

Enhancing decision support in real estate portfolio management

A dashboard redesign for the Preference-Based Accommodation Strategy based on principles of effective dashboard design

Thesis report (P5)

Name Benjamin Laagewaard

Student Number 4498496

Date 1-4-2026

University Delft University of Technology

Master Track MSc. Management in the Built Environment

Colophon

Benjamin Laagewaard

4498496

Delft University of Technology

Faculty of Architecture and the Built Environment
Management in the Built Environment
AR3MBE100 Graduation Laboratory

Graduation committee

First mentor	Dr. Ir. Monique Arkesteijn Real Estate Management
Second mentor	Dr. Ir. Ruud Binnekamp Integral Design and Management
Third Mentor	Dr. Hedieh Arfa Real Estate Management
Delegate from the Board of Examiners	Ir. Mariette Overschie Environmental Technology and Design



Preface

This thesis marks the end of my studies at the Delft University of Technology. During this time I learned many new things and discovered where my interests lie. When I started my bachelor, my aim was to become an architect. However, during my studies, my interests within the built environment changed. This led me to start with the master track Management in the Built Environment. Looking back, I am happy with the choice I made.

I am grateful for the opportunity to study at Delft University of Technology and to follow this master track. The graduation process has been a valuable learning experience, even though it took longer than expected. I fully stand behind my decision to start and finally complete this journey.

I chose to focus on a concrete topic for my thesis, which allowed me to develop a practical outcome by redesigning an existing PAS dashboard.

I would like to express my gratitude to my supervisors, Monique Arkesteijn, Ruud Binnekamp, and Hedieh Arfa, for their guidance and support throughout this process. Monique always knew how to help me get to the core of challenges and prioritise my actions. Ruud had numerous clear and interesting examples that helped me to understand complex theories. Hedieh supported me in overcoming many smaller and larger challenges and was always flexible to discuss my thesis. All of our discussions helped me to structure my thoughts and put them into this report.

Finally, I would like to thank my family and friends for their continuous support. In particular, I want to thank my father, mother, sister, and my girlfriend for their patience, time, and encouragement throughout this process. The conversations I had with them were invaluable and helped me to take a step back and regain focus when needed. Their support was essential for the completion of this thesis.

Benjamin Laagewaard

Abstract

Real estate is considered one of the five core organisational resources and is expected to add value to organisational performance. Within Corporate Real Estate Management (CREM), a central challenge is the alignment between the demand side (corporate strategy) and the supply side (real estate portfolio). Decision-making in real estate portfolio management is considered complex.

Decision Support Systems (DSS) such as the Preference-Based Accommodation Strategy (PAS) have been developed to support this alignment process by translating stakeholder preferences into measurable and comparable performance indicators. Although PAS provides a structured and preference-based approach to strategic decision-making, earlier pilot studies have indicated that stakeholders experience difficulties in using the accompanying PAS dashboard. These stakeholders mentioned that they struggled to understand the dashboard back and calculations. This resulted in reduced trust in dashboard outcomes and decreased decision-making support. While extensive literature exists on dashboard design principles and effectiveness criteria, no prior research has applied these principles specifically to a DSS context in CREM, nor to the PAS dashboard.

This thesis aims to develop and evaluate a redesigned PAS dashboard based on established dashboard design principles. The central research question is: *How can a PAS dashboard be redesigned based on identified design principles, and what lessons can be drawn for dashboard design in general?*

A Research Through Design methodology was adopted. First, a structured literature study identified dashboard design principles and criteria for effectiveness. These principles were translated into a design framework and used to analyse the existing PAS dashboard. Subsequently, a redesigned dashboard was developed iteratively. The redesign was verified and evaluated in workshops with participants. User feedback was analysed in relation to the identified effectiveness criteria.

The results indicate that applying design principles, single screen view, simplicity, layering of information, visual clarity, cognitive fit, and tailoring capabilities, contributes to improved stakeholder understanding and perceived usability of the PAS dashboard. The redesigned dashboard better supports the interpretation of preference scores, comparison of alternatives, and identification of interventions. Participants indicated improved transparency of the model backend and a clearer connection between input (preferences) and output (overall performance). This research contributes to both theory and practice. It provides a structured framework that connects dashboard design principles, effectiveness criteria, and concrete design features for DSS in CREM. Furthermore, it demonstrates how dashboard design can enhance stakeholder engagement and informed decision-making within PAS. The findings offer practical lessons for the further implementation of PAS and for the design of dashboards in comparable decision-support contexts.

Table of Contents

- Preface3
- Abstract4
- Table of Contents5
- 1. Introduction7
 - 1.1 Background and context.....7
 - 1.2 Research problem and gap10
 - 1.3 Research questions12
- 2. Research methodology14
 - 2.1 Research trough Design (RtD) Framework14
 - 2.2 Research methods.....15
 - 2.2.1 Literature review19
 - 2.2.2 Document study & researcher evaluation20
 - 2.2.3 Dashboard redesign through prototyping20
 - 2.2.4 Workshops with surveys and open discussions21
 - 2.3 Research outputs.....22
 - 2.4 Data analysis23
 - 2.5 Research ethics24
- 3. Dashboard design.....25
 - 3.1 Literature review25
 - 3.1.1 Dashboard definition, effectiveness and typologies.....25
 - 3.1.2 Categorisation for the literature review findings27
 - 3.1.2 Criteria of effectiveness for dashboards.....28
 - 3.1.3 Design principles for dashboards32
 - 3.1.4 Dashboard design features.....36
 - 3.1.5 Design patterns40
 - 3.2 Relationship between design principles and design features41
 - 3.3 Identification of design principles and effectiveness criteria (RQ1)43
- 4. Analysis of the PAS dashboard44
 - 4.1 Preference-Based Design in the Built Environment44
 - 4.2 Preference-Based Accommodation Strategy (PAS)47
 - 4.3 Document study50

4.6. Analysis and synthesis of the current PAS dashboard	51
4.6.1 Description of the current PAS dashboard	52
4.6.2 Visual overview of the current PAS dashboard	52
4.6.4 Assessment through effectiveness criteria	57
4.7 Limitations of the existing PAS dashboard (RQ2)	60
Chapter 5 – Round 1: Dashboard redesign and verification	61
5.1 Redesign objective and changes (RQ3)	61
5.2 Design changes for redesign 1	66
5.3 Workshop round 1 - Open discussion results.....	76
5.4 Workshop Round 1 - Survey results.....	88
5.5 Lessons for redesigning the PAS dashboard (RQ4)	89
5.6 Lessons for dashboard design (RQ5)	90
Chapter 6 – Round 2: Dashboard Redesign and Verification	92
6.1 Redesign objective and changes (RQ3)	92
6.2 Design changes for redesign 2	96
6.3 Workshop round 2 – Open discussion results	102
6.4 Workshop round 2 – survey results.....	106
6.5 Lessons for redesigning the dashboard (RQ4).....	109
6.6 Lessons for dashboard design (RQ5).....	111
7. Discussion	113
7.1 Interpreting the redesign results	113
7.2 Transferability of dashboard design principles to DSS.....	115
7.3 Theoretical contribution	116
7.4 Practical implications	117
7.5 Limitations	117
7.6 Recommendations	118
8. Conclusion.....	120
9. Reflection.....	123
References.....	125
Appendix A: Data management plan	129
Appendix B: workshop documents	134

1. Introduction

This chapter introduces the context of the research and outlines the main themes of the study. It first describes the background and context, followed by the presentation of the research problem and identified research gap. Finally, the research questions of this study are defined.

1.1 Background and context

Real estate is one of the five resources managed by organizations besides capital, human resources, information technology (IT) and communication (Joroff et al., 1993). In academic literature on Real Estate Management (REM), it is expected that real estate provides value to the performance of a society, organisation or individual (Den Heijer, 2011). Specifically, real estate can consist of portfolios, buildings and spaces. The benefit of added value from real estate is that it can improve the organisational performance. Therefore, the aim of Real Estate Management can be described as the maximalisation of added value of real estate to the business performance (De Jonge et al., 2009).

Globally, the development and energy usage of real estate (RE) contributes an estimated 30% of greenhouse gas emissions and 40% of energy consumption (UN, 2016). The United Nations proposed to decouple population and developmental growth from natural resource usage and energy consumption. In result, further deterioration of human well-being and the environment can be prevented (United Nations Environment Programme, 2022). In line with these, public organizations attempt reach both global and national sustainability and environmental goals within their real estate portfolios. To support this, some national and global policies and laws incentivise them to invest and improve the sustainability of their real estate. Consequently, public organisations create real estate strategies that reconsider energy consumption, material usage, CO2 emissions and through public resources (Den Heijer, 2011).

The main challenge in Corporate Real Estate Management (CREM) is argued to be the alignment of the real estate of an organisation to the corporate strategy. In portfolio management, the goal of CREM alignment is to align the business strategy to the operational side of a portfolio (Heywood & Arkesteijn, 2017).

Public organisations may have a mismatch between the demand and supply sides of their real estate portfolio due to conflicting ambitions. In result, the strategic decision-making is complicated by the possible tensions between added-values within the real estate (Den Heijer, 2021; Valks, 2021). This is problematic, since public organisations are known to struggle with meeting national and global policy demands due to challenges in, for example, financing and sustainability implementations (Den Heijer, 2021).

Alignment models have been used to match the demand and the supply side of the real estate and they have existed for over 30 years. However, after an analysis of theories and models on alignment, it was concluded by Heywood and Arkesteijn (2018) that they faced several limitations and a lack of focus of RE portfolio design and selection. According to these authors, alignment was not clearly defined in most of the models and users of the models often failed to grasp how complex and pluralistic the theories and models of alignment are. Generally, there was marginal

attention to decision-making and concrete procedures for the selection of the best alternatives were not present, as mentioned by Heywood and Arkesteijn (2018).

The Preference-Based Accommodation Strategy

The Preference-Based Accommodation Strategy (PAS) is a structured, iterative design and decision support approach developed by Arkesteijn (2019) to address the existing limitations of traditional CREM alignment models. It was evident that these models lacked procedural depth and did not properly present the complex, multi-actor reality of decision-making (Heywood & Arkesteijn, 2018).

The innovative element of PAS is the use of preference-based design, which allows for the translation of stakeholder preferences into quantifiable scores. By using a mathematical model stakeholders preferences are expressed into numerical values. In result, stakeholders can collaboratively design alternatives and systematically compare how these score on a wide range of tangible and intangible criteria. Stakeholder demands and criteria are translated in numerical values by using scales for measuring preference, and a mathematical model is used to calculate an overall preference score for alternative designs or strategic options (Arkesteijn, 2019).

The core objective of PAS is supporting stakeholders to select the most aligned alternative, which is the alternative with the so called highest overall preference score. To this end, PAS is structured in three interrelated elements: (1) procedural steps, (2) stakeholder activities and (3) mathematical model. In the procedural steps, stakeholders are able to define their own variables, rate the preferences, set constraints, generate alternatives and iteratively adjust decision variables. The PAS follows an iterative process, where stakeholders are able to revisit and alter their initial inputs during workshops that lead to new insights and feedback (Arkesteijn, 2019).

Preference measurement is done in close collaboration with stakeholders which allows them to co-design during workshops by adjusting inputs and constraints. Additionally, they can change their preferences in between sessions to have the model builder adjust model. The approach is adaptable to different cases and can be changed for specific situations and contexts. The PAS process is guided by a system engineer who creates a dynamic model by using the input of the stakeholders. This model includes mathematical equations and the calculated scores are presented through a dashboard to the stakeholders during collaborative workshops. The outcomes provide insights to stakeholders, which are beneficial for having group discussions, updating inputs, discussing constraints and creating interventions. In result, the transparency of design decisions through the preference score can increase the trust in the outcomes of the model (Arkesteijn, 2019).

Arkesteijn (2019) mentioned the possible usefulness of dashboards for the visualisation of model outcomes, identifying interventions and supporting strategic decision-making. Several evaluation studies with PAS have been conducted in collaboration with the Rijksvastgoedbedrijf (RVB) (Jongkind, 2025) and the national police of the Netherlands (Swens, 2024), as well as through various projects (such as OBT¹ optimisation) in the recent years. (Arkesteijn, 2019; Valks et al.,

¹ “Operationele Begeleiding en Training” in Dutch and “Operational Guidance and Training” in English

2021). The participants used the model outcomes in combination with their personal knowledge to create new portfolio alternatives. Therefore, it is evident that effective dashboard design could enhance stakeholder engagement and support informed decision-making. Although dashboards are used in the PAS approach to support decision-making, the dissertation by Arkesteijn (2019) does not make use of a structured design framework or set of design principles for their development.

Dashboards in Decision Support Systems

Recently, dashboards have evolved into essential tools for supporting data-driven decision-making within complex environments. Dashboards can be broadly defined as visual interfaces that present relevant or even tailored information to users, with the aim to support user awareness, monitoring and decision-making (Sarikaya et al., 2019). In detail, dashboards utilise a combination of data visualisations, metric tracking, and user interaction to help users rapidly interpret data, find patterns and make informed decisions (Yigitbasioglu & Velcu, 2012).

Decision Support Systems (DSS) can be defined as tools that are designed to support structured and informed decision-making in environments with many criteria and are usually computer-based. Dashboards have an important role within DDS, where they serve as the visual and cognitive interface between the underlying and complex data analysis and the front-end strategic usage (Ghazisaeidi et al., 2015; Pauwels et al., 2009). Dashboards can be seen as an operationalised extension of DSS that integrates the data from a multitude of sources and organises it visually to support strategic, tactical and operational decision-making (Lea & Nah, 2013). In result, the cognitive load for users is decreased and information overload is prevented (Rahman et al., 2025).

Effective dashboard design for DSS models plays an important role in enabling improved decision-making, especially in complex decision environments where DSS are used. When dashboard design is executed, users experience increased usability, reduced cognitive load and are presented with the proper information in the appropriate moment (Sarikaya et al., 2019; Yigitbasioglu & Velcu, 2012). However, dashboards with limited clarity, poor visual structure or irrelevant information hinder user engagement and results in flawed decision-making (Ghazisaeidi et al., 2015; Lea & Nah, 2013). In DSS, the dashboard design effectiveness influences the ability of users to interpretate displayed data by and to compare alternatives (Vazquez-Ingelmo et al., 2019). Therefore it can be concluded, that it is important to match dashboard design with user needs and decision environments to support decision-making in fields such as CREM.

To summarise, the complexity of decision-making environments in the public real estate sector is increasing and the role of dashboards in DSS highlight the importance of effective dashboard design. Regarding the PAS approach, dashboards are used as interfaces which enable users to engage with real estate portfolio data and create interventions. Although dashboards are incorporated in the PAS approach, their design is not performed through established set of design principles. Therefore, the goal of this thesis is developing and verifying a redesigned PAS dashboard based on identified dashboard design principles in order to support decision-making

in CREM and generate knowledge on the design of effective dashboard design for DSS. The following section outlines the currently identified problems when using the PAS dashboard. These problems are derived from stakeholder feedback from pilot studies.

1.2 Research problem and gap

This section introduces the research problem addressed in this thesis. It first outlines the challenges observed in the use of the PAS dashboard, followed by the identification of the research gap in current literature.

Research problem

The PAS approach could support real estate value maximalisation by aligning the supply to the demand side. However, pilots with the PAS approach have shown that stakeholders experienced difficulties in using the PAS dashboard for their decision-making. Some stakeholders mentioned that although the model helped, it was not always easy to keep a complete overview though the interface design (Arkesteijn, 2019). Additionally, some participants wanted to understand more of the model backend. Therefore, the dashboard could benefit from optimisation for stakeholder engagement. As a result, the effective implementation and broad user acceptance for the PAS approach could be improved (Arkesteijn, 2019). When the dashboard design of PAS is not effective enough to communicate information clearly to its users, it could limit its adaptation or effectiveness as a decision support tool for decision-making in CREM.

Several stakeholders found PAS attractive and effective and expressed interest in the application of PAS in their work. They appreciated specific things such as the transparency of the process, the iterative nature and the possibility for collaborative learning. Additionally, stakeholders mentioned the ability of the dashboard to provide immediate feedback on the selected interventions (Arkesteijn, 2019).

However, despite the positive reception of the PAS approach, several challenges were identified during the pilot studies. First, there were challenges in the application of PAS by the stakeholder organisations. In their experience, it took considerable time and effort to understand the principles of the model and to implement the right data. Additionally, it was not always clear to the stakeholder how their inputs were used by the model to generate outcomes, which decreased support for the outcomes (Arkesteijn, 2019).

Second, improvements were proposed by stakeholders regarding the dashboard of the model. Mainly improvements to the interface were suggested to understand the effect of the interventions. Participants of the pilots mentioned that the dashboard could benefit from a decreased level of content per screen and a lower number of different interfaces. Additionally, several participants expressed the desire to operate the model in between workshops by themselves to improve their understanding of the model backend (Arkesteijn, 2019).

Research gap

To gain a better understanding of the problem, a review of the literature was conducted. This review revealed that general design principles for dashboard have existed for several decades in

academic research and many are based on the foundations described by Few (2006). Similarly, research was done by Valks et al. (2021) on the selection of information requirements for dashboards in campus RE portfolio management. Dashboard design principles have been mentioned by several sources for generic application or in other cases for Business Intelligence (BI) systems, healthcare dashboards, self-service analytics and tactical/operational systems (Few, 2006; Sarikaya et al., 2019; Yigitbasioglu & Velcu, 2012).

However, the current literature lacks a generalised design framework for dashboard used in (DSS) for enhanced decision-making. Nasir et al. (2017) mentioned that dashboards already have a significant role in supporting decision-making by providing insights to its users but that developing them is currently hindered by the “limited study on a unified methodology to guide and govern the design process”. For example, challenges are mentioned about visual clutter, limited flexibility and customisation options. According to Bach et al. (2022) it is essential to overcome these challenges to make the use of dashboards more effective in decision-making processes. Furthermore, it should be considered that not all dashboard design principles are transferable to dashboards of different types and uses when considering the resulting functionality (Sarikaya et al., 2019).

Similarly, this concern is voiced by Yigitbasioglu and Velcu (2012), who mentioned over a decade ago that “little is known about what types of dashboards work best for different users or tasks”. This emphasises the limited available knowledge for the design of effective dashboards. More recently, McCoy and Rosenbaum (2019) studied the use of dashboards in higher education. They observed that although dashboards were available, their misalignment with the decision-making context resulted in limited use. Therefore, it can be argued that dashboards are developed for DSS without grounded design principles.

These findings are particularly relevant for the PAS approach. While a PAS dashboard was used in several pilot projects to support decision-making in public real estate portfolio management, its design is not guided through grounded framework or set of dashboard design principles. Therefore, this thesis has selected the PAS dashboard as a representative example of dashboards in DSS that lack design guidance.

There is practical and academic relevance to analyse the existing PAS dashboard and to develop a redesign through design principles for effective dashboard design. As mentioned earlier, these design principles do not easily transfer between different contexts and functions (Sarikaya et al., 2019). To the authors’ best knowledge there is no earlier research that presents comprehensive framework to guide the design of effective dashboards in DSS and more specifically, to the PAS dashboard. This thesis will attempt to fill this gap by:

- Identifying dashboard design principles and criteria for effective dashboard design from the literature and use the findings to analyse the current PAS dashboard.
- Redesigning the current PAS dashboard based on these design principles.
- Verification and validation of the redesigned PAS dashboard through participant feedback based on effectiveness criteria.

The aim of this study is to contribute academic insights on dashboard design for DSS and to improve the dashboard of the PAS approach to support decision-making in CREM.

1.3 Research questions

To respond the gap mentioned above, this thesis focuses on responding to the following main research question:

How can a PAS dashboard be redesigned based on identified design principles, and what lessons can be drawn for dashboard design in general?

To be able to respond to this question, several research questions have been defined:

- 1) *What are the design principles and effectiveness criteria for dashboards?*
- 2) *What limitations do stakeholders currently experience with the existing PAS dashboard?*
- 3) *What are the design principles to be considered in the redesign of a new effective PAS dashboard?*
- 4) *What are users' perceptions during the verification of the redesigned PAS dashboard in relation to the effectiveness criteria?*
- 5) *What lessons can be drawn from the redesign and evaluation process for dashboard design in general?*

The schematic overview in Figure 1 shows the order for answering the research questions. Additionally, the output of is mentioned under each research question. The main research question can be addressed once the sub research-questions have been answered. As shown in Figure 1, RQ3 is being investigated in parallel with RQ1 and RQ2 in order to analyse PAS dashboard and synthesise the findings from RQ1 and RQ2.

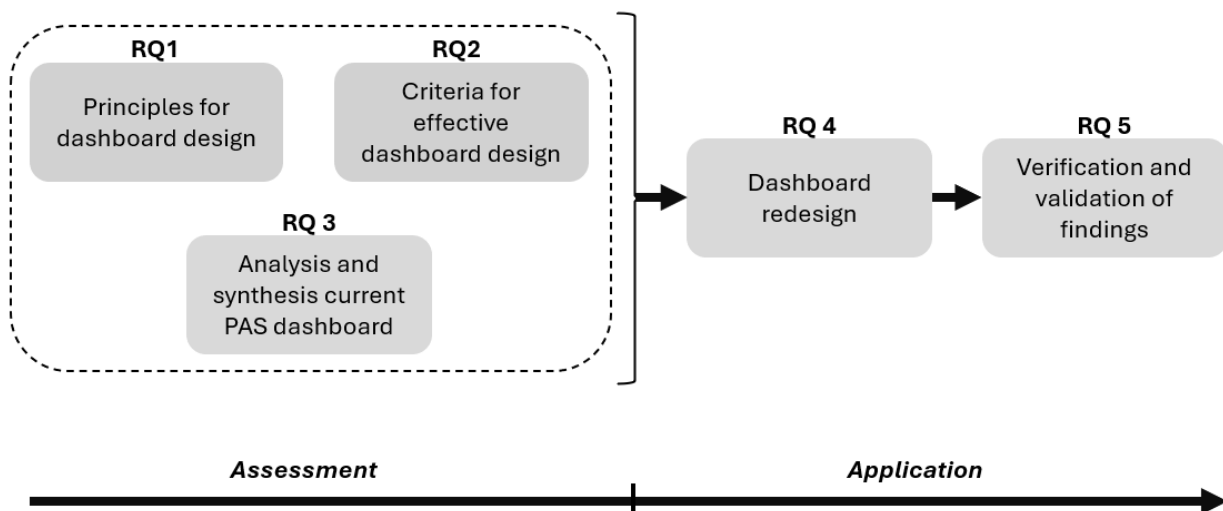


Figure 1: schematic order of answering the research questions (own figure)

Each sub research question is addressed in a dedicated section of this thesis. RQ1 is answered in Section 3.3, where a literature study is conducted to identify relevant design principles and effectiveness criteria for dashboards. Building on this theory, RQ2 is addressed in Section 4.7, which identifies the limitations of the existing PAS dashboard through a researcher review and previous experiences by stakeholders. Subsequently, RQ3 is explored in Section 5.1, where the

redesign objectives and design changes are defined for the first redesign iteration. RQ3 is answered again in Section 6.1 for the second redesign iteration.

For both redesign iterations a verification of the dashboard redesigns is performed and can be found in Section 5.5 and Section 6.5. Finally, RQ5 is answered in Section 5.6 and Section 6.6. An overview of the research design can be found in Figure 4.

2. Research methodology

The goal of this study is to research how effective dashboard design can support decision making-making in real estate portfolio management. Specifically, this is done by the redesign and verification of the PAS dashboard. This research will gather design principles and effectiveness criteria, use these for a redesign process and gather general lessons for dashboard design of DSS.

A Research through Design (RtD) methodology was adopted for this research. The identified research problem of this thesis consist of the challenges of using the PAS dashboard in workshops and the lack of generally applicable dashboard design frameworks in the current literature. This explains the selection of the RtD methodology because it is particularly suited for investigating complex and underexplored problems in real-life contexts through iterative cycles of designing and learning. RtD includes both research and design activities in which the design process itself is meant as a means to generate knowledge. Its primary goal is to produce generalizable knowledge that can be generalised beyond a specific problem through design(ing) (van Stijn, 2023).

In this thesis, the PAS dashboard serves as a concrete example to study. However, the aim is to contribute to a broader class of problems in designing of dashboards for decision support in complex environments. Specifically, it is examined how dashboards in DSS support can be made more effective through design principles and criteria. Although the PAS dashboard for the OBT case is specific to the field of CREM, the found insights can be used to contribute to the wider field of dashboard design for decision-making through DSS in the public sector.

This chapter will elaborate on the research structure and methodology applied throughout this thesis. First, the RtD framework is introduced and its use in this study is explained. Next, the overall research strategy is described and separated in four research phases to answer the research questions. Each phase includes specific research methods and leads to the eventual redesign and verification of the PAS dashboard in a real-life setting.

2.1 Research through Design (RtD) Framework

This study adopts a RtD approach to explore and iteratively improve the PAS dashboard. The RtD framework is useful when dealing with complex problems that lack firm theoretical foundations or uniform methods. RtD does not aim to resolve a problem in a linear approach but advocates the iterative development of solutions. The resolution of a problem is not the main objective, but rather “to generate generalisable knowledge for a class of problems” (van Stijn, 2023). In this thesis, the PAS dashboard is the main design object around which the learning process is structured.

RtD can be viewed as two connected, parallel components of research and design which are linked together. The RtD process used in this thesis is based on a “designedly pragmatism” approach in which the inclusion of contextual complexity and stakeholder engagement are considered essential for eventual knowledge development. The designing is supported through this interwoven processes of design and research. Designing serves as a platform for where new insights can be produced, tested and refined. The iteration and reflection allows the researcher to engage with stakeholders, implement findings and refine the design through multiple cycles. (van Stijn, 2023).

RtD is structured through an iterative design cycle that is built on the iterative design frameworks by Van Aken and Romme (2009). RtD is comprised of the steps analysis, synthesis, simulation and evaluation. The design cycle starts off by identifying the possible input followed by analysing

the problem, defining performance criteria, designing potential alternatives, simulating and testing them, and evaluating the outcomes in practice. This can be visualised through a three phase design model of analysis, synthesis and evaluation (see Figure 2).

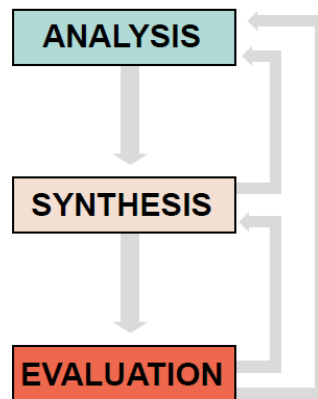


Figure 2: systematic design process described in 3 phases (van Stijn, 2023).

To guide the learning part of RtD, the action research cycle is adopted, which consists of the steps: design, propose, observe and reflect. It supports the involvement of stakeholders, allows for co-creation, testing of feasibility and validation of design outcomes. This offers a systematic method for extracting knowledge from the designing component of RtD.

In conclusion, the RtD framework supports both the creation the redesign and evaluation of a dashboard. Futhermore, generalisable knowledge is gained on the application of principles and criteria for effective dashboards of DSS in decision-making contexts.

2.2 Research methods

In RtD the selection of appropriate research methods is important to collect data and gain insights during different stages of the design process. It should be considered that the extraction of knowledge form the design activities RtD is known to often use multiple research methods from different fields like qualitative methods (e.g. interviews and workshops). It is essential to systematically understand, plan and document the design process by involving stakeholders. Stakeholder participation can be used for the co-creation of designs, testing of feasibility or desirability and the validation of findings (van Stijn, 2023). Afterwards, the generated knowledge is communicated through this thesis report. The iterative design cycle was adapted for this research and resulted in the following iterative design cycle (see Figure 3).

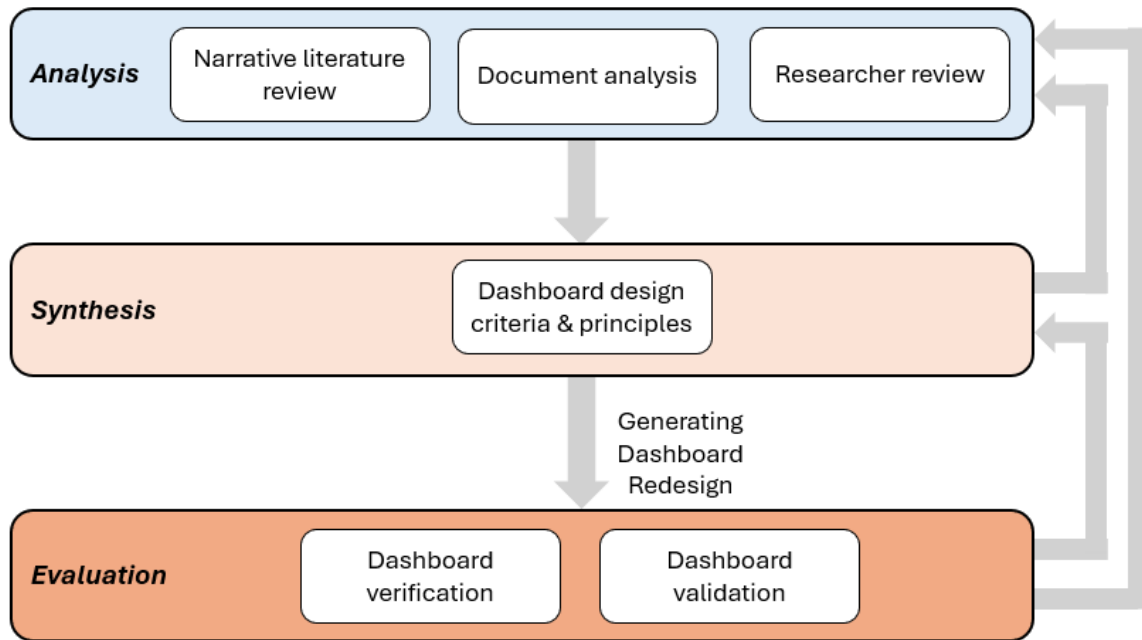


Figure 3: The iterative design cycle of this research.

Case studies

Case studies are suited for research that is explorative in nature and when the aim is to answer “why” and “how” types of research questions. Case studies focus on the personal perspective of participants and especially suited to study phenomena in their real-life context (Yin, 2018; Zucker, 2009). Therefore, case studies are suited for the collection of empirical data on user interactions with the PAS dashboard. In result, data can be gathered on user behaviour, experiences and perceptions. This will provide empirical findings on the dashboard design by performing evaluations with the criteria of effectiveness.

The case studies are used to answer research question 4 through the following actions:

- 1) Redesign of the PAS dashboard
The PAS dashboard is redesigned based on the findings from the literature review, document study and researcher review. Design changes are made based on the found criteria of effectiveness for dashboards and dashboard design principles.
- 2) Verification of the redesigned PAS dashboard
Multiple case studies methods are used to evaluate the effectiveness of the redesigned PAS dashboard and the impact of the selected design changes.

This thesis includes multiple qualitative methods in line with the earlier described research design:

- A literature review
- A document study and a researcher analysis of the PAS dashboard
- Dashboard redesign through prototyping
- Workshops including surveys and open discussions

The next sections will provide a detailed description of each method.

Participant selection

The iterative redesign process will be verified through workshops with two types of participants. The first participants are the “experts” who have been involved in the implementation of PAS or have a background in REM. Their experience provides insights into the applicability and relevance of the proposed redesign improvements.

The second group of participants are students of the Management of the Built Environment master track of the TU Delft. Due to their educational background, they have adequate knowledge of real estate management. Although they have less practical experience than experts, their academic perspective allows for a critical assessment of dashboard designs.

Dashboard selection

For the redesign process, the PAS dashboard developed for the OBT portfolio of the Dutch national police is used as the starting point. This dashboard is from a previous PAS model within the police context and provides a dashboard that was used in a real-life setting.

The selection of this dashboard is considered appropriate for usage in this thesis, since it was developed without the application of (existing) dashboard design principles. As a result, it provides a suitable object for analysis and redesign.

Using this existing dashboard enables the identification of design limitations and provides a basis for implementing and verifying design improvements. In doing so, the redesign contributes to answering research questions 4 and 5, as it supports drawing of lessons both for the design of a PAS dashboard and for dashboard design for DSS in general.

Research phases

The study can be considered explorative in nature since the aim is to broaden our understanding on design principles for an effective DSS dashboard (Stebbins, 2001). Based on the literature review, one argument for this approach is that the principles of dashboard design are relatively underexplored and vary between applications (Yigitbasioglu & Velcu, 2012). Additionally, in academic literature these design principles have not yet been applied to the DSS, and more specifically to the PAS dashboard. Therefore, this can be considered a relatively underexplored research area which needs further investigation.

Qualitative research is well-suited to explore under-researched topics. Therefore, this thesis adopted a qualitative approach to answer the research questions. A key benefit of qualitative research is that it enables the collection of participant perceptions and behaviours, potentially resulting in valuable insights and a deeper understanding of the phenomena under study (Zucker, 2009).

An overview of the research design can be found in Table 1. It describes how research phases answer to the research questions and shows the selected research method.

Table 1: Research phases and selected research methods (own figure)

search question	1 + 2	3	4	5
Phase explanation	1. Identifying the criteria and principles	2. Analysis and synthesis of the current PAS dashboard	3. Dashboard redesign and	4. Verification and validation of findings
Research methods	Narrative literature review	Cross-pilot comparison and review of the publications about PAS	Making the updated version of PAS dashboard	Open discussions and surveys
Guidelines / activities	Literature search and filtering	Reviewing the publications about PAS and providing dashboard limitations	Selection of design principles to be implemented	Preparing the workshop with surveys and open discussions
	Literature analysis	Researcher observation of current PAS dashboard	Creation of the updated version of PAS dashboard	Conducting the workshops
Output	Criteria of effectiveness & design principles	Limitations and challenges with the current PAS dashboard	The updated version of PAS dashboard	Validation of findings

Phase 1 of the research focused on the analysis of the criteria and principles of dashboard design. This responds to the first and second research questions (RQ1 and RQ2). The research methods is narrative literature review. The output is expected to be a comprehensive list of criteria of

effectiveness and design principles, which will be later used in Phase 3 of the research (“dashboard redesign”). In phase 2 of the research, the current PAS dashboard will be studied. A review of earlier publications will be conducted. This responds to RQ3. The output is expected to be a list of limitations and challenges of the current PAS dashboard. This phase is conducted in parallel with Phase 1. In Phase 3, RQ4 will be responded and dashboard redesign. The output is expected to be the updated version of the PAS dashboard. In Phase 4, RQ5 will be answered. The research methods are document study and workshops with surveys and open discussions to verify updated PAS dashboard, followed by a validation. An overview of the research design can be found in Figure 4.

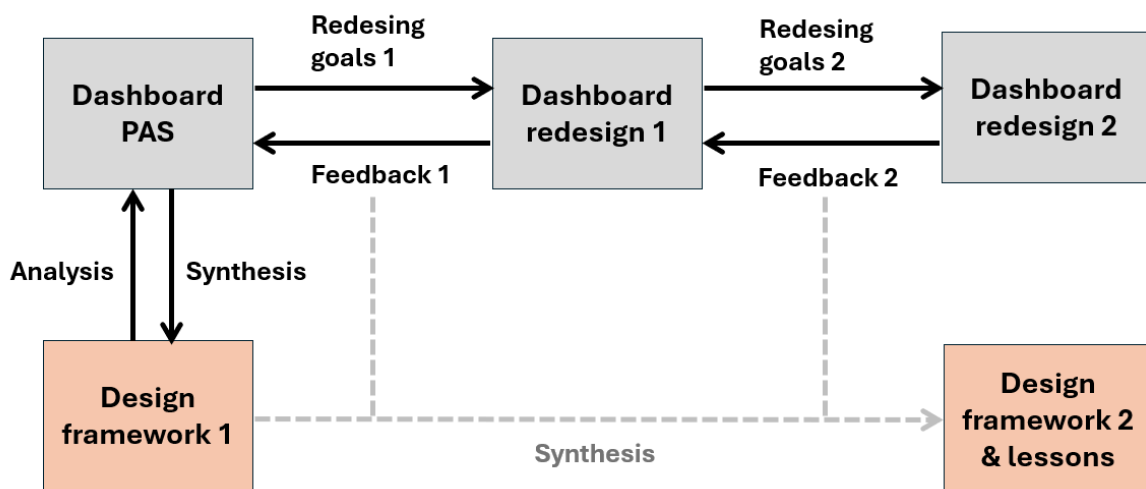


Figure 4: Research design (own image)

2.2.1 Literature review

This research conducted a literature review to answer first two sub research questions. Specifically, the objective is to identify design principles for dashboards and criteria of effectiveness for dashboards. Due to the scope of this thesis, the decision was made to perform a narrative literature review.

