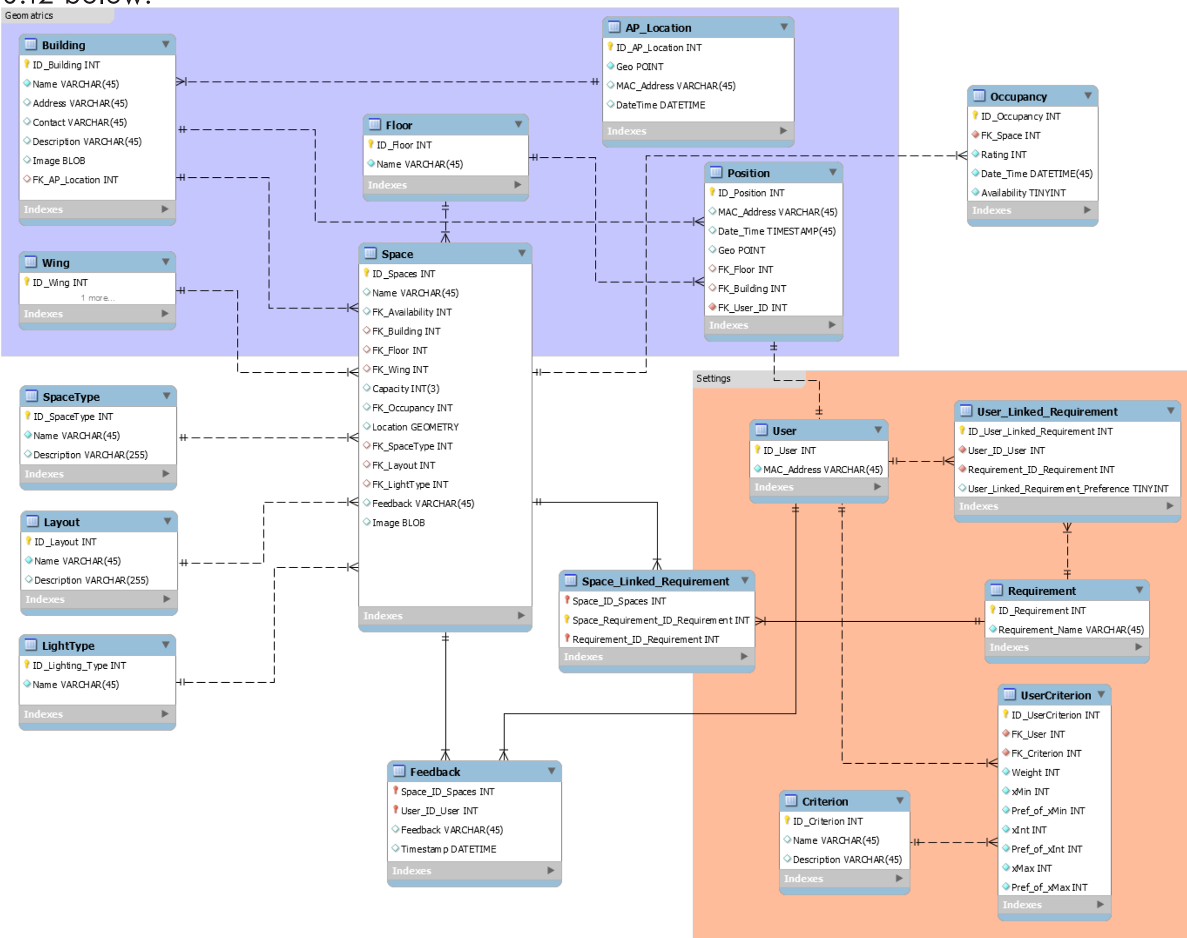


Image 10.12 Overview of the ER model (own illustration)

In the center of the ER model, the table with the most fields represents the space table. In this table all the information relation to the space is stored. To prevent data duplication and to assure referential integrity the database, and the space table specifically, is normalized. This is depicted as the several tables attached to the space table, which represent these normalized tables including: SpaceType, Layout, LightingType, Wing, Floor and Building. The relationship type from the space table to these normalized tables is many-to-one. Indicating that only one value can be assigned to a single space (i.e. a space can't have two layouts).

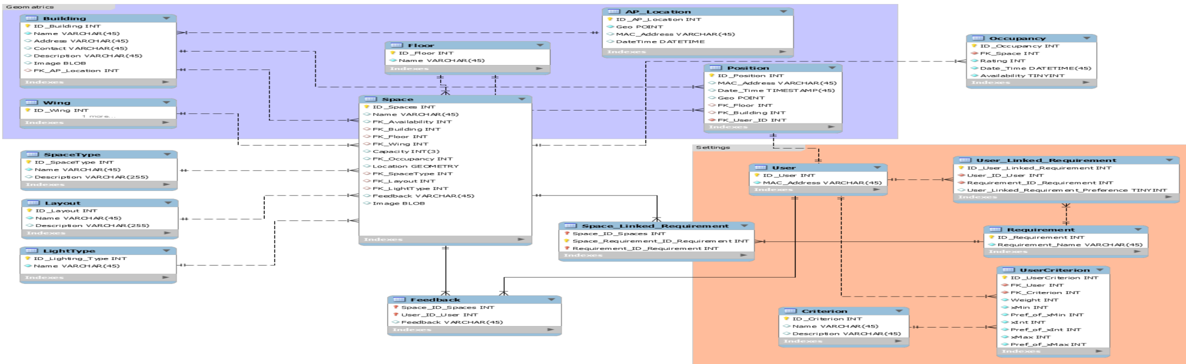


Image 10.13 Geometrics section (own illustration)

Geometrics

The Database has several tables which indicate the geometric location of spaces or users. In relation to this there are several related tables of which a combination is needed to determine or calculate the location in a building. For spaces, it is important to indicate in which building on which floor, wing is as a result of connection to a number of WiFi access points. Through connecting the spaces with the relevant Building and Floor tables, the space can be linked to a more specific location. This is needed to allow the calculation of the distance between the user and the space and enables the display of relevant information on which the user can make a decision. Similarly the position of a user in time in relation to several AP location detections is needed to determine his location, which is stored in the Position table. Additionally, these user positions are aggregated into availability of space and an occupancy rating for the specified space. The space is specified by defining a area using vector polygon stored within the database.

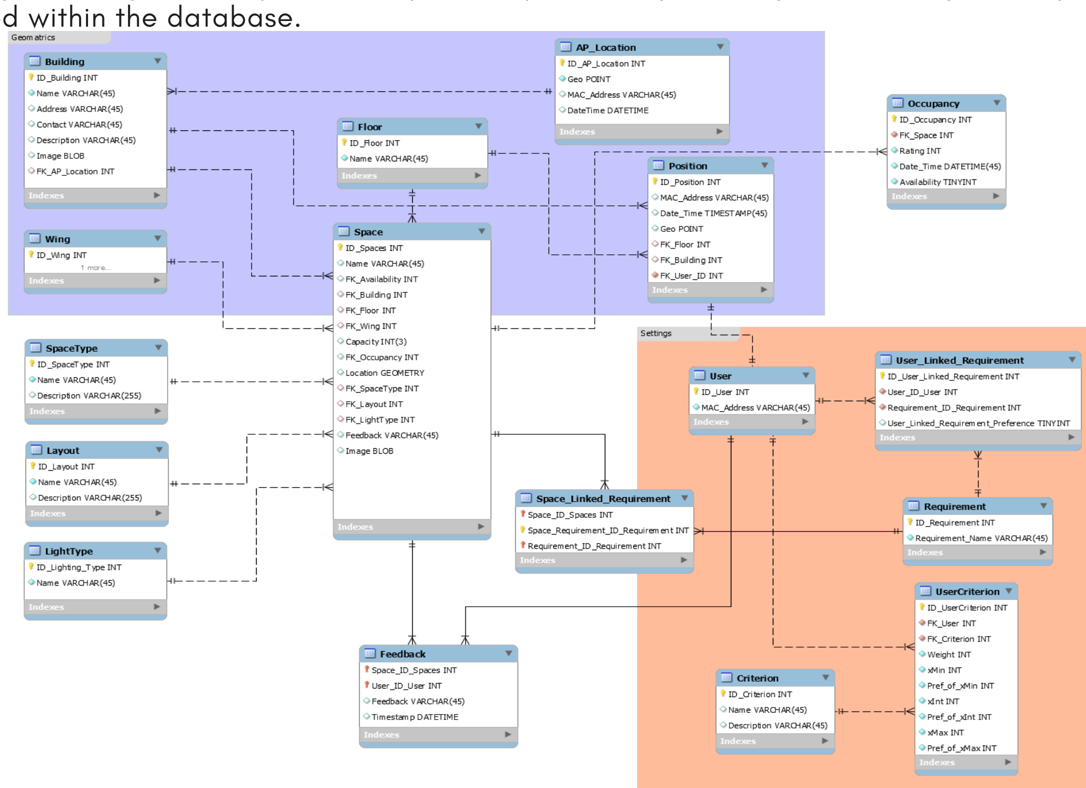


Image 10.14 User Settings section (own illustration)

User Settings

As stated above the user is firstly connected to a number of AP which enables the determination of the users position within a certain building. As a result of this a users position if relation to spaces can be aggregated to find spaces nearby. However, for determining the match based on the preference score the preferences and requirements of the user also need to be stored. For the requirements an associative table is used to enable many-to-many relationships, hence a person can only have one set of requirements. The values for user preferences are separated into a table, which in turn is linked to a table which stores the different criteria. This enables each of the users a set of values for each criterion. Concerning feedback of spaces the users are linked to spaces with a separate feedback table. This enables the user to give multiple feedback ratings over a period of time and spaces to obtain feedback from multiple users.

Through queries a view is created which shows a ranking of spaces based on preference function modelling through combining the requirements, feedback and the criteria input and settings of the user.

10.6 User Interface

This section will explore the workflow of the proposed Smart tool in a mobile application form. For this a wireframe model is constructed with use of the program Balsamiq. A wireframe is chosen in this stage of the design because it does not distract users with commenting on stylistic issues (i.e. colour schemes or transitions). Balsamiq allows users to interact with the screens allowing them to get an idea of the workflow and how to navigate the mobile application. The wireframe, however, does not work other than allow users to go from one screen to the next and is therefore dubbed a mock-up.

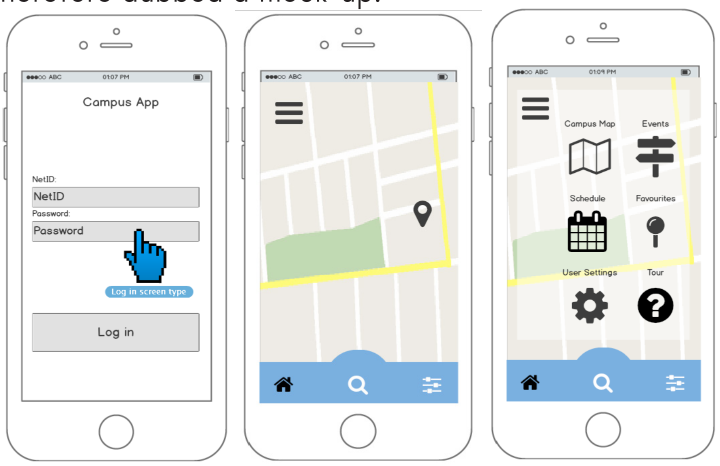


Image 10.15 Starting screens (own illustration)

Starting

After starting the application the user is asked to log in. This will allow his personal settings to be stored needed for a number of functions (i.e. favourites or schedule). When logged in the user will see his own location, a menu button at the left top corner and a navigation bar along the bottom of the screen. The navigation bar shows a home, search and settings button which can be clicked at any moment to navitage. It also indicates which function is active by changing colour. The functions of these buttons will be explained in the next section.

When clicking the menu button, an overlay shows with a number of functions including: a campus map, events, schedule, favourite spaces, user settings and a user guide. The campus map shows a digital map of the campus with all its facilities, possibly including the occupancy ratings per building or space. Events show what events are upcoming and can be personalized to relate to the faculty or interests of the student. The schedule shows the upcoming lectures, projects and workshops planned for the student. Favourites shows the favourite spaces of the user which are chosen by himself. This allows the user to quickly check what the occupancy ratings or wether the space is available are for example. The user settings include the users preference settings for finding a suitable space and other settings. Guide represents a walkthrough for users who need additional help with the functionality of the tool. When the app is used for the first time this walkthrough will show up after logging in to support users in first use.

