Design of a Digital Interactive Collaboration Facilitator in a Datacenter Development Context

Boudewijn Mol
Marieke Schriever

TU Delft

Microsoft

Design of a Digital Interactive Collaboration Facilitator in a Datacenter Development Context

by B. J. M. (Boudewijn) Mol & D. M. C. (Marieke) Schriever

to obtain the degree of Master of Science
at the Delft University of Technology,
for the faculty of Civil Engineering,
as part of the Master Construction Management and Engineering,
to be defended publicly on the 14th of March 2024.

Student numbers:	5536928 (Boudewijn)	4673271 (Marieke)
Project duration:	August, 2023 – March, 2024	
Thesis committee:	Dr. ir. R. Binnekamp,	TU Delft, Chair
	Ir. K.G. Heijne,	TU Delft, 1st supervisor
	Ir. J.P.G. Ramler,	TU Delft, 2nd supervisor
	Dr. ir. G.A. van Nederveen,	TU Delft, 3rd supervisor
	Nienke Ris,	Microsoft
	Nils Schmeling,	NECXT

This is a non-confidential version, for more information, feel fry to contact Boudewijn Mol or Marieke via LinkedIn

Preface

This graduation thesis was written at the faculty Construction Management and Engineering, in the domain Engineering and Systems at Delft University of Technology. The thesis has been executed at the Cloud Operations and Innovations (CO+I) department at Microsoft. Throughout this thesis process scientific knowledge was applied in a practical business case. To achieve this successfully, a team of business and academic committee members was involved to assist our journey.

Firstly, we want to thank Nienke Ris, for giving us the opportunity at Microsoft to execute this thesis. Your enthusiasm about our ideas and results, personal involvement, knowledge and experience along the way has greatly helped us throughout this process. Next, we want to thank Nils Schmeling for sharing his expertise, the uplifting personal phone calls, the invitation to the new years brunch among colleagues and other professionals and facilitating our thesis at Microsoft.

Furthermore, we would also like to thank the committee of the TU Delft: Ruud Binnekamp, Katrina Heijne, Hans Ramler and Sander van Nederveen. As a multi-disciplinary group of academic experts you have significantly helped us individually and collectively. Thank you for embracing our ideas to bridge Civil Engineering to the Industrial Design & Engineering department and thank you for guiding the academic merits of our thesis.

Also a special thanks to all the committee members for being understanding and flexible during the lasts months when personal circumstances made the thesis more challenging. We are particularly grateful for all the support and supervision we got from this committee throughout the whole process.

In addition, we want to thank the EMEA directors at Microsoft who participated in our thesis. We highly appreciated the handful of hours they freed up in their packed schedules to contribute to this study. We experienced a pleasant interaction with each and everyone of you and without you this thesis would not have been possible. Also, thank you to our other colleagues, especially Mara and Florien, for the team days at the office and your assistance whenever we needed it.

Next, we would like to thank our friends and family for all the loving support we got along the way. Lastly, we want to thank each other. After seven months of forty working hours per week, we not only maintained a good working relationship, but also a valuable friendships emerged from this collaboration. The endless coffee breaks, all the brainstorm sessions, the lunches, the personal talks and the milestone celebrations have made this journey a lot better.

We hope you enjoy reading our thesis!

B. J. M. (Boudewijn) Mol & D. M. C. (Marieke) Schriever
Delft, February 2024

Abstract

This thesis aims to design an interactive tool that facilitates collaboration between Microsoft's teams in the datacenter development design process. Current datacenter development strategies of Microsoft do not sufficiently take into account socio-technical aspects which is causing project delays. Such socio-technical aspects are internally represented by different teams at Microsoft, such as the Community Affairs team and the Environmental team. Incorporating the preferences of all the relevant teams during the design, results in enhanced collaboration through increased mutual insights, which can be used to develop new design solutions. Such new design solutions inherently incorporate more socio-technical aspects.

Researching new designs for constructions stems from ongoing scientific and practical trends towards integral and collaborative civil engineering asset design. Such trends can focus on developing effective information systems to enhance collaboration or design optimization. Design optimization is aimed at finding optimal design solutions given a mathematical parametrization of the project system. The used Odesys methodology was developed to specifically connect mathematical optimization with preference based decision making in design projects. The main goal of the used Odesys as a method is to maximize the purpose driven service level of the construction during its life cycle by incorporating the preferences of different stakeholders in the design and optimizing for these preferences. This aptly incorporates socio-technical aspects in complex design projects such as datacenters. The Odesys combines social vague stakeholder needs with technical asset performance criteria. To effectively apply the Odesys methodology in a dynamic and participatory process it needs to accurately reflect the relevant stakeholder preferences and facilitate a conversation by visualizing its results. This participatory process connects to a focus on collaboration. Enhancing collaboration in design can be achieved using co-design principles. From the field of Industrial Design & Engineering, valid principles and methods, such as co-design, have been used to improve a collaborative process. Additionally, serious gaming was used to facilitate a collaborative conversation.

To structure this academic foundation, this thesis has been split up into three parts; the Social Cycle, the Technical Cycle and the Design Collaboration Workshop (DCW), to develop the tool that facilitates the sought collaboration. The focus of the Social Cycle was to actively involve participants during this study, using social principles to connect Odesys with creative collaboration. These principles contained keeping them involved, creating value for them, emphasizing their importance and letting them foster a positive experience. The end goal of the Social Cycle is to collect preference curves of the participants on different design variables, which are reflecting their preferences. One-on-one meetings have been used to collect these preference curves, which is used as input for the Technical Cycle. During this meeting participants were asked to use the Thinking-Out-Loud method, while they were drawing their preferences on different design variables during the 1-on-1 meeting. The Technical Cycle developed an interactive Design Collaboration Tool (DCT) that considered the teams preferences as input for a mathematical design optimization model to find new design configurations by maximizing the aggregated group preference. The third part of the thesis consisted of the Design Collaboration Workshop. During the DCW the two cycles merged, and the results from the Social Cycle were discussed to enhance mutual insights between the participants while the interactive tool facilitated the conversation of devising new datacenter design solutions for the case study in a serious game setting.

With this new approach, teams became more actively engaged throughout the process which improves their understanding of the project at hand, the effects of conflicting preferences on the design and makes them reconsider the standard design configuration with alternatives considering all their preferences and thus socio-technical aspects. The teams explicitly acknowledged an improvement to their current practice with respect to collaboration. They also expressed sincere interest in using the tools from this study in future datacenter projects at Microsoft. For example, currently pending datacenter development principles are drafted to incorporate the socio-technical aspects based on the findings from this study. The participatory process in the Social Cycle proved successful to engage and inform participants. The used social principles functions as a foundation to adequately retrieve the required information regarding design preferences while maintaining engagement with the participants. The interactive tool contributes as a conversation facilitator integrating the input from the different teams and allowing for simulated play during the serious game on possible project scenarios. The new solutions found by maximizing the aggregated group preference prove insightful as opposed to the standard design. The use of a serious game during the DCW proved to be both usable and understandable. It allowed for controlled conversation about the different datacenter design variables and solutions and showed the potential for more complex future projects.

This development process involved an iterative process. The proof-of-concept after the first iteration was adjusted based on participants' feedback and the results of the verification and validation, resulting in an improved second version developed in the second iteration. By using two iterations, the developed process was significantly improved to meet the participants' needs and to achieve a user-friendly approach. This also enhanced the co-design aspect, where the participants had a voice in the design process. Overall, this whole approach contributed to enhance collaboration and finding new datacenter design solutions, reflecting preferences and considering socio-technical aspects.

This report is published on the TUDelft repository. Content, models and code that do not contain company sensitive information can be received upon request with the corresponding authors. Please contact one or two of the authors through LinkedIn: Boudewijn Mol and/or Marieke Schriever.

Contents

Acronyms

ACRONYM	TERM	DEFINITION
AHJ	**Authority Having Jurisdiction**	An entity that has the authority and responsibility for developing, implementing, maintaining, and overseeing the qualification process within its organization or jurisdiction.
AI	**Artificial Intelligence**	The theory and development of computer systems able to perform tasks normally requiring human intelligence, such as visual perception, speech recognition, decision-making, and translation between languages.
API	**Application Programming Interface**	A set of functions and procedures allowing the creation of applications. The communicator between a front-end and back-end.
AJAX	**Asynchronised Javascript and XML**	A method to make changes to web pages and mobile apps without reloading.
BIM	**Building Information Modeling**	Digital representation of physical and functional characteristics of assets.
CA	**Community Affairs**	Team within Microsoft that is related to datacenter development focused on the community.
DCD	**Datacenter Development**	Team within Microsoft that is related to datacenter development focused on the construction.
DCE	**Datacenter Engineering**	Team within Microsoft that is related to datacenter development focused on the design.
DCT	**Design Collaboration Tool**	The web application tool developed in this thesis.
DCW	**Design Collaboration Workshop**	The workshop that is held with the participants during this thesis with a serious game set up.
EMEA	**Europe, Middle East and Africa**	One region of operations with central management at Microsoft.
ENV	**Environmental**	Team within Microsoft that is related to datacenter development focused on the sustainability and green permits.
GUI	**Graphical User Interface**	Visual computer environment that represent programs, files, and options with graphical images, such as icons, menus, and dialog boxes on the screen.
IMAP	**Integrative Maximised Aggregated Preferences**	Aggregation method to find a solution that maximises the weighted group preference.
LDO	**Land Development and Organisation**	Team within Microsoft that is related to datacenter development focused on building permits.
MODO	**Multi-Objective Design Optimisation**	Optimisation with multiple, often conflicting, objectives.
PAS	**Preference-based Accommodation Strategy**	Current preference gathering method.
PFM	**Preference Function Modeling**	A mathematically sound framework for decision theory.
PUE	**Power Usage Effectiveness**	Unit to quantify efficiency performance of datacenters.
REST	**REpresentational State Transfer**	An architectural style to guide the development of Internet-scale hypermedia systems, such as the World Wide Web.