A narrative literature review is suited to gathering findings across separate sources and is different from statistical grouping of findings, which is fitting for systematic reviews or meta-analyses. Furthermore, narrative literature reviews are suited for underexplored topics like the research gap, when the aim is to gain clarity on concepts and add to the academic body of knowledge (Bryman, 2016).

The Scopus database was used find sources from a comprehensive database of to collect data. The first specific search query was: "decision making" AND "dashboard". A separate search was done for decision support system dashboard. This resulted in 2153 found publications. Consequently, several measures were taken to increase relevance and to limit the number of publications to a reasonable amount for this thesis. The search filters in Scopus were used to limit the database findings to the domain of decision-making. Keywords were added separately to the initial search query to discover relevant sources more rapidly. The keywords were: interactive, efficient, effective, design, dynamic, user, stakeholder, actor, experience and usability.

Next to this, the available publications were reviewed to assess the relevance of the found studies to real estate or Decision Support Systems. Preliminary screening was used to remove duplicates and irrelevant publications. This was done by reviewing the titles and abstracts of sources for niche uses of dashboards that are not relevant to the field of architecture and the built environment. Overall, the publications found per search query were generally reduced to 6-15 with the most relevant contents.

A complete review of was done for 12 highly relevant publications. Subsequently, an additional 7 publications were found by selecting relevant publications from the references lists of the selected publications. This approach is commonly known as snowball sampling (Naderifar et al., 2017). Additionally, several software programmes were used to organise the references and relevant information. References were managed through Endnote and reviewed papers were put in ATLAS.ti to organise information through labels and codes.

2.2.2 Document study & researcher evaluation

The third sub-question focusses on the limitations that stakeholder experience when using the PAS dashboard. Two studies will be done to address this. Firstly, a document analysis on dashboard of previous PAS pilot studies is conducted. Secondly, a researcher evaluation of the current PAS dashboard is performed. The findings from the narrative literature review, used to answer sub-question 1 and 2, are put in a dashboard design framework. Specifically, this framework contains the criteria of effectiveness for dashboards and design principles for dashboards. Using the criteria of effectiveness, an assessment is done on the previously reported user experiences in the document study, followed by a review of the existing PAS dashboard by the researcher.

The document study utilises existing publications of PAS pilots. The data on reported challenges, limitations or stakeholder feedback are studied. Additionally, meeting logs, comments by users and researcher notes of PAS Pilots are studied.

2.2.3 Dashboard redesign through prototyping

The redesign of the PAS dashboard follows the RtD methodology, and uses prototyping as a method to generate redesigns for the workshops. This process follows the identified framework of design principles to apply theoretical knowledge for the design of effective dashboards in DSS.

The mentioned RtD approach contains the process for the redesign of the PAS dashboard through prototyping. Prior to this research, the PAS approach was created as a model in Excel. For now, the use of Excel makes sense for prototyping for several reasons. First, the Excel software is suited to compile data from multiple sources and for the visualisation of data. Second, it is likely that participants are already experienced with using Excel.

The redesign follows an iterative process. First, the current PAS dashboard is analyzed to identify challenges and limitations. Based on this analysis, design objectives for the new dashboard version are defined. Subsequently, participant feedback requirements are integrated, drawing on feedback from PAS pilots, together with findings on design principles and criteria from the literature review.

A new dashboard version is then prototyped in Excel, incorporating visual and interface design changes. The effectiveness of these design changes is verified through workshops, after which the dashboard is refined in multiple design loops using participant feedback.

2.2.4 Workshops with surveys and open discussions

The verification of the PAS redesign becomes the focus after the redesign has been completed. A series of workshops are organised to allow for participation interaction with the renewed dashboard. These participants are asked to perform a set of realistic assignments by using the dashboard in a simulated context.

The aim of the workshops is to gather interventions created by the participants based on the dashboard. This helps to indicate the ability of participant to solve the assignments. There were two assignments. Assignment 1 was to track the performance of the whole portfolio and a few specific criteria scores. Assignment 2 was to create interventions through the dashboard.

The workshops focused on testing the redesign of the PAS dashboard in a realistic setting. The objective was to evaluate how participants interacted with the redesigned interface and how it supported their interpretation of portfolio alternatives. Attention is given to refining the dashboard based on participant feedback and observed limitations. Data collection during the workshops consisted of audio recordings, researcher observations of dashboard interactions, and field notes to capture user behaviour and discussions.

After each workshop session, participants were asked to complete a short survey to evaluate their experience with the dashboard. The survey was designed based on the identified dashboard design principles and criteria of effectiveness derived from the literature review. All workshop related documents, such as surveys, can be found in Appendix B.

In addition to surveys, open discussions were conducted to gain deeper insight into participant experiences and perceptions of the redesigned dashboard. These discussions allowed participants to elaborate on challenges, strengths, and improvement suggestions. Guiding questions for the open discussions can be found in Appendix B. The audio recordings were transcribed and analysed using Atlas.ti. A coding structure was developed to systematically label quotations and identify recurring themes. This qualitative analysis complemented the survey results and contributed to the evaluation of the dashboard redesign.

Workshop setup and data collection

This study consisted of two verification rounds. In each round, workshops were conducted with student and expert participants. The main aim of each round was to verify whether design changes resulted in improved dashboard effectiveness. Additionally, in Round 2 the preference of participants between dashboards was explored. The number of workshops and participants differed between each round.

Round 1 consisted of three workshops:

- One workshop with experts (five experts in total).
- Two workshops with students (six students in total).

Round 2 consisted of four workshops:

- Two workshops with experts (five experts in total).
- Two workshops with students (four students in total).

The surveys used in the two verification rounds differed from each other. The survey in Round 2 was adjusted to allow for a comparison between all three dashboard models, which aligns to with the research focus of monitoring dashboard improvements. Whereas the survey in the first round asked participants to score dashboards on a scale from 1 to 10, the survey from the Round 2 asked participants to disclose their preference between the different dashboard designs.

The recordings of the open discussions were transcribed and analysed using deductive coding based on findings from the literature study. The coding method included three deductive coding themes. These codes consisted of six criteria of effectiveness, thirteen functional features and thirteen visual features.

2.3 Research outputs

Goals and Deliverables

The goal of this thesis is developing and verifying a redesigned PAS dashboard based on identified dashboard design principles in order to improve decision support in CREM and generate knowledge on effective dashboard design for DSS. In result, these insights can support DSS, such as PAS, helping stakeholders in their decision-making for portfolio management. In a broader context, this research will draw lessons for DSS besides the lessons for redesigning the PAS dashboard. The PAS dashboard is used as an concrete design object on which design principles and criteria are applied in order to generate generalisable knowledge about how dashboards can support decision-making for public stakeholders. In relation to the OBT case, the Dutch National Police could gain additional added value to their business performance through the improvement of the PAS dashboard.

The deliverables of this research are:

- 1. A structured framework of dashboard design principles and criteria of effectiveness**
Derived from a narrative literature review, document study, and researcher review, synthesised into an applicable framework for Decision Support Systems (DSS).
- 2. An analytical assessment of the existing PAS dashboard**
An evaluation of the current dashboard based on the identified design principles and effectiveness criteria, including identified limitations and usability challenges.
- 3. A redesigned PAS dashboard prototype (iteration 1 and iteration 2)**
A redesigned version of the PAS dashboard developed through a Research through Design (RtD) approach, applying the identified design principles.
- 4. Verification of the redesigned dashboard through participant workshops**
Qualitative and quantitative evaluation of the redesigned dashboard based on user perceptions, workshop discussions, and survey results.
- 5. Design lessons for dashboard design in Decision Support Systems**
Generalisable insights into balancing analytical depth, transparency, usability, cognitive load, and functionality in DSS dashboards, specifically in collaborative CREM contexts.

Dissemination and audiences

The scholarly dissemination of this research is achieved by making the report available on the TU Delft Repository, which allows the findings to be used for further academic research. The practical dissemination consists of sharing the research with the participants of this research.

The targeted audience of this research are scholars or practitioners involved or interested in dashboard design for improved decision-making in real estate management. The research becomes especially relevant for the audiences in search for information about public real estate management.

2.4 Data analysis

Data is collected through the literature review, document study, researcher review and workshops and has been organised for interpretation in line with the research objectives. Data analysis can be separated in two separate parts and are described below.

Part 1 consists of the analysis of findings from the literature review, document study and researcher review. The data is reviewed in parallel to allow for triangulation and to strengthen the reliability of the findings. The found principles and criteria for dashboard design are gathered in a framework that can be used to evaluate the current PAS dashboard.

Part 2 consists of the analysis of findings from the workshops. After processing the data, a structured comparison of experiences of users and researcher observations can be made. Afterwards, the main research question can be answered now that all regular research questions have been answered.

For the data analysis of the open discussions, codes were made to systematically label quotations using the software tool Atlas.ti. For the second round of workshops, Tetra software was used to process the preferences of participants that were collected through surveys.

Data Management Plan

The data management plan for this research can be found in Appendix A.

The FAIR guiding principles are applied the data used in this research as described by Wilkinson et al. (2016). This means that the data must be findable, accessible, interoperable and reusable. The principle of findability is addressed in two ways. First, the data must be properly cited according to the APA (7t edition), referencing style, to ensure traceability. Second, research outcomes and materials are made available on the TU Delft Repository, which allows future researchers to retrieve and reference the data.

The accessibility principle is partially covered by the fact that this is an openly accessible database. Additionally, the fact that the thesis is written in English, one of the standard languages for communication, supports the interoperability across multiple institutions and disciplines. All findings and interpretations are translated and presented in English.

Finally, reusability of data was achieved by writing in a clear and structured manner. Theoretical concepts are defined and explained to make them understandable for readers that are unfamiliar with the existing information or methods.

2.5 Research ethics

A informed consent form was used to ensure integrity during the performance of the research methods based on a template of the Human Research Ethics Committee (HREC) of the TU Delft. In this form, participants are on their rights, the objective of the study and the handling of personal data. It was approved by the HREC and can be found in Appendix B.

All participating participants were contacted prior to the case studies and received an informed consent form by email. The participant are informed that participation is voluntary and that they can withdraw from the study for any reason at any time. Furthermore, conflicts of interest are prevented by avoiding participants with close connections to the researcher.

Several ethical obligation to the researcher should be considered when designing and performing the research. The objective is to prevent potential harm to individuals and reputation loss the them or their organisations. These measures include:

- The anonymisation of data. This ensures that personal information of participants is not mentioned or traceable in any published or shared thesis documents. In detail, names and any references that could result in the identification of participants are removed or altered.
- Confidentiality use of data. This is achieved by preventing the disclosure of participant information or responses.
- Data minimisation and protection. Data from recordings is deleted after transcription and access to the data is restricted to only the main research team, consisting of the student and supervisors, to prevent possible data breaches. Additionally, the data is stored on OneDrive to securely store the data and prevent potential data loss.

3. Dashboard design

This chapter aims to explore the existing academic knowledge on the design of effective dashboards, especially in context of DSS. A literature review is conducted to identify relevant design principles, effectiveness criteria, and design features for dashboards.

The findings of the literature review are synthesised into a design framework that structures the relationships between these concepts. The resulting framework is used in the later phases of this research to analyse of the existing PAS dashboard and to guide the redesign process.

3.1 Literature review

To answer the first research question (RQ1), a narrative literature review was conducted. The objective of this review was to identify existing knowledge on dashboard design principles and criteria for effectiveness, and to translate these insights into a design framework for dashboard design.

Although the literature on dashboard design is not limited to DSS contexts, the findings in this chapter were interpreted and selected with a focus on dashboards used for decision support, such as the PAS dashboard.

3.1.1 Dashboard definition, effectiveness and typologies

A performance dashboard can be defined as “a tool that enables managers to focus on more important activities, identify problem areas that need corrective actions, analyse root causes of poor performance, forecast trends, and establish benchmarks” (Ghazisaeidi et al., 2015). Therefore, the concept of effectiveness of dashboards refers to the extent that dashboards support users in monitoring performance, achieving goals and decision-making.

Almasi et al. (2023) emphasise that dashboards should provide practical feedback in order to improve performance, encourage the use of evidence-based practices and support managing the workflow and resources. This is relevant to complex domains such as CRE.

The Cambridge definition of criterion is “a standard by which you judge, decide about, or deal with something” (Cambridge Dictionary, n.d.-a). In the context of this thesis, the criteria for effective dashboards can therefore be defined as the measurable characteristics or factors that determine how successful a dashboard is in supporting its intended purpose. These criteria are described in depth in a later section.

Dashboard typologies

During the literature review an overview of the most often recurring dashboards typologies were identified and can be found in Table 2. This was done because although dashboards can fall under the same definition, they appeared to be of distinctive types and are used for different applications.

Table 2: Dashboard typologies from the literature review (own table)

Type of Dashboard	Purpose	Reference Author(s)
Performance Dashboards	For tracking organizational performance using KPIs to support strategic, tactical, and operational decision-making.	Lea (2013), Ghazisaeidi et al. (2015)
Operational Dashboards	Provide real-time data to monitor and manage day-to-day operations and improve responsiveness to ongoing business activities.	Sarikaya et al. (2019), Rahman et al. (2025)
Strategic Dashboards	Focus on high-level metrics for long-term goals and executive decision-making by consolidating KPIs and strategic performance indicators.	Sarikaya et al. (2019), Lin et al. (2018)
Tactical Dashboards	Support mid-level management with data for monitoring specific business processes, resource allocations, and short-term objectives.	Sarikaya et al. (2019)
Analytical Dashboards	Emphasize data exploration and in-depth analysis, often interactive and used for hypothesis testing, trend discovery, and root cause analysis.	Bach et al. (2022)

Sarikaya et al. (2019) did a wide study on 83 dashboard and grouped dashboards into interactive dashboards, static dashboards, dashboards for motivation, for learning and personal analytics. Additionally, dashboards were clustered based on their characteristics (see Table 3). These groupings can be used to study the PAS dashboard.

Based on these conditions, it can be argued that the PAS dashboard is most similar to a decision-making dashboard due to the presence of key performance indicators (KPI's), alignment of the portfolio to the organisational strategy and use by high-level users (e.g. managers) who make strategic decisions. Furthermore, the PAS dashboard can be linked to the communication dashboard cluster. This cluster includes dashboards that explain, educate or build consensus. This application is often used by users that are not experienced in using tools such as dashboards.

The literature review showed that research on dashboards is largely grounded in established design guidelines and performance management literature. Foundational work by Few (2006) forms an important basis, focusing on dashboards as visual interfaces of the most important information needed to achieve specific objectives. More recent studies, such as Yigitbasioglu and Velcu (2012) and Sarikaya et al. (2019), expand this perspective by examining dashboards in relation to performance management, usability, and analytical functionality. Although authors use different terminology, there is considerable overlap in how effective dashboards are conceptualised.

Table 3: Dashboard clusters (Sarikaya et al., 2019)

Goal	Cluster	# Examples	Purpose				Audience				Visual Features				Data Semantics		
			Strategic	Tactical	Operational	Learning	Audience	Vis Literacy	Domain Expertise	Construction	Interactivity	Modify Data/World	Highlighting	Multipage	Alerting+Notification	Benchmarks	Updateable
Decision-Making	1 Strategic Decision-Making	16	Y	Y	-	N	O	-	-	-	Y	N	N	Y	-	-	Y
	5 Operational Decision-Making	14	N	Y	Y	N	O	-	-	-	Y	N	N	Y	-	Y	Y
Awareness	3 Static Operational	10	N	N	Y	N	O	L	-	-	-	N	N	N	-	Y	Y
	4 Static Organizational	8	-	-	N	N	O	M	-	N	N	N	-	N	N	-	Y
Motivation and Learning	2 Quantified Self	7	N	N	Y	N	I	H	N	N	Y	N	-	Y	-	-	Y
	6 Communication	13	-	-	-	Y	P	M	N	N	-	N	-	-	N	N	Y
	7 Dashboards Evolved	15	-	-	-	-	P	H	-	-	-	-	-	-	-	-	Y

3.1.2 Categorisation for the literature review findings

In relation to dashboard design a categorisation was made to organise the findings of the literature review. The categories can be found in the table below.

Table 4: Literature findings categorised in four main topics (own table)

Category	Purpose
Criteria of effectiveness	Assess dashboard based outcomes
Design principles	Advise on how the dashboard should be created
Design features	Give functional / functional capabilities of dashboards
Design patterns	Provide reusable design templates

The relationship between principles, features and patterns in this research can be explained as a design hierarchy. Design principles guide the inclusion of design features and design patterns are a flexible set of predefined design features for the design of common dashboards. Combined, the principles, features and patterns guide the design of a dashboard. However, the assessment of dashboard effectiveness is done through a separately created set of design criteria. Design criteria are not part of the design process, but serve as an evaluation framework to determine how effective the dashboard is at supporting the monitoring performance, achievement of goals and decision-making.

To be concise, this thesis distinguishes between a **design process**, which applies design principles to develop a dashboard, and the **evaluation process**, which focusses on assessing the effectiveness of a dashboard. The relationships and both processes can be found in Figure 5.

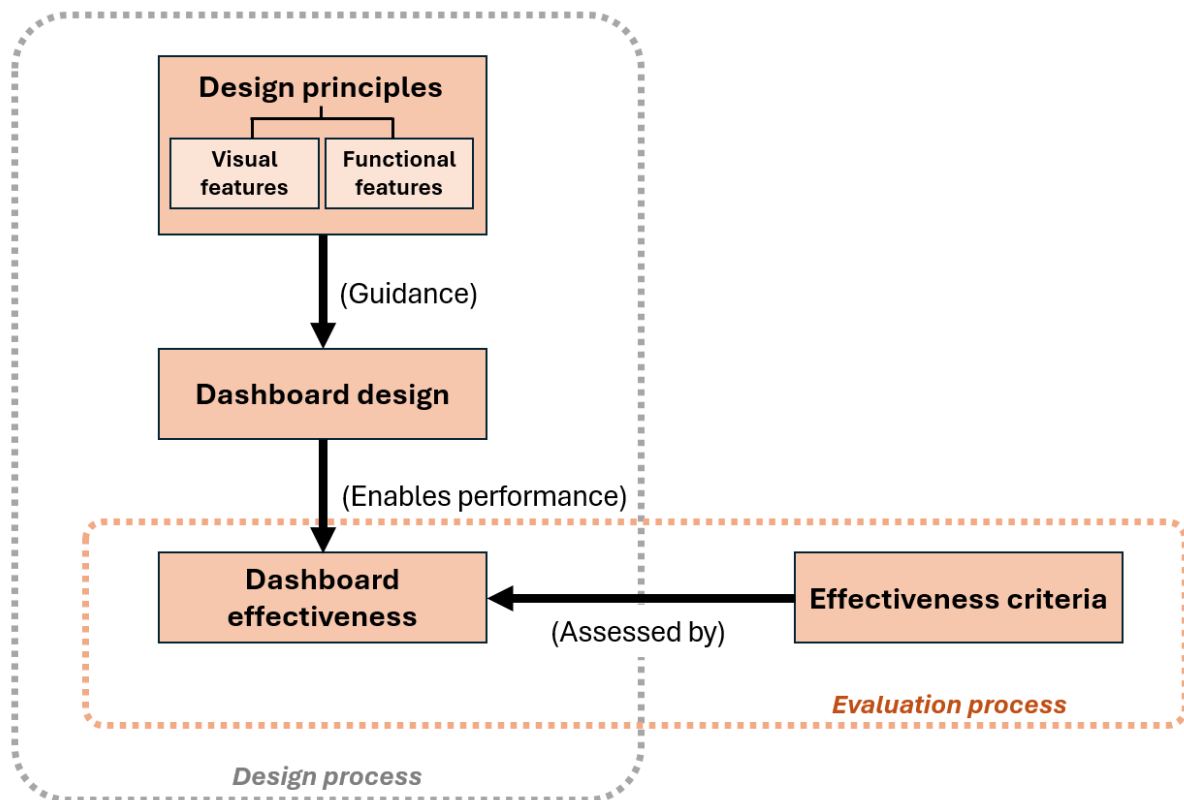


Figure 5: The relationship between principles, features, patterns and criteria (own figure).

3.1.2 Criteria of effectiveness for dashboards

The effectiveness of a dashboard can be evaluated based on the criteria of effectiveness that were found in the literature review, which can be found in Table 5. These criteria range from technical implementations to the way users interact with dashboards. These key criteria will be explained in more detail.

The literature review provided an overview of criteria for the evaluation of dashboard effectiveness. According to authors such as Yigitbasioglu and Velcu (2012), Karami (2020), and Almasi (2023), effectiveness is not limited to visual features but also includes whether the dashboard supports performance management and managerial decision-making needs. Frequently mentioned criteria include usability, flexibility and readability in combination with the extent to which the dashboard supports performance monitoring and informed decision-making.

Table 5: Dashboard effectiveness criteria found during the literature review (own table)

Criterion	Definition / Description	Authors
Usability	Extent to which users can efficiently and satisfactorily use the dashboard; includes learnability, efficiency, memorability, error recovery, satisfaction.	Almasi et al. (2023); Lea & Nah (2013); Nielsen (2012)
Flexibility	Degree to which the dashboard can adapt to varying user needs, roles, or domains through customisation, personalisation, and automatic adaptation.	Sarikaya et al. (2019); Yigitbasioglu & Velcu (2012); Vázquez-Ingelmo et al. (2019)
Interactivity	Supports user-driven exploration, filtering, and data manipulation for better decision justification and contextual understanding.	Sarikaya et al. (2019); Karami et al. (2017); Rabiei & Almasi (2022)
Knowledge Discovery	Enables users to generate new insights and understand trends or complex data relationships, especially in strategic settings.	Karami et al. (2017); Sarikaya et al. (2019)
Readability	Ease with which users can interpret visual elements such as graphs, labels, and charts, reducing cognitive effort and error.	Karami et al. (2017); Lin et al. (2018); Yigitbasioglu & Velcu (2012)
Transparency in Construction	Clarity in how data is selected, calculated, and presented; includes transparency of data sources, definitions, and alignment with goals.	Pauwels et al. (2009)

Usability

There is not yet a publication that provides a comprehensive framework to assess the usability of dashboards. This was concluded by Almasi et al. (2023) who performed a literature review. They found that questionnaires for usability evaluations are not created specifically for dashboards and therefore it cannot be ensured that they provide an appropriate measurement for the abilities and features of dashboards. In result, there are no evaluation criteria that are agreed upon in general. Therefore, it is justified to define them for this research.

Lea and Nah (2013) theorize that the usability of performance dashboards effects the usefulness of operational support and tactical support. Therefore, they argue that the usability of dashboards must be considered as a quality attribute. The usability definition by Nielsen (2012) was adopted, which is based on five quality components:

- Learnability: How easy is it for users to accomplish basic tasks during first use?
- Efficiency: Once users have learned the design, how quickly can they perform tasks?
- Memorability: When users return to the design after a period of not using it, how easily can they re-establish proficiency?
- Errors: How many errors are made, how severe are these errors, and how easy is it to recover from the errors?
- Satisfaction: How pleasant is the interface?

This definition by Nielsen (2012) mainly focusses on the ease of use. Additional dimensions were added by Lea and Nah (2013) who described perceived usefulness and operational support.

Alignment of the dashboard to the user's cognitive and strategic needs is important since the usability effects the strategic support, tactical support and operational support (Yigitbasioglu & Velcu, 2012).

Flexibility

Flexibility is another criteria that should be considered for dashboard effectiveness. It refers to the extent that a dashboard is able to adapt to different user requirements, tasks or the domains of application. As Sarikaya et al. (2019) mentioned, dashboards are used by a wide range of users with different needs and in varying sectors by users with diverse roles. For example, managers and operational staff might require different details or levels of details. To remain useful and relevant to different users, flexibility should be implemented into dashboards during the design with options for individual interaction with data. Furthermore, Yigitbasioglu and Velcu (2012) mention that flexibility can reduce information overload when the user is enabled to switch between presentation formats and several levels of detail. The result is that decision-making quality is improved.

Interactivity

Interactivity is mentioned by Sarikaya et al. (2019) as an important criteria for dashboards, particularly when users need to explore, filter and adjust data to justify their decision-making processes. By performing a systematic analysis of real-life dashboards, it was shown that there are already many systems that enable interactive elements. These offered the ability to perform real-time exploration and gave contextual understanding when compared to static dashboards. Several design features for interactivity are mentioned in earlier publications (Karami et al., 2017; Rabiei & Almasi, 2022), such as, drill-down capabilities, filtering and what-if analysis. These features will be described in further detail in the section 3.1.4.

Knowledge discovery

Knowledge discovery can be used as a separate evaluation dimension. Knowledge discovery "is essential in dashboards used to detect trends, understand relationships and support insight generation" (Karami et al., 2017). Specifically, dashboards are viewed as more than visualisations of data and can enable cognitive processes. In result, users can explore complex data and create new findings, which is useful in strategic settings.

Knowledge discovery is not the same as usability. It is about the insights that users can gain from the dashboard, whereas usability is about how users interact with the dashboard. This distinction is mentioned by Sarikaya et al. (2019) that dashboards can vary in both usability and analytical exploration. Both of the criteria are used for this thesis whilst making a clear distinction between them. Their differences can be distinguished as follows: a dashboard can have good usability but provide only few insights.

Readability

Readability is specifically mentioned as a valuable criterion for dashboards effectiveness by Karami et al. (2017) and refers to how easy and accurately users can interpret and make sense of visual elements on the dashboard. With a foundation from visual design literature, it mainly focusses on visual representations such as charts, graphs, labels and colour configurations. Similarly, "visual clarity" is mentioned by Lin et al. (2018), arguing that it is essential for users who are not experienced with representation tools or don't use them regularly.

A readable dashboard reduces the cognitive effort of users to interpret the presented data. In result, decision-making is faster and more accurate (Karami et al., 2017).

Poor readability is one of the factors that could lead to information overload and decreased task performance (Yigitbasioglu & Velcu, 2012). Additionally, could confusion could rise amongst users and the value of the data might be lost (Lin et al., 2018).

Transparency in dashboard construction and data logic

Transparency in how a dashboard is built, is a criterion for dashboard effectiveness. Pauwels et al. (2009) argue that dashboard construction processes must be transparent to the user to develop user trust in the presented information. To accomplish this, users have an understanding of which data is used, how it is selected, how the calculations are made and how information is displayed. In result, the design logic becomes transparent, which can increase user trust in the displayed information. This requires clear dashboards with definitions, retrievable data sources and clear links between the data and objectives.

3.1.3 Design principles for dashboards

Introduction

Cambridge definition of a principle is “a basic idea or rule that explains or controls how something happens or works“ (Cambridge Dictionary, n.d.-b). In the context of this thesis, design principles are considered the design guidelines for designing a dashboard. Design principles are different from criteria of effectiveness, because they are used for the creation of dashboards and not to evaluate them afterwards. According to Yigitbasioglu and Velcu (2012) “design principles provide foundational guidance for creating dashboards that are not only visually appealing but also effective in supporting users’ decision-making processes.

The performed literature review shows that there is a wide range of principles that can be used to design dashboards. Principles may vary depending on the function of the dashboard and the field in which it is applied (Sarıkaya et al., 2019). This was supported by Bach et al. (2022) who concluded that there was not yet a comprehensive framework for dashboard design. They performed an extensive literature review and showed that there are many design principles used in practice but no agreement on a comprehensive list of design principles. An overview of the found design principles can be found in Table 6. The following sections will expand on the design features that were found through during the literature review.

This structured set of dashboard design principles for DSS was derived from the reviewed literature. These principles emphasise that dashboards with the purpose to support decision-making should be focused on relevant performance indicators, and designed to communicate information clearly and efficiently. Essential factors include visual clarity, consistency in layout, appropriate selection of visualisations, and minimisation of cognitive overload. According to Few (2006), dashboards should enable users to grasp key information rapidly and avoid unnecessary visual elements. In addition, more recent literature highlights the importance of interaction, filtering, and drill-down functionality, particularly for dashboards used in analytical and decision-support contexts.

Table 6: Design principles found through the literature study (own table)

Design Principle	Description	Authors
Single Screen View	Display all essential information on one screen to reduce cognitive load and support quick decision-making.	Few (2006); Yigitbasioglu & Velcu (2012)
Simplicity	Eliminate unnecessary elements to reduce distractions and help users focus on relevant data.	Few (2006); Lin et al. (2018); Yigitbasioglu & Velcu (2012)
Layering of Information	Present data hierarchically, starting from summaries and allowing users to access more detail as needed.	Bach et al. (2022); Valks et al. (2021)
Visual Clarity	Ensure ease of interpreting charts, tables, icons, and colors to support accurate understanding.	Karami et al. (2017); Lin et al. (2018)
Cognitive Fit	Align the dashboard's visual presentation with the user's tasks and way of thinking to improve decision-making.	Yigitbasioglu & Velcu (2012)
Tailoring Capabilities	Enable dashboards to be customized, personalized, or adapted to user roles and contexts for better alignment and usability.	Vázquez-Ingelmo et al. (2019); Sarikaya et al. (2019); Yigitbasioglu & Velcu (2012)

Single screen view

One of the most prevalent design principles is the single-view screen. One of the key publications was by Few (2006), who argues that an effective dashboard should display all essential information on a singular screen. Consequently, users are enabled to rapidly gather information and perform swift decision-making. This is explained by Yigitbasioglu and Velcu (2012) who mentioned that using a single-screen view, switching between multiple screens or tabs increases the cognitive load and disrupts users. In result, the generation of cognitive insights is hindered.

Simplicity

Simplicity is a fundamental design principle that is mentioned in almost any publication on dashboard design. In order to achieve simplicity in dashboards, the goal is not to show limited data but instead to remove unnecessary elements that could confuse or distract users. Preferably, the displayed content should only provide meaningful information to the user (Lin et al., 2018). Similarly, a minimalist design is advocated by Few (2006) who mentions that elements useful for data interpretation are allowed and that decorative elements should be avoided. The benefit of simplicity in dashboard design is that users can rapidly identify trends anomalies and relationships without filtering through visual noise (Yigitbasioglu & Velcu, 2012).

Layering of information

Layering of information is a design principle that balances the need for simplicity with the need for detailed data demands. Layering allows dashboards to show complex data progressively, starting with overviews and enabling users to drill down into details. A hierarchical structure is applied, starting from a simplistic overview and moving on to detailed views when required (Bach et al., 2022; Valks et al., 2021). According to Bach et al. (2022) layering of information is especially

useful for strategic and operational tasks by lowering the cognitive load and providing in-depth insights.

Visual clarity

Visual clarity is defined as the ease of data interpretation by users through visual elements such as charts, tables, icons and colour schemes (Karami et al., 2017). It has a strong link with the earlier mentioned readability criterion.

This design principle is essential for the dashboard comprehension of users, especially when they are not versed in the use of technical tools. Without proper visual clarity, any information can be misinterpreted or ignored. Examples of visual clarity through design features are font consistency, intuitive colour use and layout consistency (Lin et al., 2018).

Cognitive fit

Cognitive fit theory was explicitly mentioned by Yigitbasioglu and Velcu (2012) in the context of dashboards. According to this theory “the type of task and the form of data presentation should match for better decision-making performance”. It focusses on creating an optimizing fit between the purposes, users, design features and outcomes. In detail, dashboards should align with the user’s way of thinking and task requirements.

This design principle advocates information presentation by dashboard are tailored to the context of use and task of the user to achieve decision-making effectiveness. When left unconsidered, a low cognitive fit result in increased cognitive load and slower user interpretations. For example, graphs enable the user to identify and understand relationships and creating comparisons (spatial tasks). Tables help to look up specific values and providing these with an (symbolic tasks).

Tailoring capabilities

Tailoring is categorised by Vazquez-Ingelmo et al. (2019) in three types. The first type is customisation, which allows users manually adjust the dashboard. The second type is personalisation, where the system itself selects the contents of the dashboard based on the user profiles. The third and last type is adaptation, in which the dashboard changes through contextual inputs. These types can support alignment of dashboards with the needs of the user, potentially resulting in improved user experience and decision-making.

Sarikaya et al. (2019) argue that generic or “one size fits all” dashboards lack flexibility.

When dashboard design allows for tailoring the user gains flexibility. This is necessary since dashboards are used by a wide range of users with different data literacy levels, goals and backgrounds. Additionally, Vazquez-Ingelmo et al. (2019) strongly advocates finding a suitable dashboard configuration given a concrete user since its use is effected by “personal experience, social factors like biases, beliefs or past experiences”.

The principle of tailoring capabilities has a strong tie to cognitive fit, which advocates for matching the dashboard structure to the user characteristics and tasks. When dashboards are tailored in this manner, the user can interpret information more effectively and the dashboard consistently. Furthermore, the user is more likely to trust and adopt the dashboard (Yigitbasioglu & Velcu, 2012).

Information overload

Information overload is a frequently mentioned challenge in dashboard design (Yigitbasioglu & Velcu, 2012). When using performance dashboards, users should receive a convenient overview of key performance indicators. However, poor dashboard design overwhelms users through excessive, non-essential or disorganised data. This may result in a high cognitive load, which

negatively effects decision-making instead of supporting it and is especially the case for complex operational or strategical environments (Sarikaya et al., 2019).

Similarly, Yigitbasioglu and Velcu (2012) advocate for extra attention to minimalization of visual and informational clutter in dashboard design. Users can miss signals or misunderstand trends due to excessive information density and poor layout choices. In result, the dashboard effectiveness to support accurate decisions is lowered.

Section summary

The design principles in this section provide essential building blocks for creating effective dashboards. Principles such as, single-screen layout, simplicity, information layering and visual clarity support the user in managing information load and making rapid interpretations.

The findings show that a dashboard design approach should meet both technical capabilities and user-centred requirements.

3.1.4 Dashboard design features

This section reviews the identified visual and functional design features during the literature review, that can operationalize the design principles and effectiveness criteria. Following the categorisation by Yigitbasioglu and Velcu (2012), design features are split into visual features (Table 7) and functional features (Table 8). They mentioned that “functional features are the features that relate indirectly to visualization but describe what the dashboard can do. On the other hand, the visual features refer to the principles of visualizing data, i.e. how efficiently and effectively information is presented to the user”. Depending on the user the functional features need to fit the characteristics of the user, for example their tasks, knowledge, and personality. At the same time, studies such as Sarikaya et al. (2019) stress that dashboard design principles are context-dependent; not all features are equally relevant for every dashboard type. The dashboard features and level of interaction should match the dashboard’s purpose, user group, and decision context.

Table 7: Visual design features found in the literature review (own table)

Visual features	Description	Authors
Single-screen layout	Keeps all essential data on one screen for quick understanding without scrolling.	Yigitbasioglu & Velcu (2012)
Maximized data-ink ratio	Reduces non-data elements and emphasizes meaningful visuals for clarity.	Yigitbasioglu & Velcu (2012)
Appropriate use of color and graphs	Ensures charts and colors are used to enhance, not distract from, the data.	Yigitbasioglu & Velcu (2012)
Frugal use of colors	Minimizes visual noise by using only necessary color contrasts.	Yigitbasioglu & Velcu (2012)
Visual gridlines for 2D/3D graphs	Uses gridlines to support accurate data reading in charts	Yigitbasioglu & Velcu (2012)
Clear, descriptive labels and tooltips	Provides users with helpful labels and hover-over tooltips for context.	Lea (2013); Sarikaya et al. (2019)
Consistent layout and design	Maintains uniformity in layout, font, and color across dashboard	Lea (2013); Sarikaya et al. (2019)
Logical tab hierarchy	Organizes dashboard content logically using tabs or sections.	Lea (2013)
Toggle between tables and graphs	Allows toggling between visual charts and tabular data views.	Karami et al. (2017); Ghazi (2015)
Presentation format guided by task type	Selects visual formats based on the type of data and user tasks.	Yigitbasioglu & Velcu (2012); Ghazi (2015)
Visual mapping of data to suitable visualization	Links data properties to visual elements automatically to guide visualization.	Vázquez-Ingelmo et al. (2019)
Constant visual cues	Uses repeated visual elements to help users recognize functions or data areas.	Lea (2013)
Simple and intuitive layout	Supports ease of use with an uncluttered and user-friendly layout.	Yigitbasioglu & Velcu (2012); Lin et al. (2018)

Table 8: Functional design features found in the literature review (own table).