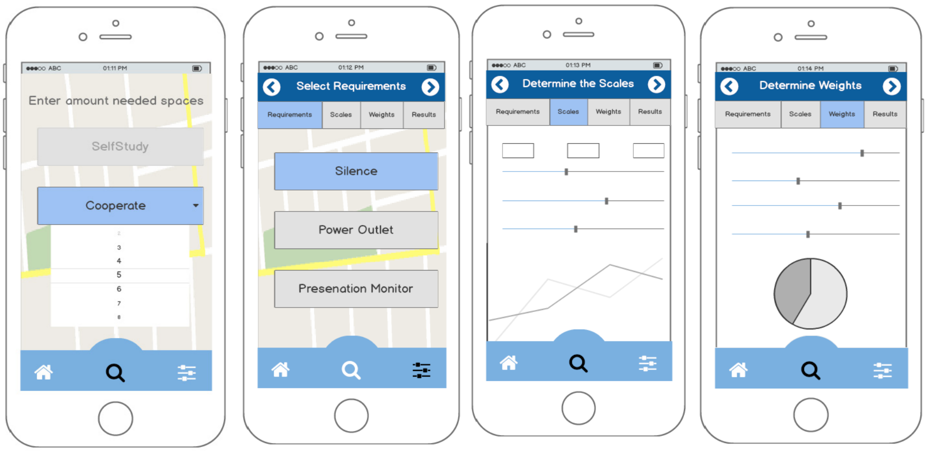


Image 10.16 Input screens (own illustration)

Input

When the search button is clicked it is asked how many are needed in the form of the buttons "Self study" or "Collaborate". When clicking self study the next step will be indicating requirements while collaborate asks for a number of people in the form of a drop down before continuing to this step. Multiple requirements can be selected or deselected before going to the next step, for which another navigation bar has appeared. By clicking the user is able to navigate to and within the following steps. However, when no data is entered the model should indicate this and show which field or step is incomplete. The Determine scales and Determine weights steps remain fairly abstract in this wireframe model, but relate to the functionalities explained in the PFM excel model.

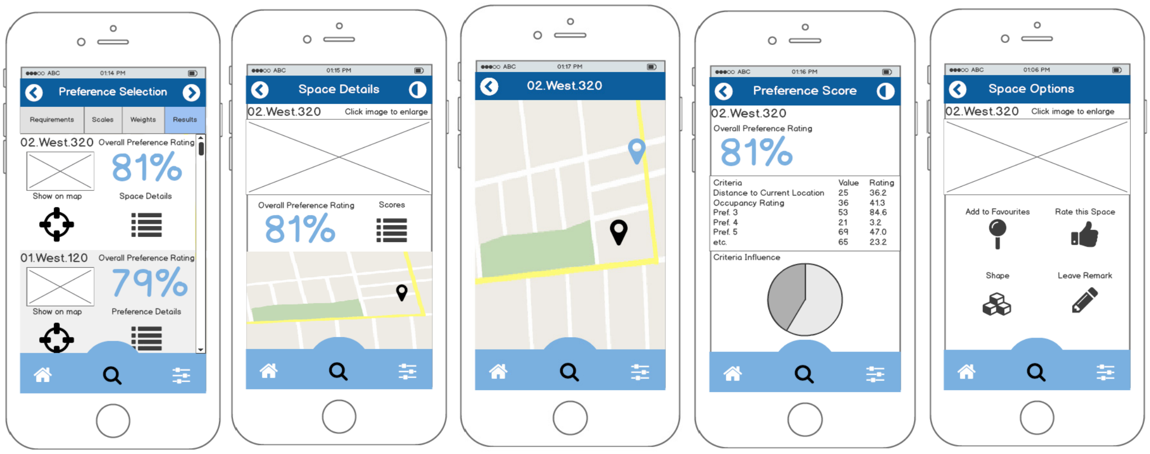


Image 10.16 Result screens (own illustration)

Results

After the values have all been put in the results are shown as as interactive list. The list contains fields for each spaces ranked according to highest overall preference rating. The fields show the overall preference rating, a small photograph, two buttons indicating ""navigate to" and "show details". When the show details button is clicked the space menu opens allowing for additional information to show. Thereafter the preference scores can be checked, the photograph can be enlarged, the space location can be shown with the buttons respectively or the options can be clicked in the top right corner. The space options allow the space to be added to favourites, a feedback rating of 0-100 to be given or remarks to be left to support facility management.

10.7 Conclusions

Reflection Deliverables

In this next section there will be reflected upon the deliverable to see how much the predetermined functionality of the Smart Tool has been met.

Must-have	Should-have
Selection model based on preferences, requirements (& availability)	Net-id integration (Single sign-on)
Preference match selection	Campus integration (2 or more faculties in the database)
Dashboard for data visualisation	UI design for mobile app
User-bound preferences (saved)	
Nice-to-have	Forget-about-it
Live link for occupancy determination	Events
Determination availability studyplace level	Way-finding
Brightspace schedule integration	3D model
Favourites	Mobile app
Booking system	Safety

Table 3.1 Deliverables

Every functionality within the 'must have' category has been realized, with the exception of the data visualisation dashboard. The (Excel) model is able to filter spaces based on availability (though not real-time), requirements and preferences. Data visualisation proved to be of lesser importance for the research as it requires larger quantities of data to visualize meaningful lessons. How this is visualized does not have much value for this research as this depends on the output of data. Thus, with the absence of data it is impossible to visualize data thus making the construction of dashboard obsolete at this stage. However, if the proposed smart tool will actually be implemented such a dashboard for data visualisation and analysation is very valuable. One could argue that it is essential for the transformation of data to management information to be useful in supporting decision making.

Within the 'should-have' category two functionalities have been realized within this research. The groundwork for the integration of multiple facilities or the entire campus has been realized by developing the database structure. Though, this database still needs to be filled with the attributes of the spaces in order to work. This is expected to take significant amount of time if this information is not present in another database. The other realized functionality is the user interface for the mobile app to show the workflow and enable to determine how users will interact with the smart tool. This proved very helpful within the research.

For the latter two categories, most has unsurprisingly not been realized with the exception of the underlying database structure for 'favourites' and 'live link for occupancy determination'. The database structure has been designed to allow these two functionalities. However, achieving the functionality of live occupancy determination will require significantly more effort and resources.

Lessons from the prototype evaluations

In the following section the results of the system is explored by using the lessons from the prototype evaluations with students. In general it is important to pay much attention to the usability of the smart tool as this determines whether the tool will actually be used. It proved to be fruitful to involve the end-users in the design of the system to determine what works and what doesn't and to make the appropriate changes iteratively. This is for example shown in the system after facilitating use by putting the input fields on one single tab to avoid navigational issues, implementing a userform to focus the users attention and integrate help buttons for guidance. Ultimately, all the students recognized the added value of the tool in finding study spaces, which is able to support them in finding study spaces.

Usability

It was made clear that using Preference function modelling is not designed for users on this scale but rather in making complex decisions and by generating alternatives. The purest form of the method is not desired from a user perspective as it was shown users need considerable (mental) effort to determine their preference values. However, if these values only need to be input once the strain on the user is significantly reduced and acceptable. Therefore it is beneficial for the workflow to place the preferences in the settings instead of requiring users to input these values on a daily basis, as it would take too long. Furthermore, the users clearly showed that once they became familiar with the system they were able to more easily adapt their preferences. This indicates that there is a level of intuitiveness in the the system, making it less daunting after first use and can stimulate users to make adjustments to their settings to meet their preferences more accurately.

It has become clear that much needs to be gained in terms of usability, as the students communicated that they are easily frustrated when something does not work accordingly. One student even stated: *'It has to work 100% the first three times I use it, otherwise i won't use it anymore'*. However, for this research the principle of the smart tool needed to be clarified to test on users and some flaws in the design are to be expected.

Preference criteria

All of the interviewed students indicated that the most important aspects were distance to the current location and the occupancy of available spaces. However, there were clear differences in the distance users were willing to travel to a space. This difference is caused by whether students have a bike to travel or not, which unsurprisingly greatly increases the distance they are willing to travel to a suitable space. The students also indicated that the travel distance also depends on their current location and situation they are in. Meaning that if a student is situated at home he is able to make a decision on what building to go to before he leaves, meaning he can travel directly to the study space. When the student just finished a lecture, this demand might be different as he needs to study or work on his projects quickly (maybe even collaborating), therefore looking for a study space nearby. In another case, during a busy exam period the available study spaces are increasingly hard to find which reinforces the need for a study space findability tool.

Considering the criteria which were implemented in the smart tool most were considered important. However, the feedback rating was not understood primarily and since users indicated that they would not actively participate to give feedback to spaces this might not need to be implemented. Additionally, this criteria was not given much weight either.

However considering the non functional criteria clear difference in preference could be seen for each user. Most users preferred a closed layout for example, but one preferred an open layout. Similarly most preferred a space with natural lighting while one preferred a space with synthetic lighting. This student showed that he preferred spaces with synthetic lighting and a closed layout, most likely because it would be a more quiet space.

The weight users assigned to the criteria also had clear differences. Some students laid more emphasis to a single criteria whereas others had a more balanced division of weights.
The former was mostly the case for the criteria occupancy rating and distance to current location, which unsurprisingly was also stated to be the most important criteria. Overall the functional aspects of spaces are considered most important which confirms the research of Beckers, van der Voordt, & Dewulf (2016).

Results
Considering the results students showed and stated that they would go through a few spaces to review them to decide which of the top (5) ranked meets preference most. Some users indicated they would review the values of the results while others were only interested in the overall preference score. However, it was communicated that to enhance the overview of the results it is best to hide these values behind a window or button. Furthermore, the location of the space is something that was considered important and even more so a way to reach that destination, especially in indoor environments.

Missing link between students, CREM and FM
In general students feel like there is a lack for them to communicate their needs and requirements with the ones responsible for the real estate supply. Even the student who was involved with the project relating a facility management service point for students agreed that even though there is a way for students to approach facility management it remains very daunting. Furthermore, students would not take the effort to use it as it usually lacks urgency or they do not feel responsible.

Some students indicated that they could be incentivized to use the system more if it was clear to them that the data the system generates is able to improve the campus. To realize this it is important to state this added value explicitly to inform the users. However, other users also indicated that they would only use the smart tool for their own benefit.

User satisfaction
In relation to giving feedback ratings of spaces to indicate satisfaction the users stated that they would not use this functionality very often. They indicated two cases in which they would use it: when a space dramatically underperforms or doesn't meet expectations and when a space performs exceptionally well. While if a space performed 'ok' or 'as expected' the users would not be incentivized to give feedback. One student stated that he would give feedback about 10% of the cases to indicate the amount he would use giving feedback. Furthermore, the evaluation showed that the users would prefer a single option button to assign feedback (i.e. like or dislike) rather than giving a rating between 0-100.

Task Load Index
The Task Load Index (TLX) was used to assess the workload on students while using the system. For this, students indicated the perceived strain while using the prototype on a scale of 0 to 100, with 50 representing neutral, on the following criteria: mental demand; physical demand; temporal demand; performance; effort; frustration. The scores of each of the students during each prototype evaluation (version 1 and 2) is analyzed alongside the criteria.