Glossary

TERM	DEFINITION
1-on-1 meeting)	Meetings held individually with participants during the Social Cycle
A-posteriori	Reasoning based on what has been observed.
Application Programming Interface	A set of functions and procedures allowing the creation of applications. The communicator between a front-end and back-end.
A-priori	Reasoning based on theoretical deduction. What has not yet been observed.
Ballard	One datacenter building, a fullscale datacenter often consists out of multiple ballards.
Collaborative asset design	The process of designing a civil engineering asset in a multi-stakeholder setting.
Creative collaboration	Creative methods that can be used to enhance collaboration.
Design configuration/ solution	A set of values for the controllable design variables.
Direct preferences	A principle as part of the Odesys methodology to plot preferences directly to a variable circumventing objective functions.
Free drawing method	A method to allow a participant to freely draw a preference curve in an empty space based on personal reflective practitioning.
Odesys methodology	A method of socio-technical design integration to confront conflicts and dissolve problems with and for people.
Participants	EMEA directors of five Microsoft teams that participated during the 1-on-1 meetings and DCW's.
Social Cycle	Part of this study that focuses on the participatory process of the stakeholders and collecting the input data for the DCW.
Socio-technical aspects	System aspects that can be both social and technical in nature.
Technical Cycle	Part of this study that focuses on the development of a digital interactive tool to facilitate a conversation about a datacenter design problem
Thinking-Out-Loud method	A method used to effectively access a higher-level thinking processes creating deeper insides into one's thoughts and foster personal awareness.

1 Introduction

In the current digital era, datacenters are cornerstone building blocks to support digitalization. Datacenters fulfill an expanding role in the infrastructure of computing networks. Datacenters mainly provide dynamically scaled computing power and centralized data storage for its users. As of 2021, an estimated 8,000 physical datacenter sites are strategically located globally in a worldwide network to meet service levels (Vardhman, 2023). The United States houses the most with approximately 5,000 datacenters, followed by Germany with around 500 datacenters, and the Netherlands ranking eighth with about 300 datacenters (Statista, 2023). A growing demand for datacenters, estimated at a 15% increase in Europe surpassing the global average of 13%, is driven by advancements in Artificial Intelligence (AI), machine learning, and next-generation security technologies, as well as the increasing low-latency digital services for industrial and private daily operations (Chance, 2023). Next to the growth in demand for computational resources, a shift has taken place from local PC use to cloud computing. This new computing model intends to offer ubiquitous availability, scaled and increased power and usage-based pricing (Zhang et al., 2010). These trends amplify the future need for powerful, cost-efficient and reliable datacenters.

Within the global datacenter network this study focuses specifically on hyperscale datacenters operated by Microsoft within the Europe, Middle East and Africa (EMEA) region, which exemplify the above mentioned demand trends. Hyperscale datacenters, characterized by their extensive capacity (>20 MW[1]), are designed to centralize the current demands of major cloud providing enterprises such as Microsoft. During the past decade, datacenter design within Microsoft has witnessed substantial innovations, focusing on standardization to stimulate deployment scalability, increasing performance through higher capacity and denser computation power per surface area while minimizing latency and improving energy efficiency and sustainability to a world-class level (JRC, 2023). Next to enhanced datacenter design through technical innovations, Microsoft strives for the improvement of the development process of datacenters, especially in the EMEA region.

The aforementioned standardization of datacenter design and development faces increasing deployment difficulties in EMEA projects, since they require tailor-made solutions to socio-technical and legislative landscapes (Kasteleijn, 2022, NOS, 2020). For example in the Netherlands, datacenters face considerable opposition due to concerns about energy (van Wijnen and van Gils, 2023) and water consumption (Verhagen et al., 2024, Nieuws, 2022), the environmental impact of their construction, such as NOx[2] emissions (Rengers and Houtekamer, 2023) and providing limited beneficial opportunities, which all categorize as concerns about the impact of the proposed datacenters. Such impacts are not limited to the datacenter compound but can transcend the compound perimeter to the local vicinity, regional, national and international levels while directly influencing the design and development on site. Such multi-level stakeholders can influence datacenter design and development through means such as legislation, policy, public participation and general public paradigms. To incorporate these impacts, a

[1] MegaWatts
[2] Nitrogen Oxides

datacenter needs to be viewed as a component within its open socio-technical purpose driven system. This open characteristic of a system allows for an interaction between the system components and its environment beyond its scope, which can be used to separate the aforementioned levels (Wolfert, 2023). Apart from external impacts, also internal multi-stakeholder settings can influence the datacenter design and development, especially in complex projects. The impact and pace of datacenter development and deployment at Microsoft has resulted in a recently re-organised complex organisational structure for the EMEA region. These different teams have independent drivers which connect to their relevant external stakeholders. This independent operation undermines the purpose of considering the broader socio-technical system of datacenters. Within such a system the interrelation and interdependence of natural, social and human-made components need to be considered. With regard to datacenter design and development this means that the objectives from multiple stakeholders need to be considered when making design decisions. Ultimately, this will positively contribute to the Quality of Service (QoS) level as part of the socio-eco purpose of the system. The effects of considering multi-stakeholder objectives during the design phase of datacenters on the QoS can be maximized using optimization modeling. A visualisation of the current situation and the desired future situation can be found in Figure 1.1.

This figure shows how a datacenter design is at the center of multiple stakeholder impacts, representing socio-technical aspects of the system. The coloured stakeholders represent internal Microsoft teams that have a link to datacenter development. Some of such stakeholders represent and communicate with external stakeholders. In the current design scope (indicated by the blue line) no external stakeholders can influence the design and even some internal teams encounter difficulties translating their preferences into the standard design process. In a future scenario the preferences of all relevant internal and external stakeholder are incorporated into the datacenter design (indicated by the orange line). Note that external stakeholders can not directly influence the design in this future scenario but their preferences are reflected through a representative Microsoft team. From this figure it becomes clear that incorporating socio-technical aspects into the design results in a strikingly different design as indicated by the photos in the figure. The left shows a current datacenter design while the right illustrates a regenerative datacenter design as developed within Microsoft's R&D.

This study uses optimization techniques to search for an optimal design solution given a mathemati-

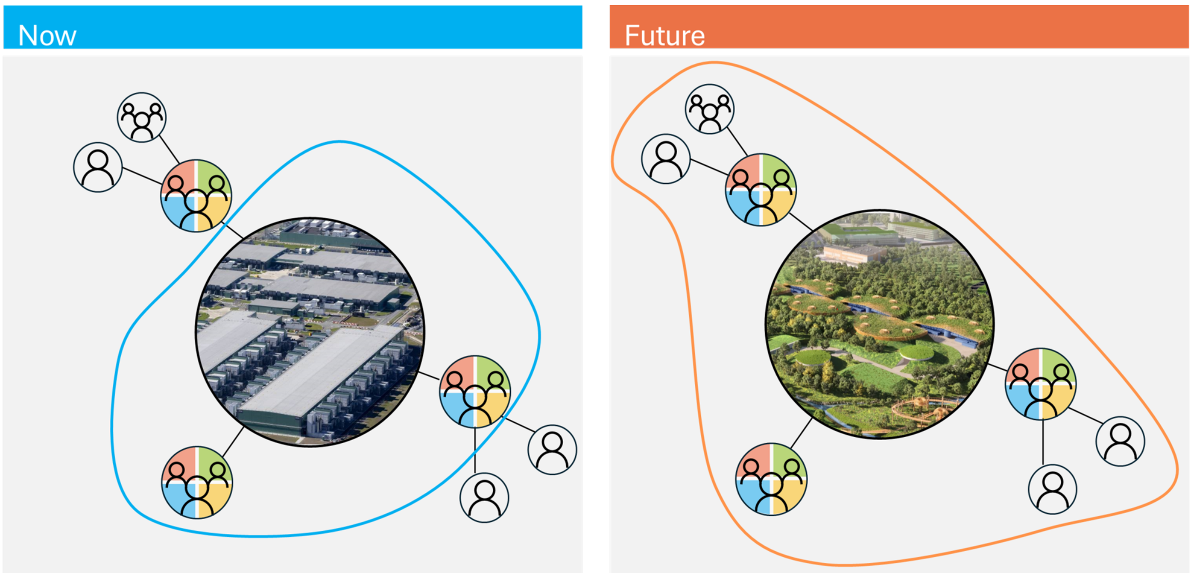


Figure 1.1: Comparison of situations: current situation vs desired situation considering internal and external stakeholders

cal description of a socio-technical datacenter system. Multi-objective optimization modeling revolves around solving mathematical models, which are numerical abstractions of real-life objects, processes, behaviour, problems and decisions. Regarding optimization models, solving means to use mathematical techniques to search for an optimal solution (Martins and Ning, 2021). In this study it focuses on optimizing for social stakeholder preferences of internal Microsoft stakeholders, their relative desirability. Note the difference between preference and desire as part of subjective satisfaction. The former compares multiple alternatives and one is preferred over another indicating relative positioning of the alternatives, while desirability considers a level of satisfaction with one alternative. Incorporating these preferences of Microsoft teams is realised through mathematical formulation of preferences called preference function modeling, as laid down in Barzilai's preference function modeling theory (Barzilai, 2006).