Functional features	Description	Authors
Drill-down/roll-up capability	Lets users click on data to explore more detailed breakdowns.	Yigitbasioglu & Velcu (2012); Lea (2013)
What-if analysis	Allows scenario testing by adjusting variables to see potential outcomes.	Pauwels et al. (2009); Sarikaya et al. (2019)
Scenario planning and budgeting	Supports planning through budget inputs and forecast comparisons.	Pauwels et al. (2009)
Automated alerts and notifications	Notifies users about important changes or thresholds being crossed.	Yigitbasioglu & Velcu (2012); Sarikaya et al. (2019)
Analytical tools (e.g., prediction, pattern ID)	Provides advanced features like predictions and pattern recognition.	Sarikaya et al. (2019)
Goal setting and gamification	Engages users by letting them set goals or gamify progress tracking.	Sarikaya et al. (2019)
Layered information structure (strategic to ops)	Structures content across strategic, tactical, and operational levels.	Lea (2013); Sarikaya et al. (2019)
Interactive view configuration	Enables users to choose which data views or filters to apply.	Yigitbasioglu & Velcu (2012); Ghazi (2015)
Customizable dashboards	Allows users to configure layout and content with system support.	Vázquez-Ingelmo et al. (2019)
Configuration wizards	Uses setup tools to simplify dashboard customization without coding.	Vázquez-Ingelmo et al. (2019)
Structured configuration files (e.g., JSON/XML)	Uses data files (e.g. JSON/XML) to customize layout and content deeply.	Vázquez-Ingelmo et al. (2019)
Cognitive/personality preference support	Adjusts dashboard functions based on user traits or preferences.	Yigitbasioglu & Velcu (2012)
Zoom-out strategic view (e.g., strategy map)	Provides a big-picture view that connects local data to overall strategy.	Yigitbasioglu & Velcu (2012)

To avoid confusion some features are explained in more detail. A discrepancy is made between drill-down/roll-up capability and layered information structure of the functional features. Drill-down/roll-up capability are interactive functional features that allow users to access more detailed data of a dashboard element, for example a performance criteria (Lea & Nah, 2013). The layered information structure is an interactive feature used to navigate between decision levels, typically strategic, tactical and operational ones. It supports users of different roles to focus on the layer that is relevant to their task (Sarikaya et al., 2019).

It is usually recommended that dashboards fit on a single screen for rapid interpretation of the displayed metrics (Few, 2006). However, features are mentioned that add additional views and data beyond a single screen. Yigitbasioglu and Velcu (2012) argue that the interactive capabilities of modern dashboard should be considered, which include features such as such as drill-down

capabilities. This allows for layered interactions and access to detailed data, without cluttering the main view and increasing the cognitive load.

Additionally, zoom-out strategic views are a feature can help users to understand how data is linked between organisational goals. An example of such a view is a strategic map. Users gain an understanding of how their area effects the broader organisational goals. Therefore, a layered approach is especially relevant for dashboards that span between multiple layers of decision-making.

3.1.5 Design patterns

Bach et al. (2022) presented the idea of reusable design solutions for common design problems during the creation of dashboards. After a systematic review of 144 real-life dashboards, design patterns were identified and grouped into several categories. These patterns describe practical approaches based on designs for managing complexity, improving usability and consistent visual design choices.

This approach is unique compared to design principles. Whilst design principles provide abstract design guidelines, design patterns offer concrete building blocks that are adaptable and can be merged for different contexts and uses (Bach et al., 2022). Therefore, these patterns are not fixed templates but instead flexible layouts that can guide designers in through options for data presentation, display structures and interactions of users with the visual elements. A summary of the eight found groups of design patterns can be found in Figure 6.

Additionally, design patterns can aid in the identification of dashboard types that are suited for strategic or operational needs (Bach et al., 2022). Design patterns can help align designers, developers and users by providing a structured vocabulary that aids communication between different disciplines. This supports balancing between information density and simplicity, which is beneficial for the design of dashboards for non-expert users. In result, the likelihood of usability issues is reduced and the dashboard becomes conform to the requirements of users, goals and tasks. In combination, design patterns help to improve design efficiency and dashboard effectiveness.

Design patterns can be categorized in the following types:

- Content design patterns
 - a) Data information patterns
 - b) Meta information patterns
 - c) Visual representation patterns
- Composition design patterns
 - a) Page layout patterns
 - b) Screen space patterns
 - c) Structure patterns
 - d) Interaction patterns
 - e) Colour patterns

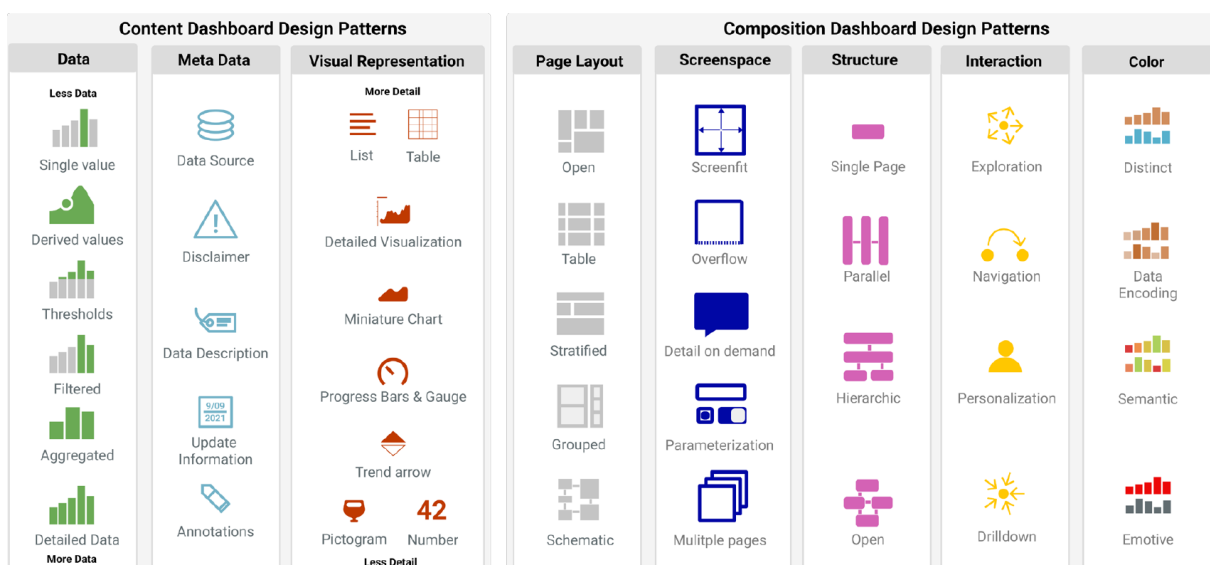


Figure 6: Summary of eight groups of design patterns (Bach et al., 2022)

In this thesis the application of design patterns to the PAS dashboard was not deemed realistic. This method offers a useful overview of design features that can be used to create a dashboard, however, the complexity of the PAS dashboard was found to be higher than the theory by Bach (2022) could handle.

3.2 Relationship between design principles and design features

This section presents a design framework that synthesizes the findings from the literature review (Section 3.1). The framework, shown in Figure 7, integrates effectiveness criteria, design principles, and visual and functional features into a single overview.

First, all the effectiveness criteria are mentioned, which are used in the evaluation of the dashboard performance. Second, these criteria are linked to design principles that provide guidance in the redesign process to improve dashboard effectiveness. Third, each design principle is connected to a set of visual and functional features that can be applied to develop concrete design changes.

In detail, this framework translates theoretical findings into an overview to help decide on design goals and design changes. It shows how relatively abstract concepts of effectiveness criteria and design principles can be operationalized in designing through the application of more concrete design features. Consequently, it can be used as a guide when redesigning dashboards, ensuring that selected design features remain in line with the underlying effectiveness criteria.

Criterion	Design principle(s)	Visual features	Functional features
Usability	Cognitive fit Visual clarity Simplicity	Clear, descriptive labels and tooltips	Automated alerts and notifications
		Logical tab hierarchy	Interactive view configuration
		Presentation format guided by task type	
		Visual mapping of data to suitable visualization	
		Constant visual cues	
		Simple and intuitive layout	
Flexibility	Layering of information		Drill-down/roll-up capability
			Layered information structure (strategic to ops)
			Interactive view configuration
			Customizable dashboards
			Configuration wizards
		Cognitive/personality preference support	
Interactivity	Tailoring capabilities Layering of information		Drill-down/roll-up capability
			What-if analysis
			Scenario planning and budgeting
			Automated alerts and notifications
			Interactive view configuration
			Goal setting and gamification
		Customizable dashboards	
		Configuration wizards	
Knowledge Discovery	Cognitive fit Single screen	Single-screen layout	Drill-down/roll-up capability
		Presentation format guided by task type	What-if analysis
			Scenario planning and budgeting
			Automated alerts and notifications
			Analytical tools (e.g., prediction, pattern ID)
			Goal setting and gamification
		Layered information structure (strategic to ops)	
		Zoom-out strategic view (e.g., strategy map)	
Readability	Simplicity Visual Clarity Single screen	Single-screen layout	Interactive view configuration
		Maximized data-ink ratio	
		Appropriate use of color and graphs	
		Frugal use of colors	
		Visual gridlines for 2D/3D graphs	
		Clear, descriptive labels and tooltips	
		Consistent layout and design	
		Logical tab hierarchy	
		Presentation format guided by task type	
		Visual mapping of data to suitable visualization	
		Constant visual cues	
		Simple and intuitive layout	
Transparency in Construction	Layering of information Cognitive fit Visual clarity		Drill-down/roll-up capability
			Layered information structure
			Interactive view configuration
			Zoom-out strategic view (e.g., strategy map)

Figure 7: Design framework with relationships between design criteria, principles and features.

3.3 Identification of design principles and effectiveness criteria (RQ1)

This section answers the first research question:

RQ1 – What are the design principles and effectiveness criteria for dashboards?

Based on the literature review presented in Section 3.1 and the synthesis in the design framework (Section 3.2), dashboard design can be understood as a combination of effectiveness criteria, design principles, and supporting visual and functional features. First, effectiveness criteria define how well a dashboard supports its intended purpose. These criteria include usability, flexibility, interactivity, knowledge discovery, readability, and transparency. Together, they determine the extent to which a dashboard supports performance monitoring, insight generation, and decision-making.

Second, design principles provide guidance for creating dashboards that meet these criteria. Key principles identified in this research include simplicity, visual clarity, single-screen design, layering of information, cognitive fit, and tailoring capabilities. These principles aim to ensure that information is presented clearly, efficiently, and in alignment with user needs.

Third, these principles and criteria are operationalized through visual and functional design features. Visual features relate to how information is presented, while functional features describe what the dashboard enables users to do.

The relationship between these concepts is shown in the design framework presented in Section 3.2. This framework links effectiveness criteria to design principles and corresponding features, which allows for the analysis and (re)design of dashboards. This framework is used in the next chapter the research to analyze the existing PAS dashboard and to guide the development of the redesigned versions.

4. Analysis of the PAS dashboard

This chapter analyses the existing PAS dashboard using the effectiveness criteria identified in Chapter 3. The objective is to gain a structured understanding of how the current dashboard supports decision-making and to identify its limitations.

First, the theoretical foundation of the PAS approach is introduced to clarify how the dashboard functions within a Decision Support System (DSS). This includes an overview of Preference-Based Design (PBD) and Preference-Based Accommodation Strategy (PAS). Next, the current PAS dashboard is described and analyzed using the effectiveness criteria identified in Chapter 3. This analysis is supported by a document study of previous PAS applications and a researcher evaluation of the dashboard.

The findings of this chapter result in a structured overview of limitations and areas for improvement. These insights form the basis for defining design goals, which are used in the subsequent redesign of the PAS dashboard.

4.1 Preference-Based Design in the Built Environment

This section explains how Preference Function Modelling (PFM) formed the theoretical foundation for Preference-Based Design (PBD) and how PBD was further developed into portfolio-level and optimization applications. The purpose of this section is to clarify the working principles of PBD before introducing PAS in the next section.

In the built environment, several models were developed for preference measurement. These included Preference-Based Design (PBD), Preference-Based Portfolio Design (PBPD), and later Preference-Based Accommodation Strategy (PAS). These models were based on the Preference Function Modelling (PFM) theory developed by Barzilai (2010).

In his research on the mathematical foundations of decision theory, Barzilai (2010) showed that classical decision theory contained mathematical errors. These errors concerned the improper use of mathematical operations on preference scales. Classical utility theory allowed addition and multiplication on scale values without the necessary mathematical foundation. According to Barzilai, this made the resulting numbers meaningless, because the operations applied to the scales were not justified by the structure of the empirical system being measured. He reconstructed the foundations of preference measurement and demonstrated under which mathematical conditions addition and multiplication were valid.

Barzilai (2010) argued that preference should be mathematically quantifiable. He stated: “Preference, or value or utility, is not a physical property of the object being valued, that is, preference is subjective, that is, i.e. psychological, property.” Preference was therefore treated as an empirical object that required correct mathematical modelling. PFM scaled preference in such a way that the preference measure score corresponded to a valid mathematical object. This made it possible to compare alternatives quantitatively and to select the alternative with the highest overall preference rating (Barzilai, 2010). The main utility of PFM was that it enabled the measurement of preferences on an individual basis.

Preference-Based Design (PBD)

Building on PFM, Binnekamp (2010) developed the Preference-Based Design (PBD) technique and related PFM to architectural decision-making. The primary distinction between PFM and PBD was

that, in PBD, design decisions changed as the process progressed rather than being predetermined.

Binnekamp (2010) described the concept of PBD as follows:

“The concept of PBD is to 1) use constraints for expressing each decision maker’s interests or criteria in terms of allowed decision variables value ranges and relationships between decision variables to define all feasible alternatives and 2) use PFM to select from these the alternative with the highest overall preference rating. A design alternative is then a combination of decision variable values and its feasibility is defined by the constraints.”

In this approach, decision variables represented design choices. Constraints defined the feasible solution space by limiting the allowed value ranges and relationships between decision variables. All feasible alternatives were generated within this space. PFM was then applied to evaluate these alternatives and to select the design with the highest overall preference rating.

A design alternative was thus defined as a combination of decision variable values, and feasibility was determined by the constraints. In contrast to traditional design approaches, alternatives were not predefined but were generated through the interaction between constraints and decision variables. PBD therefore combined mathematical modelling with architectural design logic.

Although the PBD technique was researched within architectural design issues, it had not yet been tested in actual projects (Arkesteijn, 2019; Zhilyaev et al., 2022). Nevertheless, it provided a structured method to integrate stakeholder preferences directly into the design process and to select a design based on a mathematically calculated preference rating.

Further Developments: PBPD and Designing with PFM

Arkesteijn and Binnekamp (2012) transformed the PBD technique so that it became applicable at the portfolio level instead of the building level. This resulted in the Preference-Based Portfolio Design (PBPD). This method generated several portfolio alternatives and compared them based on three preference points. To represent the relationship between decision variable values and preference ratings, Lagrange preference curves were constructed. PBPD later formed the foundation for PAS.

In addition, PBD was further developed into a design optimization technique by (Zhilyaev et al., 2022). They stated that the main objective was:

“developing a novel method for integrated stakeholder-oriented building design optimization that is based on an iterative a priori approach for finding the best-fitting design solution.”

In this development, PBD was connected to an optimization program language in order to program stakeholder preferences and incorporate them into the final design. This resulted in a “multi-criteria optimization and decision-making tool” (Zhilyaev et al., 2022). The technique determined the best solution to a design challenge by taking into account the preferences of multiple stakeholders. Zhilyaev et al. (2022) argued that this approach enhanced group discussions and produced optimum designs, because stakeholders could immediately perceive the design impact of their preferences. An overview of designing with PFM and priori optimisation can be found in Figure 8.

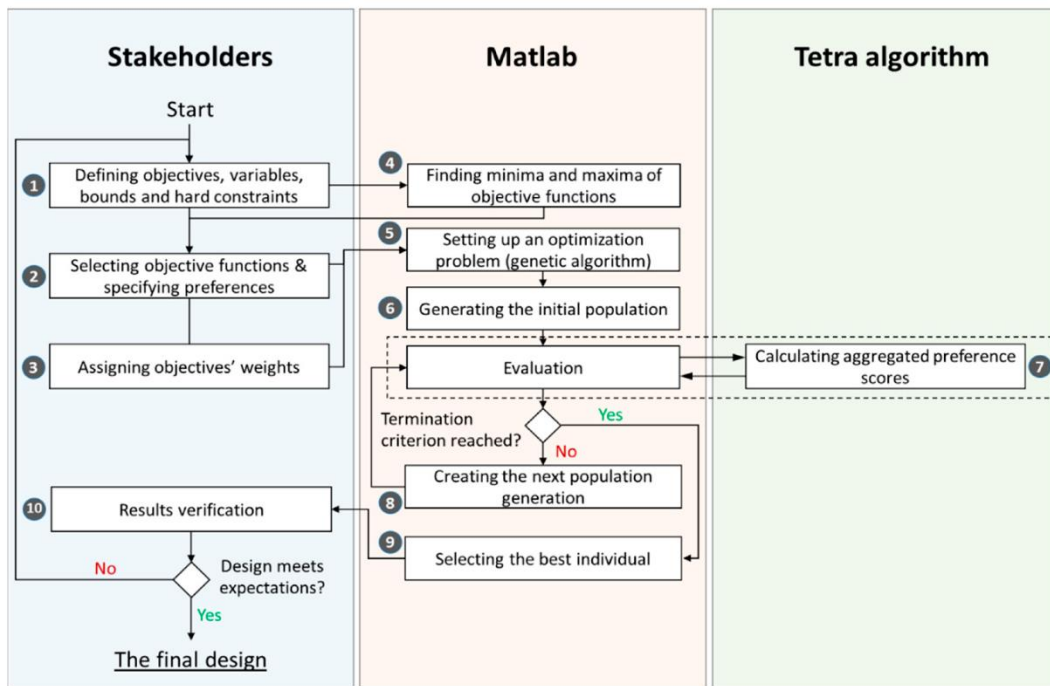


Figure 8: Designing with PFM and priori optimisation (Zhilyaev et al.,2022)

4.2 Preference-Based Accommodation Strategy (PAS)

Performance management

In CREM, the main activity can be seen as aligning the real estate portfolio to the needs of the core business to maximise the added value for an organisation. Performance measurement can be done by performing performance management (Arkesteijn et al., 2017). Previously, several CRE alignment models have been created to guide organisations in their decision making. However, traditional alignment models struggle to quantitatively evaluate and compare between the possible alternatives. This has resulted in decision-making that relied on heuristics or simple financial analyses (Heywood & Arkesteijn, 2018).

Preference-Based Accommodation Strategy

The Preference-Based Accommodation Strategy (PAS) was developed as a design and decision-making approach and uses a preference-driven approach to develop an accommodation strategy (Arkesteijn, 2019). The PAS is used to support decision-making by aligning the operational and strategic sides of the real estate portfolio. By modelling the preferences of stakeholders into quantifiable criteria, it allows for the iterative design and comparison of portfolio alternatives. In result, real estate managers are able to maximise the added value of the portfolio to the organisation. The PAS can be considered as an Inter-actor approach. The primary actors are from the same organisation, however, it is possible to include actors from outside of this organisation.

The PAS can be linked to the DAS-framework by De Jonge et al. (2009) which is used to design an accommodation strategy. The main goal is to align the accommodation to the organisational strategy by using an iterative process to develop an accommodation strategy.

However, like other frameworks it was not described how to use preferences to give scores to accommodation strategies and the DAS-framework was originally not operationalised.

Therefore, the Preference-Based Design procedure was adjusted and expanded to create the PAS approach. This technique from design and decision systems was used to resolve alignment shortcomings of CRE alignment models (Arkesteijn, 2019). The use of a preference score allows all portfolio criteria to be translated into the same preference units. Additionally, it enables the translation of tangible and intangible criteria into comparable preference units. Furthermore, all preference scores of an alternative are combined in an overall performance score. This allows for easy comparison between alternatives.

The three components of PAS

One of the functions of PAS is preference measurement is based on the theory of (Barzilai, 2010) on mathematical operations to non-physical properties. This turns preference in a possible property that can be used as input for the calculation of a preference measurement.

Through Preference-Based Design the preferences of each stakeholder are gathered and quantified. The PAS model calculates which alternative has the highest preference score based on the input of stakeholders. Consequently, PAS enables users to follow iterative design process and to test new alternatives.

The PAS method consists of three main components: Steps, stakeholders and activities, and models (see Figure 9). During the steps component, stakeholders define decision variables, iteratively refine them and change these variables through the development of alternative accommodation designs. The alternative with the highest overall preference and therefore the

best alignment to the organisation, is chosen as the option that adds the most value to the organisation. The activities of the stakeholders are comprised of a series of interviews and workshops.

A system engineer implements the criteria and preferences from the other two components in a mathematical model. This model supports the stakeholders to find the best alternative. The steps are described in further detail in the next section.

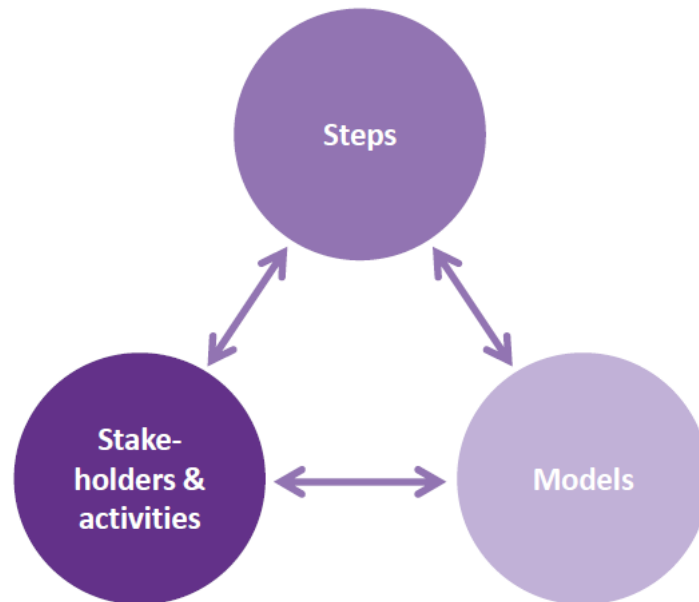


Figure 9: Three components of PAS (Arkesteijn et al., 2017).

PAS: Iterative steps

The PAS approach is an iterative process of several steps. The PAS method can be described in six steps, which can be seen in Figure 10.

1. Definition of decision variables

In this step the decision variables the stakeholders are interested in are specified. Due to the iterative approach of PAS, variables can be added and adjusted multiple stages.

2. Rating preferences

The preferences of stakeholder are rated by taking each decision variable and creating a curve for it.

3. Assigning decision variable weights

Each stakeholders assign weights to their own decision variables. The owner of the subject assigns weights to each stakeholder.

4. Determining design constraints

Each stakeholder can determine the design constraints that they are interested in.

5. Generating design alternatives

Design alternatives by the stakeholder or the system engineer are generated parallel to each other. Stakeholders can gather sensible design alternatives and test their feasibility through the design constraints. Next, the design alternatives can be compared by their overall preference scores, calculated through the PFM algorithm.

6. Selecting the best design alternative

The stakeholders can select the design alternative with the highest overall preference score.

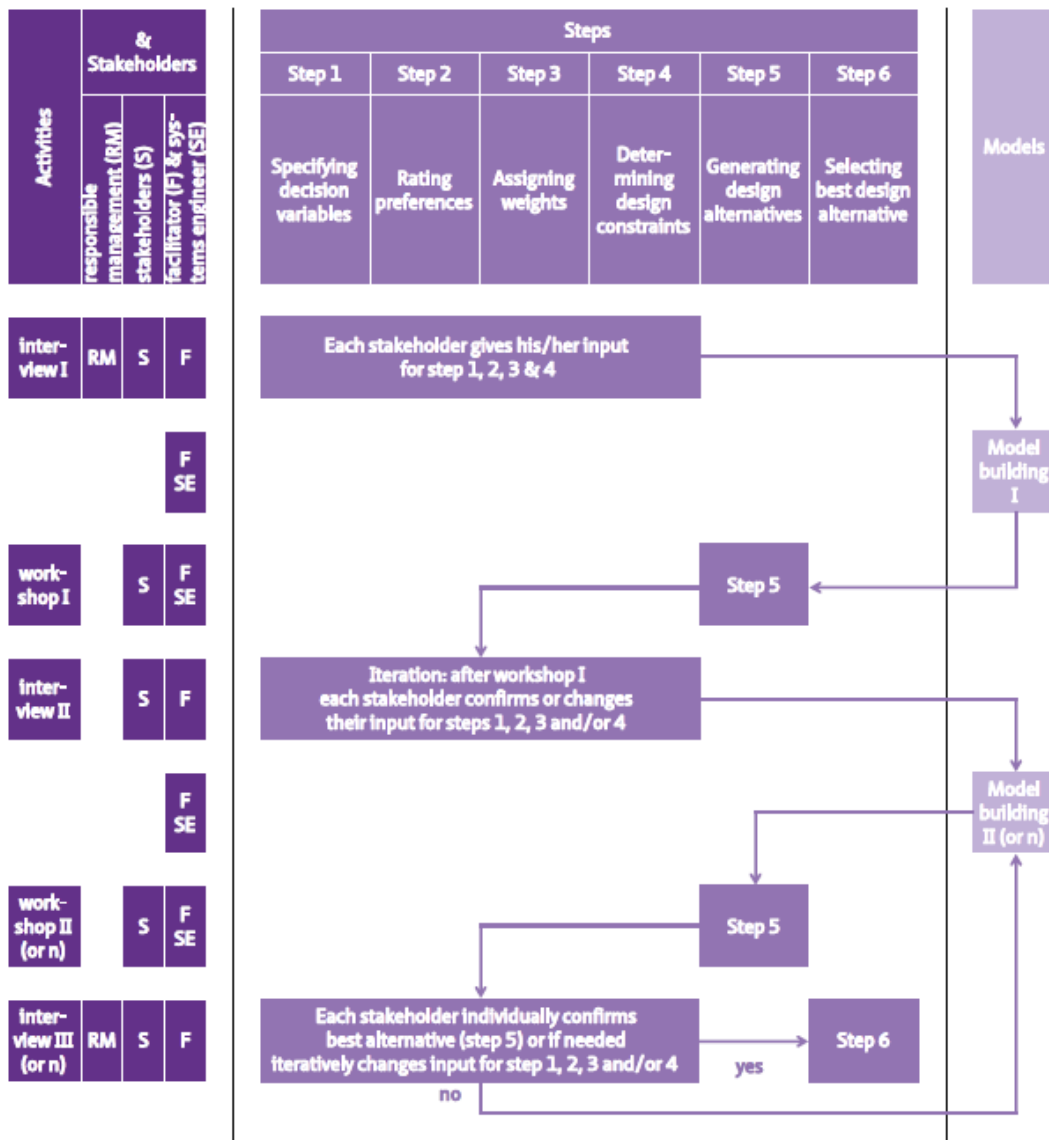


Figure 10: The 6 iterative steps of PAS (Arkesteijn, 2019)

Step 2 “Rating preferences” is performed by determining three decision variable value coordinates. The first two points determine the “top” and the “bottom” of the preference curve. The “bottom” reference alternative presents the value for the decision variable that is least favoured and always receives a score of 0. This results in point (X_0, Y_0) of the curve. The “top” reference alternative is the value for the decision variable that is most valued and is rated on a score of 100. This results in point (X_1, Y_1) of the curve. The third point on the curve is determined by rating the preference with an alternative decision variable value for the reference alternative. This results in point (X_2, Y_2) of the curve. An example of a preference curve can be found in Figure 11.

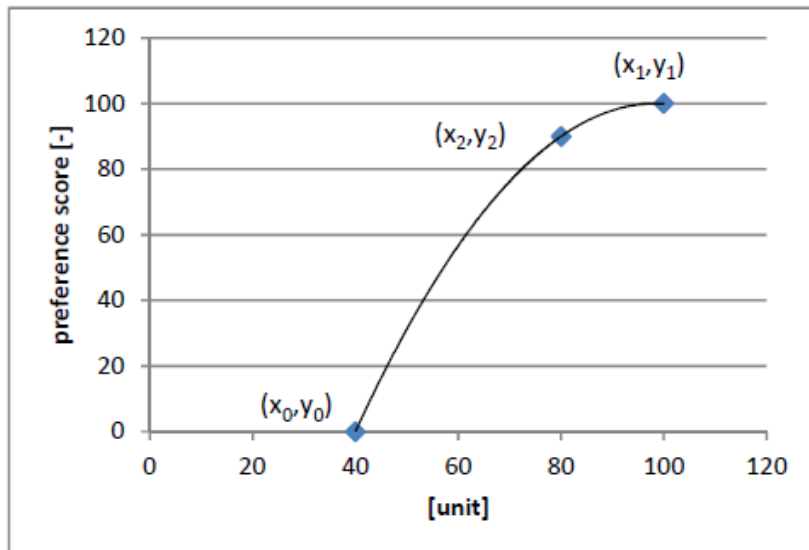


Figure 11: Example of a preference curve (Arkesteijn, 2019).

Interpretation: Gaps in literature and dashboard design relevance for PAS

As mentioned in introduction there are several dashboard design studies, however there is no clear link between design theory and DSS for real estate decision-making. Pilots with the PAS approach presented recommendations for further research on the PAS dashboard. One of the recommendation was to improve the PAS interfaces through three suggestions: lowering the amount of interfaces, decreasing the information shown per interface and testing the visualisation of portfolio recommendations. Furthermore, users of PAS could benefit from an improved description explanation] of the model, providing them with a deeper understanding of the model backend. In result, the relationship between variables and interventions is found quicker (Arkesteijn, 2019). However, there are currently limited applications of PAS in practice.

The potential benefits can be described as improved visualisation of preferences and results, enhanced user-friendliness and accessibility, improved information quality and flow and support for iterative design.

4.3 Document study

This section will discuss Found limitations of the PAS dashboard from the dissertation by Arkesteijn(2019).

1. Difficulty Maintaining a Clear Overview

Stakeholders experienced problems in keeping a complete overview of the model during workshops. “It was not always easy for them to keep an overview, although the model helped them to do so.” Even though the dashboard supported decision-making, its structure and presentation made it cognitively demanding to maintain situational awareness during interactive sessions.

2. Limited Understanding of the Backend Logic

Some stakeholders wanted deeper insight into how the model functioned internally. Two participants wanted to understand more of the backend of the model, i.e. how the relationships were defined between the variables. This would help them to define their decision variables and curves better and in the end accept the model and its results.

Implication:

- Insufficient transparency of the underlying relationships between variables.
- Difficulty understanding how preferences translate into overall scores.
- Reduced trust and acceptance when internal logic is not clear.

3. Insufficient Clarity of Intervention Effects

Although the model provided feedback, stakeholders indicated that the interface could be improved in communicating the impact of interventions. “However, many stakeholders indicated that the interface could be improved to understand the effects of the interventions.”

Implication:

- The link between selected interventions and resulting performance scores was not always intuitively understandable.
- Users required clearer cause–effect visibility within the dashboard interface.

4. Dashboard Not Operated Directly by Stakeholders

One participant expressed reduced attractiveness because the dashboard was not directly controlled by users. “Another participant stated that the model is less attractive because it is not operated by the stakeholders themselves and suggested that this might need more time.”

Implication:

- Limited hands-on interaction.
- Dependence on a system engineer.
- Reduced user autonomy and engagement.

5. Information Density and Interface Complexity

The dissertation highlights differences between pilot interfaces and notes that more condensed interfaces were preferred. “While they were more visual and similar in the first and second pilots, the model for the third pilot contained more information but was less visual.” “In general, the conclusion is that the design interfaces with a more condensed display of information were most used.”

Implication:

- High information density reduced usability.
- Visual clarity improves interface effectiveness.
- Overly information-rich layouts increase cognitive load.

4.6. Analysis and synthesis of the current PAS dashboard

This section analyses the current PAS dashboard and develops the first redesign based on the findings. Using the framework created in Chapter 3, which distinguishes between effectiveness criteria, design principles, and design features, the existing dashboard is systematically evaluated. This evaluation consists of identification of limitations and areas for improvement.

The outcomes of the analysis are subsequently synthesised into concrete design goals and improvement directions. These design goals are essential for the redesign process of the PAS dashboard presented later in this chapter.

4.6.1 Description of the current PAS dashboard

In the OBT case, the PAS dashboard is used to support the design and evaluation of the related real estate portfolio. The dashboard visualizes the performance of portfolio alternatives based on the predefined criteria preferences and weights. By making the effects of design interventions visible, the dashboard helps stakeholders explore trade-offs and develop portfolio alternatives in collaboration to suit their needs.

The current PAS dashboard is implemented in Microsoft Excel and consists of multiple sheets. While several sheets contain the underlying data and calculations, two sheets are the primary interfaces used during workshops. These interfaces are presented in full-screen mode to stakeholders and provide access to the most relevant performance scores. The first interface provides an overview of the portfolio and displays the overall performance of portfolio interventions. In addition, the interface visualizes strategic boundaries and design constraints that guide the development of portfolio alternatives. The dashboard allows stakeholders to explore different portfolio configurations by selecting interventions and activating or deactivating locations. When changes are made, the scores of the criteria and the overall portfolio performance are recalculated in real time. The second interface shows overview of all criteria with the allocated preferences, values, weights and scores. The next section provides a detailed description of the elements that make up the two described interfaces.

Within the overview interface, portfolio locations are displayed on a map. Selecting a location opens a building property window that shows detailed information about the selected asset and allows stakeholders to choose interventions for that location. The building property window is the only additional interface that appears on screen during workshops and partially overlays the main dashboard interface.

4.6.2 Visual overview of the current PAS dashboard

The components of the interfaces introduced in Section 4.6.1 are annotated and explained in this section. Elements of the interfaces are annotated with letters and are briefly described in the following subsections.

Overview interface

The interface with the main dashboard overview can be found in Figure 12.

- A. Dashboard title
The dashboard header displays the organisation name and the building portfolio being studied.
- B. Portfolio map
A map of the Netherlands shows the distribution of the portfolio buildings. Locations included in the designed alternative calculations are displayed in blue, whilst grey ones excluded from the alternative. The numbers are used to distinguish the locations.
- C. Scenario menu
The scenario menu enable users to select predefined portfolio compositions that were made prior to the stakeholder workshop. Each scenario presents a distinct portfolio configuration. Once a scenario is selected, its performance is automatically reflected in the results panels.
- D. Results: capacity values
This section displays the average facility shortage and surplus for the entire portfolio

alternative. Locations are categorised on having either a shortage or surplus. The amount of surplus or shortage is also displayed.

E. Results: Strategic boundaries

The organisation's strategic goals are translated into measurable numerical targets. Conditional formatting is applied, where red indicates exceeded thresholds to show the alignment with the goals.

F. Results: Constraints

This overview displays the design constraints that are determined for the organisation and the performance of the designed alternative in relation to these constraints. Conditional formatting is used to show exceeded thresholds in red and results within the threshold in green.

G. Results: Preference scores

This overview highlights both the overall preference scores of the existing portfolio and designed alternative. It allows for the direct comparison of the both by viewing preference scores of the entire portfolio and each criteria theme group.

H. Results: Criteria scores

This part of the interface presents a selection of criteria and their corresponding scores for both the existing portfolio and the designed alternative.

The delta column shows the difference between the designed alternative and the original portfolio. The final column indicates the remaining potential improvement required for each criterium to reach a preference score of 100.