Criteria	Findings
Mental Demand *'How mentally demanding was the task?'*	In all cases the students indicated that the mental demand was high (70-75). This comes at no surprise as the required number of values is high initially and it is not always clear what the values mean. In particular users had trouble for understanding and indicating what the intermediate value and its respective preference score was.
Physical Demand *'How physically demanding was the task?'*	Unsurprisingly, the physical demand on the users was low as it only required them to fill in values on a laptop.
Temporal demand *'How hurried or rushed was the pace of the task?'*	This relates to the timeliness of the results and the time pressure users felt during use. Because the system primarily took a long time to use (approximately 15 min.) This scored low in the first version. However, after the user form had been implemented it became clear that the understandability and usability was improved which resulted in a greater speed with which the system could be used (approximately 8 min.), which was reflected in the score for temporal demand.
Performance *'How successful were you in accomplishing what you were asked to do?'*	Relating to performance the students communicated that the system was able to help them in making decisions on where to study. Therefore, high scores were given of the performance in general (+/- 75). However, the performance was obstructed by some faults in the system. Since these are design flaws due to the inexperience of the systembuilder, it is not expected that these performance issues will translate into the actual functioning of the system.
Effort *'How hard did you have to work to accomplish your level of performance?'*	In relation to the mental demand effort was scored lower (55-65). Indicating that the users perceived the workload other than the mental demand acceptable.
Frustration *'How insecure, discouraged, irritated, stressed, and annoyed were you?'*	The level of frustration was scored divergent, which most likely is the result of some of the flaws in the system caused by the inexperience of the systembuilder. However, this also shows that users can easily get frustrated if the system does not work as expected. Therefore, making the system foolproof (i.e. working completely and understandable) is a essential for the acceptance of the system.

Image: http://www.braaksma-roos.nl/project/bk-city/

PART V

CONCLUSION

11. CONCLUSIONS

The aim of this chapter is to conclude on the findings of this thesis by answering the main research question. Before this, the (11.1) problem statement and (11.2) hypothesis are reintroduced to help the reader contextualize the research. Following this, the (11.3) research objective and corresponding (11.4) main research question is stated. Thereafter, the main research question will be answered, first more generally (11.5) and then more specifically (11.6).

11.1 Problem statement

There is a lack of information on demand to support campus management in making campus space decisions. This includes information on the utilization of space and information on user satisfaction. Students also lack information on the availability and aspects of study space which causes problems in finding preferred space to study. This can cause frustration and dissatisfaction of students, which can ultimately negatively influence the productivity and competitive advantage of universities. Therefore, it can be argued that there currently is a lack of a way to provide information to align dynamic space demand with supply on both the long- and short term.

11.2 Hypothesis

It is hypothesized that the described problem can be solved by providing information about study spaces with the use of smart tools (Valks, Arkesteijn, den Heijer, & Vande Putte, 2016, p 18). With regard to the use of the university campus or real estate, the objective is to increase both the *effectiveness* of the alignment of supply and demand while optimizing the *efficiency* of space use.

11.3 Objective and main Research Question

The research objective was developing a smart tool that provides information to improve the alignment of space demand and supply for both the user and campus management. The research objective is formulated into the following main research question:

"How can a Smart Tool provide information to align dynamic user demand more effectively and efficiently with campus space supply on both the long and short term?"

11.4 Main Conclusions

This question is answered by developing and designing a smart tool that enables the interaction between users and real estate. The research proposes a smart tool that supports users in finding an appropriate study space based on their preferences. To achieve this this Preference Function Modelling (PFM) is implemented in a smart tool to calculate which of the available spaces correspond most with the user's preferences. This has been realized by constructing an Excel model which enables users to input values for several preference criteria. Installed on this Excel model is a Lagrange function which processes the preference value input of the user. The Lagrange function is able to output a ranking of spaces according to space attributes and the user's preferences. Additionally, the user is presented options to filter out any spaces which do not comply with any requirements. For example, if a user requires a power outlet there is the option to filter out all the spaces which do not have a power outlet. Ultimately, the user is presented with a ranked list of spaces, informing of which spaces most comply with his/her preferences. Based on the evaluative interviews it is expected that this would be able to inform and support users in making a decision on where to study.

The smart tool simultaneously stores the preference input values users enter into the smart tool for two purposes, representing the short and long term respectively. The input is stored to the user settings to (1) increase usability and prevent the user to fill in his preference values every time. Usability is (very) important as it determines whether a (smart) tool will actually be used or abandoned. It became clear during prototype evaluation that the initial cognitive effort was undesirably high. Therefore, to increase the likelihood the smart tool will actually be used, it is important to store the input values for later use. This allows use of the smart tool without entering the values every single time. While also allowing users to 'tweak' their input values to represent their preferences more accurately.

The smart tool also gathers the input data of user preferences to (2) analyze at a later moment. In the case that a large number of campus users utilize the smart tool to find their preferred study spaces, a large dataset of campus user preferences can be extracted. The stored user data can be analyzed to possibly find new insights on the preferences and behaviour of users. It is expected that this will lead to a more accurate representation of demand. Consequently, this data can be compared to the current campus to see how much supply aligns with this demand. All the uses of campus management for this data are described more extensively in section 8.6, the 'added value of the smart tool'.

In conclusion, the findings from the interviews suggest that the proposed smart tool can potentially add much value for both the user and campus management. The users generally reacted very positive to the concept of the smart tool. This shows that the smart tool will have significant value in supporting study space findability when executed correctly. To achieve this, usability of the smart tool is crucial for ultimate use. As this research comprises a design problem, it is important to realize that design problems can be solved in numerous ways, each leading to various results. Therefore, this can be seen as one of the possible ways a smart tool is able to support alignment of campus space. The benefits of using the proposed smart tool is described more specifically in the next section.

11.5 Arguments for improved alignment

This section will give a more detailed answer to the main research question by describing the conclusions along four perspectives distinguished in the main research question. These include alignment effectiveness and efficiency, in the short and long term. An overview of the arguments for each of these aspects is shown in the table below. Thereafter, each of these arguments are described in more detail, starting with the short term and ending with the long term.

Alignment of demand and supply		
	Efficiency	Effectiveness
Short term	A higher efficiency is achieved by the ability to find a suitable study space more quickly. This is done by providing information on the most suitable spaces by ranking space according to preference.	Users are supported in finding a more suitable space according to needs and preferences by providing information on spaces. Therefore, it is expected that the selected space will more effectively support demand.
Long term	A findability tool allows to use space more efficiently. It is argued that the more efficient space is used, the higher the need for a findability tool will become.	With a more accurate representation of demand, supply can be aligned more accurately as a consequence. Ultimately this can lead to making better decisions concerning the real estate supply.

Table 11.1 Arguments for the improved alignment of demand and supply

11.5.1 Short Term

Following the construction of the smart tool, the prototype evaluation functioned as a way to determine how much users are supported in the short term alignment to supply in effectiveness and efficiency. Based on the student interviews to evaluate the functioning of the smart tool (see Appendix 2), it can be concluded that the smart tool is able to more effectively and efficiently align demand with supply on the short term.

Efficiency

With regard to the efficiency of the alignment in the short term, the smart tool provides information which could potentially lead to a decreased time to find and travel to a study space. The smart tool initially requires effort to input the values for the preference criteria. If this input process is not taken into consideration, the use of the smart tool will take significantly less time. Hence, the ability to store the input values in the user settings. When the results are shown to the smart tool user, he/she will be informed with the spaces are most suitable for their study activity. By providing this information, the user is prevented to search a building. Searching a building can involve travelling to a section of a building only to find out that the space does not meet the user's preferences, requirements or is simply unavailable. Thus, it can be argued that (user) demand is aligned with supply more efficiently by supplying information on the suitable spaces to allow users to travel to a space directly.

Travelling to a space can be supported even further by providing a map showing a location and possibly wayfinding, which is defined as the calculation of a route through a building. Both of these functions are currently not executed in the prototype of the smart tool, but rather expressed in the mock-up due to time restrictions. Additional value of the integration of wayfinding includes that users are incentivized to make a choice of which space to travel to. Not only does this reward the user in being supported to find the space in less time, but it also generates valuable information which can be used to analyze which spaces are chosen most often and the reasons for it.

Effectiveness

As the smart tool shows a ranking of spaces based on the preferences of the user, it is suggested that the demand can be aligned more effectively. This is the result of multiple factors. (1) As the smart tool is used in actual situations of campus use, the user is less likely influenced by misinterpretation or bias. (2) If a user is confronted by his/her demands they are more likely to change them if they do not comply with the situation. Therefore, if there are no spaces available which fully conforms with user preferences but requires the user to lower requirements, the user is presented with the opportunity to do this.

For example, in the case that a student needs to study quietly for the rest of the day, but all the library space is occupied, because the student had lectures in the morning. The smart tool is then able to provide information of other quiet study space to study the whole day, while it may require the student to travel further. Another case may be that a student needs a printer nearby because he/she needs to print to hand in an assignment for example. Therefore, this criteria is more important. Consequentially, the weight of this criteria can be increased to find a space which has a printer nearby, while it may require the student to settle for a less ideal space to study for a longer time. Contrastingly, when a student needs to work on a project in between classes for example, the preferences also might change. In this case the student is more interested in a space nearby where he/she is able to work, while having a power outlet becomes less important in that case. These are some of the examples the situation the student is in might influence preferences for a study space.

Thus, the user is able to 'tweak' his preference input values to more accurately represent demand for different situations. Furthermore, if the standards are too high, the user is confronted by the results, which can lead the user to change some of the filters or preference values.

11.5.2 Long Term

Following the construction of the smart tool by implementing PFM, it was expected that the data that was generated would support campus managers in aligning demand with supply more effectively and efficiency. This section will argue in which ways the smart tool is able to do this based on the semi structured interview with the campus managers to evaluate the results of the smart tool (see Appendix 3). For example, the data can indicate that there is not enough space of a certain function. Then, campus management can see whether this demand can be met by reallocating functions/reorganizing the building, preventing the construction of a new building. This was one of the examples given by the real estate developer of the TU Delft Campus. Therefore, it can be concluded that the smart tool is able to generate data which can potentially lead to a more effective and efficient alignment of demand with supply over the long term. However, the use of the data ultimately depends on how the data will be transformed to information and how this information is used.

Efficiency

Regarding the alignment efficiency in the long term, the main argument that can be made is that the smart tool supports the findability of study spaces improves efficient space use. As previously determined, students can quickly come to the conclusion that there are not sufficient study spaces when they have trouble locating them. When the number of study spaces is decreased, students will perceive the lack of sufficient spaces more easily. Hence, if the number of study spaces is decreased the findability will become increasingly important. Alternatively, a higher degree of study space findability will allow to decrease the amount of study spaces, leading to a more efficient use of space.

Effectiveness

As a result of the accumulated data on user preferences, real estate interventions can increase the alignment effectiveness of demand and supply over the long term. More specifically, the preference data supports campus management in making decisions by (1) serving as a quantified means to support decision making (e.g. convince stakeholders). It does this by indicating what space types and spatial aspects are most demand by stated importance. A more indepth use of the generated data to increase the effectiveness over the long term is described in section 8.6, the Added value of the smart tool.

11.6 Added value of the Smart Tool

This section will describe the added value of the proposed smart tool. It will do so by using following structure: Firstly, an in-depth description of the added value by relating the outcome to the DAS Frame. In each step the value of the generated data to the campus management process is discussed. Lastly, because the Smart tool can be seen as a contribution to the real estate supply and thus a real estate/IT solution, it is related to these ways to determine the added value. Therefore, the smart tool will be related to the ways real estate is able to add value.

11.6.1 Implications to Campus Management Process (DAS)

The DAS frame can be used to describe the steps campus manager need to take to achieve alignment of supply and demand. In this section the value the proposed smart tool can add to the steps in the DAS frame is described.

1. Assess the current situation:

The essence of assessing the current situation is to determine how much the current real estate supply meets current demand. In current management practice the assessment of the current situation is approached more traditionally. Currently the supply is assessed by benchmarking and by interviewing several students or representations of students annually.

Considering the results that the proposed smart tool yields, a better representation of campus user demand, campus management can more accurately assess assessment of the current situation. Since this representation of demand can be compared to campus space supply the match with demand can be determined in the functional perspective. In the case that certain criteria or spatial aspects appear to be more important in campus study spaces than is currently present, it should appear in the generated data. When this is discovered after analyzing the data, campus management can subsequently act to by making decisions of how this demand will be met. When the campus space supply is aligned better with the representation of demand it is expected that a higher user satisfaction is achieved.