In short, this thesis aims to explore the development of datacenters with a focus on the aforementioned socio-technical aspects, in the early design process to foster broader datacenter acceptance and sustainability on multiple levels. Therefore, this thesis aims to develop a tool that can contribute to this.

1.1. Reading guide

In Figure 1.2 below a visualisation of the reading guide is given. First the introduction of the thesis is described in Chapter 1. Chapter 2 contains the problem analysis that has been executed to indicate the main current challenge within Microsoft's datacenter development, together with the causes of this challenge. Based on this a development statement is formulated, which describes the final product of this thesis. Sequentially, this is substantiated with theoretical background, consisting of two different domains which affiliate with the defined problem, described in Chapter 3. Then, the needs and requirements are established to verify and validate the designed solutions. The needs and requirements can be found in Chapter 4. A case study is chosen within the company to apply the approach and the development. The selection of this case study is explained in Chapter 5. Subsequently, the first designs, developments and performance are explained in Chapter 6, where the methods, designs and performance can be found. After evaluating the designs and developments on the established needs and requirements in Chapter 4, an improved version is developed and again evaluated in Chapter 7. Lastly, the conclusion and recommendations can be found in Chapter 8.

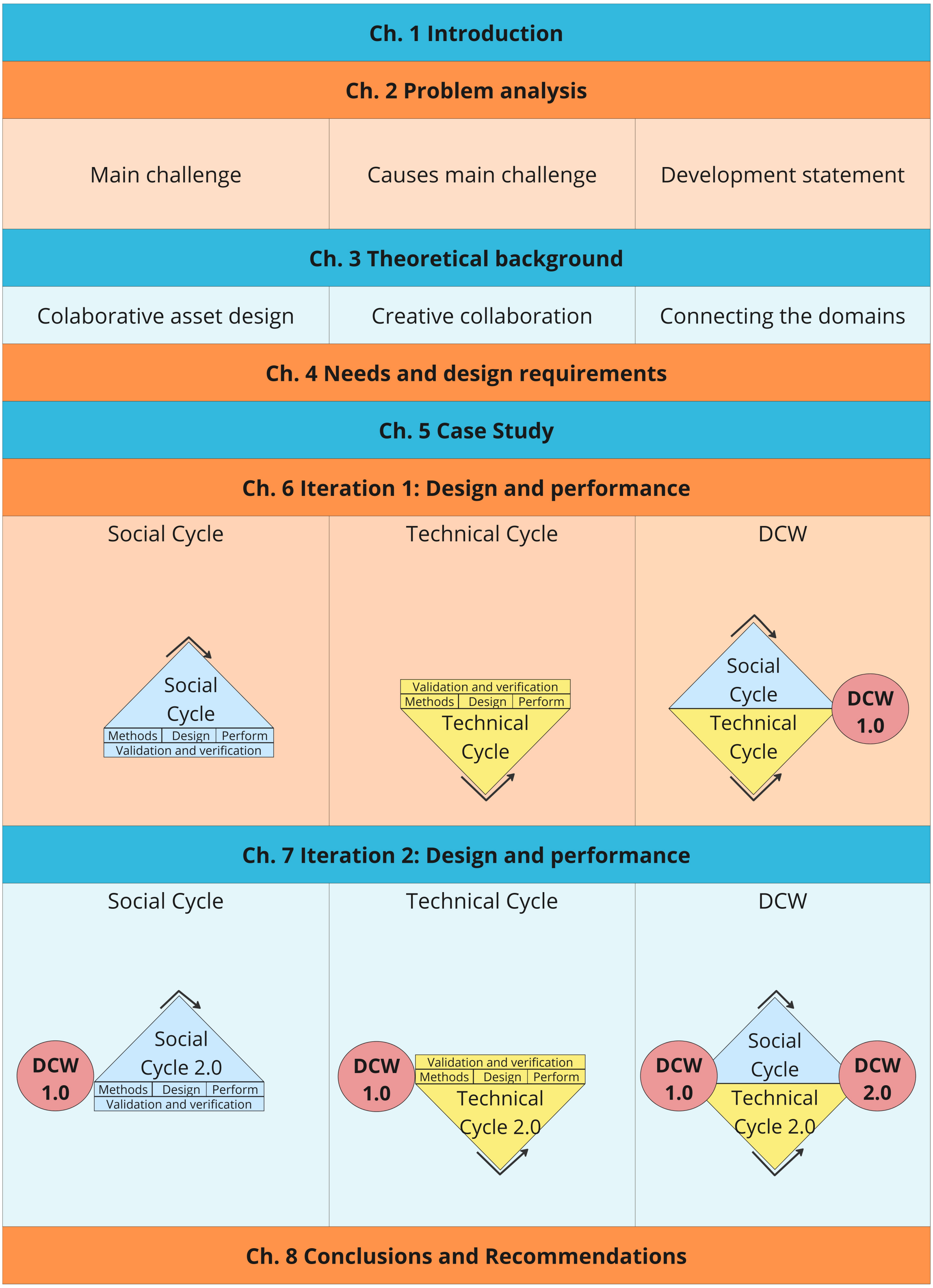


Figure 1.2: Reading guide

2
Problem analysis

This chapter focuses on the problem statement and the operational relevance of this thesis. First in Section 2.1, the company context is analysed to ensure relevance and find the main challenge for Microsoft. It dives deeper into the current datacenter design practices at Microsoft in order to highlight current problems and causes. The chapter concludes with the development statement of this thesis, that fits within the company context and solves the main challenge. The development statement can be found in Section 2.2.

2.1. Microsoft problem context

The problem context within Microsoft was explored through interviews with employees from teams involved in datacenter development, coupled with a comprehensive review of company information pertaining to datacenters and their design and development. Additionally, a site visit to a current datacenter under construction was conducted with the general contractor, to gain a deeper understanding of a datacenter construction itself. Those initial weeks of this study, with interviews and meetings, were held to gain insight into the company structure, the varying interests and responsibilities of different teams, current practices, the decision making process and existing problems.

The problem context is described in two parts. Firstly, the process of datacenter development is described, together with the main challenge Microsoft faces during the datacenter development process. This is described in Section 2.1.1. Secondly, the main challenge will be zoomed in, by describing the current practise, the problem that arises and what causes this problem. This can be found in Section 2.1.2.

2.1.1. Main challenge

Regarding the process of datacenter design and development, Microsoft follows a standardized stage gate approach. Initially, a strategic signal is raised for a site examination. Then, an extensive Site Due Diligence (SDD) report is drawn up containing all relevant social, technological, economical, legislative and environmental information. Based on this information and the analysis of costs and time, the site will receive a GO/NO-GO decision to proceed or not after which it will reach Stage Gate 0 (SG0). If the project is approved, it passes Stage Gate 0 and moves into the charter phase. This includes choices on the scope, baseline schedule, test site fits and all strategies including permitting, contractor(s), utility, network scopes among others. After completing this Stage Gate 1 (SG1), the project enters the design phase, which is Stage Gate (SG2). This covers the engineering and permitting part, where required permits have to be obtained to enable construction start. Sequentially, the construction can start in Stage Gate 3 (SG3).

The main challenges identified during the datacenter development process are the delays in obtaining building and environmental permits, and delays of the datacenter development caused by resistance of external stakeholders. The external stakeholders can be (local) authorities, NGOs, communities around the datacenter, climate groups etc. These delays lead to time and financial losses, because of the extended time to market for Microsoft and could potentially be foreseen when socio-technical aspects are increasingly considered in the datacenter design. The challenges in obtaining permits and the resistance of external stakeholders are mainly linked to problems that occur with the datacenter design. The deployment of the standard datacenter design at Microsoft does at this moment not consider project-specific socio-technical aspects. For Microsoft considering different design configurations can be best performed between SG0 and SG1, so during initial test fits in the charter phase after the GO/NOGO decision. The reason for this is that after SG1 already more than 30% of the design is completed to apply for the necessary permits which hampers flexibility in design changes. The moment between SG0 and SG1 therefore allows for flexibility in the design to discuss relevant socio-technical aspects and anticipate further design, permitting and construction. In Figure 2.2 a visualisation of the main challenge is identified.