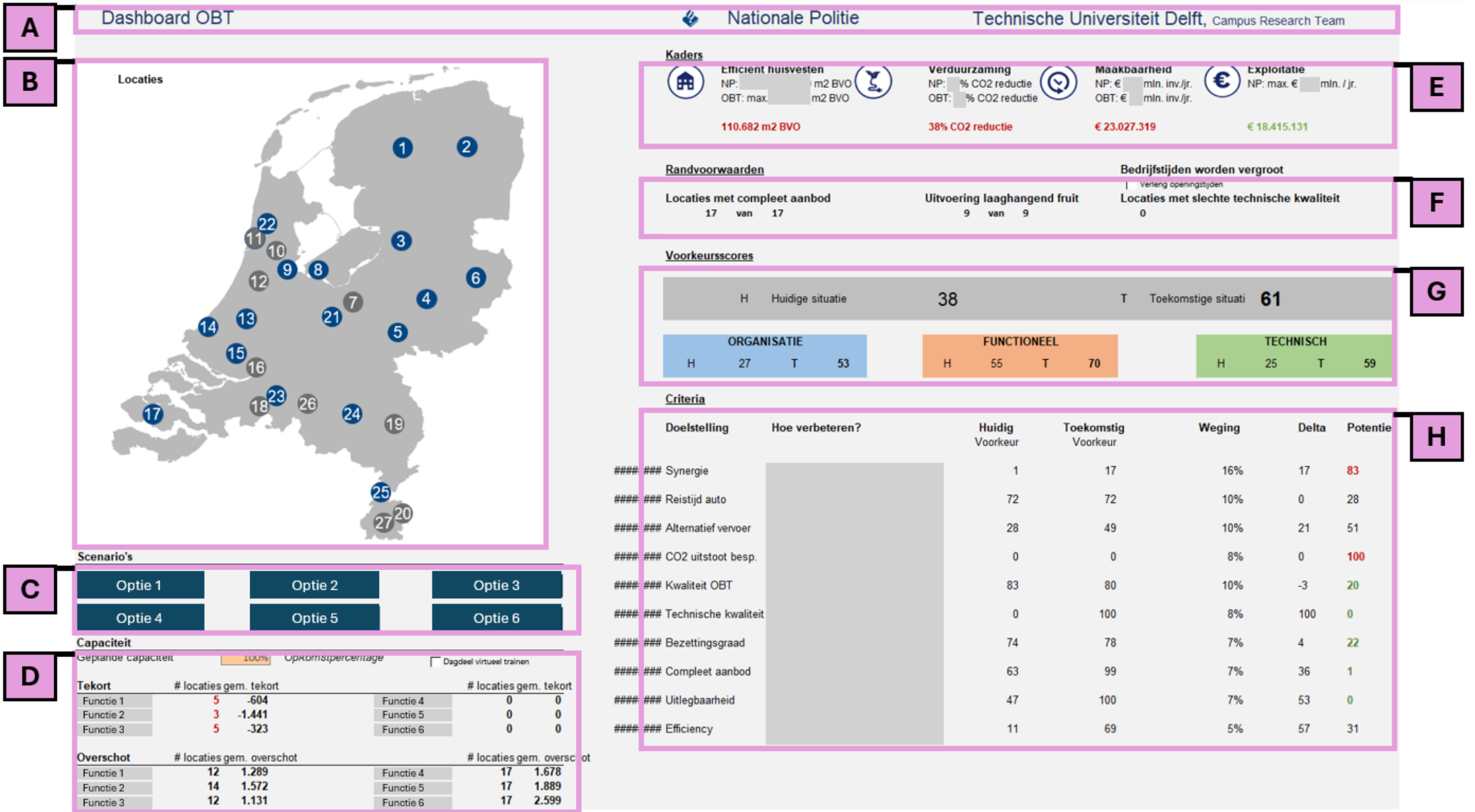


Figure 12: Main dashboard overview, annotated.

Pop-up window with location properties

This pop-up window provides building specific information, including facilities and available intervention options (see Figure 13). Changes can be made by selecting or interventions or increasing the capacity of different functions. The available options may vary between building locations. In the top right, a photo of the selected building is displayed.

The screenshot shows a 'Locatie' window with the following details:

- Properties:** Eenheid, Gebouwnummer, m2 BVO, Energielabel (A).
- Options:** Locatie Aan/Uit, Sub locatie(s) afstoten, Investering overig.
- Huidige situatie:** Cursisten (with a bar chart).
- Ontwerp:** Cursisten (with a bar chart).
- Intervention Table:**

Voorzieningen	Aantal	Behoefte	Aanbod	Match		Aantal	Behoefte	Capaciteit	Match
	5	5.393	10.500	5.107		5	7.088	10.500	3.412
	2	2.408	4.400	1.992		2	3.165	4.400	1.235
	4	4.746	8.800	4.054	<input type="checkbox"/> Toevoegen	4	6.238	8.800	2.562
	3	1.325	6.600	5.275	<input checked="" type="checkbox"/> Toevoegen	3	1.741	6.600	4.859
	2	684	6.600	5.916		2	899	6.600	5.701
	3	1.937	6.600	4.663		3	2.546	6.600	4.054

Buttons: Verwerken, Sluit

Figure 13: Pop up window with the location properties.

Results interface

The dashboard results interface can be found in Figure 14.

- Results: preference scores**
This section displays the overall preference scores of the original portfolio and the designed alternative.
- Results: preference scores of criteria theme**
This section shows the performance of one out of three criteria themes.
- Results: Preference scores of stakeholder/department**
For each criteria theme there are thematic sub groups with corresponding scores.
- Results: Detailed overview of criteria and preference scores**
This interface presents a list of all defined criteria. For each criterion, the unit of measurement, weight in calculation, original and new preference score and Delta (difference between scores) are displayed.

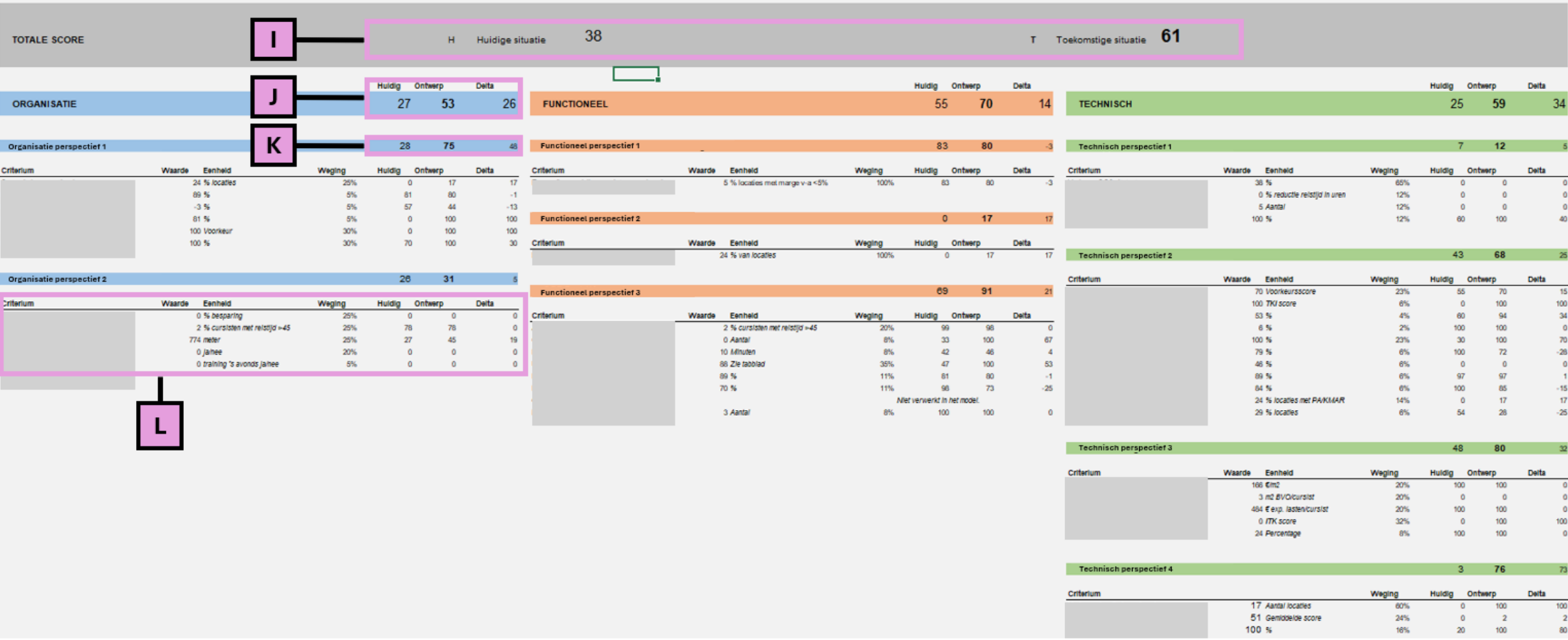


Figure 14: Results interface with criteria overview, annotated.

4.6.4 Assessment through effectiveness criteria

This section presents the evaluation of the existing PAS dashboard conducted by the researcher. The redesigned dashboard is assessed using the framework developed in Chapter 3, based on the identified effectiveness criteria. The findings are divided based on these criteria. The researcher review will indicate limitations and weaknesses of the dashboard, which can be used to set up goals for the dashboard redesign.

Usability

A. Limited guidance

There seem to be several limitations in the usability of the dashboard, especially for first-time users. On screen there are limited embedded instructions or contextual guidance on how to operate the model. Furthermore, there are no tooltips functions or labels that to help the users, which complicates performing basic tasks. When repeatedly using the dashboard, users will need to properly remember their earlier encounters to rely on prior knowledge or instructions.

B. High complexity

The dashboard is quite complex, due to the amount of elements, functions and updating scores. In result, users might need to relearn how the dashboard functions after not using it for a while. This indicates that the intuitive use and on screen support is currently limited. The dashboard should aim to support ease of use by minimizing the learning curve and improving recognizability of features.

C. Error vulnerability

Error management is at risk by not indicating adjustable options to the user. For example, values changed in the wrong Excel cells will cause the dashboard to malfunction. There is not yet a safeguard to prevent the disruption of dashboard mechanisms.

Due to the earlier observations, the overall user satisfaction may be decreased by a combination of complexity, limited guidance, and risk of errors. Although the dashboard aims to optimize the overall preference score, users may feel uncertain about choosing the right interventions or they might miss important functionalities. This uncertainty could decrease decision support by the dashboard.

Flexibility

D. Dashboard structure

The dashboard largely has a "one-size-fits-all" structure. Since the dashboard is used in workshops of multiple collaborating stakeholders, having a single variant may make more sense. In this context, there are no individual personalization options. Simultaneously, this results in limited adaptability for users to personalize a dashboard to their individual needs.

Currently, there are no options to change the configuration of the interfaces. The layout, visualization formats and positions of displayed results are set to fixed positions and these do not change during the workshop. The fixed configurations is determined by the dashboard engineer and it remains the same during use of the dashboard in the workshops. This does restrict the customization ability of users to tailor the dashboard to their personal needs or roles.

Furthermore, the dashboard does not offer predefined starting configurations to change the interface to the desired information by the users. The interfaces themselves cannot be edited by simply clicking on a button. Consequently, there is no option when starting to use the dashboard

to begin in a specific configuration. In result, the dashboard as a whole presents limited flexibility to its users.

Interactivity

E. Unclear interactions

There are several ways to interact with the dashboard, such as selecting the scenario's or adjusting individual location properties. When changes are made, the dashboard will display the updated scores immediately. However, it is not very clear which elements on the interface are interactive. Although there are buttons to activate the pre-defined scenario's, the dashboard does not introduce this option to the users or explain how it functions. Additionally, it is not described what each scenario includes or how it is composed (locations and interventions). It is also unclear which scenario is currently selected. Similarly, it is not clear which scores are updated and which ones remain the same during use of the dashboard. For example, the scores for the existing portfolio are not changed during the workshop. In contrast, the scores of the designed alternative are updated as a consequence of dashboard interactions. Users may struggle to recognize what can or cannot be changed and how their decisions affect the outcomes.

The dashboard includes several interactive options but users could benefit from a more extensive introduction to them. This reveals a potential improvement by making interactive elements more visible and intuitively usable. It could remain difficult to keep overview of the impact of these interactions. In conclusion, users may benefit from clearer feedback on how each change influences the overall preference scores and criteria performance.

Knowledge discovery

F. Unguided exploration

The model does allow users to generate new knowledge by adjusting weights, modifying preferences, and creating interventions. These functions offer the potential for exploration and learning. However, there is no clear guidance on how users can approach this process in a structured way. It is not explicitly explained which Excel inputs can be modified and which should remain unchanged. As a result, users may hesitate to experiment or may unintentionally alter elements that were not meant to be adjusted.

G. Cluttered interface

In addition, all available data is displayed on each interface at the same time. This creates a potential information overload and increases cognitive effort. Apart from the pop-up screen, which can be opened when needed, there are no options to hide, filter, or selectively display information. The dashboard does not offer simplified or layered views tailored to different user needs. This could limit accessibility, especially for users who are less familiar with the model.

H. Analysis tools

Furthermore, there are no additional analytical tools to further examine the consequences of adjustments. While changes in scores are visible, there are no functionalities such as drill-down options, comparison views, trend analysis, or extended scenario analysis to explore why certain changes occur or how significant they are. The dashboard mainly shows delta and potential values in the criteria tables, but does not support more complex data exploration or deeper analysis.

It is also unclear what data is available for further discovery and what is not. The interface does not actively guide users toward insights or highlight significant changes. For example, there are no features that show significant impacts on portfolio performance and there are there no

suggestions on which criteria require attention due to high influence or sensitivity. This reduces the dashboard's ability to actively support analytical reasoning and informed decision-making.

Readability

I. Inconsistent design

The use of colors and layout is not applied consistently throughout the dashboard. Different information themes are not clearly separated, which makes it harder to distinguish between sections. In addition, it is not explained what is presented on each interface or how users can make adjustments within the dashboard.

J. Complex overview

The first impression of the dashboard is that it requires a high level of cognitive effort to understand what is displayed on the screen. Not all visible Excel sheets are used during the workshops, which makes it more difficult for users to understand which interfaces are relevant, how to switch between them and which information can be found on them.

K. Unclear structure

The scores take up approximately three-quarters of the entire dashboard, which makes it difficult to clearly recognize the different elements. The sections are not visually separated using colors or other elements. There are no clear labels explaining the displayed results, which further reduces clarity.

L. Visual hierarchy

In addition, all results are visible at once, which can lead to information overload. There is little visual hierarchy to guide the user's attention. Some areas of the dashboard contain open or empty space, while other elements appear loosely placed. This gives the interface an unfinished appearance and may even be distracting for users.

Transparency in construction

M. Model logic

The model is relatively transparent but it does require users to already understand what is shown on the interface and how the model works. In principle, all sources can be found within the model, on the condition that the user knows where to look and how to navigate through the different interfaces.

The extent of the transparency can be questioned. Users need to actively search for the Excel sheet containing the information they are looking for, which may require navigating through several interfaces. This can make the process time-consuming and less intuitive. Additionally, the calculations behind the results are not explained in the model. While it is possible to look up the values that are used, this may require consulting multiple interfaces. The logic behind the calculations is not clarified through information buttons, tooltips, or explanatory menus within the dashboard.

Furthermore, the main dashboard overview does not display the performance of all individual criteria. To see how each criterion performs, users need to switch to the criteria overview interface. This lowers the transparency of the main overview since it cannot be seen which scores result in the overall preference score.

4.7 Limitations of the existing PAS dashboard (RQ2)

This section answers the second research question:

RQ2 – What limitations do stakeholders currently experience with the existing PAS dashboard?

To answer the second research question, a document study and researcher evaluation of the existing PAS dashboard were conducted. In addition, insights from earlier PAS applications were used to identify challenges. Feedback from previous PAS sessions was analysed to better understand stakeholder experiences during the use of the dashboard.

The findings show that stakeholders experience several limitations when working with the existing PAS dashboard. A key issue concerns the difficulty in understanding the underlying model logic and backend calculations. The translation of preference functions and weighted scores into overall preference scores is not transparent enough for users. As a result, stakeholders experience reduced transparency in how overall preference scores are calculated.

This lack of transparency could result in lowered trust in model outcomes, mainly due to the lack of insight into how individual criteria contribute to the final score. Without a clear overview of scores, it becomes difficult for stakeholders to interpret results.

When analysing the existing PAS dashboard through effectiveness criteria, several structural and interface-related limitations were identified. The dashboard is spread across multiple Excel sheets and interfaces, resulting in a fragmented structure. Users must switch between input, scores, overview interfaces, which reduces clarity and makes the decision-making process less intuitive.

The analysis also shows limitations in readability and visual structure. A large amount of information is displayed simultaneously, with limited visual hierarchy and insufficient separation between elements. As a result, stakeholders may experience information overload and have difficulty identifying key results or comparing alternatives.

Furthermore, interactivity and support for knowledge discovery are limited. Although the dashboard allows users to adjust variables and explore alternatives, it is not always clear which elements are interactive or how changes affect the results. The dashboard provides limited support for deeper analysis, such as exploring relationships between variables or understanding the impact of interventions.

The output of this phase is a structured overview of stakeholder-experienced limitations. These findings are a starting point for the creation of the redesign, which are used to guide the redesign of the PAS dashboard in the next chapter.

Chapter 5 – Round 1: Dashboard redesign and verification

This chapter presents the first redesign of the PAS dashboard and evaluates its effectiveness in a workshop setting. Using the literature review (Chapter 3) and the analysis of the existing PAS dashboard (Chapter 4), this chapter translates identified limitations into concrete design changes and verifies their impact in practice.

The chapter begins by answering the third sub research question of this thesis. This is done by connecting the identified dashboard limitations to design principles and features using the design framework developed in Chapter 3. The outcome of this step is a collection of design changes, which can be found in Table 9.

Subsequently, the first dashboard redesign is presented and evaluated through a round of workshops. Through this evaluation, new dashboard limitations are identified and lessons are drawn both for dashboard design for DSS and for the PAS dashboard specifically. These lessons and limitations are used for the second redesign iteration in Chapter 6.

5.1 Redesign objective and changes (RQ3)

This section answers the third sub-research question:

RQ3 – What design principles should be considered in the redesign of a new effective PAS dashboard?

To answer RQ3, the findings from RQ1 (dashboard design principles and effectiveness criteria) and RQ2 (stakeholder-experienced limitations) were synthesised. The literature review identified key design principles and effectiveness criteria for dashboards, while the analysis revealed specific limitations of the current PAS dashboard in Section 4.6.4. Related redesign objectives are defined in 5.1.1.

These findings are used as input for the design framework developed in Section 3.1.6, which enables the formulation of concrete design changes. Each identified limitation from Chapter 4 was analyzed and linked to the relevant effectiveness criterion, design principles and design features to resolve the identified limitations. An overview of this process can be found in Table 9 of Section 5.1.2.

5.1.1 Redesign objectives

Based on the identified limitations, the redesign objectives for this iteration are defined. The main aim of the redesign is to improve the effectiveness of the PAS dashboard as a decision-support interface. The key objectives of the redesign are formulated according to the criteria of effectiveness, resulting in the following overview:

- Improve **usability**, particularly learnability and efficiency in usage during workshops.
- Enable **flexibility** through the customization of interfaces.
- Increase **interactivity** and support for analytical functionality.
- Improve **knowledge discovery** through better analytical tools and drill-down capabilities.
- Enhance **readability** by reducing visual clutter and improving visual hierarchy. Provide a clearer distinction between results, analysis, and interactive controls.
- Improve **transparency in construction** by clarifying how results are calculated and their alignment with stakeholder goals.

These objectives reflect both theoretical insights from the literature and the practical limitations identified in the existing PAS dashboard.

Based on the literature review it was determined that effective dashboards should reduce information overload, improve visual hierarchy, support drill-down capabilities, and enhance usability and decision-making support. Meanwhile, the analysis of the existing PAS dashboard revealed specific limitations such as cognitive load caused by switching between interfaces, limited visual hierarchy, issues related to transparency of score calculations, and fragmentation of interfaces across multiple Excel sheets.

5.1.2 Formulation of design changes

To translate the redesign objectives into concrete design changes, the identified limitations were used as input for the design framework developed in Chapter 3. This framework connects effectiveness criteria to design principles and fitting visual and functional features, which enables the formulation of design changes.

The detailed translation from limitations to design changes is presented in Table 9. In this table each identified limitation is connected to relevant design principles and operationalized through specific design features, resulting in concrete design changes for the PAS dashboard. Based on this overview, the main design changes can be grouped into three areas, which are mentioned next.

First, design principles need to be applied to improve the information structure of the dashboard. The redesign aims to reduce the number of separate sheets and integrate the main analysis into a single, coherent main interface. This integration supports continuity during workshops and reduces cognitive load caused by navigating between overview, result and input interfaces. The main dashboard overview is therefore simplified by providing a clear starting point (map and results section) and by creating a clearer distinction between results, analysis and interactive features. Layered information and drill-down functionality are introduced to prevent displaying all data at once and to offer the option for detailed exploration when needed.

Second, design principles are applied to improve the visual appearance of the dashboard. Improving readability and reducing visual clutter are major design goals. A clearer visual hierarchy needs to be introduced by grouping results into separate themes. Colours, panels and labels should be used consistently to distinguish themes and improve navigation. Updated scores were required to be more visible, and conditional formatting will be used to highlight significant changes in performance. These changes aim to support intuitive interpretation and reduce the cognitive effort required to understand the dashboard.

Third, design principles need to be applied to enhance interactivity and knowledge discovery. Features to compare strategies and store alternative scores will be added to support collaborative workshop sessions. Additional analytical interfaces are introduced to provide insight into criteria performance, delta values, and the influence of interventions without overloading the dashboard overview. Help buttons and tooltips are implemented to improve understanding of dashboard features to users, by explaining how scores are constructed.

In summary, this redesign iteration for the PAS dashboard focuses on reducing cognitive load, improving visual hierarchy and transparency in construction, while expanding analytical features and interactivity.

Table 9: Formulation of design changes through the dashboard design framework.

Analysis			Redesign		
Criterion	Design principle(s)	Identified limitation(s)	Applied design features		Resulting design changes
			Visual features	Functional features	
Usability	Cognitive fit Visual clarity Simplicity	A. Limited guidance	Clear descriptive layers and tool tips	Interactive view configuration	Help buttons & tooltips
		B. High complexity, C. Error vulnerability	Simple and intuitive layout Constant visual cues	Interactive view configuration	New Layout Help buttons & tooltips Colour usage
Flexibility	Layering of information	D. Dashboard structure		Interactive view configuration Customizable dashboards Cognitive/Personality preference support	Drill-down functionality Ribbons with interactive buttons
Interactivity	Tailoring capabilities Layering of information	E. Unclear interaction		Drill-down/roll-up capability What-if analysis Scenario planning and budgeting Interactive view configuration Goal setting and gamification Customizable dashboards	Navigation redesign Drill-down functionality Additional analytical interface Help buttons and tooltips Ribbon with interactive buttons Colour scales for score changes Arrow graph
Knowledge Discovery	Cognitive fit Single screen	F. Unguided exploration		Drill-down/roll-up capability Interactive view configuration Layered information structure	Help buttons & tooltips New layout
		G. Cluttered interfaces	Single screen	Interactive view configuration Layered information structure	Drill-down functionality New layout Ribbon with interactive buttons Shapes and icons Location properties window
		H. Analysis tools		Drill-down/roll-up capability What-if analysis Analytical tools Interactive view configuration Layered information structure	Drill-down functionality Additional analytical interface Storage functionality Colour scales for score changes Arrow chart
Readability	Simplicity Visual clarity Single screen	I. Inconsistent design J. Complex overview L. Visual hierarchy	Logical tab hierarchy Simple & intuitive layout Appropriate use of colors and graphs Clear, descriptive labels & tooltips Consistent layout and design Logical tab hierarchy Constant visual cues Simple and intuitive layout		New layout Ribbon with interactive buttons Removal of Excel elements Location properties window Colour scales for score changes Colour usage Shapes and icons
		K. Unclear structure	Clear, descriptive labels & tooltips Frugal use of colors		Colour usage Shapes and icons
Transparency in Construction	Layering of information Cognitive fit Visual clarity	M. Model logic		Drill-down/roll-up capability Layered information structure Interactive view configuration	Navigation redesign Help buttons & tooltips Additional analytical interface Storage functionality

The dashboard design framework developed in Chapter 3 is presented again in this section. The design features that have been implemented in this redesign iteration are highlighted in green. This is illustrated in Table 10.

Table 10: Dashboard design framework with the selected features in green.

Criterion	Design principle(s)	Visual features	Functional features
Usability	Cognitive fit Visual clarity Simplicity	Clear, descriptive labels and tooltips	Automated alerts and notifications
		Logical tab hierarchy	Interactive view configuration
		Presentation format guided by task type	
		Visual mapping of data to suitable visualization	
		Constant visual cues	
		Simple and intuitive layout	
Flexibility	Layering of information		Drill-down/roll-up capability
			Layered information structure (strategic to ops)
			Interactive view configuration
			Customizable dashboards
			Configuration wizards
			Cognitive/personality preference support
Interactivity	Tailoring capabilities Layering of information		Drill-down/roll-up capability
			What-if analysis
			Scenario planning and budgeting
			Automated alerts and notifications
			Interactive view configuration
			Goal setting and gamification
			Customizable dashboards
			Configuration wizards
Knowledge Discovery	Cognitive fit Single screen	Single-screen layout	Drill-down/roll-up capability
		Presentation format guided by task type	What-if analysis
			Scenario planning and budgeting
			Automated alerts and notifications
			Analytical tools (e.g., prediction, pattern ID)
			Goal setting and gamification
			Layered information structure (strategic to ops)
			Zoom-out strategic view (e.g., strategy map)
Readability	Simplicity Visual Clarity Single screen	Single-screen layout	Interactive view configuration
		Maximized data-ink ratio	
		Appropriate use of color and graphs	
		Frugal use of colors	
		Visual gridlines for 2D/3D graphs	
		Clear, descriptive labels and tooltips	
		Consistent layout and design	
		Logical tab hierarchy	
		Presentation format guided by task type	
		Visual mapping of data to suitable visualization	
		Constant visual cues	
		Simple and intuitive layout	
		Transparency in Construction	Layering of information Cognitive fit Visual clarity
	Layered information structure		
	Interactive view configuration		
	Zoom-out strategic view (e.g., strategy map)		

5.2 Design changes for redesign 1

The redesign changes and additions are structured into two categories: A) Visual design changes and B) Functional design changes. The redesigned interface with the dashboard overview can be found in Figure 15. This is the interface which users see first during its use in the PAS workshops.

A: Visual design changes

New layout

- An overview of all key results was implemented in a smaller space.
- Space was reserved for a location overview and a map.
- Background colours and panels were introduced to clearly distinguish between themes (results, analysis, map, interactive options).
- All information and functions are placed within clearly defined panels or described by labels.

Ribbon with interactive buttons

- A ribbon containing buttons for interactive features was introduced. It is placed in above the centre of the screen “Keuzemenu”. The central location is chosen to suggest key interaction options to users.
- This improves discoverability of functions and clarifies which elements are interactive.

Removal of Excel elements

- Default Excel elements were removed where possible to enhance the feeling of a dedicated dashboard rather than a spreadsheet.

Location properties window

- On the main overview interface of the dashboard, space was created for a dedicated window displaying location properties. After selecting one of the locations, the window opens in a fixed location on the right of the interface and takes up one third of the width.

Colour scales for score changes

- Conditional formatting was added to display changes in scores.
- Larger shifts are displayed in brighter colours, supporting quick interpretation.

Colour usage

- Newly calculated scores are highlighted in bright yellow.
- Interactive buttons are shown in a noticeable orange colour to distinguish them from static elements.

Shapes and icons

- Buttons were rounded to create a softer and more intuitive interface.
- Additional icons and labels were introduced to support memorability and navigation.

PORTFOLIO SCORES

Delta

Alle scores

RANDVOORWAARDEN

	Totaal	Behaald
Locaties met compleet aanbod	15	15
Uitvoering laaghangend fruit	9	9
Locaties met slechte technische kwaliteit	X	0

KADERS

	Doel	Nieuw	Delta
(m2)	max. m2 BVO	102.467 m2 BVO	467 m2 BVO
(CO2 red.)	CO2 reductie	26% CO2 reductie	26% CO2 reductie
(inv./jyr.)	€ 10.000.000	€ 10.784.062	€ 784.062
(/jyr)		€ 17.769.096	

VOORKEURSCORES

	Huidig	Nieuw	Delta
Totaalscore	38	63	24
Organisatie	27	59	32
Functioneel	45	56	11
Technisch	25	59	34

CRITERIA

Doelstelling	Hoe verbeteren?	Huidig	Nieuw	Delta
		1	11	10
		72	72	0
		28	35	7
		0	0	0
		83	78	-6
		0	100	100
		74	62	-12
		63	99	36
		47	98	51
		11	76	64

CAPACITEIT

Geplande capaciteit		100%	Opkomstpercentage	
Tekort	# locaties	gem. tekort	# locaties	gem. tekort
Functie 1	3	-177	Functie 4	0
Functie 2	4	-678	Functie 5	0
Functie 3	1	-593	Functie 6	0
Overschot	# locaties	gem. overschot	# locaties	gem. overschot
Functie 1	12	2.460	Functie 4	15
Functie 2	11	2.501	Functie 5	15
Functie 3	14	1.858	Functie 6	15

Weergeven / verbergen

KEUZEMENU

Scenario's

Locaties

Analyse



Figure 15: Dashboard overview interface. Source: Author.

B) Functional design changes

Navigation redesign

The navigation structure of the dashboard was redesigned to improve usability and reduce visual clutter. An interactive button menu was introduced to allow users to navigate directly between the main overview, the criteria scores, and the newly added analysis interfaces (see Figure 16).

When activated, the button opens a navigation window displaying the available interface options. To keep the interface uncluttered, the navigation buttons remain hidden when not in use. After switching between interfaces, the navigation window automatically closes. This functionality was implemented in Excel by programming the file to hide all elements related to the navigation window once a selection has been made.

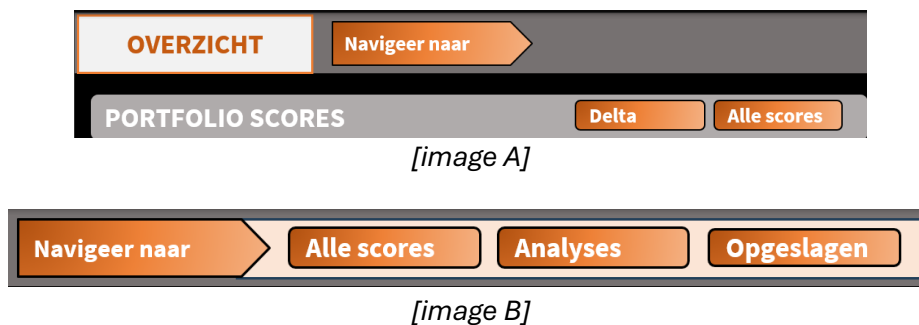


Figure 16: Navigation menu states: (a) inactive and (b) with destinations displayed.

Help buttons and tooltips

Contextual help buttons and tooltips were added throughout the dashboard interface. These elements provide brief explanations about results, functions, and underlying calculations when activated by the user (see Figure 17). Tooltips are programmed to function as op-up windows when help buttons are being clicked. By presenting information only when needed, they support transparency while preventing the interface from being overloaded with constantly visible explanations.

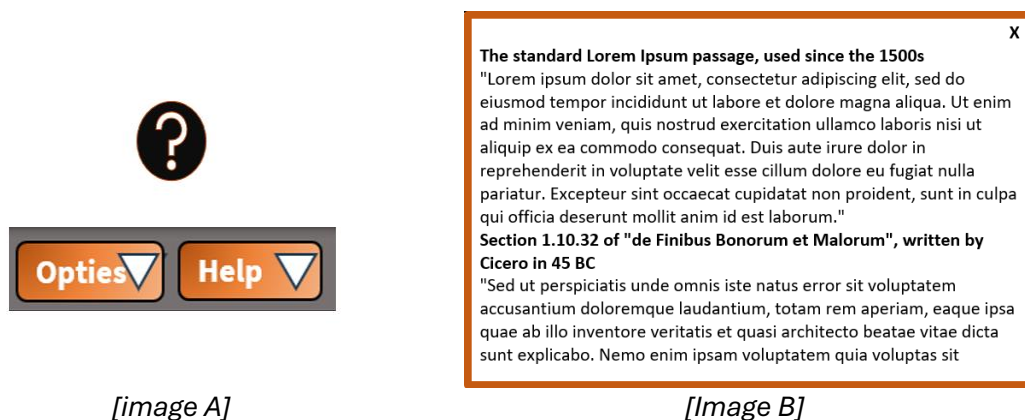


Figure 17: Example of (a) help buttons and (b) tooltips (own figure).

Hiding capacity results

A button was added to the dashboard overview interface that allows users to hide the capacity results (see Figure 18). This feature was introduced to reduce the amount of information displayed and improve the overall readability of the interface. The button remains visible at all times and can be activated whenever users want to show or hide the capacity results. This provides users with greater control over the level of detail displayed on the dashboard.

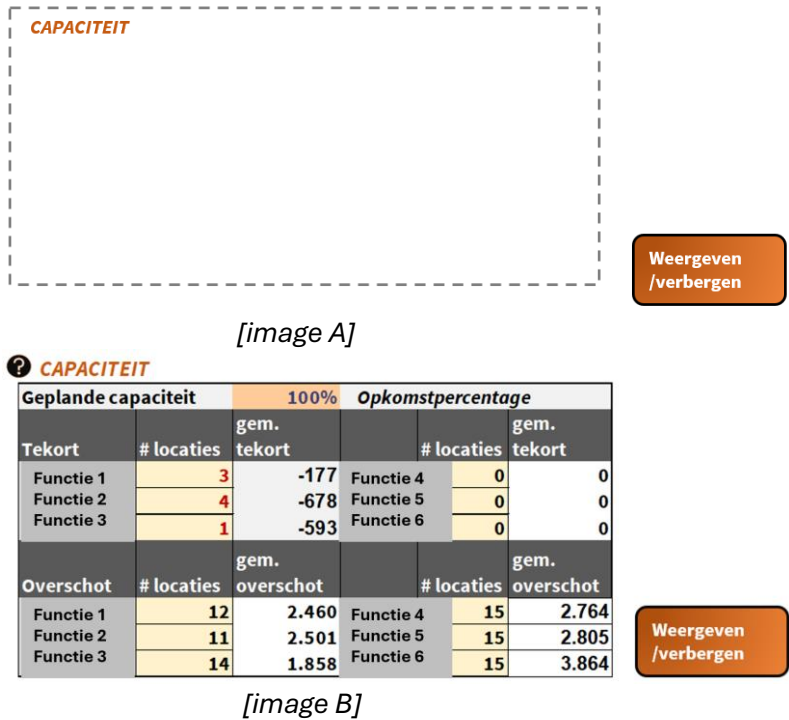


Figure 18: Capacity results (a) inactive and (b) showing.

Drill-down functionality

Users are enabled to analyse more detailed data on demand, supporting the option to disclose detailed information progressively rather than displaying all data at once. At first only the portfolio scores are displayed on the left. By using the selection menu additional information can be displayed. Users can decide to show the portfolio locations with either the selected interventions or a map and the location properties, located in the middle and right of the screen respectively. When the scenario button is pressed, a window with the scenario options appears. Additionally, the button of selected scenario now turns green. An overview of these design changes can be found in Figure 19 and in Figure 20, showing one of the alternate views that shows the location interventions.