Likewise, by giving the option to give feedback on spaces, campus management can be made aware of how users experience the current real estate supply. More specifically this can show which spaces are considered 'below standards'. When a space is can repeatedly badly rated, it indicates the need for real estate interventions and perhaps prioritizes them. Additionally, the degree to which spaces are received negatively or positively by its user gives an indication of the overall user satisfaction. In any case, when space is frequently considered as 'below standards' campus management is able to more specifically analyze why the space is underperforming and how improvements can be made.

By no means does this mean that gathering qualitative information of interviewing users becomes obsolete. Both forms of information gathering will support one another by acting as a form of verification or contradiction leading to a better representation of demand. This can be seen as trilateration (i.e. the use of multiple sources of information results in a better representation). However, because the smart tool generates more data it is expected that this will lead to a better representation of demand and becomes easier to identify underperforming space.

2. Explore the future demand:

For exploring changing demand many tools are able to explore trends and developments of the future campus on the basis of qualitative information. However, it is important for campus managers to generate quantitative data to support the identification of trends and developments affecting the organisational, financial, functional and technical requirements. These developments can be expressed as programmatic requirements in terms of m2, required qualities, function mix and available budget (Den Heijer, 2011, p. 166).
atoi Since the proposed smart tool is able to give a better representation of campus user demand and this data is being generated passively it is possible to analyse the accumulated

data over a periods of months or years to see whether patterns or trends can be recognized. After this recognition campus management can be informed of developing trends and have quantified means to support decision making. This can be done by mining or analyzing the data to find long term patterns which can be used to anticipate the future. After these patterns are translated into expected future demand the supply can be adapted accordingly.

It is important to realize that the trends cannot be followed blindly but has to be thoroughly evaluated and supported with qualitative information. This is because there is significantly valuable to understand the underlying reasoning behind these trends and patterns. Furthermore, the degree to which the generated data is useful depends on the quality of the analysation of this data. However, one must remember that no matter how much information, the future remains very hard to predict.

3. Generate future models:

The objective of 'Generating future models' is finding a satisfying match between future demand and future supply. The generated future models (supply) should match with the changing organisational demands determined in the previous step (exploring changing demand). For a university, future models can be determined for four different physical scales relating to four different organisational levels. On the supply side this includes future models for the (knowledge) city, campus, building and places or functions within a building (workplaces, lecture halls and libraries). On the demand side these models need to align with the changing goals of the municipality, university, faculty and individual users of the campus: students and (academic) staff members (Den Heijer, 2011, p. 175). Thus the objective in this step is to make a model of the supply side satisfying the demand side on various scales. In current campus management practice, future models are being generated without much user involvement.

With regards to this step, the outcomes of the data analysation can provide inherent suggestions for adaptations to the real estate. The preferences of the individual users of the campus, can indicate that some functions are more frequently needed or more important. These preferences can inherently suggest models for the supply on the campus, building and functional level. For example, the demands can show a higher demand for a certain study space (e.g. collaborative spaces) after which the future model can include more of these studyspaces, leading to a more effective alignment. These demands can then be translated to the amount this type of space is implemented on a building or campus-wide level. Hence, choices can be made to comply with these demand by translating them into different levels of scale. Similarly, the weight users give to certain criteria can be translated into the building or campus models to reflect this.

4. Define projects:

In the fourth step of the DAS frame, projects are defined to transform the current campus into the future campus. When new projects are defined campus managers make business cases by specifying the project in terms of input and output of resources. This requires specific input in CREM variables, but also output data from comparable projects to generate management information. It is important to remember that defining projects requires the
assessment of its contribution to the future campus. Therefore, the presumed contribution to the university's performance (ex ante) is made explicit to evaluate decisions over time (ex post).

There are several ways the more accurate representation of demands through generating data can support the definition of projects. Similarly to the first step of the DAS frame, underperforming spaces or least popularity can be recognized to focus attention to improve these spaces. Likewise, when the demands of users show a highly recurring demand for a particular function or spatial aspect it can be seen as highly important. As a result, the priority to implement these demands into projects can become higher. This means a particular project might be implemented before another on the basis of a higher demand. Thus, by gaining more information on what the actual demand of users are, decisions can be made to prioritize and plan projects.

The information can only suggest a certain prioritization of projects, but it cannot determine what the effect of the project on the organisational performance will be. Therefore, the value of projects with regard to the effect on key performance indicators still needs to be assumed. This is because the extent to which the for example user satisfaction will change is still very hard to determine. However, it can indicate more effectively show that previous reasons for dissatisfaction are removed. Furthermore, pilots and innovative projects can also be used as a form of experimentation for which the smart tool can indicate of how the project is received. This is because it is expected that if a new project is implemented, users are more likely to leave feedback as it is a change of the previous situation. This can lead to new insight in the performance of the projects which can be related to the overall organisational performance.

11.6.2 Implications to the Real Estate Supply

Since the smart tool is an application to improve the use of real estate, it can also be seen as an extension real estate. Therefore, the smart tool is related to the ways real estate is able to add value to an organisation as described by De Vries (2008) and expanded upon by Den Heijer (2011). The smart tool is related to these ways to add value to use as a structure to clarify the added value of the smart tool. Each of the ways have a symbol beside it indicating the degree to which the effect the smart tool has. The symbols include a "=" representing no significant effect, "-" representing a negative influence and a "+" sign to express positive effects. In the case that the negative or positive effects are great it is indicated by two symbols.

Ways to add value	
1. Increasing real estate value =	7. Supporting image +
2. Controlling risk +	8. Supporting culture =
3. Decreasing costs +	9. Stimulating collaboration +
4. Increasing flexibility +	10. Stimulating innovation =
5. Supporting user activities ++	11. Improving quality of place +
6. Increasing user satisfaction ++	12. Reducing footprint +

Table 8.2. ways to add value showing the effect of the smart tool

1. Increasing real estate value =

The objective of the smart tool is not to increase the value of the real estate but to optimize the alignment of real estate the organisations primary processes. However, if the information the smart tool generates results in improvements of the supply, it is highly likely that the value of the real estate also increases. However, this is limited to the degree it increases satisfaction in general, rather than a specific use. Still, one can view this as an indirect effect and it becomes hard to determine how much the value of real estate would increase after implementation.

2. Controlling risk +

With regard to the financial risk, because the smart tool is able to give more information about the utilization of the campus patterns and trends can be discovered which decrease risk. For example, if there is a downward trend in the use of campus space because of the implications of e-learning this should be recognized in the utilization information. With this information, the decision to decrease the total amount of space can be made sooner, which decreases the risk that the real estate costs become unnecessarily high.

Another added value of using a smart tool that provides information about the real estate is the ability to decrease risk by improving safety. Utilization information can provide useful information to improve the safety on campus. Campus management is able to decrease risk by having better insight of how buildings are used. However, during dangerous situations or evacuations smart tools can provide information on the nearest exit which can possibly streamline evacuation. Due to insufficient knowledge of exit routes and panic, users can bypass exit routes and clutter the more obvious exit routes leading to a sluggish and potentially life threatening evacuation. Despite these possibilities, the smart tool in its current form does not provide any added value to control risk by providing information to users. Therefore, it is valuable to research how a smart tool is able to do this.

3. Decrease real estate costs +

The real estate costs can be decreased by decreasing the amount of space needed. This is done by providing information about study space and gaining insight through the generated data. By providing information about study space the findability of spaces is improved, which can reduce the perception that there is a lack of study space. By gaining insight into the actual needed m2 per student, the total amount of space can be reduced by using the space more efficiently. While reducing the amount of space it is important to monitor user satisfaction to make sure the cost reduction goals do not negatively influence the user satisfaction goals. This can in turn reduce costs, by either selling off a certain building which has turned out to be obsolete or subletting part of the space to another party to reduce the costs for renting the real estate.

4. Increasing flexibility +

Primarily, the smart tool provides information to users which are more likely to be distributed more across campus. As as result, faculty specific space can be decreased by having a higher amount of study space for the whole university. This means the campus is more inclusive and space can be used more flexible by different disciplines.

Furthermore, this point correlates with some of the arguments made in 'decrease real estate costs'. By gaining a greater understanding of needed space per discipline the remainder of space can be designated as flexible space. This flexible space can act as space which can be used by different disciplines and stimulate collaboration as described later. When sudden spikes in demand for a particular study subject occurs, other faculties are then more able to absorb this change. Additionally, space can be also be let out to another party.

5. Support user activities ++

Similar to the first point the main objective of the smart tool is to support user activities by providing information about Real Estate. This entails finding a suitable study space for the student, which is needed for most learning activities. It thus, supports learning activities indirectly by offering a variety of learning spaces to students according to their preferences.

6. Increasing user satisfaction ++

One of the primary objectives of the smart tool is to support the users of the building by displaying information about occupancy and building aspects. In theory, displaying usable information alone will decrease the number of frustrations previously had. Especially when considering the user did not have any means to gain information about the building or an available workspace. Thus, this will support user activities with regard to the existing real estate possibly obtaining a greater fulfilment of the demands solely by displaying information. Furthermore, the proposed smart tool also shows information about the aspects of the space, which is able to more effectively help users in finding a preferred space to study.

The smart tool is also designed to quantify the demands of the users, so that the CREM can act on these demands by altering the real estate portfolio. Thus, in the long term, when the demands have accumulated and later on analysed, projects can be defined to align the demands of the users to a greater extend. Also, new innovative concepts can be tested in the work environment on which the performance can be measured. When these projects have been implemented the increase in user satisfaction can be measured by analyzing any changes in use after implementation. This can show a satisfactory increase in use of the newly adapted space or a staggering and disappointing use of the space. From this point on, lessons can be learnt and new decisions can be made to make improvements.

7. Supporting Image +
In terms of supporting image the proposed smart tool is able to stimulate users to choose for the university. Since it was concluded that universities are increasingly competitive implementing a tool to support students in their activities would most likely be greatly appreciated. Furthermore, the smart tool will not only show that the university is concerned with the end user, but also shows that it is equipped with the latest technology and supports innovative ideas.

8. Supporting culture =
In terms of supporting culture, the smart tool can have different effects of the culture of the university campus. Considering the university culture the smart tool can have positive effects by familiarizing users with other campus buildings. As its users will use more faculty buildings they are more likely to come into contact with students of other faculties. This will show students what other faculties are able to accomplish and is even able to inspire and stimulate collaboration among students of different faculties. While on the scale of university faculty it might actually have negative effects on culture building within faculties. Because, as stated in the interviews, faculties want to stimulate collaboration within the faculty. This is harder to achieve when the students of a particular faculty are distributed across other buildings of the university campus. Therefore it is argued that the degree the smart tool supports culture remains equal.

9. Stimulating collaboration +
Collaboration can be supported by stimulating mobility between the buildings on campus by showing the available suitable space. If the most suitable space happens to be in another faculty somewhere else on the campus, the students are stimulated to move to the faculty to work there. Hence, it is expected that students will be more likely to study at different faculties and have more chance in being affected or inspired and collaborate with different disciplines.

Furthemore, if students gain the impression that it is easy to find a suitable space for group projects, they might be more inclined to work together in the same space. When the portfolio is properly aligned with its demand, this should be the case. If not, the portfolio can be adapted to the degree that the generated data shows. What helps this even more is by implementing a booking function into the smart tool, which enable students to book spaces for group projects. Researching how to add this function to the smart tool can therefore prove valuable.

10. Stimulating innovation =
As stated in supporting culture, as students are stimulated to use other faculty buildings it increases the chance for cross contamination and chance encounters with other disciplines. This means that students can get inspired by different disciplines and can find new innovative approaches outside their study subject to apply within their study subject. However, how much students are influenced by studying in another faculty building is hard to determine and questionable. Therefore it is assessed as remaining equal.

11. Improving quality of place +
By focussing on the most important attributes of the user preferences, it is expected campus management is able to improve space. However, the generated data mostly covers the functionality of space. This does not include the overall quality of place in terms of perceived ambiance for example. Nevertheless, valuable insight into what is desired by campus users can be extracted by analyzing the most [preferred and selected spaces. This can lead to a new approach of how to upgrade campus space to improve the quality of the individual study spaces.