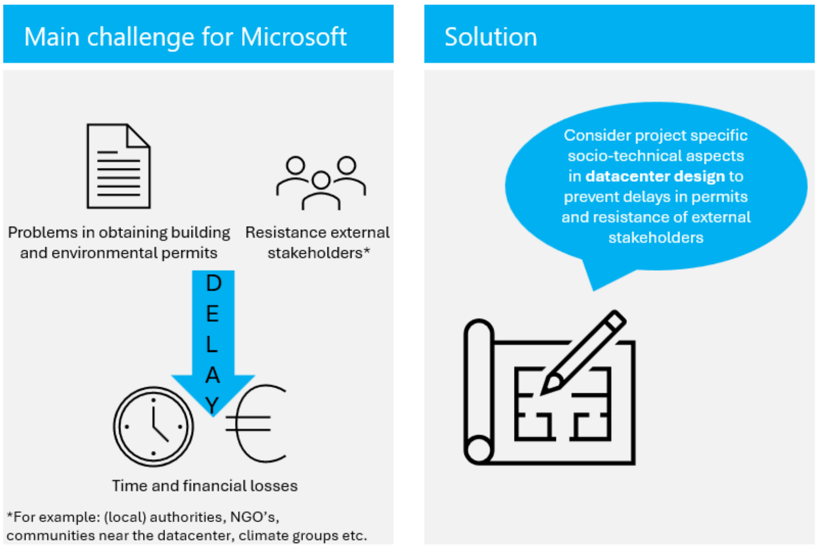


Figure 2.1: Main challenge and possible solution

2.1.2. Causes main challenge

To understand the causes of the main challenge, the teams within Microsoft that are involved in the datacenter development process have been identified and researched. There are five key teams that are involved in the datacenter development process. These teams are Community Affairs (CA), Land Development Organisation (LDO), Environmental, Datacenter Development (DCD) and Datacenter Engineering (DCE). Each of these teams have their own responsibility and KPIs. All of these teams together reflect multiple socio-technical aspects. Community affairs represents and considers the community around the datacenter site. They want to improve the reputation of Microsoft and wants to be a good neighbor for the community around the site. Their goal is to improve the license to operate at datacenter locations, considering the community and environment. The Land Development Organization wants to develop acquired land as soon as possible to start the construction of the datacenters. They need to mitigate the risks of delays and get the formal approvals and permits approved on time. The Environmental team is accountable for meeting the environmental regulations and minimising the environmental impact of the datacenters. Their goal is to have a low environmental impact and wants the datacenters to sustainability fit into the landscape. The team that is responsible for the design of the datacenters is the Datacenter Engineering team. They strive for maximum datacenter capacity with minimal costs. The Datacenter Development team deals with the construction of the datacenters. They oversee the construction and execution of the datacenters and deliver them. An overview of the teams responsibilities can be found in the Classified Appendix CA. Other teams that initially were considered for this study, but were left out, can be found in Classified Appendix CB. An extensive overview of the teams specific interests and goals, are defined from the gathered information of the interviews with the teams and can be found in Classified Appendix CC.

All of these teams have a lot of information and research available about their own specific expertise. There are biomimicry studies, SDD reports and a lot of research and development projects, that consider multiple socio-technical aspects, also for specific datacenter projects. However, while all this information about project specific socio-technical aspects is available, these aspects are not all considered in the design choices of the datacenters. This clearly shows that teams have insufficient mutual insights in each other's preferences representing their socio-technical aspects for a project which hampers collaboration during the design. Regarding this limited collaboration several causes could be identified:

1. Teams are driven by different KPIs. Some teams feel the pressure to minimize costs and time while others want to spend more money on environmental friendly solutions. This leads to teams with each unique interests and design preferences.
2. Expressing design preferences in relation to their impact on aspects such as time and costs is challenging.
3. Quantifying the impact of design choices is difficult in relation to risk mitigation actions.
4. The socio-technical aspects of each datacenter vary greatly from site to site that no single optimal design exists. Therefore an optimal solution has to be found between tailor made solutions and the standardized design.

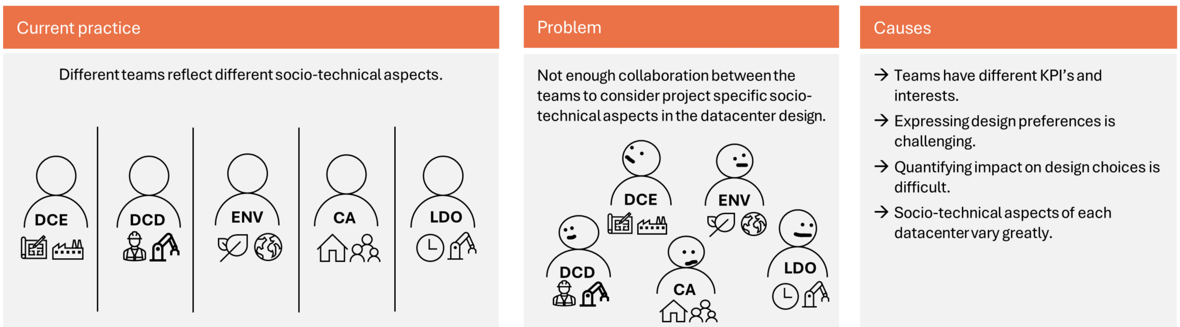


Figure 2.2: Causes main challenge

2.2. Development statement

To overcome the problem that there is not enough collaboration between the teams within Microsoft that leads to not considering socio-technical aspects in the datacenter design. That can cause financial and time losses in the datacenter development projects. This thesis will bridge the gap to an in-practice viable tool to stimulate collaboration among these different teams. It aims to strive for a higher goal of shared collaboration in the datacenter development design process, to get to early consensus on the design choices, considering socio-technical aspects, leading to project success in time and budget. Therefore, this research aims to

design an interactive tool that facilitates collaboration between Microsoft's teams in the datacenter development design process.

3

Theoretical background

Now that the development statement has been defined, theoretical background and academic state-of-the art theories will be researched to find suitable solutions and to substantiate its developments. Given the main component of the problem definition at Microsoft, which is a datacenter design problem in a multi-stakeholder context, a domain that was called collaborative asset design was reviewed. Particularly the so-called OpenDesignSystems (Odesys) methodology was used as the foundation for this study since it focuses particularly on stakeholder involvement and incorporates socio-technical aspects of civil engineering projects. To tailor the Odesys methodology to the purposes of this study, a connection was sought in a separate domain, which was called creative collaboration. The elements from the creative collaboration domain function as a possible extension to the Odesys methodology, to further enhance stakeholder involvement.

The first domain, described in Section 3.1, is collaborative asset design. This focuses on the collaborative design of civil engineering assets (in this study datacenters). The second domain, described in Section 3.2, is creative collaboration. The elements described in this domain look into creative methods that can be used to facilitate enhanced collaboration. Then, in Section 3.3, the extension of the Odesys methodology using elements from the creative collaboration domain will be explained together with a diagram of how these domains were defined in distinct elements of this study. This diagram fulfilled a vital role during the rest of this study.

3.1. Domain 1: Collaborative asset design

The domain of collaborative asset design is defined as *studies related to the process of designing a civil engineering asset in a multi-stakeholder setting*. Collaborative asset design can be considered as an element of Engineering Asset Management (EAM). Civil engineering assets are physical assets as part of the (public) infrastructure. This includes buildings, roads, railways, bridges, tunnels and datacenters among others. The design of such physical assets is becoming more complex due to increasing environmental demands and other transitions. So the amount and variety of socio-technical aspects that need to be considered during design is increasing. Due to the increasing complexity of asset design, continuous research into improved decision-making is being performed.

Traditionally, civil engineering projects have been characterized by their focus on functionality and structural integrity. Also, the design process has long been considered a separate process next to construction, operation and maintenance processes. This resulted in a relatively narrow scope during asset design. Due to growing industrialization and an increased demand for buildings and infrastructure (Xu and Wang, 2020) this has shifted towards design optimization mostly with respect to costs (Lin et al., 1982, Ho-Huu et al., 2015, Rajput and Datta, 2020, Zhao et al., 2020). Minimizing material use while maintaining structural integrity of constructions proved to function as an initial integration of optimization in the design process (Tsiptsis et al., 2019). Such design optimization tools emerged by the virtue of improved modeling techniques (Mei and Wang, 2021). More and more advanced models started a trend that more information on all aspects of constructions could yield enhanced predictability, safety, maintainability, sustainability etc. on constructions (Brown and Mueller, 2016, Penadés-Plà et al., 2019). The idea that information on such -ty aspects should be centrally organized underlined the essence of sufficient information systems. Moreover, such aspects should be connected to the design of constructions to further establish this centralization, therefore also broadening the scope of the designs. The essence of information systems in civil engineering asset design lies in their ability to synthesize diverse data and facilitate collaboration among stakeholders. A connection between information systems and the construction design can be made using Building Information Modeling (BIM). BIM centralizes project information within a unified platform to streamline workflows, reduce errors, and improve communication among project stakeholders. Moreover, BIM enables stakeholders to explore scenarios, simulate potential risks, and evaluate alternative design options, empowering them to make informed decisions that align with project objectives. BIM has emerged as a transformative technology in civil engineering asset design, revolutionizing the way projects are conceptualized, planned, and executed. BIM exemplifies the shift from separate design and development process to an integral approach that enriches 3D design visualizations with additional project information such as 4D for time, 5D for costs and higher order dimensions for additional project parameters. The BIM approach enables project stakeholders to visualize such project parameters in a digital environment, which could facilitate better decision-making and collaboration throughout the project lifecycle.