PORTFOLIO SCORES

Delta Alle scores

RANDVOORWAARDEN

	Totaal	Behaald
Locaties met compleet aanbod	15	15
Uitvoering laaghangend fruit	9	9
Locaties met slechte technische kwaliteit	X	0

KADERS

	Doel	Nieuw	Delta
(m2)	max. m2 BVO	102.467 m2 BVO	467 m2 BVO
(CO2 red.)	CO2 reductie	26% CO2 reductie	26% CO2 reductie
(inv./jr.)	€	€ 10.784.062	€ 784.062
(/jr)		€ 17.769.096	

VOORKEURSCORES

	Huidig	Nieuw	Delta
Totaalscore	38	63	24
Organisatie	27	59	32
Functioneel	45	56	11
Technisch	25	59	34

CRITERIA

Doelstelling	Hoe verbeteren?	Huidig	Nieuw	Delta
		1	11	10
		72	72	0
		28	35	7
		0	0	0
		83	78	-6
		0	100	100
		74	62	-12
		63	99	36
		47	98	51
		11	76	64

CAPACITEIT

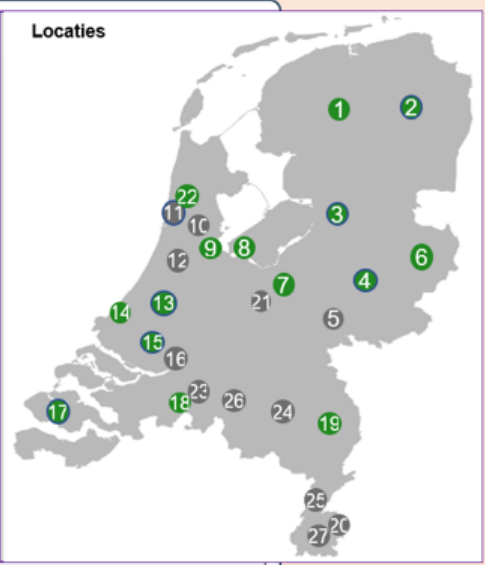
Geplande capaciteit		100%	Opkomstpercentage	
Tekort	# locaties	gem. tekort	# locaties	gem. tekort
Functie 1	3	-177	Functie 4	0
Functie 2	4	-678	Functie 5	0
Functie 3	1	-593	Functie 6	0
Overschot	# locaties	gem. overschot	# locaties	gem. overschot
Functie 1	12	2.460	Functie 4	15
Functie 2	11	2.501	Functie 5	15
Functie 3	14	1.858	Functie 6	15

Weergeven /verbergen

KEUZEMENU

Scenario's Locaties Analyse

- 1 Locatie 1
- 2 Locatie 2
- 3 Locatie 3
- 4 Locatie 4
- 5 Locatie 5
- 6 Locatie 6
- 7 Locatie 7
- 8 Locatie 8
- 9 Locatie 9
- 10 Locatie 10
- 11 Locatie 11
- 12 Locatie 12
- 13 Locatie 13
- 14 Locatie 14
- 15 Locatie 15
- 16 Locatie 16
- 17 Locatie 17
- 18 Locatie 18
- 19 Locatie 19
- 20 Locatie 20
- 21 Locatie 21
- 22 Locatie 22
- 23 Locatie 23
- 24 Locatie 24
- 25 Locatie 25
- 26 Locatie 26
- 27 Locatie 27



Kaart

Scenario's

- Huidig
- Optimalisatie 1
- Laaghangend fruit
- Optimalisatie 2
- HVP1.0
- Ontwerp Workshop 1

Locatie

(Locatie) Cursisten

(adres)

Eenheid Landelijke Eenheid

Gebouwnummer xxx

m2 BVO xxx

Energielabel F

Huidige situatie

Cursisten xxx

Voorzieningen

	Aantal	Behoefte	Aanbod	Match
Functie 1	2	4.668	3.564	-1.104
Functie 2	1	4.453	3.608	-845
Functie 3	1	3.701	2.317	-1.384
Functie 4	1	1.511	3.608	2.097
Functie 5	1	1.058	1.804	746
Functie 6	2	2.949	5.412	2.463

Ontwerp

Cursisten xxx

Voorzieningen

	Aantal	Behoefte	Capaciteit	Match
Functie 1	2	4.668	4.781	113
Functie 2	1	4.453	4.840	387
Functie 3	1	3.701	3.108	-593
Functie 4	1	1.511	4.840	3.329
Functie 5	1	1.058	2.420	1.362
Functie 6	2	2.949	7.260	4.311

Opties

Locatie Aan/Uit

Investering duurzaamheid

Investering overig

Verversen Sluit

Figure 19: Map view, scenario's and location properties.

	Locatie	Afstoten	Overig	Duurzaam
1	Locatie 1			
2	Locatie 2			
3	Locatie 3			
4	Locatie 4			
5	Locatie 5			
6	Locatie 6			
7	Locatie 7			
8	Locatie 8			
9	Locatie 9			
10	Locatie 10			
11	Locatie 11			
12	Locatie 12			
13	Locatie 13			
14	Locatie 14			
15	Locatie 15			
16	Locatie 16			
17	Locatie 17			
18	Locatie 18			
19	Locatie 19			
20	Locatie 20			
21	Locatie 21			
22	Locatie 22			
23	Locatie 23			
24	Locatie 24			
25	Locatie 25			
26	Locatie 26			
27	Locatie 27			

Aanpassing aan
 Aanpassing mogelijk

Figure 20: Location intervention overview.

Additional analytical interfaces

Two additional analytical interface were created to support extended portfolio analyses. These interfaces focus on analysing the performance of the portfolio and saving selected portfolio scores.

The analysis interface includes several options for analysis that can be selected with buttons on the left of the interface (see Figure 21). The selected analysis appears in a new panel. The analysis options include:

- Overview of criteria performance
- Identification of lowest and highest scoring criteria (including delta values)
- Impact on overall performance from intervention
- Criteria scores of each stakeholder and theme
- Overview of most and least impactful interventions

There also is the option to change scenarios within this interface to view their impact within the selected analysis. The aim of this interface is to enhance knowledge discovery and analytical depth without information overload on the dashboard overview interface.

Arrow chart

The analysis interface includes a chart with arrows (see Figure 21). A study into graph design was performed to determine which visualisations can effectively display the change in scores when making interventions. It was decided that the following visualisations were suited based on the research of Cleveland and McGill (1984):

- Bar charts – provide a clear and straightforward comparison of scores

- Dumbbell charts – useful for visualising differences between two score outcomes (e.g. before and after changes to the building portfolio).

The dumbbell chart was eventually transformed into the arrow chart that is implemented into the dashboard. These visualisations allow users to compare values without needing to calculate the score differences. Pie charts or other visual coverage views were avoided, as they require relative judgement of proportions and are less suitable for precise score comparison in decision-making contexts (Few, 2006).

Criteria scores overview

The existing interface displaying the criteria preference scores and weights was redesigned (see Figure 22). The previous version did not fully fit on the screen and required horizontal scrolling to view all results. To prevent breaking the immersion of the dashboard, all data was reorganized to fit within a single interface view.

The difference between the scores of the existing portfolio and the designed portfolio is displayed in the “Delta” column. In this column, conditional formatting was applied to highlight increases in scores in green and decreases in scores in red. Additionally, the scenario menu was added to the interface to allow users to easily switch between different scenarios.

Data filters

10 hoogste & 10

Criteria scores

Meest toegenomen

Meeste invloed op uitkomst.

stakeholder / thema scores

Vergelijken opgeslagen

Scenario's



Huidig

Optimalisatie 1

Laaghangend fruit

Optimalisatie 2

HVP1.0

Ontwerp Workshop 1

Criteria scores

(Criteria veranderingen)

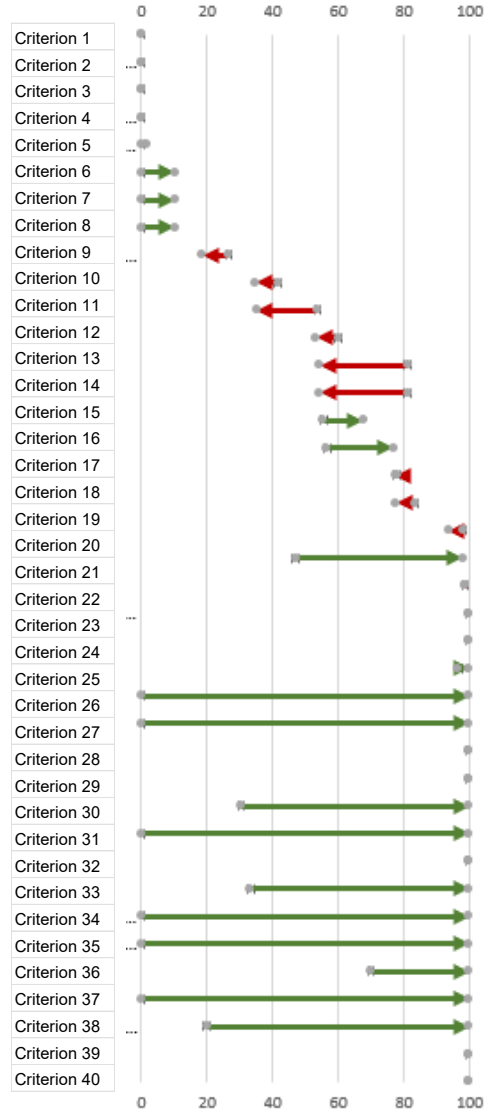


Figure 21: Overview of analytical interface, including the arrow graph(own figure).

Scores			
	Huidig	Nieuw	Delta
Totaalscore	38	63	24
Organisatie	27	59	32
Technisch	45	68	22
Fuctioneel	25	59	34

Scenario's ?

- Huidig
- Optimalisatie 1
- Laaghangend fruit
- Optimalisatie 2
- HVP1.0
- Ontwerp Workshop 1

Technisch						
Technisch perspectief 1	Waarde	Eenheid	Weging	Huidig	Nieuw	Delta
(criteria)	38 %		65%	0	0	0
	0 %	reductie reistijd in uren	12%	0	0	0
	5	Aantal	12%	0	0	0
	100 %		12%	60	100	40
Technisch perspectief 2						
(criteria)	70	Voorkeurscore	23%	55	68	12
	100	TKI score	6%	0	100	100
	53 %		4%	60	53	-7
	6 %		2%	100	100	0
	100 %		23%	30	100	70
	79 %		6%	100	100	0
	46 %		6%	0	0	0
	89 %		6%	97	100	3
	84 %		6%	100	100	0
	24 %	locaties met PA/KMAR	14%	0	10	10
29 %	locaties	6%	54	35	-18	
Technisch perspectief 3						
(criteria)	166	€/m2	20%	100	100	0
	3	m2 BVO/cursist	20%	0	2	2
	484	€ exp. lasten/cursist	20%	100	100	0
	0	ITK score	32%	0	100	100
24	Percentage	8%	100	100	0	
Technisch perspectief 4						
(criteria)	17	Aantal locaties	60%	0	100	100
	51	Gemiddelde score	24%	0	0	0
	100 %		16%	20	100	80

Organisatie						
Organisatie perspectief 1	Waarde	Eenheid	Weging	Huidig	Nieuw	Delta
(criteria)	24	% locaties	25%	0	10	10
	89 %		5%	81	55	-27
	-3 %		5%	57	77	20
	81 %		5%	0	0	0
	100	Voorkeur	30%	0	100	100
Organisatie perspectief 2						
(criteria)	100 %		30%	70	100	30
	0 %	besparing	25%	0	0	0
	2 %	cursisten met reistijd >45	25%	78	78	0
	774	meter	25%	27	19	-8
	1	ja/nee	20%	0	100	100
1	training 's avonds ja/nee	5%	0	100	100	

Fuctioneel						
Functioneel perspectief 1	Waarde	Eenheid	Weging	Huidig	Nieuw	Delta
(criteria)	5	% locaties met marge v-a <5%	100%	83	78	-6
	24	% van locaties	100%	0	10	10
Functioneel perspectief 2						
(criteria)	2	% cursisten met reistijd >45	xcel sli	99	98	0
	0	Aantal	8%	33	100	67
	10	Minuten	8%	42	35	-7
	88	Zie tabblad	35%	47	98	51
	89 %		11%	81	55	-27
	70 %		11%	98	94	-4
	3	Aantal	8%	100	100	0

Figure 22: : Criteria scores interface, including "Delta" and scenario menu

Storage functionality

A storage function was added to allow users to save calculated overall preference scores and criteria scores of a designed portfolio. These saved results are stored in a separate interface, where they can be reviewed and compared at a later stage. Scores can be stored using the “Opslaan” button in the “Opties” menu available at the top right of each interface (see Figure 23).

The interface with the saved results can be found in Figure 24. Each time scores are saved, they are automatically stored in a new column within the storage interface, allowing multiple results to be displayed side by side for comparison. This functionality supports iterative workshop processes, where different portfolio compositions may be explored and compared across sessions. To support memorability, each stored result automatically receives a timestamp, and users can assign a name and add notes describing the characteristics of the stored portfolio composition. The storage interface stores all dashboard overview scores except for the capacity scores.

In addition, the overall preference score and the scores of the criteria themes are visualized in a chart in the bottom right of the interface, allowing for a quick visual comparison between stored results.

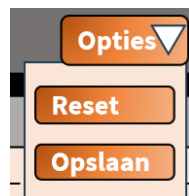


Figure 23: Option menu with storage feature opened up.

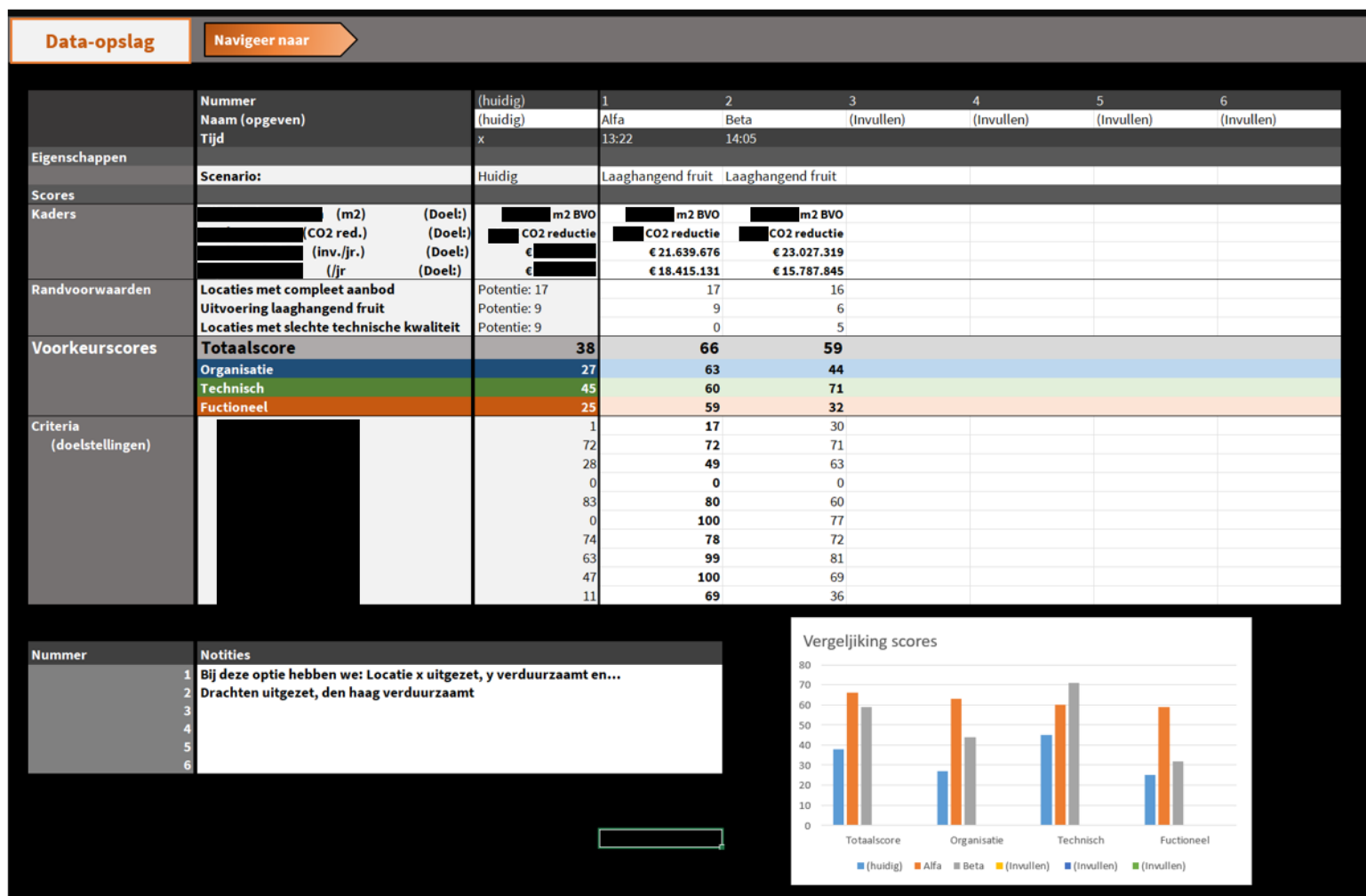


Figure 24: interface for storage and comparison of alternative scores from portfolios.

5.3 Workshop round 1 - Open discussion results

An evaluation of the original dashboard was done (Chapter 4) based on the dashboard design framework from the literature review (Chapter 3). In the earlier parts of Chapter 5, a dashboard redesign was developed. This section highlights the results of the first verification round. After a structured walkthrough of the original dashboard and the first redesign, participants were asked to evaluate the performance of each dashboard through a survey and during an open discussion. The purpose of this section is to present the related findings on the participant perceptions. This is done by structuring their feedback according to the six criteria of effectiveness, namely: usability, flexibility, interactivity, knowledge discovery, readability and transparency in construction.

First, a general overview of participant feedback is provided. This includes the main improvements and remaining challenges identified during the workshops. Second, the findings from the open discussions are presented, which will also discuss the results of the deductive coding analysis. The analysis was done with the deductive codes for the criteria of effectiveness and the design features. Third, the survey results are shown, which includes the qualitative scores given to each dashboard. Finally, the findings are synthesised into lessons for redesigning the PAS dashboard and into broader lessons for effective dashboard design in DSS.

5.3.1 General feedback

The first research round consisted of three workshops in which participants interacted with the original dashboard and the first dashboard redesign. After completing a structured walkthrough of each version, participants filled in a survey and participated in an open discussion. These discussions were recorded and transcribed for analysis.

According to participants, the most significant improvements of the redesigned dashboard came from changes in readability and functionality compared to the original. The improvements are mainly due to the revised layout, which grouped the contents of the dashboard more clearly, and the addition of data analysis options. As a result, the overall usability of the dashboard was perceived to have improved substantially. Despite these improvements, the dashboard redesign faces several challenges that became clear during the workshops. Especially, the balance between the added functional features options and the overall readability requires attention. Although the added functions allowed for new data analysis options, which were greatly appreciated to gain insights on portfolio performance, they also increased the number of visible interface elements. This resulted in reduced visual clarity for some users.

Between workshops, it was mentioned repeatedly by participants that the purpose of a dashboard should be to guide users through the process of evaluation and design. It was emphasised that how essential intuitive interaction and gradual information disclosure are to prevent cognitive overload.

5.3.2 Open discussion – coding analysis

The first research round consisted of 3 workshops in which participants interacted with the original dashboard and the first dashboard redesign. After completing a thorough walkthrough for each dashboard, participants filled in the survey and participated in an open discussion. These discussions were recorded and transcribed for analysis purposes.

The coding of the transcripts was done by creating deductive codes using the literature research. The text of the transcripts were labelled using the codes when it matched their description.

There were three themes in these amounts: 6 design criteria, 13 functional features and 13 visual features. These codes were applied to the quotations from each workshop.

Design criteria - frequencies

The design criteria had a large variation in how often they were mentioned. Usability and readability were mentioned most often, 39 and 63 times respectively (see Table 11). Meanwhile, flexibility, knowledge discovery and transparency in construction were mentioned considerably less often than the other criteria, 10, 19 and 16 times respectively.

Table 11: Quotation frequency of effectiveness criteria.

Criterion	Frequency
Usability	39
Flexibility	10
Interactivity	26
Knowledge Discovery	19
Readability	63
Transparency in Construction	16

Functional and visual features - frequencies

In addition to the criteria, several functional and visual features were mentioned in varying frequencies (see Table 12). The most and least frequently mentioned features can be found in Table 13.

For the functional features, interactive view configuration (18), analytical tools (17), drill-down/roll-up capability (11), layered information structure (10), and what-if analysis (10) were mentioned most often. For the visual features, simple and intuitive layout (21) and visual mapping of data to suitable visualisations (18) were mentioned most often. Other features that were mentioned regularly include constant visual cues (11), logical tab hierarchy (11), consistent layout and design (10), and clear descriptive labels and tooltips (10).

Table 12: Frequency of functional features & frequency of visual features.

◆ F - Analytical tools	17	◆ V - Appropriate use of color and graphs	8
◆ F - Automated alerts and notifications	4	◆ V - Clear, descriptive labels and tooltips	10
◆ F - Cognitive / personality preference support	7	◆ V - Consistent layout and design	10
◆ F - Configuration wizards	2	◆ V - Constant visual cues	11
◆ F - Customizable dashboards	9	◆ V - Frugal use of colors	1
◆ F - Drill-down/ roll-up capability	11	◆ V - Logical tab hierarchy	11
◆ F - Goal setting and gamification	8	◆ V - Maximized data-ink ratio	6
◆ F - Interactive view configuration	18	◆ V - Presentation format guided by task type	1
◆ F - Layered information structure	10	◆ V - Simple and intuitive layout	21
◆ F - Scenario planning and budgeting	0	◆ V - Single-screen layout	4
◆ F - Structured configuration files	0	◆ V - Toggle between tables and graphs	5
◆ F - What-if analysis	10	◆ V - Visual gridlines for 2D / 3D graphs	0
◆ F - Zoom-out strategic view	0	◆ V - Visual mapping of data to suitable visualization	18

Table 13: most and least frequently mentioned features.

Funtional features		Visual features	
Most often mentioned	#	Most often mentioned	#
Analytical tools	17	Simple and intuitive layout	21
Interactive view configuration	18	Visual mapping of data to suitable visualization	18
Least often mentioned	#	Least often mentioned	#
Automated alerts and notifications	4	Frugal use of colors	1
Configuration wizards	2	Presentation format guided by task type	1
Scenario planning and bdgeting	0	Single-screen layout	4
Structured configuration files	0	Visual gridlines	0
Zoom0out strategic view	0		

Co-occurrence - criteria

The co-occurrence overview of the criteria shows that they are frequently interconnected (see Table 14). In most quotations there were two or more criteria assigned simultaneously. This indicates that participants often mentioned aspects about the dashboard that related to several criteria rather than a single one.

The criteria of visibility and interactivity had a frequent co-occurrence. An example that can be coded as such is when participants would mention an orange button. Regarding visibility, this button can easily recognisable due to its noticeable orange colour. The fact that a click can activate a functional of the dashboard aligns closely to interactivity.

The results shows that changes to a single criterion are likely to influence others, which highlights the interdependence of the design criteria of dashboard design.

Table 14: Co-occurrence of effectiveness criteria.

	1 Usability 39	2 Flexibil... 10	3 Interac... 26	4 Knowle... 19	5 Readab... 63	6 Transp... 16
1 Usability 39		7	8	4	24	1
2 Flexibility 10	7		3	2	3	1
3 Interactiv... 26	8	3		5	13	4
4 Knowled... 19	4	2	5		5	9
5 Readability 63	24	3	13	5		3
6 Transpar... 16	1	1	4	9	3	

The table presenting the co-occurrence of criteria with other criteria shows that most criteria predominantly occur with one specific other criterion. In most all cases except one close exemption, this strong co-occurrence accounts for half or more of the total number of occurrences of that criterion. This result can be found in table 15. In contrast, the co-occurrences of the remaining criteria are relatively evenly distributed. The distributions does not reveal any surprisingly low co-occurrence frequencies for the other criteria. In other words, each individual criterion does not have another criterium with which does not co-occur. This is another indication that the design criteria are interconnected rather than appearing in pairs or smaller groups.

Neither interactivity and flexibility are mentioned as most frequent co-occurrence criterion by any of the other criteria. Nevertheless, Interactivity still accounts for almost a quarter of the

quotations coded with readability. Flexibility has its highest co-occurrence with usability, appearing together in 7 out of its 10 total occurrences. The most frequently found co-occurrences can also be found in Table 14.

Table 15: Most prevalent criteria co-occurrences.

Criterion	Times coded	Highest co-occurrence	Highest co-occurrence with criteria
Usability	39	24	Readability
Flexibility	10	7	Usability
Interactivity	26	13	Readability
Knowledge discovery	19	9	Transparency in Design
Readability	63	24	Usability
Transparency in construction	16	9	Knowledge discovery

Visual features – co-occurrence

The co-occurrence of visual features to the criteria of dashboard design are less evenly distributed than for the functional features (see Table 16 and Figure 26). The criteria that appears most prominently is *readability* and after that *usability*. Other criteria show an increasingly lower number of co-occurrence.

The most frequent connections are between the readability criterion and the two visual features of simple and intuitive layout and visual mapping of data to suitable visualizations. The visual features that have a strong connection to readability. Another strong connection is between the visual mapping of data and consistent layout and design. Other visual features also display a higher frequency of connections to readability. Simple and intuitive layout is mainly connected to readability and usability.

Table 16: Co-occurrence table criteria and visual features.

		1 Usability 39	2 Flexibil... 10	3 Interac... 26	4 Knowle... 19	5 Readab... 63	6 Transp... 16
V - Appropriate use of color and graphs	8			2		7	1
V - Clear, descriptive labels and tooltips	10	3	1		2	7	3
V - Consistent layout and design	10	3		3		10	
V - Constant visual cues	11	2		5	1	9	2
V - Frugal use of colors	1					1	
V - Logical tab hierarchy	11	6		2	4	6	6
V - Maximized data-ink ratio	6	4	1		1	6	
V - Presentation format guided by task type	1			1		1	
V - Simple and intuitive layout	21	10		2	4	13	4
V - Single-screen layout	4	2	1	1		2	1
V - Toggle between tables and graphs	5	2	1	2	1	3	
V - Visual gridlines for 2D / 3D graphs	0						
V - Visual mappig of data to suitable visualization	18	5	1	4	2	14	2

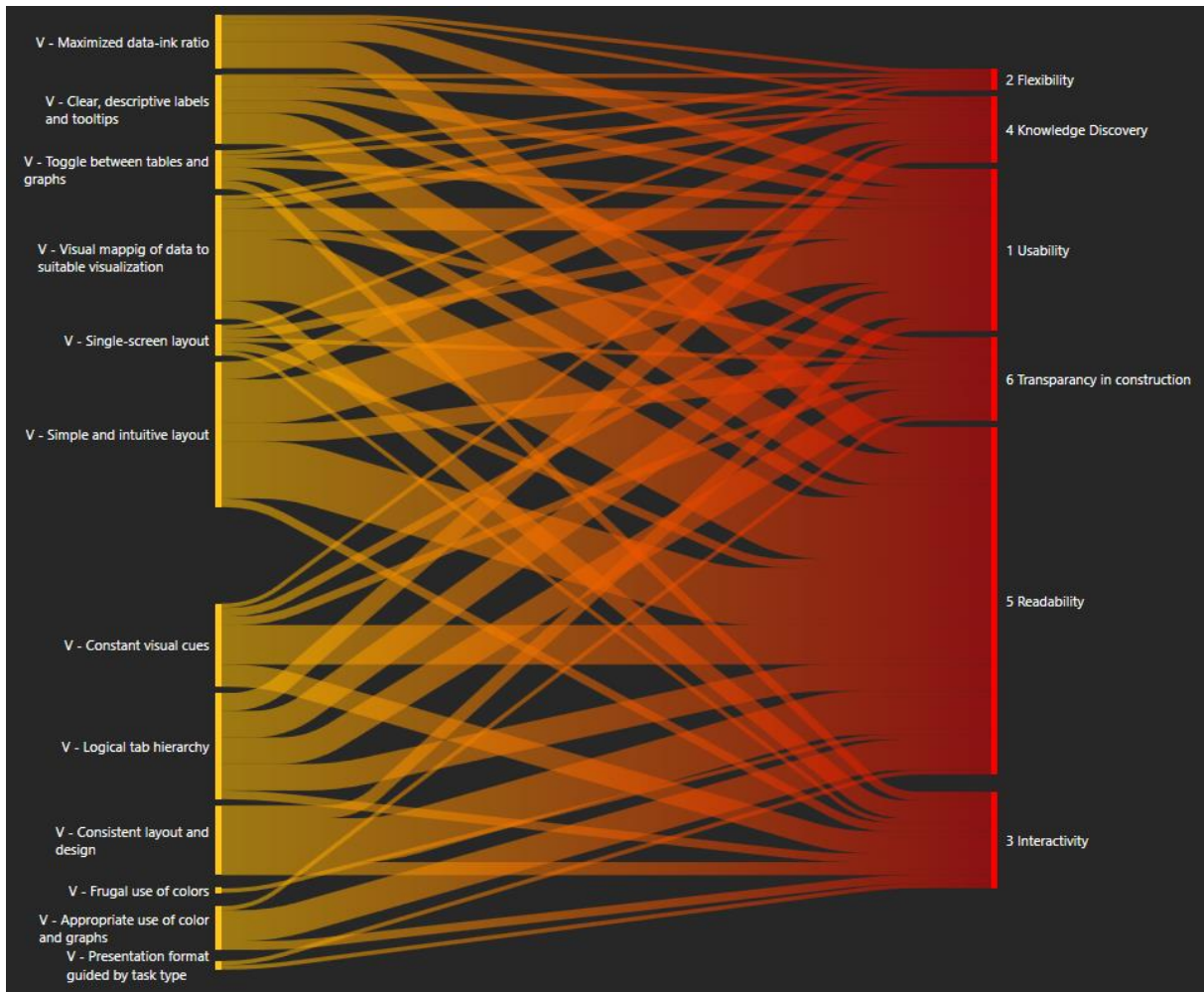


Figure 25: Co-occurrence table criteria and visual features.

Functional features – co-occurrence

The co-occurrence between criteria and functional features show a wide distribution of connections across the data (see Table 17 and Figure 27). All criteria are connected to multiple functional features. This can be explained partially by the coding process, in which multiple codes were assigned to a single quotation, increasing the likelihood that functional features are linked to criteria and vice versa.

Generally, the connections are broadly and quite evenly distributed. One relationship stand out, which is the connection between the criterion of knowledge discovery and the functional feature analytical tools. This co-occurrence is higher than the others, which can be attributed to the fact that analytical tools was quoted quite often compared to other functional features. This results in a higher number of connections with this criterion. Furthermore, knowledge discovery is often found in combination with analytical tools,

The Swanky chart in Figure 27 provides a visual representation of the co-occurrences and further displays the high level of connectivity within the data. It shows that each coded functional feature almost always has a connection to all the criteria, indicating again that the criteria and functional features are widely interconnected.

Table 17: Co-occurrence table criteria and functional features.

		1 Usability 39	2 Flexibil... 10	3 Interac... 26	4 Knowle... 19	5 Readab... 63	6 Transp... 16
F - Analytical tools	17	4	2	7	11	5	4
F - Automated alerts and notifications	4	2	1	3	1	3	
F - Cognitive / personality preference support	7	5	1	3	1	5	1
F - Configuration wizards	2		2	1		1	
F - Customizable dashboards	9	4	2	6		5	1
F - Drill-down/ roll-up capability	11	4	3	3	6	4	5
F - Goal setting and gamificatiton	8	2	1	3	5	1	3
F - Interactive view configuration	18	6	4	6	6	9	7
F - Layered information structure	10	7		2	1	6	3
F - Scenario planning and budgeting	0						
F - Structured configuration files	0						
F - What-if analysis	10	2		2	4	4	4
F - Zoom-out strategic view	0						

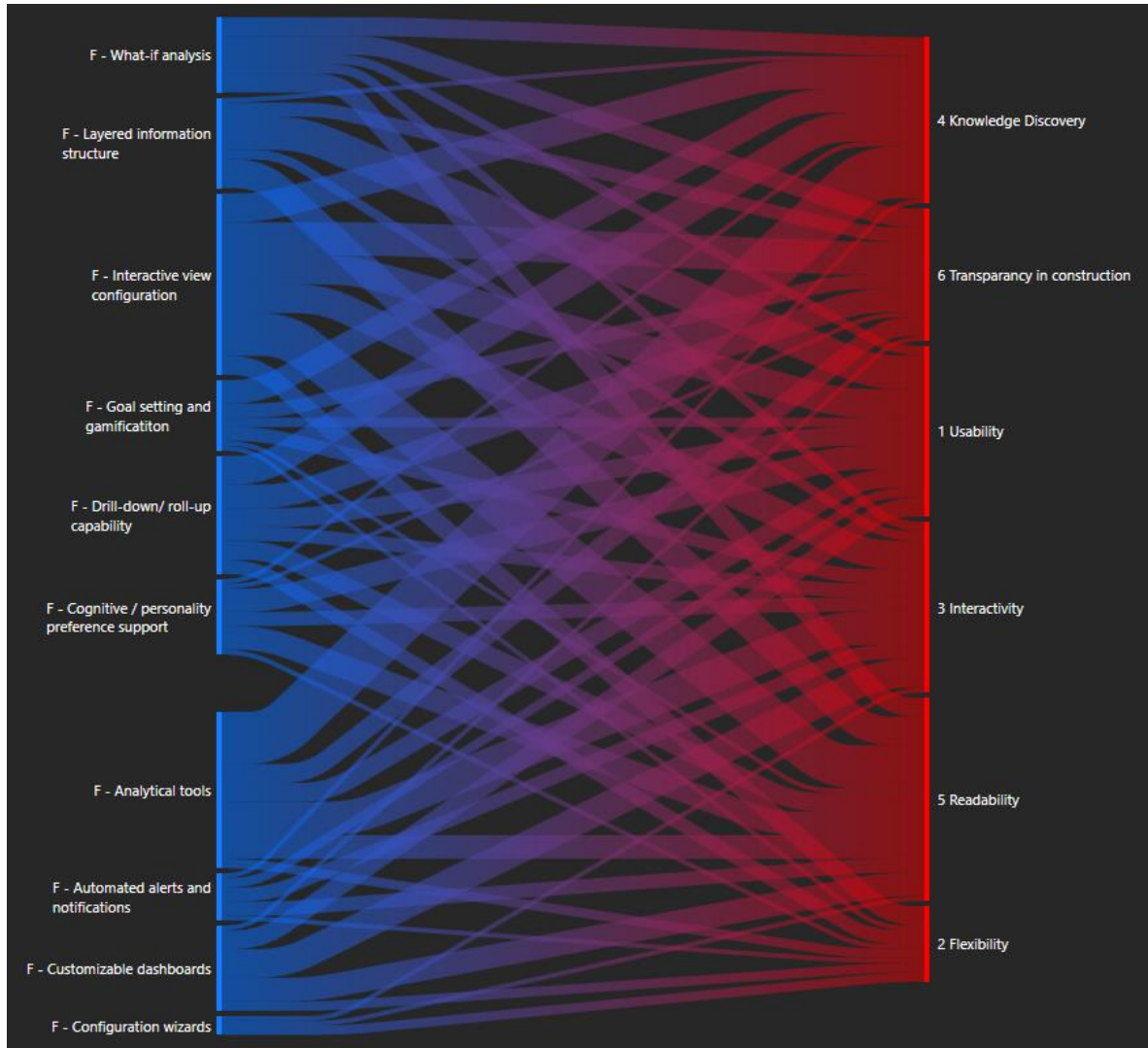


Figure 26: Co-occurrence table criteria and functional features.

Functional features and visual features – co-occurrence

The co-occurrence of functional and visual features is widely distributed (see Table 18 and Figure 28). However, compared to the earlier discussed co-occurrences, there are more features that do not simultaneously.

The features that occur most often are the visual features *simple and intuitive layout* and *visual mapping of data to suitable visualizations* (21 and 18 occurrences), and for the functional features *analytical tools* and *interactive view configuration* (17 and 18 occurrences). The most frequent co-occurrences are between the visual features *simple and intuitive layout* and *logical tab hierarchy*, and the functional feature *interactive view configuration*.

The Swanky chart in Figure 28 provides a visual representation of the co-occurrences and further displays the high level of connectivity within the data. However, compared to the earlier Swanky charts there are significantly less widely distributed.

Table 18: Co-occurrence visual and functional features.