12. Reducing footprint +

Reducing the footprint symbolizes the degree in which the smart tool supports decreasing the environmental footprint. This includes the CO2 emission, material use and amount of space. As the smart tool stimulates the distribution of students, more of the campus will likely be used. By itself, this will not reduce the footprint of the campus. However, if campus management is able to reduce the amount of used space as a result of better study space findability, a reduced footprint can be achieved. As described in decrease real estate costs, a reduction of the amount of real estate supply is possible when user satisfaction is monitored. Thus, the smart tool will not decrease the footprint in the short term, but the smart tool leads to possibilities to reduce the total amount of space in the long term. Additionally, possibilities exist to synchronize utilization information with the HVAC systems to achieve a reduced energy usage. This, however, is beyond the scope of this research.

11.6.3 Relating added value to organisational performance

The process of adding value through real estate is shown by relating the 12 ways to add value to the four stakeholder perspectives, which is illustrated in the model below (image 8.1). This model is based on a more elaborated model of the stakeholders perspectives found in the dissertation of Den Heijer (2011). CREM (i.e. campus management) is placed in the center of the model. From this point CRE managers influence the different perspectives through real estate interventions. These interventions have varying degrees of influence on the perspectives based on the scale of the real estate project. Hence, the indication of the quality ambition, number of users involved, budget and space types of the project.

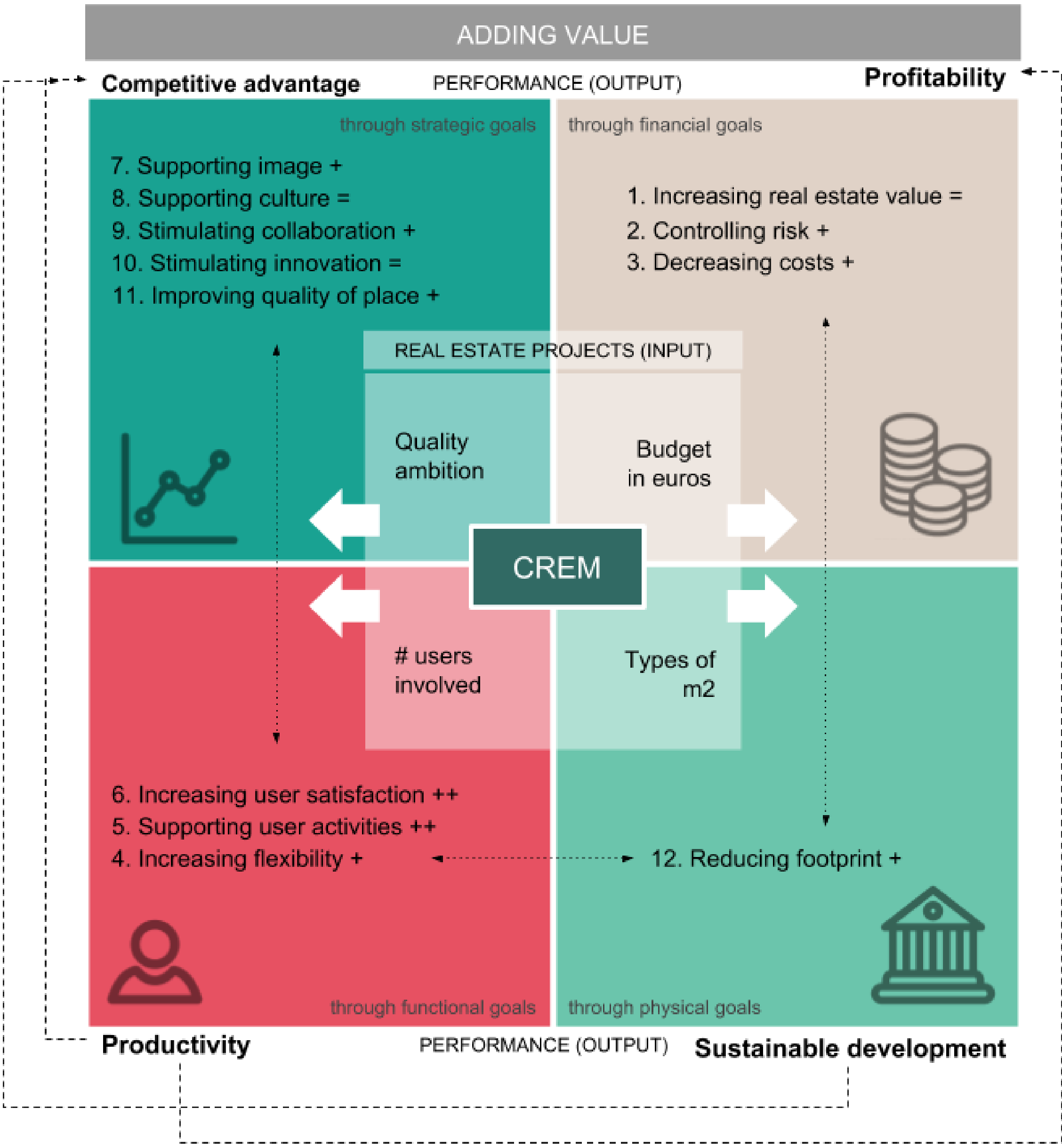


Image 11.1 Adding value related to organisational performance

It can be seen that the smart tool mostly support the added values in the functional perspective, by improving the user satisfaction, supporting user activities and increasing flexibility. The added values of increasing user satisfaction and supporting user activities is also related to some of the added values found in the strategic perspective, which is indicated by the arrow. These include improving quality of place, stimulating collaboration and supporting organisational image. The added value to increase flexibility is also indirectly related to the financial perspective through the of reducing the footprint of the campus.

Surrounding the perspectives is the performance of the organisation with its related key performance indicators. The underlying relations of the key performance indicators are indicated by the arrows. This shows that the functional perspective is related to the productivity dimension. In turn, it can be seen that through the productivity, the competitive advantage and profitability is influenced. While sustainable development is able to influence solely the competitive advantage. Because the smart tool is able to support adding value in multiple perspectives, it can be argued that it is very likely that the smart tool can have significant effect on organisational performance.

12. DISCUSSION

In this chapter some of the issues of the results are described, signifying the bottlenecks for the value of the smart tool or limitations of the research.

12.1 Transformation of data to information

The quality of the data increases with the amount of input, leading to a more reliable and accurate representation of the campus end user's preferences and needs. Thus when the input is reflected upon tens of thousands of users there will most likely be interesting data to analyze. However, eventually the quality of the information is not only dependent on the quality of the data but also on the techniques used for the transformation of data to information.

Statistical methods offer ways to analyze data. The objective of this analysis is to find relationships or patterns within the data that could be used to the advantage of the decision-maker (Lohman, 1999, p. 47). An example of a statistical method is data mining, which can be used to analyze the generated data to see which of the requirements /constraints are most important when finding a studyspace. Data mining can be used to discover new insight from data, which can be used in the decision making process. In essence, data mining consists of performing several analyses on the available data to find unknown patterns, which is done automatically. Data mining techniques are designed to search for possible relationships between data elements and to select the most interesting relationships (Lohman, 1999, p. 48-49).

However, issues relating to statistical methods are also present. These include translating the data mining results into appropriate actions. It is also difficult to determine the added value before data mining sessions take place.

12.2 Dependence on Technologies

Despite the added values of the proposed smart tool, it remains dependent on the integration of several technologies. These technologies include occupancy detection, user localisation and wayfinding, each having their own value for implementation.

12.2.1 Occupancy detection

Occupancy detection is needed for the determination of study space availability and the match with preference. Showing availability is dependant on the accuracy and speed with which occupancy is detected and shown. The occupancy rating is a factor which determines where users want to study and is seen as one of the most important criteria.

12.2.2 User localisation

Another criteria that was appointed one of the most important was distance to current location. For this the position of the user needs to be known to enable the calculation of the distance between the user position in relation to the spaces. As the position of a user changes the results the proposed smart tool will gives will be different. This is also important when multiple, or large quantities of students use the smart tool, otherwise the likelihood that users will be sent to the same spaces will increase.

12.2.3 Wayfinding

When a result is shown including its aspects and preference scores the user needs to be incentivized to actually choose the space. This will generate data of which space users choose more or less, which is able to give valuable insight into the popularity of spaces. Choosing can be incentivized by subsequently guiding the user to the space through wayfinding.

12.3 Strategic behaviour

Strategic behaviour problems exist when information is considered not 'neutral', meaning the information might influence outcome. Lohman (1999, p. 31) stated that strategic manipulation of the employees was labeled as one of the major reasons for the existence of inaccurate data. In relation to the proposed smart tool users might deliberately give spaces they like to scare off other users in using the space, leading to them having the space for their own.

Not only employees are tempted to behave strategically, managers are also in a position to use information to improve their personal position instead of bothering about organizational contribution (Lohman, 1999, p. 66). Ultimately, it is the decision-making process carried out by management that is responsible for the contribution of management information. Despite negative impact on organizational performance, managers can withhold information or decide to not undertake any action. A plausible reason might be that using the information could result in a negative impact on them personally and their personal interests outweigh the organization's interest (Lohman, 1999, p. 7).

12.4 Similarity to SpaceFinder

Since the smart tool has similarities to the SpaceFinder developed by Cambridge, it is important to state where the differences exist. The main difference between the proposed smart tool and SpaceFinder is that SpaceFinder solely focuses on providing information for users, whereas the proposed smart tool also generates information to be used by campus management. The other difference is the fact that SpaceFinder primarily focuses on providing information to new university students. This is because they figured that their students have the highest need for information about spaces to study in the beginning of their studies. Therefore, it also transcends the campus by also showing spaces to study outside the campus (e.g. coffee bars or a public library). Once students became acquainted with the preferred study spaces it was assumed that users will not return, which is exactly what the traffic of the SpaceFinder showed (Priestner, 2016). However, it is argued that because the tool does not include occupancy rating, students are not incentivized to use it on a daily basis. As Spacefinder does not give any information on whether the preferred study space is actually available, users are not sure of whether travelling to the space is worthwhile. By including occupancy rating it is expected that users are able to make a better decision of where to study beforehand, increasing the likelihood that the user will find an available space. Therefore, it is assumed that with the inclusion of information on both spatial aspects and occupancy the smart tool is able to provide more useful information, leading to more frequent use.

12.5 Learning of Campus Space

Similar to the SpaceFinder, when users have used the proposed smart tools several times they will most likely learn where spaces are located on campus. Thus, users will subconsciously learn the locations of their preferred spaces and, as a result, the need to use the smart tool will becomes less. If the user is also given insight into the occupancy rating of those particular spaces, he might even remember a what time space is available. This will most likely lead to a significant decrease in frequency of use after some time. As a result, the overall traffic will also decrease significantly.

However, when demands change for whatever reason the user is able to adapt his preferences in the smart tool. This will support the user to discover new spaces that meets his preferences. Thus, keeping up with and reflecting the dynamically changing demand of users. At times when the traffic increases it can be assumed that end-users are having trouble finding a suitable study space. This could be an indicator for campus managers to analyse whether the situation was incidental or structural. On the basis of this information the campus manager is able to make changes to real estate to prevent these situations. Moreover, when traffic increases and occupancy ratings increase, it also becomes interesting to see which criteria become apparently less important to the users.

12.6 Required Mental Effort

The amount of mental effort required to use the smart tool prototype was assessed with the use of a Task Load Index (TLX) questionnaire. The assessment showed that the amount of mental effort required to use the smart tool prototype was quite high. Because of the high degree of mental effort required to to operate the smart tool, Preference Function Modelling might not be suitable in its purest form. Since some of the criteria are of less interest to the users, it becomes worthwhile to see which criteria can be deleted or how it can be simplified to improve usability. In particular, the middle values and its respective preference values were the values users struggled with the most. Additionally, CRE managers stated that every value was interesting to them, however the middle values had the least priority. Additionally, the middle value is needed in Preference Function Modelling generate a greater number of alternatives, something that is not necessary in this case since the alternatives are already existing. Therefore, with usability in mind, it might be desirable to remove the middle values.