In the light of this thesis BIM can best be seen as a process consisting of asset decomposition, process- and view integration and task reengineering (Van Nederveen and Tolman, 1992 , Liu et al., 2017). Especially when considering collaboration through BIM the latter touches some 'soft' factors of BIM such as organizational and social management during construction processes. The use of BIM has become more common throughout the building life cycle for effective collaboration among construction project participants (Oh et al., 2015). Liu et al. (2017) distinguished eight concepts to enhance collaboration through BIM and explicitly recognizes the importance of such 'soft' factors in addition to the more technical side of BIM in design visualizations. The results of this study showed how incorporating people focused concepts can connect the technological and process focused aspects. Next to this, BIM can be viewed as a socio-technical system (Sackey et al., 2015) because of this combination between social and technical factors. These socio-technical aspects of BIM recognize its implementation in multi-disciplinary organisations. Considering different views of different stakeholders through a socio-technical system perspective, when implementing a BIM process, can assist in the success of a construction project.

Despite the described application possibilities for BIM for the problem defined in this thesis these possibilities were not further researched. One reason is the expertise of the developers in other areas such as optimization modeling and the close relation of this type of design optimization with the defined problem at hand. Another reason is the data heavy aspect of BIM where much in-depth information is needed from Microsoft to develop a comprehensive and extensive model while a mathematical model could be developed more independently.

As described above, information systems show potential benefits in collaborative asset design problems based on design trends in construction projects. From the trend of minimizing material cost through design optimization also another type of broadly scoped design processes emerged. Such methods are commonly known as parametric design, where some design variables are unknown and different values for these variables yield different design configurations[1] which can be evaluated. Such a numerical approach to design opened the door for design optimization techniques which use mathematical and computational methods to find a most optimal design configuration. This way an asset is designed by optimizing for an objective, often some form of monetary attribute of the asset. More complex design optimization problems can incorporate multiple objectives by employing different solving algorithms to the defined mathematical problems. Based on such multi-objective design optimization problems also the Odesys methodology was developed. The Odesys methodology focuses on preference-based decision making, incorporating socio-technical aspects. The fundamentals are based on the work of Barzilai (2010) in Preference Function Modeling (PFM). The use of PFM in the Odesys pertains to the use of specified scales for relative alternative scoring. This overcomes a major shortcoming of most multi-objective optimisation methodologies which do often not consider rel-

[1] Note that parametric design and information systems such as BIM can also be combined

ative scoring of the alternatives among other flawed outcomes. The Odesys covers multi-objective and multi-attribute decisions, meaning it covers multiple preferences from multiple stakeholders as well as multiple co-attributes of the alternatives considered respectively.

The Engineering Assets Management department at the TUDelft has been pioneering with publications about the development of the so-called Odesys methodology (Wolfert, 2023). This methodology strives to provide a practical approach for complex systems design while facilitating a participatory process that connects stakeholder preferences with the systems' performance. Within the socio-technical context of a construction system, the Odesys methodology stimulates multi-objective decision-making. Multi-objective means that multiple objectives normally from multiple stakeholders are included in the decision. During the management of rapidly growing infrastructure networks, the use of optimisation methods with regard to decision-making have been extensively researched (Chen and Bai, 2019). Microsoft's' datacenter development status quo and projected expansions fully align with such infrastructure network growths. It is characterized by rapid expansion rates, high capital investments and complex network and construction aspects (Xia et al., 2017). The latter also encompasses the development of the datacenter structures within the cloud computing network of Microsoft. Effectively deploying an optimisation method to improve decision making during the development of these datacenters thus provides significant potential. Furthermore, the Odesys methodology emphasizes a participatory process. This increases stakeholder involvement in the multi-disciplinary nature of construction projects. This multi-disciplinary nature is also apparent during the datacenter development at Microsoft. As mentioned in Section 2.1 the teams involved at Microsoft range from community and sustainability to energy and design. The increased participation intended by the Odesys methodology provides additional arguments to test its application within datacenter projects at Microsoft since it directly influences gaps found in the current practice as mentioned in Section 2.1.

The Odesys methodology allows for a-priori multi-objective design optimisation. This optimisation means it tries to maximise stakeholder desirability for some values of the variables. It therefore gaps current shortcomings in design optimization methods as described by Wolfert (2023). Firstly, the a-priori aspect of the Odesys, as opposed to a-posteriori evaluation methods, allows to consider all physically possible solutions rather than evaluating a given set of potentially sub-optimal compromise solutions. Please note that even research combining optimisation with a-posteriori evaluation can suffer from this shortcoming (Mueller and Ochsendorf, 2015). Secondly, the specific state-of-the-art optimisation method used in this research is based on the work performed by Van Heukelum, Binnekamp, and Wolfert (2023) which was preceded by Zhilyaev et al. (2022).

The work performed by Arkesteijn et al. (2015) demonstrates how such a preference-based decision-making process can be designed. Additionally, the work of Van Heukelum, Binnekamp, and Wolfert (2023) combined the aggregated stakeholder preferences with asset performance based on mathematical optimisation. The academic goal is to combine these two approaches by focusing on designing the process from which the preference input for mathematical optimisation is gathered, since this is lacking in current literature and making the mathematical optimisation practically applicable.

Focusing on this preference gathering process is important with respect to the quality of the outcomes. The output is not only determined by the optimal design functions, but also on the reflection of human preferences of the input. The need for improvement for the preference input is stated in Wolfert (2023), where a recommendation is done for further elicitation research to arrive at balanced preference functions with corresponding individual preferences as input. In order to focus on the reflection of the human preferences, it is important to ensure that the whole process and the collection of preferences is understandable for people who are not familiar with the above mentioned multi-objective design optimisation. Previous studies on this topic did not specifically address how to foster engagement, participation and cooperation among the various stakeholders.

3.2. Domain 2: Creative collaboration

This section describes two applications in the domain of creative collaboration namely, co-design and serious gaming. These two applications are selected due to a close relation to design and participatory processes.

3.2.1. Co-design

Co-design is a type of co-creation. From an analysis of 11 models of types of co-creation by De Koning et al. (2016), three general criteria are derived to identify the types of co-creation. These criteria relate to the level of collaboration, the amount of benefit or change there is for the co-creating end-user and the moment the co-creation takes place. This thesis strives for enhanced collaboration in design through stakeholder integration and participation. It combines initial designers with other stakeholders and makes these stakeholders designers as well (Stappers et al., 2011). This way more stakeholders can participate in the design to ensure the most successful connection to the end use of the design. Therefore, the level of collaboration is very high. Furthermore, there will be direct value created for the users/participants, while their preferences are gathered and will be used as input. However, this created value will be focused on what the value means for the participants and not for the the greater totality. Lastly, as explained in Chapter 2.1 this study can be best executed in an early design phase. Therefore, looking at the three general criteria in the model developed by De Koning et al. (2016) in Figure 3.1, co-design is used for the execution of this thesis. The principles that have been used in order to stimulate the co-design aspects are elaborated in Section 4.2.1. Additionally, co-design emphasizes the role of the researcher as facilitator in a process (Sanders and Stappers, 2008). Since the aim of this thesis is to facilitate collaboration, co-design is suited as well.

These co-design aspects are of interest to this thesis in two ways. Firstly, the problem this thesis

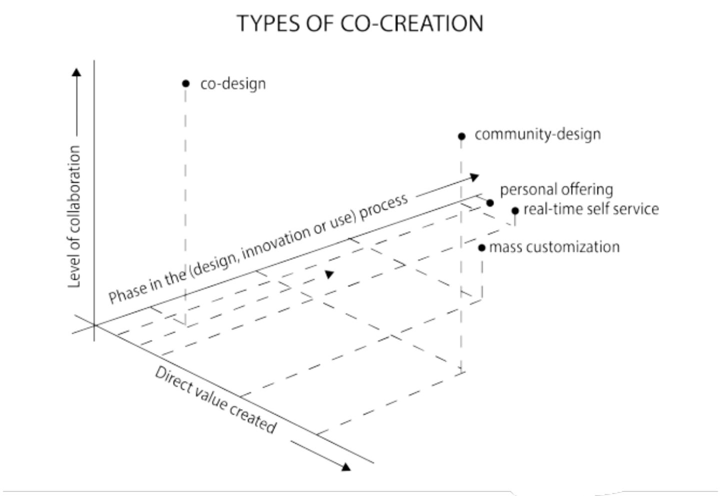


Figure 3.1: Types of co-creation (De Koning et al., 2016)

aims to study concentrates around the design of datacenters and the participating aspects of these design processes. This way the design process of datacenters could benefit from adapting co-design tools and strategies to enhance the collaboration aspect and therefore improve the success of projects. Secondly, this thesis aims to design an interactive collaboration facilitator to work as tool in datacenter design processes at Microsoft. Therefore, this thesis is a design process of itself that could exemplify the main goal its design intends to have. In both, these design processes co-design methods and tools could contribute to fostering improved collaboration. Tools such as context mapping and concept evaluation can be used in a co-design and co-evaluation process (Sleeswijk Visser et al., 2005). More on the use of such tools during this research will be explained later.