	F - Analy... 17	F - Auto... 4	F - Cogn... 7	F - Confi... 2	F - Custo... 9	F - Drill... 11	F - Goal... 8	F - Intera... 18	F - Layer... 10	F - Scena... 0	F - Struct... 0	F - What... 10	F - Zoo... 0
V - Appropriate use of color and graphs 8					1			1					
V - Clear, descriptive labels and tooltips 10	3						2	2					3
V - Consistent layout and design 10			2		2								
V - Constant visual cues 11	3		1		2	1	1	2					2
V - Frugal use of colors 1													
V - Logical tab hierarchy 11	1		2		1	3		4	3				2
V - Maximized data-ink ratio 6						1		2					
V - Presentation format guided by task type 1			1		1								
V - Simple and intuitive layout 21	4		3		1	2	2	5	3				2
V - Single-screen layout 4						1		2	1				
V - Toggle between tables and graphs 5	1		3	1	3	1		1					1
V - Visual gridlines for 2D / 3D graphs 0													
V - Visual mapping of data to suitable visualization 18	3	1	1		1	1		3					3

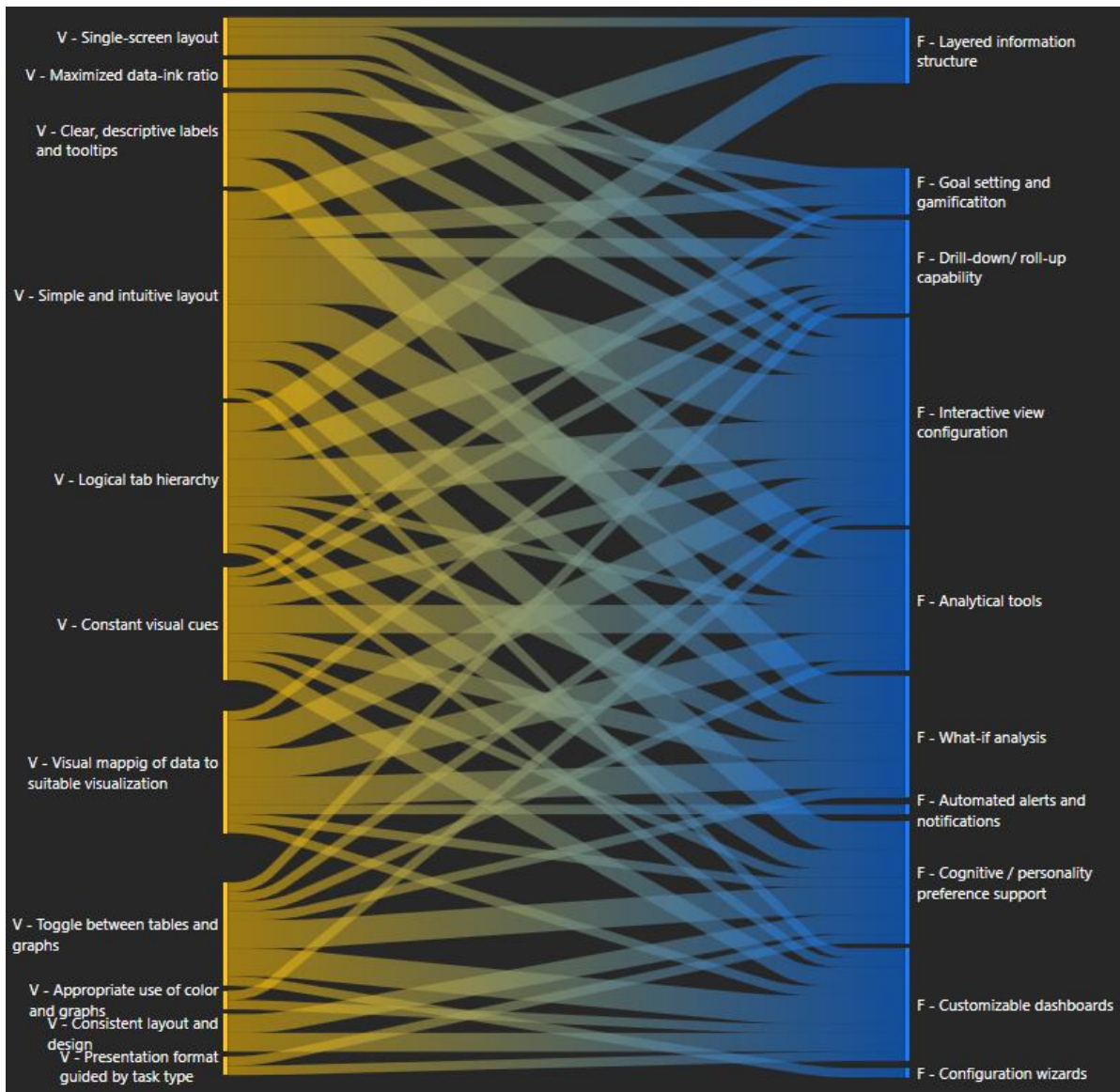


Figure 27: Co-occurrence visual and functional features.

Interpretations and limitations

The initial findings show strong connections between the visual feature “simple and intuitive layout” and the functional features “interactive view configuration” and “interactive tools”. However, because some codes appear more often than others, the total co-occurrence counts may overrepresent these frequent codes. Therefore, it is important to consider the overall occurrence of each code when interpreting these relationships.

The frequency of coded quotations provides an indication of which design elements were most important to participants. However, these quotations include both positive and negative feedback and refer to both the original dashboard and the redesign, as no separate codes were assigned. Therefore, frequency and co-occurrence results do not by themselves determine the urgency of specific redesign actions.

The interpretation of the data requires an examination of the actual quotations to understand the meaning of participant feedback. This provides user suggestions and explanations that cannot be derived from the frequency of labels or from the co-occurrence tables alone. The frequency of co-occurrences does not indicate the urgency of redesigning specific parts of the dashboard by itself or problems with the dashboard. Therefore, the occurrence analysis should be in combination with the interpretation of quotations to support grounded redesign decisions.

The co-occurrence analysis shows that both criteria and design features are widely distributed across the dataset and frequently appear in combination with multiple other codes. Most criteria are not linked to a single dominant feature, and vice versa. Instead, the combinations are diverse and spread across different parts of the coding framework. The results therefore suggest a strong interconnectedness between criteria and features.

5.3.3 Open discussion – assessment through effectiveness criteria

During the workshops, open discussions were conducted to gain qualitative insights into how participants experienced the performance of the original dashboard and the first redesign. Guiding questions were prepared in advance to steer the discussions towards specific themes and moments of comparison between the two versions.

This part of the workshops was recorded and transcribed. The transcripts were analyzed using deductive coding based on the effectiveness criteria and the functional and visual features identified in the literature study. The feedback provided by participants was subsequently organized according to the effectiveness criteria. The identified limitations are listed and used as input for the second redesign phase.

Usability

The redesign offered an improved layout which supported learnability and efficiency of performing tasks. Participants mentioned that a dashboard should be immediately usable upon opening. The redesign resulted in a higher overall satisfaction due to a structured dashboard overview and the fact that possible actions were clear without extensive explanations.

Participants appreciated that the redesigned dashboard introduced a more gradual introduction to functionality. The interface allowed users to start with a simplified overview before exploring additional functions, which helped in the general ease of use. This was mentioned as a preference in most workshop sessions.

The ability to save an overview of the real-time scores of a portfolio to a separate interface was seen as highly valuable. Furthermore, the possibility to compare the saved scores to the performances of other saved portfolio compositions was appreciated.

For this criterion, the following limitation was identified:

A) Navigation memorability. Additional analytical interfaces were added in the redesign, however the downside of navigating between interfaces was that it demanded increased memorability from participants. This included remembering the option to navigate, how to navigate and the possible interfaces to select. Furthermore, they had to recognise multiple new layouts of the interfaces and the additional interactive in those locations.

Flexibility

The redesign introduced additional features that enabled users to switch between different interfaces for viewing criteria scores, analytical results and stored portfolio scores. Furthermore, the option to change the interface configuration was introduced. For example, users could choose to display an overview of location interventions or switch to other analytical interfaces when required.

Participants perceived the content of the different interfaces as useful for the optimization of portfolio alternatives. The ability to move between interfaces that provided different types of information increased the perceived flexibility of the dashboard.

The option to close and show information panels in the dashboard redesign allowed participants to gradually change the configuration of the interface according to their needs. The dashboard presented a simplified overview as a starting point and allowed users to access more detailed information when required. According to the participants, this progressive disclosure of information and the addition of drill-down functionality improved the flexibility of the dashboard.

For this criterion, the following limitation was identified:

B) Interface layout. The portfolio locations are shown through either the geographic view (map) or table overview. There was consensus that both views are essential and complement each other. However, users differed in their preference for which view should be shown first. Some participants indicated they preferred to start with a map as this helped them to gain an overview of the real estate portfolio composition more easily.

Interactivity

Participants appreciated the interactive features that were introduced in the redesign. The drill-down functionality allowed users to explore additional information when required. In particular, the possibility to store scenario results was considered valuable for workshops that take place over multiple sessions. This allowed participants to compare portfolio alternatives and reflect on earlier results.

The additional analysis interface was also appreciated, as it supported a better understanding of portfolio performance. Especially the arrow chart was positively received. Participants mentioned that this visualization provided a clear and intuitive way to quickly understand differences in criteria scores.

The help buttons were considered useful for gaining additional insight into the functions of the dashboard. These buttons helped participants understand the available features and how they could be used during the workshop.

Participants emphasized that dashboard interactivity only works effectively when the elements that support it are clearly visible and function intuitively. Interactive buttons should clearly indicate it when they are activated or selected. In addition, participants expected immediate visual feedback when performing actions in the dashboard. This feedback should be visible through changes in scores, deltas or graphs so that the consequences of adjustments become immediately clear.

For this criterion, the following limitations were identified:

C) Interface navigation. Navigation between interfaces was generally easy to perform. However, the introduction of additional interfaces increased the amount of information users had to process and remember.

D) Panel locations. Interactive panels in the dashboard should appear in fixed positions. Moving them around would increase the cognitive load for users and make it more difficult to maintain an overview.

E) Redundant features The button for hiding the capacity results in the results overview was perceived as unnecessary. Participants indicated that this function added an extra button to the interface and could contribute to information overload.

F) Missing explanations. Adding brief descriptions to interactive elements could help participants better understand which elements can be used and how they function.

Knowledge discovery

The selected design changes aimed at improving knowledge discovery were generally effective and appreciated by participants. As also described under the flexibility criterion, the drill-down functionality and the additional analysis interface supported participants in exploring the dashboard results. These features helped participants to better understand trends and relationships between the displayed data.

In particular, the arrow graph was positively received. Participants mentioned that this visualization provided clear insights by displaying changes in criteria scores. By visualizing the differences between portfolio configurations, the redesign made it easier to understand the consequences of adjustments made during the workshop.

Participants emphasized that knowledge discovery is best supported when users can explore information through a drill-down structure. The dashboard should first present an overview containing only the essential information, while more detailed information should remain accessible when required. According to the participants, this approach supports understanding without overwhelming users with excessive information.

For this criterion, the following limitations were identified:

G) Model backend. The underlying calculations of the model were still not entirely clear to participants. Some student participants in particular did not fully grasp the complexity of the model and how certain results were derived. For example, two participants mentioned that they would occasionally like to view the preference curves used for the calculation of the criteria scores.

Readability

The new layout improved the readability of the dashboard. Information was grouped according to the themes of results, analysis and interventions. Participants perceived this structure as easier to read compared to the original dashboard, where information was more spread out across the interface.

The use of labels helped to separate sections within the dashboard and clarified which results were displayed in each area. These labels supported users in understanding the structure of the interface and the type of information presented.

Panels were introduced to visually separate different information themes in the dashboard. According to participants, these panels helped to organize the information and made the dashboard easier to interpret.

The color usage was generally perceived as helping to recognize elements and features intuitively. The interactive buttons stood out clearly and their function was immediately recognizable. In the redesign, all fields containing calculated scores were highlighted with a yellow background color. Participants mentioned that this helped them to quickly recognize calculated results within the interface.

Participants also mentioned that the redesign no longer strongly resembled a typical Excel environment. The removal of standard Excel elements and the use of panels and labels created a more professional dashboard appearance.

For this criterion, the following limitations were identified:

H) Visual emphasis. At this moment, all result scores appear to have equal importance. A colour scheme based on a hierarchy of importance could support users in prioritising which results should be interpreted first. Information that is more important or should receive immediate attention should therefore be visually emphasised. Currently, the large variety of colours in the dashboard makes it more difficult to quickly recognise the most relevant information. Key outcomes should therefore be displayed more prominently.

I) Color overuse. The use of coloured elements was perceived as slightly excessive in the redesigned dashboard. In particular, the colour of some background panels was considered too strong, which could distract from the actual information presented.

Transparency in construction

Participants generally understood that the dashboard results were calculated based on preferences and weights assigned to the portfolio criteria. The redesign helped to clarify some aspects of the model through the addition of help buttons and tooltips. These elements were perceived as useful for explaining dashboard features and providing additional context about the displayed results.

Participants also indicated that complete access to all model formulas or underlying datasets is not necessary within the dashboard itself. Instead, they preferred brief explanations that help users understand how results are generated without overwhelming them with excessive technical detail. Here, the help buttons and information tooltips contributed to improving the transparency of the dashboard by offering short explanations of functions and results. During the workshops, these elements supported participants in understanding how the dashboard could be used and how the displayed scores should be interpreted.

At the same time, participants emphasised that transparency could be further improved by providing clear explanations about the origin of the data and the logic behind the calculations. One participant suggested implementing help buttons that display explanations about the mechanics of the dashboard, allowing users to access clarification when they become confused.

For this criterion, the following limitation was identified:

J) Model backend. The underlying calculations of the model were not fully clear to all participants. Some student participants in particular needed repetitive explanations about the calculation of criteria scores. Additional tooltips and help buttons could potentially improve transparency, participants indicated that additional explanations or links to deeper information layers could further support understanding.

Additionally, some participants suggested that preference curves could be shown as an optional deeper layer, as this would help explain calculations with stakeholder weights and preferences.

5.4 Workshop Round 1 - Survey results

The survey included 18 questions evaluating dashboard performance based on the criteria of effective dashboard design on a scale from 1 to 10 (highest score). An overview of the survey questions can be found in Appendix B. The results indicate that the redesign led to an overall improvement compared to the original dashboard (see Table 19). For 16 of the 18 questions, the redesigned dashboard scored higher, with most improvements showing an average increase of around one point or more.

The smallest differences in score were observed in Question 9 (Interactivity: “how well the dashboard helps to see portfolio performance?”) and Question 10 (Knowledge discovery: “how well the dashboard helps users gain new insights?”), both showing only marginal increases (+0.1). The largest changes in score were found in Question 4 (Usability: how well the dashboard prevents confusion during workshop use, +1.8) and Question 16 (Readability: how easily information can be understood without additional explanation, +1.7).

Table 19: Dashboard performance scored from 1-10 in the survey.

Criterion	Question	Existing	Redesign	Difference
Usability	1	6,8	7,8	1,0
	2	6,9	8,2	1,3
	3	6,9	7,7	0,8
	4	6,3	8,1	1,8
	5	6,6	7,7	1,1
Flexibility	6	7,3	7,9	0,6
Interactivity	7	7,2	7,9	0,7
	8	7,0	7,6	0,6
	9	8,3	8,4	0,1
Knowledge discovery	10	8,0	8,1	0,1
	11	7,5	8,5	1,0
	12	6,0	7,0	1,0
Readability	13	6,7	7,7	1,0
	14	6,4	7,8	1,5
	15	7,2	7,5	0,4
	16	6,2	7,9	1,7
Transparency in design	17	4,5	6,0	1,5
	18	4,8	5,7	0,9

5.5 Lessons for redesigning the PAS dashboard (RQ4)

Based on the results of both workshop rounds, lessons can be derived for further redesign of the PAS dashboard. In line with the structure of previous chapters, this section answers the fourth research question:

RQ4 – What are users' perceptions during the verification of the redesigned PAS dashboard in relation to the effectiveness criteria?

The dashboard evaluation was structured around the effectiveness criteria identified in the literature review, namely, usability, flexibility, interactivity, knowledge discovery, readability and transparency in construction.

First, regarding usability and readability, the clearer layout, improved visual hierarchy and structured grouping of results were positively evaluated by participants. The distinction between results and analysis sections supported users in understanding the dashboard and navigating between interfaces. Participants indicated that the grouping of results into structured themes and the use of clearer labels improved readability and reduced visual clutter. However, participants also indicated that when multiple elements were presented with equal visual importance, it was not always immediately clear which outcomes should receive the most attention. A clearer visual hierarchy is therefore required. Key outcomes should be more prominently visible, for example by applying stronger visual emphasis through positioning, size or color use.

Second, although color usage was generally perceived as intuitive, the use of colored elements was close to excessive. Too many colored components may reduce clarity and increase cognitive load, especially when multiple elements compete for attention. Color should therefore be applied more functionally, for example to highlight score deviations or to indicate notable data rather than to decorate multiple elements.

Third, transparency in the construction of the scores appeared to be important. Participants understood that the results were calculated based on preferences and weights of the portfolio criteria. However, the exact calculations were not always clear and some participants had misconceptions about them. This was more frequently observed among participants with less experience with the PAS method. At the same time, participants did not express the need to access all formulas or datasets directly within the dashboard. This indicates that conceptual transparency is sufficient. Short explanations about how scores are constructed and what data sources are used should be integrated, for example through brief descriptions or tooltips. Furthermore, the added tooltips and question marks were perceived as helpful. These small explanatory elements support usability without overloading the main interface and should therefore be further developed. Participants also indicated that they did not always fully understand how overall preference scores were constructed and how their input influenced the results.

Fourth, regarding interactivity, flexibility and knowledge discovery, participants appreciated the possibility to compare alternatives and to show or hide analysis sections on the main dashboard overview. The added analytical features provided insight into criteria performance, difference in scores and intervention effects. However, switching between interfaces and opening multiple panels was sometimes found to lead to a higher cognitive load. It was mentioned that the added flexibility supported knowledge discovery. Participants also indicated that they wanted better support in recognizing patterns, understanding the influence of each criterium on overall preference scores and gaining insight into the consequences of their adjustments.

Finally, it became clear that the focus during the workshop should remain on analyzing the performance of the portfolio and comparing alternatives. Although preference curves are important in the model construction phase, including them in the dashboard risks shifting attention away from the main purpose of the workshop. The workshop facilitator is responsible for adjusting preference curves between sessions if necessary. Detailed information about the model can be provided separately, for example in a handout. The dashboard itself should support discussion of results, not the technical structure of the model.

Overall, the verification of the redesigned dashboard shows that users perceived improvements on most effectiveness criteria, particularly usability, structure and analytical support. At the same time, challenges remain in transparency in construction, cognitive load and interpretation of results.

5.6 Lessons for dashboard design (RQ5)

Using the findings from the workshop evaluations, several broader lessons for dashboard design can be drawn. This section contributes to answering the fifth research question: **RQ5 – What lessons can be drawn from the redesign and evaluation process for dashboard design in general?**

A first lesson concerns the importance of visual hierarchy. When all elements are presented with equal visual importance, users struggle to identify key outcomes. Especially in the context of DSS, dashboards should guide user attention towards the most important information.

Second, transparency in construction does not mean giving all technical details or data from a model. Users require an understanding of how results are constructed, but not necessarily need access to underlying formulas. Effective dashboards communicate the logic of calculations at a conceptual level, while keeping complex calculations in the background.

Third, cognitive load plays an important role in collaborative decision-making settings. While additional features and analytical options can enhance insight, excessive information or interaction possibilities may hinder understanding. A balance is required between providing sufficient flexibility in analytical depth and maintaining readability and usability. This implies that flexibility should be limited to meaningful interactions, whilst maintaining a stable and clear interface layout and structuring of information.

Fourth, the information displayed by the dashboard needs to be relevant for the decision-making process in the workshops. In the PAS context, preference curves are relevant during the model construction, but less relevant during the workshop analysis of the real estate portfolio. The dashboard content needs to remain aligned with the specific objective of the workshops. Therefore, the addition of irrelevant information should be prevented.

Finally, the workshop facilitator plays important role in supporting stakeholders in using and understanding the dashboard of a DSS. When the interaction with the dashboard is guided, the facilitator becomes his responsible for explaining its features and opening tooltips whenever necessary. This is required due to the technical complexity of the dashboard and the included functional features that allow for in depth options rather than simply viewing the calculated

scores. The dashboard should support the increased transparency of portfolio design and support stakeholder discussions.

In summary, the lessons derived from Chapter 5 show that effective dashboard design requires a balance between readability, interactivity and transparency in construction, whilst supporting its decision-making purpose.

Chapter 6 – Round 2: Dashboard Redesign and Verification

This chapter presents the second redesign of the PAS dashboard and evaluates its effectiveness through a second round of workshops. Using the findings from Chapter 5, this iteration translates the identified limitations and lessons learned from the first redesign into new design changes and verifies their impact in practice.

The chapter begins by again addressing the third research question of this thesis. Similar to Chapter 5, this is done by linking the identified limitations from the first workshop round to design principles and features using the design framework developed in Chapter 3. The outcome of this step is a new set of design changes, which are presented in Table 19.

Subsequently, the second dashboard redesign is presented and evaluated through a new round of workshops. Based on this evaluation, additional limitations and insights are identified. These insights are used to formulate lessons for both the PAS dashboard and dashboard design for dashboards for DSS in general.

6.1 Redesign objective and changes (RQ3)

This section answers the third sub-research question:

RQ3 – What design principles should be considered in the redesign of a new effective PAS dashboard?

To answer RQ3 for this second iteration, the findings from the evaluation of the first redesign (Chapter 5) were synthesized. The workshop results and survey responses revealed new limitations and areas for improvement, particularly related to usability, readability, and flexibility of the dashboard.

These findings were combined with the design principles and effectiveness criteria identified in Chapter 3. The limitations identified in Section 5.3.2 serve as the main input for this iteration. Based on these insights, new redesign objectives are formulated in Section 6.1.1.

Similar to the first iteration, the design framework developed in Section 3.1.6 is used to translate these limitations into concrete design changes. Each identified limitation was analyzed and linked to relevant effectiveness criteria, design principles, and corresponding design features. An overview of this process is presented in Table 19 in Section 6.1.2.

6.1.1 Redesign objectives

The second redesign aimed to further improve the effectiveness of the PAS dashboard based on the evaluation findings from the first redesign iterations. In contrast to the previous iteration, this redesign focused on a smaller set of criteria, primarily addressing issues related to readability and usability. The key objectives of the redesign can be formulated from the analysis results on the criteria of effectiveness:

- Improve **readability** by revising the visual hierarchy and visual clutter.
- Improve **usability** by refining the layout and layering of dashboard interfaces.
- Increase **flexibility** in view configuration to allow users to better adapt the dashboard to their needs.

These objectives reflect the evaluation results of the first redesign, where users indicated difficulties in interpreting certain visual elements, navigating between layers of information, and adjusting the dashboard to different analytical tasks.

6.1.1 Formulation of design changes

To translate the redesign objectives into concrete design changes, the limitations identified in Section 5.3.2 were used as input for the dashboard design framework developed in Chapter 3. This framework connects effectiveness criteria to design principles and corresponding visual and functional features, allowing for the formulation of design changes.

The detailed translation from limitations to design changes is presented in Table 20. In this table, each identified limitation is linked to relevant design principles and operationalized through specific design features, resulting in concrete design changes for the second redesign of the PAS dashboard. Based on the overview in Table 20, the main design changes can be grouped into the following groups.

First, design principles are applied to improve usability by addressing the difficulties users experienced in navigating and using the dashboard during the first workshop round. Participants indicated that the organization of information and interaction between elements was not always intuitive, which made it harder to perform tasks efficiently. To resolve this, the layout and interaction structure of the dashboard are refined by improving the organization of interface elements and changing the layering of information. This should allow users to access relevant information more efficiently and reduce the effort required to operate the dashboard.

Second, design principles are applied to increase flexibility in response to the limitations observed in how the dashboard could be used across different workshop situations. The first redesign still presented a relatively fixed structure, which limited users in adapting the dashboard to their analytical needs. To address this, the redesign introduces changes that allow the user to adjust how information is displayed and accessed. This supports the use of the dashboard in line with the needs of users, which enables them to focus on specific data without needing to follow the existing interface structure.

Third, design principles are applied to enhance interactivity and knowledge discovery to improve user understanding on how their actions influenced the results. During the first workshop round, it was not always clear how changes in inputs affected outcomes, which reduced the ability of users to explore the model effectively. The redesign focuses on improving the clarity of interactions and making the effects of user actions more visible. This enables users to better explore relationships between inputs and outcomes.

Fourth, design principles are applied to improve readability, based on feedback that some elements of the dashboard could be easier to interpret. Despite improvements in the first redesign, issues related to visual hierarchy and information density remained. The redesign focuses on reducing visual clutter, improving the grouping of information, and applying consistent visual elements. These changes make key results more clearly visible and support faster and more intuitive interpretation of the dashboard outputs.

Finally, design principles are applied to improve transparency in construction by increasing their understanding on how results are calculated. Feedback from the first workshop round indicated that the relationship between inputs, calculations, and outputs was not always clear. To resolve this, the redesign strengthens the visibility of these relationships and adds explanation on how results are generated. This could support better understanding of the underlying model mechanics and increases trust in the dashboard outcomes.

Table 20: Formulation of design changes through the design framework.

Analysis			Redesign		
Criterion	Design principle(s)	Identified limitation(s)	Applied design features		Resulting design changes
			Visual features	Functional features	
Usability	Cognitive fit Visual clarity Simplicity	A. Navigation memorability	Clear descriptive layers and tool tips	Interactive view configuration	Integration of interfaces Layout of dashboard overview
Flexibility	Layering of information	B. Interface layout		Interactive view configuration Customizable dashboards Cognitive/Personality preference support	Layout of dashboard overview
Interactivity	Tailoring capabilities Layering of information	C. Interface navigation, D. Panel locations		Interactive view configuration Customizable dashboards	Integration of interfaces Layout of dashboard overview
		E. Redundant features		Interactive view configuration Customizable dashboards	Removing redundant buttons
		F. Missing explanations	Clear, descriptive labels & tooltips		
Knowledge Discovery	Cognitive fit Single screen	G. Model backend		Drill-down/roll-up capability Layered information structure Analytical tools	Preference curves remain hidden
Readability	Simplicity Visual clarity Single screen	H. Visual emphasis, I. Color overuse	Appropriate use of colors and graphs Logical tab hierarchy Frugal use of colors		Visual hierarchy & elements
Transparency in Construction	Layering of information Cognitive fit Visual clarity	J. Model backend		Drill-down/roll-up capability Layered information structure	Preference curves remain hidden

The dashboard design framework developed in Chapter 3 is presented again in this section. The design features that have been implemented in this redesign iteration are highlighted in green. This is illustrated in Table 21.

Table 21: Dashboard design framework with the selected design features.

Criterion	Design principle(s)	Visual features	Functional features
Usability	Cognitive fit Visual clarity Simplicity	Clear, descriptive labels and tooltips	Automated alerts and notifications
		Logical tab hierarchy	Interactive view configuration
		Presentation format guided by task type	
		Visual mapping of data to suitable visualization	
		Constant visual cues	
		Simple and intuitive layout	
Flexibility	Layering of information		Drill-down/roll-up capability
			Layered information structure (strategic to ops)
			Interactive view configuration
			Customizable dashboards
			Configuration wizards
			Cognitive/personality preference support
Interactivity	Tailoring capabilities Layering of information		Drill-down/roll-up capability
			What-if analysis
			Scenario planning and budgeting
			Automated alerts and notifications
			Interactive view configuration
			Goal setting and gamification
			Customizable dashboards
	Configuration wizards		
Knowledge Discovery	Cognitive fit Single screen	Single-screen layout	Drill-down/roll-up capability
		Presentation format guided by task type	What-if analysis
			Scenario planning and budgeting
			Automated alerts and notifications
			Analytical tools (e.g., prediction, pattern ID)
			Goal setting and gamification
			Layered information structure (strategic to ops)
	Zoom-out strategic view (e.g., strategy map)		
Readability	Simplicity Visual Clarity Single screen	Single-screen layout	Interactive view configuration
		Maximized data-ink ratio	
		Appropriate use of color and graphs	
		Frugal use of colors	
		Visual gridlines for 2D/3D graphs	
		Clear, descriptive labels and tooltips	
		Consistent layout and design	
		Logical tab hierarchy	
		Presentation format guided by task type	
		Visual mapping of data to suitable visualization	
		Constant visual cues	
Simple and intuitive layout			
Transparency in Construction	Layering of information Cognitive fit Visual clarity		Drill-down/roll-up capability
			Layered information structure
			Interactive view configuration
			Zoom-out strategic view (e.g., strategy map)

6.2 Design changes for redesign 2

Based on the limitations found in the first workshop round, several concrete design changes were formulated for the second dashboard redesign. This section elaborates on all the design changes listed in Table 10 from the previous section.

Integration of interfaces

The number of separate interface was reduced. Instead of navigating between multiple sheets, the storage and analysis interfaces are now integrated into the main dashboard screen. This supports continuity and reduces cognitive load caused by switching between interfaces. The redesigned main dashboard overview can be found in Figure 29.

Layout of dashboard overview

First, the main screen was simplified. The redesigned layout starts with the geographic map on the left and the results section on the right. This provides a clear starting point for users, while allowing them to decide which actions or analyses they want to use (see Figure 29).

OVERZICHT

Kaart

Resultaten

Locaties



Figure 28: Dashboard main overview interface.

To improve the flexibility of the dashboard interface, the configuration of the information panels was revised. Participants are now able to display information in one of the three available panel locations, allowing the interface to be adjusted depending on the information needed during discussions. To create sufficient space for these panels, the interactive toolbar was repositioned higher in the interface.

For example, a dedicated interactive button was created in the left panel to switch between the map view and the model score results. Brief descriptions were also added to several interactive elements to clarify their function and make it easier for participants to understand how these elements can be used. Each of the three panels got several information options. From left to right the panels contained the following information.

- Panel 1 can toggle between the **map of locations and results**.
- Panel 2 can display **results or location-specific interventions**.
- Panel 3 can display the **location characteristics, map of locations, analysis, and saved portfolio scores**.

One possible configuration of the dashboard is a map panel on the left, a results panel in the middle and analysis panel on the right. This is shown in Figure 30.

OVERZICHT

Kaart ↔ Resultaten



Resultaten

RANDVOORWAARDEN

	Totaal	Behaald
Locaties met compleet aanbod	14	14
Uitvoering laaghangend fruit	9	9
Locaties met slechte technische kwaliteit	X	0

KADERS

	Doel	Nieuw	Delta
(m2)	max. m2 BVO	98.519 m2 BVO	-3.481 m2 BVO
CO2 red.)	CO2 reductie	32% CO2 reductie	32% CO2 reductie
(inv./jr.)	€ 10.000.000	€ 10.784.062	€ 784.062
(/jr)		€ 17.230.768	

VOORKEURSCORES

Totaalscore	Huidig	Nieuw	Delta
Organisatie	38	63	25
Functioneel	27	61	34
Technisch	45	56	11
	25	59	33

CRITERIA

Doelstelling	Hoe verbeteren?	Huidig	Nieuw	Delta
		1	13	12
		72	72	0
		28	30	2
		0	0	0
		83	76	-7
		0	100	100
		74	70	-4
		63	99	36
		47	100	53
		11	79	67

CAPACITEIT

Geplande capaciteit		100%	Opkomstpercentage	
Tekort	# locaties	gem. tekort	Functie	gem. tekort
Functie 1	3	-177	Functie 4	0
Functie 2	3	-349	Functie 5	0
Functie 3	1	-593	Functie 6	0
Overschot	# locaties	gem. overschot	Functie	gem. overschot
Functie 1	11	2.484	Functie 4	14
Functie 2	11	2.501	Functie 5	14
Functie 3	13	1.936	Functie 6	14

ANALYSE

(Selecteer analyse)

10 hoogste & 10 laagste Meeste invloed op uitkomst.

Criteria scores (Toename / Opgeslagen)

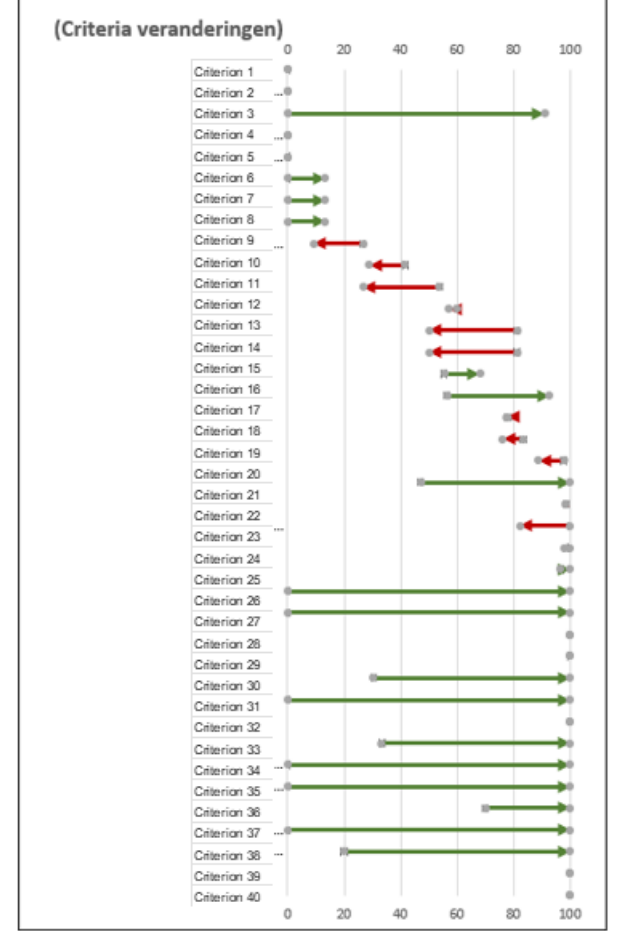
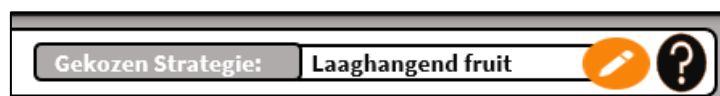


Figure 29: One of the possible dashboard configurations: map panel, results panel and analysis panel.

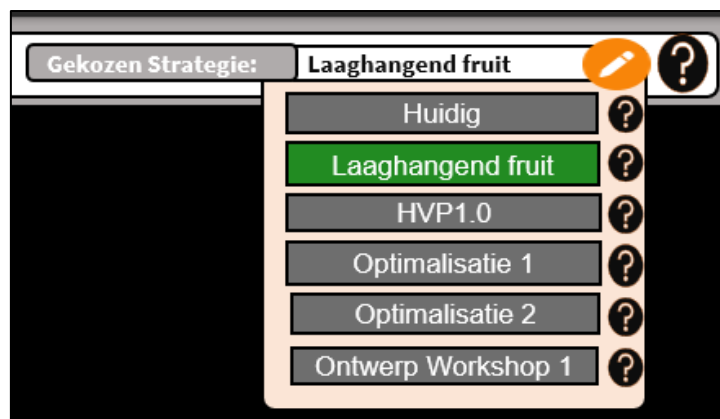
Strategy menu

Another change in the dashboard layout concerns the location and presentation of the scenario selection menu (see Figure 31). The name of this function was changed from “Scenario” to “Strategy” since strategy represents a planned combination of interventions designed to achieve certain objectives. This term better aligns with the role of the function in the dashboard, where users select and evaluate different intervention configurations.

Because this function is not one of the primary tools used during discussions, its visual prominence was decreased. As a result, the element was repositioned to the top right of each interface and redesigned to lower the number of visible elements on the screen and reduce visual clutter. The available strategy options are now displayed in a pop-up window when the function is activated. After the window is closed, the selected strategy remains visible in the interface, allowing participants to easily keep track of the currently active strategy. In the opened window, the button of the selected strategy turns green.



[image A]



[image B]

Figure 30: Strategy menu (a) inactive and (b) with the window opened.

Visual hierarchy & elements

The presentation of results on the dashboard was reorganised. A new visual hierarchy was introduced in which helps users to focus on relevant levels of information. The map and results were kept on the left, whilst the analytical and interactive feature were placed on the right of the interface.

Changes were made to the dashboard colours. The number of brightly coloured elements was reduced to prevent distraction. Additionally, neutral tones were used for panels and backgrounds. In result, the displayed results receive the primary focus.

Figures were revised by adding clearer labels. This ensures that visualisations are self-explanatory and reduces the need for clarification during workshops.

Removing redundant buttons

Some previously used option buttons were removed to simplify the interface. The capacity outcomes were permanently implemented in the results overview to avoid confusion. Consequently, the button that was created to hide the capacity results was removed.