12.7 Online Learning

Because the proposed smart tool is in fact a type of search engine for study space, it became interesting to see what existing knowledge of search engines is applicable to the smart tool. One technique is Machine- or Online Learning and the best example for this is the google search engine. The Google search engine is ofcourse a very developed set of algorithms which is able to process large amounts of data to obtain the best search results. There are algorithms which are able to link the query (text string for the search input) to the selected website. By storing this data the most selected websites will appear at the top of the search results as this satisfied the majority of former users the best. By implementing this technique, this could for example show a average user input to save new users time to fill in the preference scores. In turn this could greatly improve the workflow and decrease the time needed to use the smart tool, which is beneficial for the end-user.

However, because the proposed smart tool is based on subjective data this type of support will decrease the reliability of the data. This is because the value in the generated data exist in the more accurate representation of user preferences. When the subjective data of users will be changed by a algorithm the user is less in control and is not confronted with his/her own demands. Furthermore, people are generally want to put in as little effort possible and might feel even less motivated to fill in the preference values, thus settling for the input of the average user. When these preference values are not changed by each user, the values hold significantly less usable information to support decisions. The preference values will then constantly reinforces itself, leading to a self-fulfilling prophecy. This will not be a fully personalized and subjective data anymore which makes it severely less useful for making decisions. This will be especially, when criticized by stakeholders on the grounds of contested information.

Furthermore, if the smart tool alters the preference settings of the user based on the selection of space automatically and without their knowledge or consent, the preference settings might be changed to represent actual preference less. The chosen space might be most applicable at that point in time but this doesn't mean that it is always the case and therefore the preferences are adapted. Choosing a space which does not fully meet your requirements is a form of mitigating and can be dependent on the situation you are in.

12.8 Modularity

The smart tool is modular and can be improved upon by removing or adding criteria which are interesting at a certain point in time. When, because of changes to the educational environment, different criteria are becoming increasingly important, it is possible to add these criteria. This requires a number of changes to the database, when the spaces need an additional attribute for example. Furthemore, for calculating the preference score it becomes important to determine whether it is possible to measure this attribute. An example for an additional attribute can be the amount of light is preferred for a space. Since light can be measured in Lux it is possible to add (real time) measurements by adding Lux meters to spaces. This can serve as another criteria of user preferences. Other examples include temperature meters, humidity meters, air movement meters, decibel meters, sustainability ratings or energy consumption measurements. However, the smart tool is interesting for the end-user because there are clear benefits to him: finding the most preferred study space. When criteria are added that do not have anything to do with the study spaces it will be less interesting for end users to use in the process of finding a study space.

12.9 Feedback

Concerning the feedback rating users are able to give to spaces, users most likely won't be stimulated to use this function other than on two occasions: when a space severely disappointed and is below standards or when a space performs exceptionally. This relates to with the what Sundstrum (1986) described as a dissatisfier. Sundstrom (1986 in Vries, 2007, p. 86) distinguished two types of factors which influence employees satisfaction: satisfiers and dissatisfiers. The physical environment is acknowledged as a dissatisfying factor. Meaning that if no problems are apparent it is experienced as positive, while when it doesn't meet requirements it can strongly decrease performance and cause dissatisfaction (Vries, 2007, p. 340). In the case of exceptional performance users will most likely not even give a feedback rating unless they are incentivized to do so. Incentivizing them can be done by explicitly stating that their feedback is able to help the campus make more of these kinds of spaces. What might be a better indicator for feedback is the spaces users store as favourites, since they can protect the space from becoming too popular by not informing other users about the quality of the space.

12.10 Distribution of Users

The smart tool is inherently designed to find spaces which meet its users preferences. Since it is suggested that most students like to study in a silent space and one with a low occupancy rating, students will be sent all across the campus. There are several issues relating to increasing the distribution of users among the campus.

Some of the faculty members will be less enthusiastic if they find out students do not study in their own faculty anymore. This could seriously obstruct the formation of communities among faculties. Furthermore, distributing users across the campus does only concern faculty members, but also the technical managers and controllers who are concerned with decreasing the amount of m2, footprint and costs of the real estate supply. If users prefer to study in spaces that are occupied to a lesser extent (e.g. 20%) this will negatively influence the efficiency of space use, obstructing cost reductions. Furthermore, this results in additional spaces which need to be heated or air conditioned leading to a greater energy expenditure or footprint.

13. RECOMMENDATIONS

This section will describe the recommendations for future research as a consequence of the results and limitations of this thesis.

13.1 Find ways to increase usability

Though much improvements have been made over the course of this thesis, before the proposed smart tool is implemented it still needs improvement with regard to usability. As stated numerous times in this research, usability is ultimately very important for the degree the proposed smart tool will be used. It is imperative for the generation of large amounts of data that many users will use the smart tool as often as possible. Thus, the data reliability, quality and representativeness increases parallel with its use (i.e. the more data input the better). Simultaneously, the more input an individual user gives on its preferences the more accurate the representation of demand will be and the higher the potential for interesting findings. Therefore, the continuation of the design of the proposes smart tool needs to balanced with regard to the benefits for the user and the generation of useful data. Researching to which degree both ends of information provision is optimized will be a valuable continuation from this point on.

13.2 Increase the accuracy of occupancy detection

By increasing the accuracy of occupancy detection in buildings, users can be supported with this information more effectively. Meaning that occupancy and availability can be determined on a workplace level, rather than that of its surrounding space. Because the main criterias for users are the availability and occupancy of a study space, improving this can lead to a significant value increase. As of this moment WiFi occupancy detection is not accurate enough to inform about workplaces. This means the user still misses information about which workplace are available in the designated space. This information is valuable as it can inform users about the exact location of a preferred available workplace, after which the user can travel more directly. However, this increased accuracy requires other types of sensors. Because this needs additional investment, it is worthwhile to research the costs and benefits to give insight on whether this is a worthwhile and feasible improvement.

13.3 Research possibilities on the operational level

By integrating the smart tool with facility management software, users are able to give feedback on the operational level on the spaces. It was stated in the interviews that there is a need for a less daunting, more approachable way for users to comment on facilities. Potentially, this could improve the time in which facility management can respond to occuring problems, allowing facility management operate more effectively and efficiently. This can also lead to a higher user satisfaction as the problems are resolved more adequately. This can potentially also lead to added value of the smart tool for facility management, which can support the business case of the smart tool.

13.4 Effect of the smart tool on user behavior

As the smart tool is developed to support user activity, it becomes interesting to see how much user behaviour is influenced by use of the smart tool. For example, it is interesting to determine how much users will actually use the smart tool in their study life. This can be done by analyzing how much unique users return use of the smart tool and how frequent. When use of the smart tool decreases or diminishes, users most likely have a good idea of where there preferred spaces are and when they are most likely occupied. Therefore, it is interesting to find how quickly users will cognitively 'learn' campus space. By learning it is meant that over time users will remember from past experience which study spaces comply with their needs and are available at a certain period of time. After the use of the smart tool has declined over a period of time and then unexpectedly starts to peak, one can expect this signifies moments when students have difficulty or want to be supported in finding a space. The reasoning for why that peak in use has occurs can then be analyzed to determine whether it was for example caused by business or a real estate intervention.

Another aspect which is important with regard to user behaviour, is distribution of users among the campus as a result of smart tool use. This is because the distribution of users on the campus can inhibit the reduction of space, which can ultimately constrain cost and footprint reduction. To obtain real estate goals like reducing the footprint, researching how much the implementation of the smart tool increases the distribution of users on campus becomes relevant.This can provide insight into how much the efficiency of space use is affected. Similarly, researching the degree to which users are stimulated to and by sharing facility buildings can be potentially supportive in making a business case for the smart tool. However, the degree to which users are inspired by other faculties is especially hard to measure.

13.5 Applicability to commercial organisations

The smart tool is originally designed for a university campus and considers students in its functioning. This is evident in the criteria and in the argument that the smart tool is very applicable to a university environment because students (usually) do not have an assigned workspaces. Because several authors argued that the university is increasingly operating similar to flexible workspaces it is expected that the proposed smart tool can also be applied to commercial organisations. The same need for individual focus workspaces, group work spaces and conference space exist in both commercial organisations and higher education. Because the need for information on users by real estate management equally exists in commercial organisations, it is interesting to see what the differences are between these organisations and higher education. This can lead to insight in how one should approach applying the findings of this research, to a smart tool for a commercial organisation.

14. REFLECTION

In this chapter there will be reflected upon the research by firstly describing the process and the used research methods. Thereafter, the research will be placed it into the broader context by exploring the societal and scientific relevance and position within the master and practice.

14.1 Research process

14.1.1 Exploration

As stated in the Foreword, the research started with the realisation that the existing ways to gain useful information about the building are inconvenient or absent. This especially concerned finding an available and preferred studyspace fitting the needs at that particular moment in time. This led to the exploration of the problem area by using several ways to gain information, consisting of: discussions with friends and students and reviewing literature.

Even though I was eager to find my own solution for this problem I first started by looking at existing tools to learn valuable lessons. It became clear that many before me had already tried to solve similar problems using smart tools. In this phase the 'Smart Campus Tools' book released in 2016 was very useful as it had most of the information I required. Then, on the basis of my experience with other applications I started to get an idea of how I wanted the smart tool to function. This resulted in the decision tree as shown in the report and when comparing this to the final result it is clear that there was no mayor deviation from this original structure.

In order to get a greater understanding of how to make this smart tool I engaged in discussions with friends and students who had experience in developing software. Since one of them worked at a supposedly 'Smart Building' he invited me there to see what current smart tools already exist. This visit led me to believe that the current smart tools weren't used to its full potential. After proposing my ideas for the smart tool they were able to help me to cultivate it and figure out how to execute it. For this they proved especially valuable in gauging what was feasible with the limited experience and time. From that point on I started to learn what was possible within IT and how to actualize it.

14.1.2 Moving to P2

The most important objective for the P2 was to have a proper research structure and basis of a literature study, resulting in a research proposal. Leading up to the P2 I set the goal to finish my literature study, allowing me to increase my focus on the development of the smart tool. Considering my inexperience with developing software, it was expected that the development of the smart tool would take a lot of time. Therefore I had set the goal to finish processing most of the literature for the P2. For this, the available literature on current campus management practice provided a good basis for this aspect of the research, consisting of: 'CampusNL' and 'Managing the University Campus'. Even though I was unable to finish the literature research completely, it was rather far along and it motivated me to work extensively on my report.

A reason the literature research was obstructed was because of the unknowns in developing the smart tool. To get a better idea of how the smart tool was going to be built it was key to start with the design of a prototype for the P2. This meant working parallel on the report and model after the P2.

14.1.3 Moving to P3

Since the report was far along and my research structure had been fully set up it presented the opportunity to find an appropriate company for an internship. LoneRooftop was very interesting as it already had a solution similar to my own and had the required WiFi occupancy detection. Luckily I was able to get into contact with and got accepted by LoneRooftop to do an internship.

During the first stage of the internship I was working solitary for quite some time as I was trying to finish my literature research. When this was finally finished I developed the prototype to carry out the data collection. In this phase it became clear that the internship was very helpful as they provided me with useful information on several subjects. One tip that was particularly helpful was evaluating software with end-users by using a wireframe mock-up (Balsamiq). These tools allowed me evaluate the smart tool to iteratively improve upon the smart tool design.

14.1.4 Moving to P4

From this point on I worked to finish my report by finalizing the literature study, data collection and conclude the research. Unfortunately, this took more time than I had anticipated. For the conclusion it was important to gather all the findings and analyze it. However, because there was not enough time between the final data gathering and handing in the report, the conclusion was not completely finished. However, there was still time available leading up to the P5 to finalize the report.

14.1.5 Moving to P5

From the P4 to the P5 the pressure was off, which was very welcome since I had worked quite hard up till this point. However, the backlash of this was that I needed to reignite my motivation to finish the report in the desired quality. After a short period of taking it a bit slower I was able to find my motivation again for the finalization of the thesis. The feedback on my P4 report mostly included making the report more coherent to improve readability and understandability. Hence, this was the main objective I focused on.

14.1.6 Supervision

From the outset the supervision was very helpful to increase my understanding of what I had read and heard. I experienced a pleasant mix of the 'management' perspective of how to use the generated data in real estate management and a more 'technical' perspective of how to construct and test a smart tool. For this, Alexandra and Rein provided guidance respectively. The mentor sessions assisted in the reflection on the progress and results of the research which helped to focus on the essence.