3.2.2. Serious gaming

Next to co-design elements also serious gaming is used as a creative collaboration mechanism in this thesis. Regarding the purpose of a serious game Abt (1970) stated that serious games offers risk-free, active exploitation. In this case, participants can review alternative design options of datacenters, without any restrictions or consequences. Serious games have been widely used to deal with complexity (Bekebrede, 2010; Bellotti et al., 2010; Haan et al., 2016; Harteveld, 2011; Meijer, 2012). Awareness, training, and a shared understanding are also the results of serious gaming. Duke and Geurts (2004) described understanding complexity, simulating creativity, improving communication, and reaching consensus, as goals of serious games. A study performed by Heijer et al. (2023) proved that serious gaming creates awareness of complexity and the habits of others. The participants in that study indicated that the serious game contributed to listening to each other and value others' arguments. These goals and results of serious gaming, as stated above, fully align with the goal of this study. Enhancing collaboration during a datacenter design process between different involved teams of Microsoft, considering different teams interests. Additionally, in the current practice communication is limited while datacenters are technologically complex structures including the development process to build them on the pace and scale that Microsoft envisions. Therefore, a serious game was considered to suit the context of this research best.

3.3. Extending Odesys with Co-design and Serious gaming

The aforementioned domains illustrate elements that were used for this thesis. Domain 1, more specifically the Odesys methodology, focuses on collaboration in asset design processes while Domain 2 offers creative methods and tools to facilitate collaboration. For this thesis a connection was established between the two domains where the Odesys methodology will be used as collaborative asset design application, which will incorporate elements of both co-design and serious gaming. The Odesys methodology was chosen due to its strong affiliation with the problem described in Chapter 2 in combination with the expertise of the researchers in this regard. The co-design and serious gaming elements from the creative collaboration domain function as an extension to the current state of the Odesys methodology. It focuses on the social and preference side of the Odesys in the practical context at Microsoft. For the social and preference based side of the Odesys it is essential that the preferences from the stakeholders portray a good enough reflection of their in practice preferences in datacenter projects.

These preferences are the input of the tool and influences the output of the tool; the datacenter design solutions. The more accurate the preference input is, the better the preferences are reflected in the newly found design solutions, which increases the acceptance of the newly design solutions of the participants. Using a tool to find new datacenter solutions together with the participants as part of co-designing, does not only increase the datacenter design acceptance of the different participants. It can also reduce time and costs, while a co-design process decreases the risk of controversy and objections in the implementation phase (Heijne et al., 2018). Figure 3.2 illustrates the added value of implementing a decision using co-design versus an unilateral decision. Co-design is initially more time consuming to get all the participants aligned and engaged to gather all the information before a decision can be made. However, the implementation will be faster, since there is a decrease in the risk of controversy and objections due to the fact that the different participants are already involved and engaged from the start. By applying co-design principles, the project can save time and money.

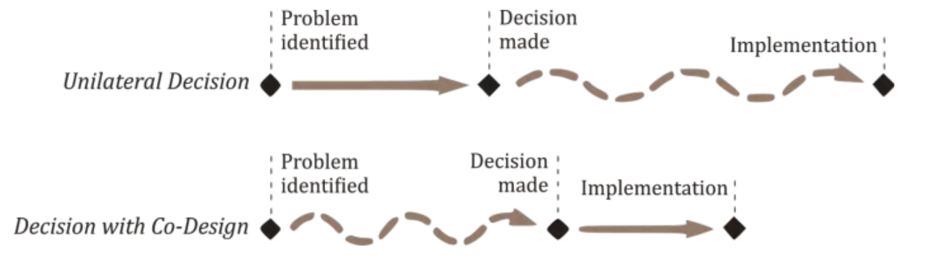


Figure 3.2: Comparison of project duration: unilateral decisions vs co-design (Heijne et al., 2018)

3.4. Research method

To guarantee the quality of the preference part it is important for this thesis to correctly gather, process and translate the preferences into a comprehensible process from a practical point of view. This was executed during the Social Cycle. Next to this, the practical context of the Odesys methodology in this thesis means that tools are needed to understandably process input data, calculate optimized design configurations and visualize the process for the stakeholders in a practically applicable tool. The development of this tool was performed during the Technical Cycle. The Social Cycle and the Technical Cycle distinguish between two equally important but different elements of designing a solution for Microsoft. The Social Cycle and the Technical Cycle are reconnected during the Design Collaboration Workshop (DCW). This measuring moment reconnects the preference input from the Social Cycle with an interactive digital tool from the Technical Cycle, that facilitates a conversation between the stakeholders about the datacenter design problem. During the DCW both the quality of the Social Cycle and the Technical Cycle can be assessed since their intended purposes become apparent during the Design Collaboration Workshop.

Since the DCW functions as a measuring moment for the two cycles it was expected to show the strengths and the weaknesses of the two cycles. Given the importance for the practical use of the DCW, since the DCW is intended for Microsoft's employees, their feedback is crucial for further development of the cycles and the DCW. Including and engaging these employees and integrating their feedback is also part of the co-designing principles. To integrate the wishes and the feedback of these employees into these developments, an iterative approach was adopted. This iterative process can positive effect the exploration of concepts, finding and correcting the flaws, and it enables development under complexity, uncertainty and change (Le, 2012). This iterative approach enhances stakeholder engagement, while their feedback is used after the first iteration, to improve the final design in the second iteration. The feedback is gathered with feedback forms and interviews, that have been sent and held after the first iteration. Using two iterations the Social Cycle, Technical Cycle and the DCW could be assessed midway during the thesis and specific improvements could be implemented to converge to the best end-result. This iterative process also allowed for comparable situations with respect to the verification and validation. Since Microsoft has no prior experience with any of the methods and tools used in this thesis the first iteration functions as a benchmark to assess the final (second) iteration of the cycles and the DCW. In Figure 3.3 a visualisation is given of the Social Cycle and the Technical Cycle which are reconnected in the DCW for two iterations. The overall method is an iterative approach including feedback collection of the participants. However, for the Social Cycle and the Technical Cycle more specific methods have been used. For the Social Cycle this is elaborated in Section 6.1.1 and 6.1.1 and for the Technical Cycle this is elaborated in Section 6.2.1 and Section 7.2.1.

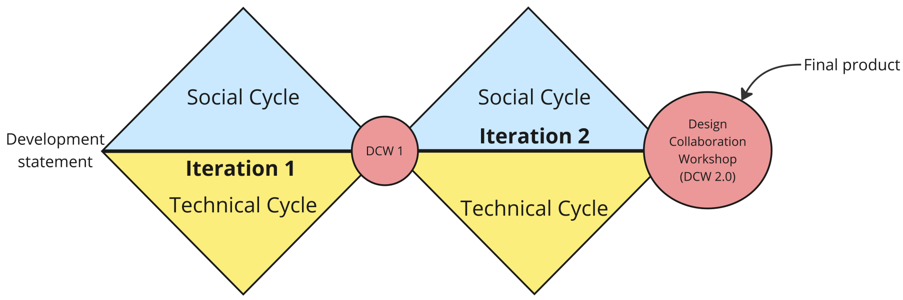


Figure 3.3: Visualisation of the development process

3.5. Research questions

Next to the defined development statement in Section 2.2 a main and sub-research questions were formulated based on the theoretical background described above. These research questions portray the extensions to the current Odesys methodology that are being proposed as well as highlights the practical side of the problem at Microsoft. The main research question is formulated as:

How can the use of an interactive tool facilitate stakeholder collaboration during a datacenter design process?

Based on this question, especially in the light of developing the Odesys methodology some sub-questions are defined:

- *How can stakeholders be engaged during the whole process?*
- *How can the level of the reflection of human preferences be improved when*
- *How can the preferences be collected from the participants?*
- *To what extent can the Odesys methodology stimulate stakeholder collaboration?*
- *What model performance criteria determine successful stakeholder collaboration?*
- *How can Odesys be connected to an interactive Graphic User Interface (GUI)?*

4

Needs and design requirements

This chapter describes the needs and requirements. The needs illustrate a feasible future world, within the scope of the study, that is desired. The development statement that has been defined in Section 2.2 arises from a practical need at Microsoft, namely to improve collaboration between teams in order to improve the datacenter development process. In addition to this practical need, this study also researches several academic needs based on the context described in Chapter 3. These academic needs can also be considered as deltas or improvements to the current academic state-of-the-art regarding the Odesys methodology. The relevant needs for this study are described in Section 4.1. The requirements specify a set of deducted performance criteria, metrics, or heuristics upon which a proposed design solution is evaluated. The requirements used during design evaluation in this study are described in Section 4.2.

4.1. Needs

This section elaborates on the needs for each of the two cycles and the DCW. The separation of these cycles is explained in Section 3.3. Initially, the most broad need of the DCW is described in Section 4.1.3. Then, the more specific academic needs or deltas are described for the Social Cycle in Section 4.1.1 and for the Technical Cycle in Section 4.1.2.

4.1.1. Needs Social Cycle

The needs for the Social Cycle focus on the level of good reflection of the human preferences as part of the Odesys. Wolfert (2023) highlights the importance for a process that guarantees this level of good reflection. This need of good reflection of human preferences is divided into two parts. Firstly, to achieve a good level of reflections participants should be able to express their preferences whatever these may be. This means there is a need to allow for any type of preference, more specifically preferences curves without limiting the stakeholders to fit some pre-described curves to their in practice preferences. There is a need for a format that is as free as possible and therefore allows stakeholders to define a curve that fits their preference. Secondly, the need for a higher level of good reflection of preferences induces a need to enable stakeholders that are inexperienced with the Odesys methodology to express their correct preferences. Therefore it is essential that the stakeholders understand what their preference represents with respect to the outcomes. The current Odesys methodology is practically considered complex undermining the participative aspects with the stakeholders, this is further elaborated in Section 6.1.1.2.