Help buttons & tooltips

Additional tool tips were added to explain what is displayed and how calculations in the model are made. This enables quick clarification during the workshops when there is confusion amongst users. After selecting one of the new help buttons, explanation windows will appear and offer textual or visual explanations. This aim is to support intuitive use of the dashboard.

Organising saved portfolio alternatives

The functionality to store the scores of portfolio alternatives data was further developed based on participant feedback. Users expressed the need to compare saved variants to the designed portfolio alternatives. To address this, a feature was implemented to display the saved scores in a separate table next the scores of the portfolio alternative. This table shows the scores of multiple saved variants, allowing direct comparison. This feature is now implemented into the dashboard overview interface to eliminate the navigation step to another interface.

Preference curves remain hidden

It was mentioned by some by participants that they would like to view a specific preference curve during the workshop. However, there is a firm reason to not show it in a dashboard re-design. The facilitator of the workshop should keep the focuses of stakeholders on the portfolio scores. The preferences were already gathered in the interviews.

If there is a struggle to increase the overall portfolio scores, it is up to the facilitator to find and create a new strategy to for the next workshop. Then a change to this curve can be made in between sessions. A handout can be given to the participants to access more detailed information by themselves. However, it would be best not to distract from the workshop activities themselves. The focus during the workshop must be analysing the results to understand the performance of the portfolio. This allows to design and compare portfolio alternatives. When including the preference curves, it would risk drawing away attention away from the main purpose of the workshop.

6.3 Workshop round 2 – Open discussion results

This section presents the results of the second verification round. During this workshop, participants interacted with the first and the second dashboard redesign and were asked to reflect on the design changes and dashboard performance. Similar to the first workshop round, participants took part in an open discussion and filled in a survey after a walkthrough of both dashboards. The open discussions were recorded and transcribed for analysis purposes.

First, a general overview of the feedback is provided, highlighting the main improvements and remaining challenges identified through participants feedback. Second, the feedback is structured according to the six criteria of effective dashboard design. Third, the outcome of the survey is discussed. Finally, the findings are synthesised into lessons for redesigning the PAS dashboard and into broader lessons for effective dashboard design in DSS.

6.3.1 General feedback

Overall, participants gave positive feedback on the design changes in the second redesign. There were some significant changes but mostly the changes were experienced as smaller points of improvement compared to the first redesign. Furthermore, tensions between design criteria were found to appear in the redesign.

A recurring theme during the discussions was the need to maintain a balance between maintaining a usable dashboard overview and the option to discover more information without causing information overload for users. For example, flexibility allowed for screen configurations and additional analysis features but simultaneously increased the amount of displayed information to keep the dashboard usable. This caused a loss of readability and caused it to be no longer be in line with the principle of visual clarity. Therefore, during the review of a dashboard design it should be considered whether design changes result in a decrease in the performance some effectiveness criteria. Then it can be determined whether a potential decrease is worth the trade-off for the implementation of additional design features.

Another balancing need was found for the level of flexibility in interface configurations. Participants appreciated the possibility to perform flexible analysis and switch between views, but also mentioned that too much flexibility may reduce predictability for users. They therefore suggested maintaining a balance between flexible analysis and a fixed, recognisable interface layout to support memorability.

Participants also emphasised that the dashboard should mainly support workshop discussions rather than become the main focus itself. When extensive explanation or interaction is required prior to using the dashboard, attention may shift away from the workshop purpose of collaborative discussion and design of the real estate portfolio to improve the overall preference score. For example, too many visual elements distracted the users.

While the dashboard already presents some effects of portfolio interventions, participants indicated that they would like to see additional analysis options that allow them to explore the criteria scores in more detail. This includes the scores of their own criteria and how these influence the overall scores. Such analysis options could support a deeper understanding of the model outcomes and help participants interpret the implications of different portfolio interventions.

6.3.2 Feedback filtered through design criteria

This is an overview of the feedback from the workshop about the comparison between dashboard redesign 1 and redesign 2. If the feedback is about the original dashboard it is mentioned explicitly. All feedback is split between the by the criteria of effective dashboard design.

1. Usability

The redesign improved the overall layout and supported both learnability and efficiency in performing tasks. Participants emphasized that a dashboard should be immediately usable upon opening, without requiring extensive explanation. The redesigned version achieved higher satisfaction due to a clearer structure and a more intuitive overview, where possible actions were directly visible.

A key improvement was the gradual introduction to functionality. Users could start with a simplified overview and progressively explore more advanced features, which supported ease of use. This approach was preferred in most workshop sessions. Additionally, the ability to save portfolio scores and compare them with other saved configurations was still perceived as highly valuable for decision-making.

For this criterion, the following limitations were identified:

A. First, the increased number of functionalities and interactive elements introduced additional cognitive load. While these features enhanced analytical options, participants noted that they could also make the interface more complex, particularly for first-time users. This could be strengthened by the complexity of the PAS method itself, which already requires considerable cognitive effort to understand. As a result, learnability and memorability could be hindered, especially for users without prior experience.

B. Second, participants highlighted that the dashboard still required substantial explanation during workshops. This reduced the time available for actual analysis and discussion, indicating that the interface is not yet fully self-explanatory. This was explicitly reflected in the discussions, where participants mentioned that explaining the dashboard “takes a lot of time” and reduces the time spent on the actual workshop objectives.

C. Additionally, the presence of large amounts of data within the result interfaces contributed to cognitive overload. Participants indicated that result and analysis components should be more clearly separated and consistently positioned within the interface. A fixed and recognizable layout would support switching between tasks and reduce the effort required to interpret different types of information. Finally, it was suggested that result panels should first remain empty, allowing users to request information when needed. This would support a more task-driven interaction and reduce unnecessary visual load, thereby improving overall usability.

2. Flexibility

The redesigned dashboard introduced a higher degree of flexibility, particularly in the configuration of result, map, and analysis views. In general, participants were able to understand how these flexible elements functioned and appreciated the possibility to customize the interface according to their needs. The ability to show or hide analysis panels directly within the main dashboard overview was perceived as a valuable addition, as it allowed users to access more detailed information without leaving the dashboard overview interface. This helped comparison between portfolio alternatives on their performance.

The main improvement of the redesign was the integration of multiple interfaces into a single one. Participants valued the option to simultaneously display results, the map of locations, and

analyses. This reduced the need to navigate between separate interfaces and helped especially for the comparison of saved portfolio alternatives.

For this criterion, the following limitations were identified:

D. The increased flexibility also introduced usability challenges. The option to reposition panels led to confusion about where interface elements could or should appear. Participants reported because it negatively affected predictability and as a consequence their confidence. This indicates that while flexibility supports knowledge discovery, excessive interface configuration options can reduce clarity and increase cognitive load. This was a recurring theme and participants had a clear preference for a more structured form of flexibility. They wanted that core elements remain fixed while other elements can be adjusted. For example, it was suggested that the map should always be positioned in a consistent location, such as on the left side of the interface, to create a more recognizable configuration.

3. Interactivity

The interactivity of the dashboard enabled users to explore the model outcomes and switch between different views, such as the map with locations, results and analysis. Participants appreciated that the dashboard allowed them to control which information is visible, which supports the exploration of the portfolio characteristics. In particular, the possibility to open and close analysis panels was valued, because it allowed users to gradually show the desired information and limited visual clutter.

The combination of multiple themes within a single interface further supported interactive use. Participants indicated that this helped them to observe the immediate impact of adjustments on the portfolio scores, for example viewing the impact of location interventions on scores. Additionally, visual feedback on selected elements, such as highlighting the selected strategy, helped users to keep overview of their actions.

However, participants also indicated that interactivity should be carefully balanced with visual clarity. Frequent changes in the layout or switching between views could result in a loss of focus during the workshop. While the available interactions provided flexibility, they also increased cognitive load when the interface changed continuously.

For this criterion, the following limitations were identified:

E. Although switching between views adds functionality, participants mentioned that the continuous changes in the dashboard layout reduced visual clarity. This led to a higher cognitive load, because participants would struggle to remember the locations and mechanics of interactive options.

F. Participants mentioned that it was not always clear which elements were interactive or where actions could be performed. Additionally, users did not always recognize whether an interaction would change the data or only display additional information. For example, selecting a strategy or interacting with certain controls was initially perceived as a viewing action rather than a design action that modifies the portfolio. As a result, the distinction between actions that display information (like analysis or results) and actions that change the portfolio was unclear, which could reduce the effectiveness of interactions.

Some suggestions for improvement included adding visual cues, such as colour or layout distinctions, to better indicate interactive functions. Additionally, grouping buttons was suggested to make it more intuitive where actions can be performed.

C. Some participants indicated that it should be possible to change location properties directly from the location table overview, enabling more efficient interaction with the portfolio. Currently, this can only be done through interaction with the map with locations.

4. Knowledge discovery

For the second dashboard redesign, participants experienced a moderate improvement in knowledge discovery compared to the first redesign. The dashboard enabled participants to identify the main differences between portfolio alternatives. Participants indicated that the overall comparison between alternatives was clear, particularly when observing differences in total scores. This supported the evaluation of portfolio interventions at a general level.

However, the identification of more detailed differences between strategies can still be improved. While the dashboard presents outcomes, it could further support underlying relationships within the data. As a result, there is a potential in helping participants understand how results are constructed and how different elements within the model relate to each other.

For this criterion, the following limitations were identified:

G. The dashboard provides limited support in identifying detailed differences between strategies. Participants indicated that could use additional features to analyse how specific criteria, interventions or strategies influence the overall performance.

H. The dashboard currently focuses on presenting results, but provides limited support in interpreting these results. Participants expressed the need for insights that explain why a certain strategy performs better and what adjustments could improve the score. This shows a demand for both explanatory and prescriptive insights. The dashboard does not yet explicitly support the recognition of patterns or relationships within the data. Participants indicated that they would like the dashboard to help identify patterns, show the consequences of their preferences, and clarify the influence of individual criteria.

5. Readability

When participants compared all three dashboards, the original dashboard was generally perceived as the most calm and visually clear. Participants indicated that this version provided a strong overview due to its simplicity and limited number of visual elements. However, this visual clarity came at the cost of decreased functionality, as the original dashboard offered fewer possibilities for analysis and insight.

The second dashboard redesign improved readability in several ways. Participants appreciated the reduction of bright colours, which resulted in a calmer visual appearance. The increased use of neutral backgrounds contributed to a more consistent and less distracting interface. Additionally, the option to show or hide elements was valued, as it allowed users to reduce the number of visible components and focus on specific tasks.

The introduction of a map as a starting point was also positively received. This overview helped users to quickly understand the scope of the portfolio and provided a clear entry point for further analysis.

For this criterion, the following limitations were identified:

I. Despite improvements, participants indicated that the overall visual clutter increased compared to the original dashboard and the first redesign. The larger amount of information and interface elements made it more difficult to maintain a clear overview, which reduced readability.

J. The use of multiple buttons, including several with bright colours, contributed to visual clutter. This made it harder for users to distinguish between different interface elements and increased information overload. The dashboard does not clearly distinguish between buttons that display model outcomes and those that open analysis views. This lack of distinction reduced ease of use and made it more difficult for users to understand the purpose of different elements.

K. The visual hierarchy of the dashboard can be improved. Participants indicated that the most important information is not emphasised more than less relevant elements, making it harder to quickly identify key insights.

6. Transparency in construction

In the second workshop round, participants indicated that the transparency of the model construction had improved compared to earlier versions of the dashboard. The dashboard provided more insight into the outcomes of the model, which helped participants to better understand the results.

However, the extent to which participants understood the underlying model differed between user groups. Participants with prior experience or expertise in the PAS method were generally able to follow the logic of the model more easily. In contrast, participants who were less familiar with the method, particularly students, experienced more difficulty in understanding the underlying calculations and mechanisms.

This difference could be partially attributed to the fact that in the current workshop setup both the theoretical background of PAS and the dashboard interface are presented within a limited time frame. As a result, participants are required to simultaneously understand the method and interact with the model, which may be too much for a single workshop.

For this criterion, the following limitations were identified:

L. The understanding of the model backend was less for participants who not familiar with the PAS method or DSS. Participants indicated that they sometimes forgot how the model functions during the workshop, which affected their interpretation of the results. Participants occasionally misinterpreted the meaning of the scores. For example, some participants confused criteria scores with percentage values.

M. The influence of preference curves and previously defined stakeholder inputs was not always understood. As a result, participants sometimes assumed that the weights between criteria were the main driver of the final scores, rather than understanding the combined effect of preferences, weights and interventions.

N. The relationship between input and output is not sufficiently transparent. Participants indicated that they wanted to understand how specific choices or criteria directly influence the outcome, rather than only observing the final score. Additionally, some participants mentioned that they struggled to identify the effect of their own input on the model output.

The current dashboard could provide more support in explaining the underlying calculations. Participants indicated that they would benefit from additional guidance during the workshop to better understand how the model operates.

6.4 Workshop round 2 – survey results

The survey results from Round 2 are used to determine the relative performance of the dashboard variants. First, the performance per effectiveness criterion is analysed. Second, the combined results across all criteria are used to compare the dashboards overall.

Participants were asked to assign their least preferred dashboard a score of 0 (lowest performing) and their most preferred dashboard a score of 100 (highest performing). They then positioned the remaining variant somewhere between these two extremes. The relative distance between the

three variants indicates the perceived performance differences. A dashboard positioned at 100 is considered the best within that comparison, but the extent to which it outperforms the others depends on how far the other variants are positioned from it.

6.4.1 Performance of effectiveness criteria

The performance of each dashboard can be found in Figure 32. Across most criteria, Redesign 2 is positioned at the right end of the scale (see Figure. This indicates that Redesign 2 is most frequently perceived as the highest performing dashboard. This confirms that the redesign process helped to improve the perceived performance by participants. This suggests that the iterative redesign process contributed positively to the perceived effectiveness of the dashboard.

Especially for usability, knowledge discovery and transparency in design, Redesign 2 is clearly positioned above the other variants. Redesign 2 also performs best for flexibility and interactivity, although the differences are less pronounced for these two criteria. For example, for interactivity Redesign 2 is positioned at 100 and Redesign 1 is the closest with a score of 69,5 relative to the original positioned at 0. This suggests that both redesigns improved interactivity considerably compared to the original, while the difference between Redesign 1 and Redesign 2 is less pronounced. In contrast, for knowledge discovery Redesign 2 is positioned clearly above the original dashboard, but also significantly further from Redesign 1. This indicates that the second redesign introduced a larger perceived improvement compared to the other variants.

One of the most surprising scores can be found for the readability criterion. The results show that the original dashboard still performs best on readability. After the design changes, Redesign 1 is positioned lowest and Redesign 2 close to the existing variant. Redesign 2 did improve the readability compared to Redesign 1, but is still outperformed by the original. This might highlight a trade-off between adding functionality and maintaining visual clarity.

The findings related to usability are unexpected. In the first workshop round, the redesign was generally perceived as an improvement compared to the original dashboard on several points of usability. According to the survey of Round 2, the original dashboard performs better than Redesign 1. However, this is in contrast to the findings from Round 1 because participants mentioned that they experienced an improvement in usability for Redesign 1.

Lastly, the criteria are studied where Redesign 1 and Redesign 2 were considered to be preferred to the existing dashboard. The largest design improvement was by Redesign 1 for flexibility and interactivity shows that, whereas a similar improvement was made through each redesigns for knowledge discovery. Only for transparency in design did Redesign 2 show the largest improvement.

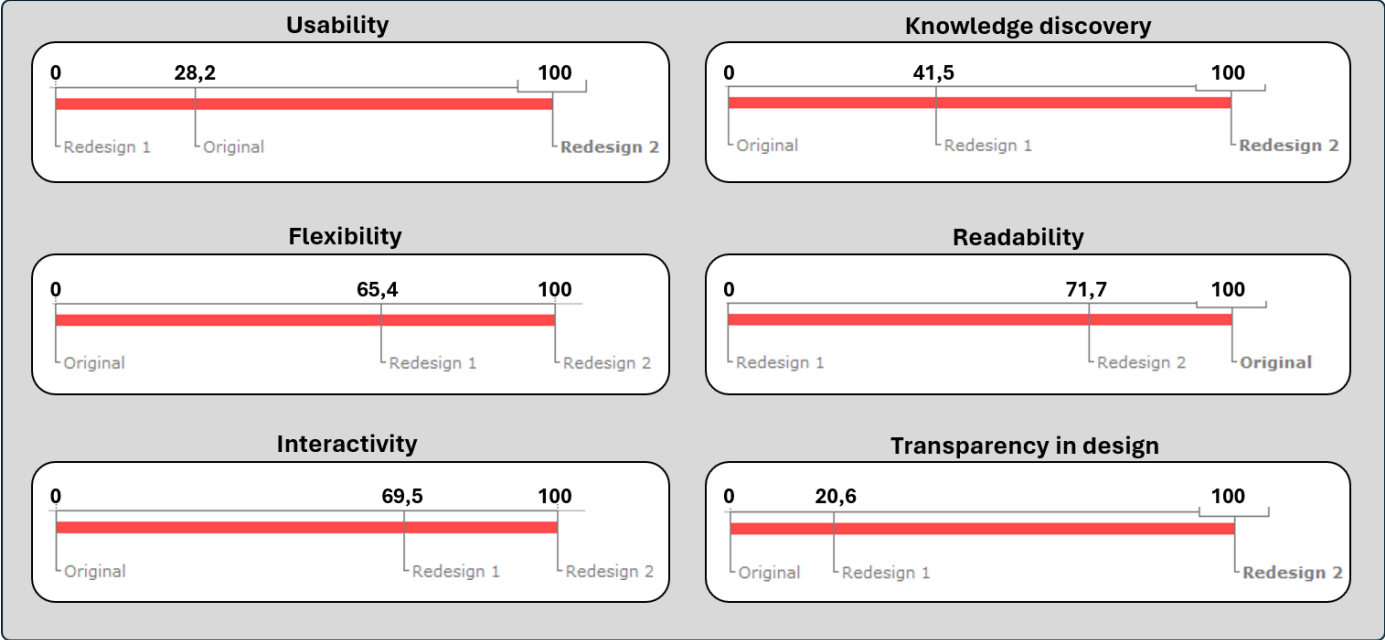


Figure 31: Dashboard preference for each effectiveness criterion.

6.4.2 Overall dashboard preference

To determine the preference between the dashboard variants, the preference scores for all effectiveness criteria were combined into a combined score. For this calculation, all criteria were assigned equal weights. This means that all criteria are considered equally important in the calculation.

The results show that Redesign 2 is preferred overall (see Figure 33). It is positioned significantly higher relative to both the existing dashboard and Redesign 1. Redesign 1 did perform better than the existing dashboard. Therefore, the iterative redesign process seems to have contributed positively to the overall perceived dashboard effectiveness. The distance between the existing dashboard and Redesign 1 is only 15,9, which indicates a smaller improvement compared to redesign 2.

It should be noted that all the calculation assumed all criteria to be equally important. In practice, stakeholders may prioritise certain criteria over others depending on the dashboard’s purpose or the context of use. When different weights were applied, the overall ranking could change.

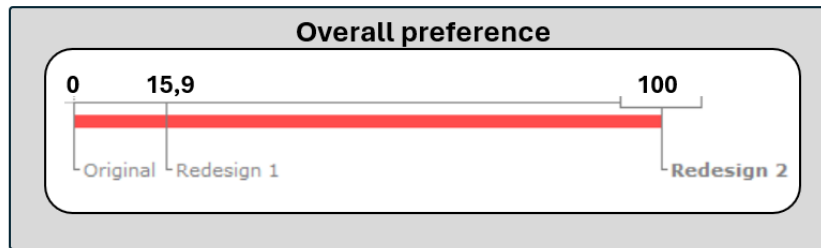


Figure 32: Overall dashboard preference.

6.5 Lessons for redesigning the dashboard (RQ4)

In line with the structure of the report, this section further elaborates on the fourth research question:

RQ4 – What are users’ perceptions during the verification of the redesigned PAS dashboard in relation to the effectiveness criteria?

Based on workshop round 2, several additional lessons can be drawn for further redesign of the PAS dashboard. An important outcome of workshop round 2 is that users were generally able to use the dashboard proficiently. Participants understood how to navigate between views and appreciated the possibility to customise the interface. In particular, the combination of adjustable views and drill-down functionality was valued positively. This allowed users to access more detailed information about criteria, scores and weights when needed.

Balance between functionality and cognitive load

Although redesign 2 was generally received positively, it became clear that adding functionality does not automatically result in a better user experience. Participants appreciated the extended analysis options and the possibility to customise views. However, the additional layers of data and interactive elements increased the cognitive load by adding visual clutter. It should be considered that although the added analytical features provided insight into criteria performance and intervention effects, these benefits should be balanced with their impact on usability.

The dashboard now contains multiple layers of information, which makes it more detailed, but also more complex. Especially for first-time users, the combination of understanding the PAS method and interacting with the dashboard within a limited timeframe was a demanding task. The takeaway is that additional features must always be weighed against their impact on visual clarity and learnability.

Predictable flexibility

Participants appreciated the possibility to show and hide analysis panels and to customise the interface. At the same time, too much flexibility led to a high cognitive load and confusion. When panels could change position or scale freely, users experienced confusion. It was mentioned that flexibility up to a specified level is preferred, with core dashboard elements in fixed positions and predictable placement of appearing panels.

The lesson is that flexibility should be structured. Core elements, such as the map and main result sections, should have fixed positions. Secondary elements can be adjustable, but only within a certain limit. This ensures predictability and preserves user confidence. Participants explicitly gave the feedback that unlimited customisation options were not desired by them, in fear of excessive cognitive load.

Clear separation between results and analysis

Participants indicated that the distinction between results and analysis was not always clear. When buttons and panels were visually similar, it became unclear whether users were viewing results or interactive data. This reflects earlier findings that a clearer distinction between results and analysis sections improves understanding and supports more effective use of the dashboard. The dashboard should therefore include a clear visual and structural distinction between result views and analysis tools. This can be achieved through colour differentiation, labelling and fixed spatial positioning

Supporting novice users

A significant difference was observed between expert participants and students. The experts were more familiar with decision-support systems and tolerated greater complexity of the model. Students struggled more with understanding the backend logic and the influence of preference curves.

The lesson is that it is very difficult to design interfaces which optimally serve all user of varying backgrounds and varying speed of comprehension. Consequently, it is likely that some users will struggle to understand it. This emphasizes the need for helping features to support users. In workshop settings, the dashboard must support understanding without requiring extensive prior knowledge. The initial briefing prior to the actual workshop played an important role in explaining the model contents to participants. This shows that the introduction and explanation of the dashboard plays an important role in effective usage.

Dashboard as tool, not the main focus

Participants repeatedly mentioned that the dashboard should support discussion, not become the main topic of discussion itself. The reasoning is that when too much time was required to explain the interface, there will be less time remaining for analysing portfolio alternatives. The redesign should therefore aim to minimise the amount of required explanations. The dashboard interaction must be intuitive to allow the workshop to focus on content rather than interface mechanics.

Knowledge discovery beyond scores

Participants expressed a need to better understand how scores are constructed and influenced. They were interested in overall preference scores, but also in patterns, the influence of individual criteria, and possible strategies to improve performance. Some participants struggled to understand how overall preference scores were constructed and how their input influenced the results. This supports the use of PAS functions not only as a design-support tool, rather than a tool for viewing score outcomes. The dashboard should therefore make relationships between criteria, themes and outcomes more visible, without causing an excessive cognitive load from the main overview. Participants also indicated that they wanted better support in recognising patterns, understanding the influence of each criterium on overall preference scores and gaining insight on the consequences of their adjustments.

Survey results

Through a survey in the second phase of dashboard verification, participants were asked to rate the performance of the existing dashboard, redesign 1 and redesign 2 relative to each other for each of the identified effectiveness criteria. When combining the scores across all effectiveness criteria, redesign 1 performed in between the original dashboard and redesign 2, while redesign 2 demonstrated a more significant improvement compared to the others.

Redesign 2 was preferred in most criteria and analytical support.

However, the original dashboard received the highest score on readability, with redesign 2 scoring closely behind. This suggests that although redesign 2 improved structure and analytical

possibilities, the more simple and compact layout of the original dashboard was still more appreciated by the participants.

Overall reflection on dashboard effectiveness

Overall, the dashboard verification through the two workshop rounds shows improvement on most effectiveness criteria, especially on usability during workshops through the added analysis support. Meanwhile, it became clear that there are differences between user groups and that there are continued challenges in understanding score calculations. Furthermore, it is confirmed that dashboard effectiveness is influenced not only by dashboard design but also by the user background, familiarity with PAS and the facilitation of the workshop.

6.6 Lessons for dashboard design (RQ5)

In addition to project-specific insights, workshop round 2 provides broader lessons for dashboard design in decision-support contexts.

More functionality does not equal better usability

The results confirm that increasing functionality can improve analytical options, but that it can simultaneously reduce usability and clarity. Dashboard design should therefore focus on a balance between them. Each added feature must be evaluated not only on its usefulness, but also on its potential negative impact on the cognitive load.

Structured flexibility improves usability

Users prefer predictability in the dashboard interface configuration, rather than having limitless customisation. The results show that they prefer stable spatial structures in the interface configurations. A dashboard should therefore offer controlled flexibility, where core elements remain fixed and secondary elements are adaptable within clear boundaries.

User background influences dashboard perception

Differences in experiences between experts and novice users show that dashboard complexity is perceived differently depending on prior knowledge and personal backgrounds. Decision-support dashboards should either define a clear target user group or include support mechanisms to support users, such as tooltips or layered information tools.

Transparency requires alignment with workshop context

Participants in a short workshop setting struggled to fully grasp model logic. Transparency is therefore not only a matter of interface design, but also of context and facilitation. Dashboards used in workshops should communicate logic clearly, but a clear explanation process is still required.

User instructions improve perceived transparency of dashboard construction

Participants indicated that several complex aspects of the dashboard became clearer after the initial briefing. This suggests that transparency in construction is not only determined by the interface itself, but also by how the underlying logic is explained. When users receive a clear introduction to the model, including how scores are calculated and how preferences influence scores, they gain more trust in the model outcomes.

Decision-support dashboards must facilitate group discussions

In group settings, a decision making dashboard should function as a tool to support discussion

between its users. However, when participants need to spend time understanding what is visible on the interface and how specific features work, their attention and time shifts away from collaborating. Additionally, this is strengthened by frequently changing interfaces configurations and options, which results in the focus moving from the content to understanding the mechanics.

Knowledge discovery through model explanations and insights

Users expect dashboards to do more than display the criteria scores of the portfolio. They want explanations about the scores and improved guidance on what can be improved. This again highlights the importance of the dashboard to gain insights besides monitoring performance.

7. Discussion

This chapter is focused on bringing the points that were already discussed in previous chapter. First, an interpretation of the results will be done to improve the original design of the dashboard. Then, the results of the workshop (feedback) of the students and experts were compared with the goal to understand the differences in their feedback. This was important as it helped to better understand and analyse the workshop results. Then the contradictions between the survey results and open discussed are discussed with the goal to try to understand and explain the reasons behind this contradiction which could help in redesigning of the dashboard.

7.1 Interpreting the redesign results

Improvements compared to the original dashboard

The redesign process for the PAS dashboard resulted in clear improvements compared to the original version. These improvements were mostly related to the changed structure and added analytical features.

First, the revised layout and configuration options significantly improved readability and usability. In the original dashboard, information was available but not always hierarchically organised, making it difficult for users to quickly identify the most relevant model outcomes. The redesign introduced new hierarchy of information and separation of information themes.

Second, the redesign strengthened the analytical capabilities of the dashboard. Features such as drill-down functionality, extended analysis interfaces, and storage of scores from alternative scenarios enabled users to explore portfolio performance in more detail.

Participants were enabled to study underlying criteria, compare interventions, and examine differences between alternatives. This aligns with the need of participants to review alternative results, but also to understand why a portfolio performed in a certain way. The new analytical views made relationships between criteria, themes, and interventions more visible. This improved the perceived knowledge discovery.

The dashboard improvements helped to address the research problem identified in the introduction. Previously, users experienced difficulties in understanding the model back end and with trusting the model outcomes. The redesigns reduced these challenges and support the use of PAS for CRE alignment.

Overall, Redesign 1 and Redesign 2 were widely seen as improvements over the original dashboard. However, when additional were added features in 2 it caused tensions between analytical power and dashboard readability. Therefore, added functionality should be balanced with the simplicity principle to prevent a decrease of readability. Participants mentioned that the complexity of additional features should not distract from the dashboard purpose to present portfolio performance.

Differences between experts and students

A clear distinction emerged between expert participants and students. Experts were more familiar with design and decision-making systems, which led them to tolerate and even expect a higher level of dashboard complexity. They were better able to grasp the backend logic and the influence of preference curves.

Students struggled to understanding the mechanics of the model and the calculations behind the scores. Even though there was an introduction to the dashboard and its use was guided

throughout the workshop, they often experienced a high cognitive load. The short workshop duration intensified this effect. This difference suggests that dashboard effectiveness is partly dependent on user background and prior knowledge.

In result, the transparency in construction was perceived differently. For some participants, the model backend became clearer during the workshops. For others, especially students, transparency remained limited. This shows that transparency is not only a property of the interface, but is also influenced by user expertise and background.

Contradictions between workshop survey results and open discussions

In the first round, Redesign 1 was viewed as an improvement on most effectiveness criteria. However, in the second round the preference survey results did not fully align with these findings. Redesign 2 performed was an improvement for most criteria, despite being described as complex and less suited for students. However, the usability score of Redesign 1 in the second survey appeared lower than both the original dashboard and Redesign 2. This is surprising, as qualitative findings from Round 1 clearly presented the usability of Redesign 1 as improved compared to the existing dashboard.

A possible explanation for this discrepancy is the different focus of the second workshop round. In Round 2, the discussion primarily centred on the design changes between Redesign 1 and Redesign 2 and there was less focus on the original dashboard. During the survey of Round 2 participants had to compare all three versions, which could have highlighted the most recognisable characteristics features and shifted attention towards specific strengths and weaknesses of each version. Participants may have perceived the simplicity of the original as more usable in contrast to the added functionality of Redesign 1, even if Redesign 1 had previously been evaluated as an improvement in Round 1.

Keeping the focus on discussion of outcomes not the tool itself

When using dashboard design principles to design a dashboard, it is important to prevent information overload by not structuring the information in a structured manner.

The PAS dashboard is used in facilitated workshops and not by individual users. It functions as a shared interface that supports collective decision-making in a structured alignment process.

Participants emphasised that the dashboard should support discussion on portfolio outcomes rather than being main topic of discussion itself. When excessive time was required to explain dashboard features, attention shifted away from analysing portfolio alternatives.

The points below help keeping the focus on the content instead of the tool. The points are based on the analysis of the workshops. According to the users, several features supported decision-making in all three dashboards; the features include:

- real-time updates of recalculated results.
- storage options for alternative scores.
- the possibility to compare portfolio alternatives.
- drill-down options to analyse the performance of criteria and strategies.

Additionally, the workshops revealed that not all PAS dashboard features are equally relevant for stakeholder discussions. Preference curves, for example, are crucial during model construction but are not shown to the users by the facilitator. When such technical information is displayed during evaluation workshops, it risks drawing attention away from the discussion on portfolio performance.

Overall, dashboard design does not only result in a visual outcome but shapes how information is interpreted and discussed in the decision-making environment. This relates back to the

effectiveness criteria of knowledge discovery and transparency in construction (Chapter 3), which are important to help users interpret outcomes in the dashboard and understand the calculation of scores. This results in improved understanding portfolio performance and supports decision-making for CRE alignment.

7.2 Transferability of dashboard design principles to DSS

The application of established dashboard design principles to the PAS dashboard demonstrates that many principles are transferable to a decision-support system context. However, their successful implementation is also dependent on contextual considerations. While design principles provide general guidance for dashboard development, they do not prescribe concrete design solutions. In the redesign process, the selection of specific design features were therefore essential to translate principles into interface changes. What remains underdeveloped in the literature is the process of selecting appropriate design features that match the dashboard's purpose and user needs. Suitable features may even differ between workshop sessions, depending on the workshop focus and participant background.

The findings also reveal clear limitations. The implementation of additional design features did not automatically improve overall dashboard effectiveness. For example, there were several situations where readability decreased after functionality was added. This can be explained by the relationship of simplicity and cognitive fit: every added feature potentially increases cognitive load. The next sections will discuss each design principle separately.

The principle of **single screen view** was applied in the second round of redesign after users initially mentioned the cognitive load of switching between overview and analysis screens. Changes were appreciated by participants. However, once results and analysis were combined, users also indicated that simplicity and visual clarity decreased since too many elements were visible simultaneously. This indicates a tension between the principles of simplicity and single screen view. In the PAS dashboard, a single-screen design conflicts with the analysis options to support decision-making. Portfolio analysis and design might be too complex to display all relevant on a single screen. A revised interpretation of this principle could therefore be: apply a single-screen view only when it does not decrease simplicity and cognitive fit.

The principle of **simplicity** proved highly transferable. Workshop participants often mentioned a preference for simplified interfaces with fewer visual distractions. This results in a trade-off between simplicity and analytical capability necessary for decision-making. Therefore, simplicity needs to be balanced with dashboard functionality.

Layering of information was done by adding drill-down functionality and gradual disclosure of more detailed information. This was appreciated by participants in combination with the option to limit the amount of information on screen. However, layering functionality only reduces cognitive load when the information structure is clearly organised and not too many different levels are not displayed simultaneously.

The principle of **visual clarity** aligns with the findings that users required a clearer distinction between results and analysis sections. By applying separations, hierarchy and consistent grouping of this data, users were more easily able to get an overview of portfolio outcomes.

Applying **cognitive fit** proved more challenging. There was a clear difference between expert and student participants. Experts tolerated and expected more complexity, while students struggled with understanding both the PAS logic and the interface within limited workshop time. Therefore, cognitive fit depends not only on interface design, but also on explanation before dashboard use, guidance by the workshop facilitator and user background. This is currently not emphasized in the formulation of the design principle.

Finally, **tailoring capabilities** were appreciated only when structured. Participants valued view configurations and drill-down features but did not want unlimited customization. Predictability in layout, where information panels appear fixed positions, was considered important for usability. Since the dashboard was used in group settings, individual personalization options were less relevant. Participants preferred limits to customization to prevent distraction and maintain focus on results and collaborative discussions.

The data analysis of the open discussions revealed a high degree of interconnectedness between the effectiveness criteria and the applied design principles. Changes in the dashboard design frequently affected effectiveness of multiple criteria simultaneously and influenced the appreciation of design features. As a result, the successful application of an isolated design principles to optimise a single effectiveness criterion seems unlikely. The implementation of one principle may strengthen or weaken another. Dashboard design for a DSS must therefore not be approached as a series of separate optimisations. Instead, it requires an integrate design process in which the interdependencies between design criteria and design principles are considered. Therefore, the table in section 3.1.6 should be reconsidered, as the relationships between design principles and design features are more dynamic than previously presented.

7.3 Theoretical contribution

This research contributes to the existing body of knowledge by linking dashboard design principles to a preference-based decision-support system in a Corporate Real Estate Management (CREM) context. It was identified in the introduction that dashboard design principles have been widely discussed in literature, but their application to decision-support systems for strategic real estate alignment, such as the PAS dashboard, remained underexplored. This study addresses this gap by empirically testing the principles within the PAS environment.

First, the findings show that dashboard effectiveness for a DSS cannot be viewed as the sum of individual design principles. Instead, the interactions between the principles need to be carefully balanced to gain dashboard effectiveness. This consists of analytical depth versus cognitive clarity, flexibility versus predictability, and transparency versus information overload.

The redesign rounds showed that increasing functionality did not always improve decision support to users. In the redesign process, added features reduced readability and increased cognitive load. Dashboard design should refrain from maximising isolated principles and instead account for interdependencies between principles and effects on the overall dashboard effectiveness.

Second, this research refines the concept of transparency in construction principle. The workshops revealed that transparency was not achieved by exposing more technical details or calculation explanations within the interface. Instead, it seemed more effective to add a structured layout, visual hierarchy, and proper introduction of the PAS method. This resulted in improved user trust and understanding of the model backend. This suggests that transparency in

DSS contexts is not solely an interface characteristic, but also dependent on explanation and facilitation.