During each mentor session I took notes, which I transferred into small reports. This was a great way to document the most valuable information, collect thoughts, and inform the mentors that everything that was discussed was understood correctly. This is something that definitely has value for increasing effectiveness of important meetings later on in my career.

14.1.7 Motivation

The process of writing this thesis required considerable effort, self-discipline and time. However, because I thoroughly believed in this subject I had a natural curiosity towards the outcome of the research, which was able to motivate me throughout the thesis. Overall I was very motivated to end this final objective of my studies with something I could be proud of and would give me confidence in starting my career.

As several students had also embarked on their own theses around the same time, getting into contact with them was very helpful and motivational. Their perspectives helped to figure out where the knowledge gap was in this particular subject. While also confirming the missed opportunity that was present, which motivated me even more to develop a smart tool of my own. Additionally, this also led to the realisation that whenever I got stuck it was beneficial to engage with a fellow student or friend to take a step back to regain motivation.

Sometime before the P2 I kept To-Do lists with prioritized tasks for keeping me informed about what needed to be done and in what order. Throughout the process of writing my thesis a frequent to-do was to update my report constantly. This was done to get into the habit of finishing things and decreasing the effort in looking up previous findings. In the later stage of the research I also made a planning for each week in order to finalize the report. However, it also became painfully clear that the actual time to complete tasks is often higher than expected. Especially concerning analyzing, reflecting and concluding the research.

14.2 Research methods

14.2.1 Literature research

With regard to the literature research the dissertation of Den Heijer 'Managing the University Campus' and the more recent 'Smart Campus Tools' and 'Campus NL' books served as a great basis to gain understanding of current campus management practice. This allowed me to have a good foundation from which I could delve into more specific subjects.

Concerning the development of the smart tool I realized that it was important to not only learn but also document this. After some research I found in the 'Business Intelligence guidebook' which covered most of the aspects of designing a proper database which would form the backbone of the smart tool.

14.2.2 Informal interviews

My internship at LoneRooftop presented me with opportunities to learn about every aspect of developing software for real estate management. When after some time questions arose I was able to make appointments for informal interviews with the discipline able to answer the questions for that specific aspect of software development. Through these informal interviews useful information was extracted which helped me improve my understanding of: privacy legislation, front- and back-end development and data science. Being able to easily make these appointments made my internship very worthwhile.

14.2.3 Model Development

At the start of the research my objective was to have an actual working mobile application. However, as the researched progressed I realised the amount of time needed to research was too great to achieve this. Furthermore, my inexperience with software also proved to be a bottleneck for this objective. Therefore, most of the coding was done in Excel which proved to be more functional than expected. For the development of the mock-up Balsamiq was an excellent way to visualize ideas quickly and supporting design iteration.

14.2.4 (Evaluation) Interviews

The data collection consisted of interviews with students and real estate managers. 'User centric evaluation methods' provided me with useful methods to interviews the students. Combining this with prototypes and a mock-up in balsamiq the interviews went very smoothly. Considering the semi structured interview with the real estate managers, it became clear that during the interview it was easy to lose track of what questions were answered. Luckily, there were possibilities to complete the interview by asking more specific questions later through email.

14.2.5 Case study

Using TU Delft as a case for this study was a good decision as it was easy to contact the necessary people for data collection (i.e. students and real estate managers). Furthemore, since the campus was already familiar it was less abstract what needed to be considered. However, when further researching how to implement this it becomes interesting to see what differences exist among campuses.

14.2.6 Ethical dilemmas

No real ethical dilemmas have come across during the research. However, considering the ultimate use of the generated data there are some ethical dilemmas which can become possible issues. These issues include the possibility of users to manipulate the data and that the degree to which the data is useful remains dependent on the behaviour of the decision maker. Considering the personal information that is required as input, it is expected that a simple statement should inform the users and they should have no real reason to object to its use. Furthermore, protecting this information is increasingly regulated and when complying to these regulations the information should be secure enough to protect it from misuse.

14.2.7 Personal learning goals

Leading up to the research I became aware of the opportunities information and smart tools offered and, simultaneously the relatively traditional methods of decision making in real estate management. Since then I was very interested in these opportunities, which this thesis allowed me to explore more. In doing so, my research skills needed to develop in structuring research and meeting scientific requirements. Over the course of this thesis, I believe these skills have developed significantly during the research process.

Clearly, the thesis also required me to establish my software development skills. While I might not have transformed into a full fledged software developer, I am somewhat able to speak the 'language'. Which was one of my learning goals: to be able to bridge the gap between software development and real estate management.

As this master thesis took a substantial amount of time and effort, it can be seen as the biggest project I was involved in during my studies. Moreover, the thesis was a very personal project as I had selected and completed the thesis myself completely. This allowed me to take charge of such a project, really develop approaching research and making project decisions. This enabled to develop my planning, leadership and ultimately skills in documentation of a large project. Furthermore, I have really developed using my network and knowledge of others to progress research. These are all thing I consider to be very valuable in the continuation of my career.

14.3 Dissemination

14.3.1 Societal relevance

The results of this thesis indicate possibilities for real estate management (and campus management in particular) to develop information sources on user demands through smart tools. The main benefits of this thesis, can be found in the fact that it shows what value the proposed smart tool initially has while also providing value over the long term. Initially it is expected that it will increase user satisfaction by supporting user activities. Simultaneously the smart tool shows ways to generate data to improve the campus. The generated information can prove valuable in supporting decision making with respect to indicating which spaces are underperforming and what functions are most in demand by users. Because, this information is quantified there are also possibilities to analyse the data to make new discoveries about what is expected of future demand. Furthermore, the principle of using smart tools for both supporting users while generating data on their demands can also lead to new developments of similarly useful software.

14.3.2 Scientific relevance

The relevance of this thesis in the scientific field primarily exist in the understanding of the development of software for real estate management. With these insights it has become (more) clear what is possible by using smart tools in both the use of buildings and how to generate data to support decision making. The research also showed how Preference Function Modelling can be used on a greater scale which can also be used for other purposes. Furthermore, it can be concluded that the proposed smart tool has a potential to add significant value to real estate users and management processes. Therefore, it becomes valuable to extend these principles to discover more potential.

14.4 Research Position

14.4.1 Position within Smart Real Estate Management

Since the end result of this thesis is a smart tool which firstly supports campus users in their activities it is argued that the smart tool mostly operates in the functional perspective of CREM. More specifically, this thesis mostly focuses on the product side of smart tools, encompassing the needs of end users in the use of such a smart tool. Thus, the research has taken on a user centric approach, while simultaneously generating data to support real estate management decision making. Taking this approach has given insight into what is important for users in using a smart tool, possibilities with the available sensors and the capabilities of software development to support real estate management overall.

14.4.2 Position within Management in the built environment

Since the data generated by the smart tool ultimately focuses on optimizing use of existing structures it is argued that, within the master 'Management in the built environment', this thesis is most applicable to real estate management practice. However, the results also suggest that smart tools can be implemented to a wide variety of other uses within the built environment. This type of smart tool can also be applied to optimize urban development by gathering more data on urban areas for example. Moreover, for project development the lessons learnt from the generated data can also be accumulated over time to integrate it into a new project.

Image: BKCityGuide 2017/2018

REFERENCES

REFERENCES

Algemene Rekenkamer. (2016). Vastgoed bij universiteiten, Twintig jaar na overdracht van eigendom. Algemene Rekenkamer.

Appel-Meulenbroek, R., & Haynes, B. (2014). An overview of steps and tools for the corporate real estate strategy alignment process. *Henry Stewart Publications, No. 1*(Vol 4.), 44-64.

Arkesteijn, M. (2016). *Dear is durable: liber amicorum for hans de jonge*. S.l.: TU DELFT.

Arkesteijn, M., Valks, B., Binnekamp, R., Barendse, P., & Jonge, H. D. (2015). Designing a preference-based accommodation strategy: A pilot study at Delft University of Technology. *Journal of Corporate Real Estate*, *17*(2), 98-121. https://doi.org/10.1108/JCRE-12-2014-0031

Autoriteit Persoonsgegevens. Last onder dwangsom Bluetrace, Pub. L. No. z2015- 00981 (2016). Den Haag: Autoriteit Persoonsgegevens. Geraadpleegd van https://autoriteitpersoonsgegevens.nl/nl/nieuws/ap-legt-wifi-tracker-bluetrace-last-onder-dwangsom-op

Barzilai, J. (2010). Preference Function Modeling: The Mathematical Foundations of Decision Theory. *Trends in Multiple Criteria Decision Analysis*, *3*, 57—86.

Beckers, R. (2016). *A learning space odyssey*. University of Twente, Enschede.

Beckers, R., & van der Voordt, T. (2014). CORPORATE REAL ESTATE ALIGNMENT STRATEGIES IN DUTCH HIGHER EDUCATION. Gepresenteerd bij European Real Estate Society 21st Annual Conference, Bucharest University of Economics.

Beckers, R., van der Voordt, T., & Dewulf, G. (2015a). A conceptual framework to identify spatial implications of new ways of learning in higher education. *Facilities*, *33*(1/2), 2-19. https://doi.org/10.1108/F-02-2013-0013

Beckers, R., van der Voordt, T., & Dewulf, G. (2015b). Aligning corporate real estate with the corporate strategies of higher education institutions. *Facilities*, *33*(13/14), 775-793. https://doi.org/10.1108/F-04-2014-0035

Beckers, R., van der Voordt, T., & Dewulf, G. (2016). Learning Space Preferences of Higher Education Students. *Building and Environment*, *104*(2016), 243-252.

Binnekamp, R. (2010). *Preference-based design in architecture*. Delft, Holland: Delft University Press.

Braggaar, R. (2018, januari 30). Large Scale Indoor Localisation through Wi-Fi Monitoring, The Case of the TU Delft Campus. TU Delft.

Buckman, A. H., Mayfield, M., & Beck, S. B. M. (2014). What is a Smart Building? *Smart and Sus-*

tainable Built Environment*, *3*(2), 92-109. https://doi.org/10.1108/SASBE-01-2014-0003

De Jonge, H., Arkesteijn, M., den Heijer, A., Vande Putte, H., De Vries, J. C., & van der Zwart, J. (2009, januari). Designing an Accommodation Strategy (DAS Frame). TU Delft.

de Visser, H. (2016, juni 24). Testing the improved PAS methodology, Implementation of a search algorithm. TU Delft.

De Vries, J. C., & den Heijer, A. (2004, juni). Benchmarking universiteitsvastgoecl managementinformatie bij vastgoedbeslissingen. TU Delft.

de Vries, Jackie C., de Jonge, H., & van der Voordt, T. J. M. (2008). Impact of real estate interventions on organisational performance. *Journal of Corporate Real Estate*, *10*(3), 208-223. https://doi.org/10.1108/14630010810922094

den Heijer, A. (2012). Managing the university campus: Exploring models for the future and supporting today's decisions. TU Delft.

den Heijer, A., & van de Water, L. (z.d.). Deelstudie Universiteiten, Deel 2. TU Delft.

Dym, C. L., Little, P., & Orwin, E. J. (2014). *Engineering design: a project-based introduction* (4th edition). New York: Wiley.

Erickson, V., Lin, Kamthe, & Brahme. (z.d.). Energy Efficient Building Environment Control Strategies Using Real-time Occupancy Measurements. Geraadpleegd van http://andes.ucmerced.edu/papers/Erickson09a.pdf

Göçer, Ö., Göçer, K., Ergöz Karahan, E., & •han Oygür, I. (2017). Exploring mobility & workplace choice in a flexible office through post-occupancy evaluation. *Ergonomics*, 1-17. https://doi.org/10.1080/00140139.2017.1349937

Haik, Y., & Shahin, T. M. M. (2011). *Engineering design process* (2nd ed). Stamford, CT: Cengage Learning.

Hailemariam, E., Goldstein, R., Attar, R., & Khan, A. (z.d.). Real-Time Occupancy Detection using Decision Trees with Multiple Sensor Types. *Autodesk Research*. Geraadpleegd van https://www.autodeskresearch.com/publications/occupancydetection

Harrop, D., & Turpin, B. (2013). A Study Exploring Learners' Informal Learning Space Behaviors, Attitudes, and Preferences. *New Review of Academic Librarianship*, *19*(1), 58-77.