4.1.2. Needs Technical Cycle

The needs for the technical cycle are separated into two parts: 1) understandability and 2) utility. The former entails the need for an understandable tool connected to MODO. Such a tool enables better implementation of the MODO theory in practice, which is necessary for implementation at Microsoft. To maximize the practical impact of a tool, understandability of the theory, its use and opportunities is important. Next, also the utility of a tool is important for a successful implementation into a current practice. Once the theory, use and opportunities are understood stakeholders must be able to start using a designed tool. To achieve this collaboration the digital tool, as a product of the technical cycle, intends to function as a conversation facilitator. Therefore, the utility of the tool focuses on the conversation facilitating level of the digital tool during the DCW.

4.1.3. Needs Design Collaboration Workshop

Considering this shift Microsoft needs to take socio-technical factors into account as well as they are expanding their datacenter supply. A lot of different teams of Microsoft are involved in the datacenter development process and those teams cover such factors. In several EMEA projects the standard does not adequately incorporate the necessary socio-technical aspects. The teams involved need to collaborate in order to find the best datacenter design solution and look beyond their own interests and drivers. An improvement in this collaboration is needed. In the current practise it was also noticed that teams were not aligned on how certain design choices influences datacenter development delays and objections. These delays and objections result from not taken all socio-technical aspects properly into account. To overcome this, an improve the collaboration between the teams is needed. As stated in Section 2.1 teams need better insights in each other's preferences and reasoning on certain design variables. Additionally to stimulate real collaboration and decision making, these insights need to be used to converge to some consensus design solution, taking into account more than only time and costs. In order to achieve this, an interactive product that can facilitate stakeholder collaboration to find consensus during a datacenter design process has been developed.

The end need is to increase the collaboration between the teams within Microsoft and to enhance datacenter design solutions considering different socio-technical aspects. Teams need to gain insights into each other's preferences and how that can change if the circumstances change. In the end the goal is to find new datacenter design solutions to fulfill the need of better collaboration between teams resulting in having considered multiple teams interests that reflects different social-technical aspects in the design solutions. This will be the focus of the mixed cycle, where the social and technical cycle are coming together.

4.2. Requirements

During the development of the cycles, there are some requirements that needs to be met. This section focuses on the requirements on for the Social Cycle in Subsection 4.2.1, for the Technical Cycle in Subsection 4.2.2 and the requirements for the DCW are stated in Subsection 4.2.3.

4.2.1. Requirements Social Cycle

In order to execute the Social Cycle, there are certain requirements established to create an approach to collect the preference curves from the participant and keep the participants engaged. As mentioned earlier and in the literature review section, the use of Odesys and MODO did not involve any focus on stakeholder engagement and collaboration. The research significantly depends on the participants in the process. The participants are important in the collaboration between the teams, but also their expertise and experience are needed to make the DCW and the interactive tool fit for purpose. Furthermore, the input that will be gathered from the participants is also used to test the tool. For these reasons general principles for the Social Cycle have been drawn up, to have a foothold of requirements to increase the willingness to participate and collaborate. These principles are the basis for the participants' engagement and some are linked to co-design aspects . They can be divided into three main principles.

The first one is emphasizing the participants importance in this research, by stating that their expertise and experience is really useful for contributing to the design of the DCW and that it is really valued (Mattelmäki and Sleeswijk Visser, 2011). To make this more practical this means there should be room created to listen to their experiences, and there should be shown to them that their input actually is considered and can influence the content and the design of the DCW.

The second principle is that there should be a buy-in for the participants. Generating a buy-in for the participants is central to ensure that the DCW fits within the current practise and the systems in which they are going to be embedded (Hickey et al., 2018). Furthermore, a buy-in can contribute to the willingness to participate while the stakeholders also benefit from the DCW and are more likely to put time and effort into it. To create these buy-ins it is necessary to know what their interests are and when the DCW will be successful for them. Using these buy-ins in the design of the DCW, there will be value created for the co-creating end-user.

The last principle is keeping the participants engaged, to increase the willingness to participate and increase level of collaboration. The high level of collaboration is important for the co-design aspect. Keeping the participants engaged can be divided into three different principles: keep the participants informed, create an emotional connection, and let them foster a positive experience. In order to foster a positive experience Csikszentmihalyi (1990) drew up eight conditions when performing a (creative) task. These principles are integrated in the principles of the Social Cycle. These principles are: set a clear goal, a challenging task, a clear vision, the feeling that the task can be completed, participants' skills are fully utilized, participants are able to concentrate, the feeling of control of the situation and receiving immediate feedback. A complete overview of the Social Cycle principles, that is used as basis of the Social Cycle, is given in Figure 4.1.

4.2.2. Requirements Technical Cycle

The requirements for the technical cycle entail the performance of the digital tool that will be used during the DCW. Since the performance of the digital tool partially overlaps with the performance of DCW the same literature will be used to define a set of metrics for evaluating the performance of the digital tool. This literature is collected by Heijer et al. (2023) and Sweetser and Wyeth (2005). Note that the metrics for the digital tool do differ from the metrics for the DCW, as described in Section 4.2.3 below. The metrics for the digital tool are focused on the visualisations of the information needed for the DCW and facilitating the DCW flow. Table 4.1 below shows the selected metrics for the digital tool.

Table 4.1: Digital tool metrics with their definition

METRIC	DEFINITION
Feedback	The tool gives interactive feedback based on decisions of participants so they can change tactics together.
Increasable	The tool increases in difficulty with growing participant's ability.
Immersion	Participants experience periods of deep involvement in group play.
Control	Players have a sense of control to implement their actions, decisions and strategies into the tool.
Scalable	The tool is scalable when it is widely accessible, implementable, and easy to moderate.

4.2.3. Requirements Design Collaboration Workshop

To stimulate collaboration between the different teams, a serious game set up was used. Serious gaming combines a serious purpose with elements of gaming (Heijer et al., 2023).

To successfully design a serious game that fosters the most foreseen impact, much research literature lists some characteristics of effective serious games (Pavlas et al., 2010; Ferrera, 2011; Zhou et al., 2016; Diepersloot, 2019). These characteristics were combined into a single taxonomy of six characteristics and used on a case study by Heijer et al. (2023). Next to this, similar characteristics have been proposed aimed at fostering game flow and learning within games (Sweetser and Wyeth, 2005) and more specifically digital games (Fu et al., 2009). This extension to the digital serious game domain, of particular interest in this research, was compared and redefined in the work of Bachen and Raphael (2011). The literature comparisons can be found in Appendix F. Based on this literature seven serious game metrics were defined for this research. Table 4.2 below lists the seven metrics and their definition based on the mentioned literature. Note that other serious game frameworks were considered for this research (Harteveld, 2011; Avila-Pesantez, 2017), but none aligned as well with this research and were therefore abandoned.

Additionally, there were two extra requirements that needed to be complied with in order to design the serious game. First of all, the serious game needs to be held online, since the teams are spread

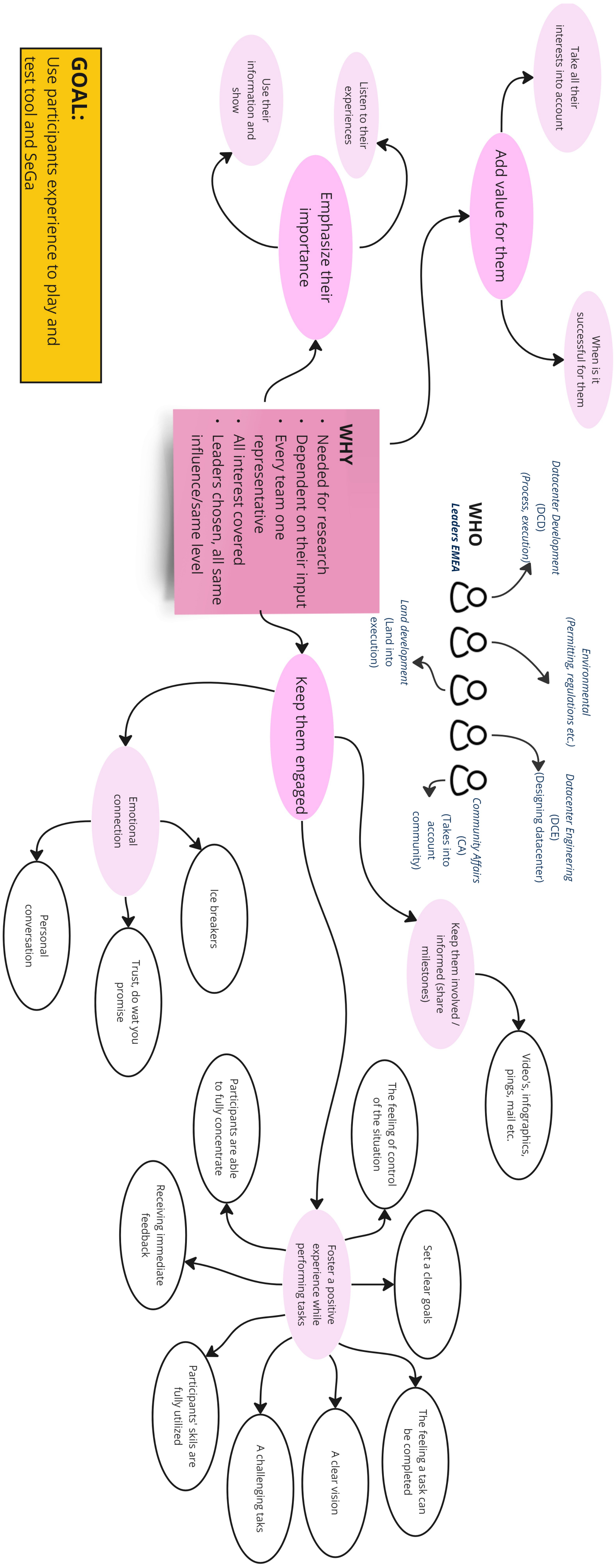


Figure 4.1: Social Cycle principles

all around Europe. Secondly, the serious game cannot take longer than one hour, otherwise it would be too time-consuming for the participants.