Third, the study highlights that dashboard design in facilitated group-based decision processes differs from dashboards designed for individual monitoring or business intelligence use. In the PAS workshops, the dashboard functioned as a shared interface to support collaborative portfolio analysis. When interface mechanics required excessive attention, the decision-making process was disrupted. This indicates that dashboard theory should more explicitly account for collaborative and workshop-based applications, particularly environments characterized by multiple stakeholders with different backgrounds. Taken together, this research demonstrates that the relevance of dashboard design principles in DSS environments.

7.4 Practical implications

The findings of this research provide practical implications for the further development and implementation of the PAS dashboard in CRE alignment processes. First, dashboard design should balance functional features and readability. The redesign process showed that additional features such as extra analysis interfaces, saving scores and comparison tools increased analytical depth, but simultaneously risked reducing readability and increasing cognitive load. In workshop setting excessive visual and functional complexity distracts from the primary goal of collaboratively designing and analysing portfolio alternatives. Future dashboard iterations should therefore consider whether added features impact negatively visual clarity and usability.

Second, flexibility in the dashboard interface should be limited to a certain level. Participants appreciated the possibility to adjust views and use drill-down features, but did not want too many configuration options. Specifically, they demanded predictability in layout and fixed positioning of core elements for information panels, such as the portfolio map and key results. This ensures that the cognitive load remains a manageable level.

7.5 Limitations

This research aimed to identify dashboard design principles and evaluate them by redesigning a PAS dashboard. Although the research helped to deliver several insights into dashboards design within the DSS context, several limitations need to be acknowledged.

Workshop rounds and participants

The dashboard redesign process consisted of a limited number of workshops rounds with a relatively small group of participants. Several interesting qualitative and quantitative insights were found, but a larger sample size would have enabled more well-supported conclusion.

Specifically, a higher number of participants could have provided more diverse feedback on the redesign from a broader backgrounds.

The research completed two iterations of redesign but an additional iteration would have strengthened the validation of the applied design principles. The second round of workshops was mainly focussed on the implementation of functional features. As a result, some improvements of visual elements were not tested to a similar extend. A third iteration would have allowed for the refinement and further implementation of visual features.

The composition of the participant group may also have influenced the findings. Some participants were already familiar with the PAS approach, whilst most students had not previously worked with PAS. This difference could have affected the interpretation of the dashboard

redesigns and assessment. In addition, the study could benefit from including more stakeholders who are active in CREM within their own organisations. Participants who are actual decision-makers might perceive dashboards differently depending on their roles.

Dashboard context

The PAS approach contains several structured steps, which includes the development of a that includes a dashboard to support stakeholder workshops. The dashboard in this research was designed for one of the real estate portfolios of the Nationale Politie. In result, the redesigns were evaluated in the context of a large public organisation.

This context may limit the generalisability of the findings. Public portfolios have other characteristics compared to, for example, corporate or commercial portfolios. As a result, other portfolios may have different dashboard needs. The application of dashboard principles in other contexts may result in different design choices and implementations. Further research is recommended to examine the application of dashboard principles on other portfolio types.

Research implementation

The scope of this research are the dashboard design principles and their application to DSS context of PAS. However, there are other organisational factors that influence a successful implementation of DSS in organisations that fall outside the scope of this research. The adoption and effective use of the PAS model and its dashboard may be influenced by elements such as organizational culture, strategic behaviour and trust in decision-making processes. These factors can affect both the acceptance of the models and the outcomes shown in the dashboard.

Measurement of effectiveness

The effectiveness of the redesigned dashboard was assessed through user perceptions, based on the effectiveness criteria found in the literature review. Whilst these criteria are suited to evaluate the support that dashboards provide for decision-making, they do not measure the effect of the redesign on decision quality. The outcomes of the decisions would reveal how the portfolio would perform or align to organisational demand.

7.6 Recommendations

One direction for future research could be to measure the decision quality as a result of a dashboard design. In the current study the dashboard effectiveness was mostly assessed through user perceptions. However, it remains unclear whether the redesigned dashboard actually results in improved decision outcomes.

Future research could compare different dashboard designs by having participant groups interact with different dashboard versions. The resulting portfolio alternatives could then be evaluated based on other criteria, such as the overall preference score within PAS or the consistency of decision outcomes.

The dashboards of this study were developed in Excel and each redesign iteration required manual adjustments by the researcher. Although this offered transparency in the design changes, it was time-consuming and has limited scalability. Future research could focus on software automations that could design dashboards through an adjustable set of design parameters. This would simplify the design process to entering the data of a portfolio in a file and generating a dashboard design specific to a portfolio composition. Additionally, software could offer flexibility by offering a selection menu with dashboard features, for example, the available analysis options or visualisation types.

Another software opportunity lies in the use of AI-supported programming for dashboard generation. Future research could explore how artificial intelligence may support both the analysis and automated generation of dashboard designs. There is the potential to generate multiple dashboard configurations for the workshop from which the workshop facilitator can repeatedly select the most suitable option. AI generation could in theory remove the need for manual design efforts. When fully functional, it would only require the input of a detailed portfolio data overview to have AI generate several dashboard designs.

8. Conclusion

The main research question of this thesis is:

How can a redesigned PAS dashboard be developed and evaluated based on the identified design principles of effective dashboards?

This question will be answered in the following two sections.

8.1 The redesign of the PAS dashboard

The redesign of the PAS dashboard was guided by a design derived from the identified design principles and criteria of effectiveness. This framework combined both the analysis of the original dashboard and the subsequent iterative redesign phases. Based on the iterative workshops and evaluation rounds, it can be concluded that the redesign process led to a clear improvement in perceived dashboard effectiveness.

In workshop round 1, participants indicated that the new structure provided more clarity and better supported collaboration during the PAS session. The visual hierarchy and grouping of information improved the usability of the dashboard within the workshop setting.

In workshop round 2, the second redesign was evaluated as the best performing dashboard version on most effectiveness criteria. The combined preference score showed that the second redesign received the highest overall preference from participants. This indicates that the iterative redesign refinement based on user feedback positively influenced the perceived effectiveness of the dashboard.

The improvements were particularly visible in three of the six design criteria:

- **Usability during workshops:** Participants reported that the redesigned versions better supported structured information presentation and comparison of alternatives.
- **Knowledge discovery:** The introduction of layered information and drill-down functionality improved insight into underlying indicators and trade-offs.
- **Transparency of design and construction:** Participants experienced a clearer understanding of how overall scores were built up from underlying criteria.

At the same time, the redesign process revealed important tensions. The original dashboard scored highest on readability. The addition of functionality, indicators and drill-down options increased analytical depth, but also increased perceived cognitive load. This complexity was experienced more strongly by students than by expert users. Improvements in analytical support therefore sometimes came at the expense of simplicity and thus readability.

Furthermore, the perceived improvement proved to be context-dependent. Transparency was interpreted differently depending on participants' background and level of expertise. The participants themselves demanded that the dashboard should not function only as analytical tool, but primarily as a shared discussion instrument within a facilitated PAS workshop.

Overall, it can be concluded that the iterative redesign process positively influenced the perceived effectiveness of the PAS dashboard. The redesigned versions improved analytical support, transparency and workshop usability. However, the process also shows the presence of trade-offs between functionality and simplicity.

8.2 What lessons can be drawn for dashboard design in general?

The redesign and evaluation of the PAS dashboard provided insights that extend beyond the existing PAS dashboard and offer broader lessons for dashboard design in DSS contexts. The process demonstrated that dashboard effectiveness is not solely determined by the application of separate design principles, but by how these principles interact with each other and the implementation of design features. Several general lessons can be drawn from the redesign and evaluation process.

Balancing functionality and cognitive load

A first important lesson concerns the relationship between functionality and cognitive load. The redesign introduced additional indicators, interactive elements and drill-down possibilities in order to enhance analytical depth and support decision-making. Although these features increased the analytical potential of the dashboard, they also increased its complexity.

The evaluation showed that adding functionality does not automatically improve effectiveness. An increased number of indicators and interactive elements can make the dashboard more complex to use and may require additional cognitive effort from users. In some cases, participants experienced difficulties in navigating through layers of information or interpreting multiple data elements simultaneously.

This indicates that dashboard design requires conscious trade-offs. More information and more interactivity do not necessarily lead to better decision support. Functionality should therefore be added selectively with the consideration of the users' cognitive capacity and the intended use of the dashboard.

The role of visual hierarchy and structure

A second lesson relates to the importance of visual hierarchy and a clear dashboard structure. The evaluation of the original PAS dashboard revealed that limited visual hierarchy reduced intuitive understanding of performance information. Relationships between input, calculation and output were not always immediately clear, which hindered interpretation.

In the redesigned version, information was grouped more explicitly, structured according to stakeholder perspectives and supported by clearer visual differentiation. These adjustments positively influenced usability, understandability and the interpretation of overall preference scores. Participants were better able to identify relationships between indicators and to understand how different components contributed to the overall outcome.

This demonstrates that clear visual hierarchy is essential for effective dashboard design. Grouping related information, structuring content logically and making relationships visually explicit supports interpretation and reduces cognitive effort. Effective dashboards should enable users to gain insight "at a glance," while still providing access to more detailed information when required.

Conceptual transparency over full technical transparency

A third lesson concerns transparency. The evaluation indicated that users need to understand how the overall preference score is constructed, but not necessarily at the level of full mathematical detail. Conceptual transparency proved more important than full technical transparency.

When users were able to grasp the conceptual logic behind the calculation of the overall preference score, their trust in the model outcomes increased. Improvements in conceptual transparency positively affected perceptions of reliability and legitimacy of the results. However, presenting full technical formulas or extensive mathematical details was not required for all users and could potentially increase cognitive load.

This suggests that dashboards in DSS contexts should make the logic of the model understandable at a conceptual level. Technical details may be made accessible for expert users,

but they should not dominate the interface. Transparency should therefore be tailored to the needs and expertise of different user groups.

Supporting both overview and deep analysis

A fourth lesson concerns the importance of combining overview and detailed analysis. The redesigned dashboard introduced structured drill-down possibilities that enabled users to move from overall performance indicators to underlying criteria and variables. This gradual approach supported knowledge discovery and facilitated deeper understanding of the model.

At the same time, the evaluation showed that navigation between input, calculation and output environments needs to be structured and intuitive. Without clear navigation, drill-down structures can increase complexity rather than enhance insight.

The lesson is that dashboards should support layered information structures: an initial overview that provides immediate insight, combined with detail-on-demand for deeper analysis. The navigation structure is an integral part of dashboard design and should explicitly support switching between different levels of abstraction.

Interconnectedness of design principles and effectiveness criteria

The redesign process also demonstrated that design principles and effectiveness criteria are interconnected. Changes in visual hierarchy influenced usability, understandability and interpretation simultaneously. Improvements in conceptual transparency affected trust in model outcomes and perceptions of reliability. Functional features such as drill-down options influenced both decision support capability and cognitive load. Structural integration of information affected clarity, flow and overall user perception.

This indicates that dashboard design should be approached holistically. Design principles do not operate in isolation. Adjusting one element often has consequences for multiple effectiveness criteria. Evaluation should therefore not focus on individual design aspects separately, but on their combined effect on user experience and decision-making processes.

Concluding reflection

In conclusion, the redesign and evaluation of the PAS dashboard demonstrate that effective dashboard design is not simply focussing on aesthetics or technical functionality. It involves enabling interpretation, reducing cognitive load and strengthening trust in model outcomes.

The lessons from this process emphasize the importance of balancing functionality and cognitive load, establishing a clear visual hierarchy, prioritizing conceptual transparency, supporting layered analysis options and approaching dashboard design holistically. These insights contribute to broader knowledge on dashboard design for DSS.

9. Reflection

My graduation process began with selecting the field on which I wanted to focus my research on. At that time, I had a strong interest in Real Estate Management and wanted to find a related topic I could contribute to. I was particularly eager to learn more about the decision-making processes in this field and how real estate portfolios are shaped. I discovered that these processes were complex and that Decision Support Systems appear to offer guidance.

One such method, the Preference-Based Accommodation Strategy (PAS), supports organisations to optimise their real estate portfolio uses quantified criteria and stakeholder preferences in a collaborative process. Performance scores increase transparency and allow for a fair comparison between designed alternatives. PAS has been used in real-life context several times, however, the implementation of PAS faces challenges in the usage of the dashboard which is partially due to its dashboard. This sparked my interest to study dashboard design process.

I wanted to better understand how effective dashboard design can support decision-making. This aligned with my preference to work on a concrete product. My goal was to widen the knowledge on dashboard design to improve DSS organisations design and compare their real estate portfolios.

Method

My research is structured according to the Research through Design (RtD) approach as described by Van Stijn(2023), which applies an iterative design process for designing and researching simultaneously. Throughout the process, lessons were learned from each iteration. These lessons contributed to the improvement of the PAS dashboard and to broaden the knowledge on dashboard design for DSS. RtD provided an appropriate structure to both develop and verify a redesigned PAS dashboard and to generate academic insights on dashboard design. This helped to answer the main research question.

To analyse dashboard effectiveness, multiple methods were applied. This provided multiple perspectives on effective dashboard design. Both quantitative and qualitative data were gathered through document analysis, researcher review of the existing dashboard, surveys and open discussions.

Process and planning

Looking back on my graduation process, I recognise that I have experienced several challenges. The diversity of activities required me to have to rapidly learn new skills. During the redesign process I was responsible for formulating and implementing design choices, organising and facilitating workshops to verify the design changes and engaging in open discussions with participants to gather their feedback.

The most significant challenge was keep an overview of tasks and setting priorities in the redesign process. This process proved more difficult than expected and completing the first dashboard redesign took longer than planned. Especially, understanding how the existing model functioned, how features in Excel function and how to implement new features.

In this stage, my supervisors gave the valuable feedback to focus on the testing of the design changes rather than perfecting them or making the dashboard fully functional. I realised that I had

been too focused on changing too many elements at once and creating a fully functional dashboard. Due to the extra time the first redesign took, the P4 had to be scheduled to a later date. Additionally, academic writing remained an ongoing learning process throughout the graduation process. Creating a clear outline and clearly describing the redesign process and results required me to scrutinise my own work.

Outcome

The thesis resulted in valuable design lessons for effective dashboard design and an improved PAS dashboard prototype. Furthermore, the findings contribute to the knowledge on the practical concrete application of design principles to DSS. and design principles to the PAS dashboard adds knowledge to the relationship between dashboard design and DSS.

References

- Almasi, S., Bahaadinbeigy, K., Ahmadi, H., Sohrabei, S., & Rabiei, R. (2023). Usability evaluation of dashboards: A systematic literature review of tools. *BioMed Research International*, 2023(1), 9990933.
- Arkesteijn, M. (2019). Corporate Real Estate alignment: a preference-based design and decision approach. *A+ BE| Architecture and the Built Environment*(12), 1-414.
- Arkesteijn, M., Binnekamp, R., & De Jonge, H. (2017). Improving decision making in CRE alignment, by using a preference-based accommodation strategy design approach. *Journal of Corporate Real Estate*, 19(4), 239-264.
- Bach, B., Freeman, E., Abdul-Rahman, A., Turkay, C., Khan, S., Fan, Y., & Chen, M. (2022). Dashboard design patterns. *IEEE Transactions on Visualization and Computer Graphics*, 29(1), 342-352.
- Barzilai, J. (2010). Preference function modelling: the mathematical foundations of decision theory. *Trends in multiple criteria decision analysis*, 57-86.
- Bryman, A. (2016). *Social research methods*. Oxford university press.
- Cambridge Dictionary. (n.d.-a). *Criterion*. Cambridge University Press.
- Cambridge Dictionary. (n.d.-b). *Principle*. Cambridge University Press.
- Cleveland, W. S., & McGill, R. (1984). Graphical perception: Theory, experimentation, and application to the development of graphical methods. *Journal of the American statistical association*, 79(387), 531-554.
- De Jonge, H., Arkesteijn, M., Den Heijer, A., Vande Putte, H., De Vries, J. d., & Van der Zwart, J. (2009). Designing an accommodation strategy (DAS frame). *Delft University of Technology, Delft*.
- Den Heijer, A. (2021). Campus of the future: Managing a matter of solid, liquid and gas.
- Den Heijer, A. C. (2011). *Managing the university campus: Information to support real estate decisions*. Eburon Uitgeverij BV.
- Few, S. (2006). *Information dashboard design: The effective visual communication of data*. O'Reilly Media, Inc.
- Ghazisaeidi, M., Safdari, R., Torabi, M., Mirzaee, M., Farzi, J., & Goodini, A. (2015). Development of performance dashboards in healthcare sector: key practical issues. *Acta Informatica Medica*, 23(5), 317.

- Heywood, C., & Arkesteijn, M. (2017). Alignment and theory in Corporate Real Estate alignment models. *International Journal of Strategic Property Management*.
<https://doi.org/10.3846/1648715x.2016.1255274>
- Heywood, C., & Arkesteijn, M. (2018). Analysing fourteen graphical representations of corporate real estate alignment models. *Journal of Corporate Real Estate*.
<https://doi.org/10.1108/jcre-02-2017-0005>
- Jongkind, A. (2025). *Strategic behavior in Decision-Making Environments Supported by Decision Support Systems* [Delft University of Technology]. Delft.
- Joroff, M. L., Lambert, S., & Louargand, M. (1993). *Strategic management of the fifth resource: corporate real estate*. International Development Research Council.
- Karami, M., Langarizadeh, M., & Fatehi, M. (2017). Evaluation of Effective Dashboards: Key Concepts and Criteria. *The Open Medical Informatics Journal*, 11, 52-57.
<https://doi.org/10.2174/1874431101711010052>
- Lea, B.-R., & Nah, F. F.-H. (2013). Usability of performance dashboards, usefulness of operational and tactical support, and quality of strategic support: A research framework. *Human Interface and the Management of Information. Information and Interaction for Health, Safety, Mobility and Complex Environments: 15th International Conference, HCI International 2013, Las Vegas, NV, USA, July 21-26, 2013, Proceedings, Part II 15*,
- Lin, C.-Y., Liang, F.-W., Li, S.-T., & Lu, T.-H. (2018). 5S dashboard design principles for self-service business intelligence tool users. *Journal of Big Data Research*, 1(1), 5-19.
- McCoy, C., & Rosenbaum, H. (2019). Uncovering unintended and shadow practices of users of decision support system dashboards in higher education institutions. *Journal of the Association for Information Science and Technology*, 70(4), 370-384.
- Naderifar, M., Goli, H., & Ghaljaie, F. (2017). Snowball sampling: A purposeful method of sampling in qualitative research. *Strides in development of medical education*, 14(3).
- Nasir, M. H. A., Genovese, A., Acquaye, A. A., Koh, S. C. L., & Yamoah, F. (2017). Comparing linear and circular supply chains: A case study from the construction

- industry. *International Journal of Production Economics*, 183, 443-457.
<https://doi.org/https://doi.org/10.1016/j.ijpe.2016.06.008>
- Nielsen, J. (2012). Usability 101: Introduction to usability.
- Pauwels, K., Ambler, T., Clark, B. H., LaPointe, P., Reibstein, D., Skiera, B., Wierenga, B., & Wiesel, T. (2009). Dashboards as a service: why, what, how, and what research is needed? *Journal of service research*, 12(2), 175-189.
- Rabiei, R., & Almasi, S. (2022). Requirements and challenges of hospital dashboards: a systematic literature review. *BMC medical informatics and decision making*, 22(1), 287.
<https://bmcmedinformdecismak.biomedcentral.com/counter/pdf/10.1186/s12911-022-02037-8.pdf>
- Rahman, M., Alam, M., Alam, S., & Mrida, M. (2025). HOW INTERACTIVE DASHBOARDS IMPROVE MANAGERIAL DECISION-MAKING IN OPERATIONS MANAGEMENT. *American Journal of Advanced Technology and Engineering Solutions*, 01, 122-146. <https://doi.org/10.63125/cqm5jk84>
- Sarikaya, A., Correll, M., Bartram, L., Tory, M., & Fisher, D. (2019). What do we talk about when we talk about dashboards? [Article]. *IEEE Transactions on Visualization and Computer Graphics*, 25(1), 682-692, Article 8443395.
<https://doi.org/10.1109/TVCG.2018.2864903>
- Stebbins, R. A. (2001). *Exploratory research in the social sciences* (Vol. 48). Sage.
- Swens, E. (2024). *Alignment in Public Real Estate*
A study on implementing a(n) (improved) case specific PAS design and decision-making method to enhance the real estate management of the office portfolio of the Netherlands Police Delft University of Technology]. Delft.
<https://repository.tudelft.nl/record/uuid:1f73e566-b332-4b63-84cf-e3f3fc510681>
- UN. (2016). Sustainable Real Estate Investment. Implementing the Paris Climate Agreement: An Action Framework. *United Nations*.
- United Nations Environment Programme. (2022). *2022 Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector*. UNEP.

- Valks, B. (2021). Smart Campus Tools: Technologies to support campus users and campus managers [Review]. *A+BE Architecture and the Built Environment*, 18, 1-456. <https://www.scopus.com/inward/record.uri?eid=2-s2.0-85173700588&partnerID=40&md5=c1280bd3dd21e784d3dc101ae72627a9>
- Valks, B., Arkesteijn, M., Koutamanis, A., & Den Heijer, A. (2021). Towards smart campus management: Defining information requirements for decision making through dashboard design. *Buildings*, 11(5), 201.
- Van Aken, J. E., & Romme, G. (2009). Reinventing the future: adding design science to the repertoire of organization and management studies. *Organization Management Journal*, 6(1), 5-12.
- van Stijn, A. (2023). Developing circular building components: Between ideal and feasible. *A+ BE| Architecture and the Built Environment*(05), 1-740.
- Vazquez-Ingelmo, A., Garcia-Penalvo, F. J., & Theron, R. (2019). Information Dashboards and Tailoring Capabilities-A Systematic Literature Review [Review]. *IEEE Access*, 7, 109673-109688, Article 8789402. <https://doi.org/10.1109/ACCESS.2019.2933472>
- Wilkinson, M. D., Dumontier, M., Aalbersberg, I. J., Appleton, G., Axton, M., Baak, A., Blomberg, N., Boiten, J.-W., da Silva Santos, L. B., & Bourne, P. E. (2016). The FAIR Guiding Principles for scientific data management and stewardship. *Scientific data*, 3(1), 1-9.
- Yigitbasioglu, O. M., & Velcu, O. (2012). A review of dashboards in performance management: Implications for design and research [Article]. *International Journal of Accounting Information Systems*, 13(1), 41-59. <https://doi.org/10.1016/j.accinf.2011.08.002>
- Yin, R. K. (2018). *Case study research and applications: Design and methods*. Sage Books.
- Zhilyaev, D., Binnekamp, R., & Wolfert, A. R. (2022). Best fit for common purpose: A multi-stakeholder design optimization methodology for construction management. *Buildings*, 12(5), 527.
- Zucker, D. (2009). How to do case study research. Teaching research methods in the humanities and social sciences. *College of Nursing Faculty Publications Series*.

Appendix A: Data management plan

Plan Overview

A Data Management Plan created using DMPonline

Title: Effective dashboard design for decision making support

Creator: Benjamin Laagewaard

Affiliation: Delft University of Technology

Template: TU Delft Data Management Plan template (2025)

ID: 192795

Last modified: 12-12-2025

Effective dashboard design for decision making support

0. Administrative questions

1. Provide the name of the data management support staff consulted during the preparation of this plan and the date of consultation. Please also mention if you consulted any other support staff.

Question not answered.

2. Is TU Delft the lead institution for this project?

Yes, the only institution involved

I. Data/code description and collection or re-use

3. Provide a general description of the types of data/code you will be working with, including any re-used data/code.

Type of data/code	File format(s)	How will data/code be collected/generated? <i>For re-used data/code: what are the sources and terms of use?</i>	Purpose of processing	Storage location	Who will have access to the data/code?
Audio recordings from workshops	Audio format (.m4a)	Workshops will be recorded with an audio recorder	Analysis of participant feedback on dashboard	TU Delft Onedrive	Me TU supervisors : Monique Arkesteijn, Ruud Binnekamp, Hedieh Arfa
Anonymized transcripts	Text format (.docx) .xlsx files .csv files	Audio recordings will be transcribed into written text	Analysis of participant feedback on dashboard	TU Delft Onedrive	Me TU supervisors : Monique Arkesteijn, Ruud Binnekamp, Hedieh Arfa
Survey responses	Text format (.docx)	Surveys are answered by participants during the workshop.	Analysis of participant feedback on dashboard	TU Delft Onedrive	Me TU supervisors : Monique Arkesteijn, Ruud Binnekamp, Hedieh Arfa
Field notes	Text format (.docx)	Personal notes from the workshops based on observations	Analysis of participant feedback on dashboard	TU Delft Onedrive	Me TU supervisors : Monique Arkesteijn, Ruud Binnekamp, Hedieh Arfa
Contact information	Text format (.docx)	Names, email addresses	Managing correspondence with participants	TU Delft Onedrive	Me TU supervisors : Monique Arkesteijn, Ruud Binnekamp, Hedieh Arfa
Informed consent forms	Text format (.docx)	The research can only gather data after participants sign the form prior to the start of the workshop. The form is send by email or signed in person.	Permission by participants to collect data for this research	TU Delft Onedrive	Me TU supervisors : Monique Arkesteijn, Ruud Binnekamp, Hedieh Arfa

II. Storage and backup during the research process

4. How much data/code storage will you require during the project lifetime?

- < 250 GB

5. Where will the data/code be stored and backed-up during the project lifetime? (Select all that apply.)

- TU Delft OneDrive

III. Data/code documentation

6. What documentation will accompany data/code? (Select all that apply.)

- Data – Methodology of data collection

IV. Legal and ethical requirements, code of conducts

7. Does your research involve human subjects or third-party datasets collected from human participants?

If you are working with a human subject(s), you will need to obtain the HREC approval for your research project.

- Yes – please provide details in the additional information box below

Audio recordings from the workshops are used to collect data and to perform the data analysis. These recordings are anonymised during transcription. After finishing the analysis, the recordings will be deleted.

The thesis report will not include any personal data and only uses anonymised quotes or paraphrased information.

8. Will you work with personal data? (This is information about an identified or identifiable natural person, either for research or project administration purposes.)

- Yes

9. Will you work with any other types of confidential or classified data or code as listed below? (Select all that apply and provide additional details below.)

If you are not sure which option to select, ask your [Faculty Data Steward](#) for advice.

- Yes, data which could lead to reputation/brand damage (for example, animal research, climate change)

10. How will ownership of the data and intellectual property rights to the data be managed?

For projects involving commercially-sensitive research or research involving third parties, seek advice of your [Faculty Contract Manager](#) when answering this question.

The owner of the data is me. Additionally, my supervisors from the TU Delft have access to the research files. Only the involved researchers have access to the storage locations with collected data .

At the publication of the thesis report, the thesis outcomes will become publicly available.

11. Which personal data or data from human participants do you work with? (Select all that apply.)

- Free text fields (for instance, in questionnaires) in which participants could unintentionally share personal data
- Proof of consent (such as signed consent materials which contain name and signature)
- Audio recordings
- Telephone number, email addresses and/or other addresses as contact details for administrative purposes
- Names as contact details for administrative purposes

12. Please list the categories of data subjects and their geographical location.

The data subjects will consist of:

Previous users or developers of the Preference-based Accommodation Strategy (PAS) .

Students from the TU Delft faculty Architecture and the Built Environment from the master track: Management in the Built Environment. Stakeholders who participated in a pilot of PAS.

13. Will you be receiving personal data from or transferring personal data to third parties (groups of individuals or organisations)?

- No

16. What are the legal grounds for personal data processing?

- Informed consent

17. Please describe the informed consent procedure you will follow below.

The researcher will inform the potential participants about the goals and procedures of the research project. The researcher will also inform them about the personal data that are being processed and for what purpose. This information will be provided to the potential participants as follows: an overview of the workshop through email. All participants will be asked for their consent for taking part in the study and for data processing by signing a physical/digital informed consent form prior the start of the workshop.

18. Where will you store the physical/digital signed consent forms or other types of proof of consent (such as recording of verbal consent)?

TU Delft OneDrive

19. Does the processing of the personal data result in a high risk to the data subjects? (Select all that apply.)

If the processing of the personal data results in a high risk to the data subjects, it is required to perform a [Data Protection Impact Assessment \(DPIA\)](#). In order to determine if there is a high risk for the data subjects, please check if any of the options below that are applicable to the processing of the personal data in your research project.

- None of the above apply

23. What will happen with the personal data used in the research after the end of the research project?

- Other – please explain below

Personal data will be deleted after the end of the research project.

24. For how long will personal research data (including pseudonymised data) be stored?

- Personal data will be deleted at the end of the research project

25. How will your study participants be asked for their consent for data sharing?

- In the informed consent form: participants are informed that their personal data will be anonymised and that the anonymised dataset is shared publicly

V. Data sharing and long term preservation

27. Apart from personal data mentioned in question 23, will any other data be publicly shared?

Please provide a list of data/code you are going to share under 'Additional Information'

- I do not work with any data other than personal data

29. How will you share research data/code, including those mentioned in question 23?

Select all that apply and provide additional details below.

I am a Bachelor's/Master's student at TU Delft and I will share the data/code in the body and/or appendices of my thesis/report in the TU Delft Repository

30. How much of your data/code will be shared in a research data repository?

- < 100 GB

31. When will the data/code be shared?

- As soon as corresponding results (papers, theses, reports) are published

32. Under what licence(s) will the data/code be released?

- Other – please explain below

Does not apply.

VI. Data management responsibilities and resources

33. If you leave TU Delft (or are unavailable), who is going to be responsible for the data/code resulting from this project?

My supervisor: Monique Arkesteijn, associate-professor Real Estate Management

34. What resources (for example financial and time) will be dedicated to data management and ensuring that data will be FAIR (Findable, Accessible, Interoperable, Re-usable)?

There is no additional funding required.

35. Which faculty do you belong to?

- Faculty of Architecture and the Built Environment (ABE)

Appendix B: workshop documents

1. Informed consent form

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
A: GENERAL AGREEMENT – RESEARCH GOALS, PARTICIPANT TASKS AND VOLUNTARY PARTICIPATION		
1. Ik doe vrijwillig mee aan dit onderzoek, en ik begrijp dat ik kan weigeren vragen te beantwoorden en mij op elk moment kan terugtrekken uit de studie, zonder een reden op te hoeven geven.	<input type="checkbox"/>	<input type="checkbox"/>
2. Ik begrijp dat mijn deelname aan het onderzoek het volgende betekent. Er wordt data verzameld via: <ul style="list-style-type: none"> • Het invullen van een enquêtevragenlijst door de deelnemer. • Een audio-opname van de groepsdiscussie. • Geschreven notities van de onderzoeker. 	<input type="checkbox"/>	<input type="checkbox"/>
3. Ik begrijp dat de studie uiterlijk binnen 5 maanden eindigt of bij een eerdere afronding van het onderzoek.	<input type="checkbox"/>	<input type="checkbox"/>
B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION)		
4. Ik begrijp dat mijn deelname de volgende risico's met zich meebrengt: <ul style="list-style-type: none"> • Potentieel fysiek of mentaal ongemak, zoals lichte stress of vermoeidheid. Ik begrijp dat deze risico's worden geminimaliseerd door: <ul style="list-style-type: none"> • De mogelijkheid om de sessie op elk moment te stoppen zonder gevolgen. 	<input type="checkbox"/>	<input type="checkbox"/>
5. Ik begrijp dat mijn deelname betekent dat er persoonlijke identificeerbare informatie en onderzoeksdata worden verzameld, met het risico dat ik hieruit geïdentificeerd kan worden en reputatieschade op professioneel vlak oploopt.	<input type="checkbox"/>	<input type="checkbox"/>
6. Ik begrijp dat de volgende stappen worden ondernomen om het risico van een databreuk te minimaliseren, en dat mijn identiteit op de volgende manieren wordt beschermd in het geval van een databreuk: <ul style="list-style-type: none"> • Data wordt getranscribeerd en geanonimiseerd. Audiobestanden worden hierna verwijderd. • Data wordt opgeslagen op een TU Delft server. • Data is alleen toegankelijk voor het onderzoeksteam. 	<input type="checkbox"/>	<input type="checkbox"/>
7. Ik begrijp dat de persoonlijke informatie die over mij verzameld wordt en mij kan identificeren, zoals naam en contactgegevens, niet gedeeld worden buiten het studieteam.	<input type="checkbox"/>	<input type="checkbox"/>
8. Ik begrijp dat de persoonlijke data die over mij verzameld wordt, vernietigd wordt na afloop van de dataverwerking.	<input type="checkbox"/>	<input type="checkbox"/>

Contactgegevens van de onderzoeker voor verdere informatie:

Benjamin Laagewaard

2. Guiding questions for workshop round 1

These questions were used to help participants provide feedback on the dashboard.

- "Wat was jullie eerste indruk van beide dashboards?"
- "Wat droeg het meest bij aan de effectiviteit van het dashboard?"
- "Hoe ervaren jullie de overzichtelijkheid en informatie-opbouw van beide dashboards?"
- "Is er iets dat momenteel nog ontbreekt of wat nuttig zou zijn?"
- "Zijn er onderdelen die verwarrend of overbodig aanvoelen?"

3. Survey questions of workshop round 1

A. Gebruiksvriendelijkheid

1. Hoe gemakkelijk was het om het dashboard te begrijpen bij eerste gebruik? *

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

2. Hoe eenvoudig was het om met het dashboard te werken? *

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

3. Hoe goed kunt u in deze sessie onthouden hoe het dashboard werkt? *

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

4. Hoe goed voorkomt het dashboard verwarring gedurende het gebruik in de workshop? *

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

5. Hoe tevreden bent u over het gebruik van het dashboard? *

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

B. Flexibiliteit

Hoe goed sluit het dashboard aan op uw behoeften als gebruiker?

6. Hoe goed sluit het dashboard aan op uw behoeften als gebruiker? *

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

C. Interactiviteit

7. Hoe goed ondersteunt het dashboard het verkennen van de data? *

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

8. Hoe goed ondersteunt het dashboard het filteren of aanpassen van data? *

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

9. Hoe goed helpt het dashboard om te zien hoe goed een portfolio presteert? *

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

D. Kennisontdekking

10. Hoe goed helpt het dashboard u om nieuwe inzichten te krijgen? *

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

11. Hoe goed is het effect van een aanpassing op de totaalscore te herkennen? *

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

12. Hoe duidelijk geeft het dashboard de relaties tussen data weer? *

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

E. Leesbaarheid

13. Hoe duidelijk zijn de grafieken en visualisaties? *

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

14. Hoe duidelijk zijn de labels, titels en teksten? *

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

15. Hoe logisch is de ordening van de informatie? *

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

16. Hoe gemakkelijk kunt u de informatie begrijpen zonder extra uitleg? *

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

F. Transparantie van data & berekeningen

17. Hoe duidelijk is het waar de gegevens in het dashboard vandaan komen? *

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

18. Hoe duidelijk is het hoe de berekeningen of scores tot stand komen? *

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

4. Survey questions of workshop round 2

A. Gebruiksvriendelijkheid

1. Rangschikking (best presterende boven, minst presterende onder) *



Origineel

Herontwerp 1

Herontwerp 2

2. Score middelste: *

Voer uw antwoord in

B. Flexibiliteit

Hoe goed sluit het dashboard aan op uw behoeften als gebruiker?

3. Rangschikking (best presterende boven, minst presterende onder) *

Origineel

Herontwerp 1

Herontwerp 2

4. Score middelste: *

Voer uw antwoord in

C. Interactiviteit

5. Rangschikking (best presterende boven, minst presterende onder) *

Origineel

Herontwerp 1

Herontwerp 2

6. Score middelste: *

Voer uw antwoord in

D. Kennisontdekking

7. Rangschikking (best presterende boven, minst presterende onder) *

Origineel
Herontwerp 1
Herontwerp 2

8. Score middelste: *

Voer uw antwoord in

E. Leesbaarheid

9. Rangschikking (best presterende boven, minst presterende onder) *

Origineel
Herontwerp 1
Herontwerp 2

10. Score middelste: *

Voer uw antwoord in

F. Transparantie van data & berekeningen

11. Rangschikking (best presterende boven, minst presterende onder) *

Origineel
Herontwerp 1
Herontwerp 2

12. Score middelste: *

Voer uw antwoord in