Heijer, A. C. den. (2011). *Managing the university campus: information to support real estate decisions*. Delft: Eburon Academic Publishers.

Heywood, C., Kenley, R., & Waddell, D. (2009, 21/01). The CRE Toolbox: Addressing Persistant Issues In Corporate Real Estate Management. Pacific Rim Real Estate Society (PRRES) Conference 2009.

Jensen, P., & van der Voordt, T. (2016). Towards an Integrated Value Adding Management Model for FM and CREM. *Proceedings of the CIB World Building Congress 2016*, *2016*, 332-344.

Jordan, M., McCarty, T., & Velo, B. (2009). Performance measurement in corporate real estate. *Journal of Corporate Real Estate*, *11*(2), 106-114. https://doi.org/10.1108/14630010910963142

Kothari, C. R. (2004). *Research methodology methods & techniques*. New Delhi: New Age International (P) Ltd. Geraadpleegd van http://site.ebrary.com/id/10318734

Lohman, F. (1999, december 7). The Effectiveness of Management Information, A design approach to contribute to organizational control. TU Delft.

Maguire, M. (2001). Methods to support human-centred design. *International Journal of Human-Computer Studies*, *55*(4), 587-634. https://doi.org/10.1006/ijhc.2001.0503

Mahlon Apgar, I. V. (1993, mei 1). Uncovering Your Hidden Occupancy Costs. Geraadpleegd 8 oktober 2017, van https://hbr.org/1993/05/uncovering-your-hidden-occupancy-costs

Mautz, R. (2012). Indoor positioning technologies. https://doi.org/10.3929/ethz-a-007313554

Maycock, A. L., Abeles, R. H., Salach, J. I., & Singer, T. P. (1976). The structure of the covalent adduct formed by the interaction of 3-dimethylamino-1-propyne and the flavine of mitochondrial amine oxidase. *Biochemistry*, *15*(1), 114-125.

Oguejiofor, O., Okorogu, V., Adewale, A., & Osuesu, O. (2013). Outdoor Localization System Using RSSI Measurement of Wireless Sensor Network, *Volume-2*(Issue-2). Geraadpleegd van https://pdfs.semanticscholar.org/0469/160727e05dfa6148fb1556ece3fe1aea610e.pdf

ORAS. (2015, december). Position Paper December 2015. TU Delft.

ORAS. (2017). Verslag ORAS komt naar je TU - Tijden van studeren. TU Delft.

Priestner, A., Marshall, D., & Mehrer, S. (2016, juni). Spacefinder, Illuminating study spaces at the University of Cambridge and matching them to user need and activity. Cambridge.

Seybold, J. S. (2005). *Introduction to RF propagation*. Hoboken, N.J: Wiley.

Sherman, R. (2015). *Business intelligence guidebook: from data integration to analytics*. Amsterdam: Elsevier, Morgan Kaufmann is an imprint of Elsevier.

Sithole, G., & Zlatanova, S. (2016). POSITION, LOCATION, PLACE AND AREA: AN INDOOR PERSPECTIVE. *ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences*, *III-4*, 89-96. https://doi.org/10.5194/isprsannals-III-4-89-2016

Supheert, L. (2018, april 13). *Choosing your place, Making a user journey to illuminate the possibilities of smart tools to support new users of the campus in choosing their workplace.*

TU Delft, Delft, Holland.

Valks, B., Arkesteijn, M., den Heijer, A., & Vande Putte, H. (2016a). *Campus NL*. TU Delft.

Valks, B., Arkesteijn, M., den Heijer, A., & Vande Putte, H. (2016b). *Smart campus tools*. TU Delft.

van der Zwart, j, & van der Voordt, T. (z.d.). Pre-Occupancy Evaluation of Patient Satisfaction in Hospitals., *Vol. 9*(1), 110-124.

van Hoek, T. (2016, november 3). Is this spot taken? : Using smart tools within real estate management to support the users. Delft University of Technology.

Vries, Jacoba Cornelia de. (2007). *Presteren door vastgoed: onderzoek naar de gevolgen van vastgoedingrepen voor de prestatie van hogescholen*. Delft: Eburon.

Weinstein, L. (2017, augustus). Review of the TfL WiFi pilot. Transport for London. Geraadpleegd van tfl.gov.uk

Wohlers, C., & Hertel, G. (2017). Choosing where to work at work - towards a theoretical model of benefits and risks of activity-based flexible offices. *Ergonomics*, *60*(4), 467-486. https://doi.org/10.1080/00140139.2016.1188220

Wu, K. (2015, juni 23). Managing the University Campus, Towards a maturity model for campus management. TU Delft.

Zhao, Y., Zeiler, W., Boxem, G., & Labeodan, T. (2015). Virtual occupancy sensors for real-time occupancy information in buildings. *Building and Environment*, *93*, 9-20. https://doi.org/10.1016/j.buildenv.2015.06.019

Zlatanova, S., Liu, L., Sithole, G., Zhao, J., & Mortari, F. (2012). *Space subdivision for indoor applications* (Vol. 66). TU Delft/OTB Research Institute for the Built Environment.

Image: BKCityGuide 2017/2018

APPENDICES

1. ROADMAP

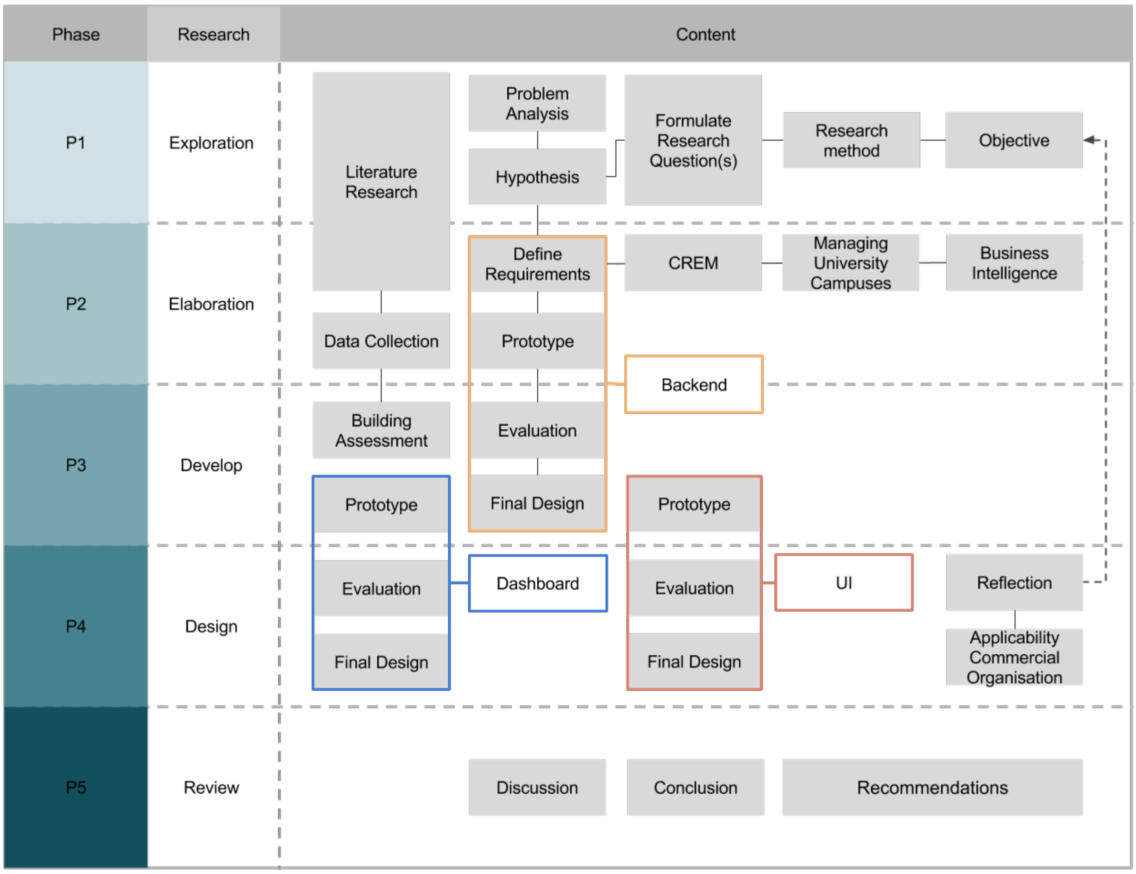


Image 3.4 Roadmap (own illustration)

In image 3.4 the roadmap of the research is shown. The roadmap shows the most important tasks of the research within its respective research phase. First the Exploration phase is the start of the research which is spent looking for a subject of interest within the graduation lab derived from either a scientific or social need. It is important to clearly determine and describe the problem and its main causes while linking this with existing scientific literature. Therefore the literature research and problem analysis are the first tasks in the roadmap. From the problem analysis a scientific standpoint will be taken in the form of a hypothesis. The objective of the research is to test the hypothesis on its truthfulness. From this hypothesis, research questions are formulated which target various aspects of the required information. When the research questions are formulated there is a need to determine the methods to answer these questions. Therefore the task research method is a product of the research questions. To complete this all a research objective is defined which differentiates from the hypothesis, which is not to be proven or not, but simply the ultimate goal of the research.

It can be noticed that the literature research block extends from the first phase to the second phase. For this research literature will be used to set the fundamentals of the research including problem definition and requirements as stated in the previous sub chapters. Thus, the literature research supports the design process and the validation of the research outcomes. The defined main literature subjects are thus far: Corporate real estate (CREM), Managing the University Campus and Business Intelligence. However, as stated, literature research concerning Smart Campus Tools, Learning Space Preferences and Privacy Laws as a supporting role. CREM will act a general introduction to the field of Corporate Real Estate management and its main objectives. Managing the University Campus is researched to determine the state-of-art of Campus management and discover the problems in current practice. Business Intelligence is researched to establish how reliable management information can be made and stored to optimally support decision making. Learning Space Preferences involves student needs and input for implementation in the Smart Tool. Privacy Laws is explored relating to user data gathering in order to make a smart tool that is allowed in the current regulatory climate. Available data will be collected. Lastly, a backend prototype of the Smart Tool is made offering a solution for the design problem. This will offer a sense of direction and gauge the feasibility of the features.

In Phase three the maturation of the backend will be the main objective. Users are involved to make the Smart Tool tailored to their needs and the Data streams need to be secured. In particular a Building Assessment needs to take place to gather the data which is unavailable at this stage. The Smart tool development starts with the prototype of the former phase which will be improved after two iterations in the form of evaluation interviews, resulting in a preliminary- and final design. In this phase the literature research should be mostly finished but it can be required to support research and Smart Tool development with further literature research in some cases.

Phase Four primarily concerns the design of front-ends in the form of the dashboard, which will be used by the campus management and a UI for the students. Similarly to the design of the backend these design will have two iterations in the form of interviews. After the system has been completed the Smart Tool will be tested in the form of a Pilot. It is crucial to establish a working Smart Tool, implementation can prove difficult, requiring much attention is in this phase. At a later stage the Campus Integration implies implementation of other faculties meaning possible new data streams and significant changes for the Smart Tool. Moreover, the Smart Tool can be analyzed on applicability to other organisations and if possible even applied to an organisation. Reporting the findings of the research will also become a large part of this phase as the scientific findings need to be analyzed thoroughly to be able to answer the research questions and hypothesis with accuracy.

In the fifth and final phase a step will be taken back to review the process and results of the research. In the Conclusion all the results of the research and its process will be described. A Discussion is needed to take a critical standpoint on the research and its results. This is designed to make both the researcher and the the reader think. Finally, in Recommendations new ideas for other researches and needs within the scientific body will be pointed out to stimulate further research, meant to show where to continue after the thesis.

2. PROTOTYPE EVALUATION

The prototype evaluation interview reports can be sent upon request. For more information, contact terveer.sven@gmail.com.

3. SEMI-STRUCTURED INTERVIEW RE MANAGERS

The campus manager interview reports can be sent upon request. For more information, contact terveer.sven@gmail.com.