Table 4.2: Serious game metrics with their definition used in this development

METRIC	DEFINITION
Valuable	The game and the results contribute for the participant's daily practice within Microsoft.
Collaborative	Participants experience periods of deep involvement in group play; participants recognize clear and authentic goals that can only be achieved by a group; participants sense that goal interdependence is matched with reward interdependence.
Feedback	The game gives interactive feedback based on decisions of participants so they can change tactics together. Also the participants give feedback to each other during the game.
Simulative	The game events selectively represent an accurate depiction of reality.
Respect	Participants can not have the feeling there are personally attacked. Participants have a sense of control over their individual decisions, their groups' strategies, actions within the game, and their group's influence on the game.
Challenge	Participants perceive challenges of different levels that match the group members' collective knowledge and skills, including their collaborative abilities.
Scalable	The game is scalable when it is widely accessible, implementable, and easy to moderate.

5 Case Study

Now that the needs and requirements to evaluate solutions are clear an experimental test set-up is required to apply a solution. Given the context of the problem for this study a representative datacenter case study was selected. Such a case study allows for the application of the methods to test solutions filling the development gap, accentuate engaging the involved participants and emphasize the practicality of the Odesys. It is worth mentioning that given the current problem at Microsoft, as described in Section 2.1, that EMEA projects face a wide variety of socio-technical aspects per project. Given the scale of the variety however and the focus on developing an understandable solution this thesis opts to select one case study as initial proof-of-concept. Additionally, the case study was used to give the participants context to define their preferences on datacenter design variables.

The selection of this datacenter that has been used as is described in Section 5.1. Subsequently, participants for this study have been selected in Section 5.2. Additionally, the case study context is explained in Section 5.3. In Section 5.4 the explanation of the selected design variables together with their bounds are stated. Since the datacenter case study is classified as confidential, the name, location and details will not be mentioned in this report.

5.1. Datacenter selection

A considerable amount of research was done before a decision could be reached to identify the appropriate case study. Various meetings of different (new) located datacenters were attended, and multiple cases were read through all the related documents to get a good understanding of the cases and the processes that come along. Having reviewed this, there were three different possible case studies established:

1. A fictional datacenter case study
2. A datacenter in construction phase
3. A datacenter in the beginning of its design phase

The advantages of choosing a fictional case study includes the absence of confidentiality concerns, enabling the entire research to be published after finishing the research. Additionally, it would facilitate discussions with fellow students and researchers about certain decisions as the information is not classified. However, using a fictional case study could cause a gap between theoretical scenarios and real practice within Microsoft. Participants might not feel engaged since it doesn't involve real decision-making. This will not benefit the willingness to participate, which is one of the goals of Social Cycle. This lack of engagement can also negatively influence the accurateness of the preference reflection of the participants. Since this is also a crucial aspect of the Social Cycle – obtaining good human preferences input for the DCT based on the participants preferences. It has been decided not to select a fictional case study.

The second option is to choose a datacenter that is currently under construction, specifically focusing on the one that is being built in Amsterdam. Choosing this location, which is in the same country as our team and supervisors, offers advantages like visiting the site easily, knowing the people who are working there and having a better understanding of the country and site context. In a case that is already under construction, most design choices are already made. This provides a benefit of using it as a validation for the DCT. The outcomes of the DCT can be compared with the decisions made during the datacenter design process. Subsequently, participants can be asked about whether the DCT outcomes present a realistic and better solution or if it doesn't and the outcomes are not useful for the process. The reason for not choosing this case stems from its political sensitivity and significant media coverage in the Netherlands. Decisions regarding this datacenter are partly influenced by uncommon external factors. Using this as a case study will not accurately represent the typical datacenter development process at Microsoft. The impact of these external factors on participant preferences on design choices would make the case too specific and deviates from its usual practice.

The third option is to select a datacenter which is in the initial stage of development. The main condition is that there should be some information available about the site, to define a context that participants can use to define their preferences. Therefore, a case which has already successfully passed the feasibility and charter phase will be best suited for this. Passing those phases means that there is information available about site due diligence (background study on a lot of different aspects), the project scope and test fits that have been done to get an idea of the standard of the datacenter. Additionally, the project has also gotten a go, so they are sure the project will be executed. After these phases the project enters the design phase, where factors such as zoning requirements, permitting, power and network agreements and the adjustments of datacenter design will be identified. As a starting point, Microsoft works with an EMEA standardised datacenter design, that they adjust to a specific site context. If the project is in an early stage of the design phase, modifications to the standard design are possible and still needs to be made to align them within the site context. Choosing a datacenter in this phase enables the DCW to contribute to facilitating collaboration between the teams to find the optimal design for the datacenter, with the option to actually implement those design choices. The biggest advance of this is that the DCW can be designed to contribute to the current practice of Microsoft. This was the decisive factor to choose a datacenter at the start of the design phase.

During the selection of the case study there was one case that was exactly at that stage and aligned with the thesis planning. This case will be called **DC2023** due to confidentiality reasons.

5.2. Participant selection

To facilitate collaboration between the teams of Microsoft, representative participants of these teams are needed to reflect the socio-technical preferences for that team. The choice of which teams are participating in this study is already explained in Chapter 2. Representative participants are operational experts within their team but with a decision-making mandate on datacenter projects. Therefore, the directors of the selected teams within the EMEA region were selected. These are the directors of the Land Development Organization (LDO), Environmental (ENV), Datacenter Design (DCD), Datacenter Engineering (DCE) and the Community Affairs (CA) team. With this team's selection, different interests and different socio-technical aspects are covered for this specific case study, however more broadly these teams can be considered core contributors to datacenter designs. A reason behind choosing these participants is because they are at the same level of hierarchy within the organisation. Therefore it minimises the chance of hierarchical barriers and power struggle. Another reason for choosing these EMEA directors is because of their expertise and experience. Additionally, they are decision makers with decision power to influence datacenter projects both operationally (top-bottom) and to higher leadership (bottom-up). These participants and other colleagues that were interviewed during the first weeks, to identify the project, but not selected received an info graphic about the direction of the research (Appendix A). The selected directors got an invitation with the question to participate. This was also done using an info graphic (Appendix B) together with a text message. They all agreed and were willing to participate in this study.

5.3. Case Study context

Access was granted to look into the Case Study project information. This included information about the permits needed, zoning requirements, community risks, specific location details, the Site Due Diligence (SDD) report, project definitions, project schedules, costs, and capacity. In addition to this information, several meetings were attended on the project progress with local colleagues. Based on the available information with regard to the Case Study, the important socio-technical aspects for this project were selected. The relevant information with regard to the Case Study will be described below. Note that this information was also used as the script for the context video that was sent as an introduction to the participants. In Figure **redacted due to confidentiality** the site plan can be found. The textual description of the site is redacted due to confidentiality. The description of the case study continues with the community priority score.

A community priority score has been calculated. This score indicates some important community risk factors to highlight the current license to operate and anticipate what impact the community can have on the dc development.

Risks that are identified which have a **medium** impact are:

Complexity of permitting: The new required zoning plan is not entirely approved yet. Also, sustainability requirements are not concretely specified by AHJ. Lastly, three permits are required with long assessment phases.

Power of individuals: The immission permit has a public consultation period. During this period people and NGOs can object. Therefore, individuals have significant power over permitting delays.

Proximity to residential zones: Due to residential area nearby, generator operation hours need to be significantly limited due to nitrogen oxides immission regulations. Also noise mitigation is likely to be required but not expected to be complex.

Additionally there are some risks that have been identified as **high** risks;

DC Design: The height of the datacenter can be max. 16 meters high in current zoning meaning proposed DC capacity cannot be achieved. Next to this, there are no built areas in places along the sites' boundaries. AHJ has sustainable design aspirations. However these are not clarified. Also, aesthetics are important according to AHJ.

Environmental issues: From internal experience environmental NGOs can be influential in the region impacting both design and permitting phases. AHJ currently does not have enough capacity to provide sufficient water supply. AHJ announced it will be upgrading this in two years to meet Microsoft's demands.

Based on the information above, several critical, project specific socio-technical aspects could be retrieved. This information was also used to define the design variables. These design variables are the controllable degrees of freedom in the datacenter design. This means that the values of these variables can still be altered and these are therefore suitable as input for the mathematical model. A set of specific values for each variable make up one design configuration. The selected variables span a n-dimensional space where n is the number of variables. Within the boundary constraints of these variables lie the feasible design solutions. Outside the bounds the solutions are infeasible. The next section will describe which variables were chosen based on the Case Study context information.

5.4. Design variables selection

Analyzing all these documents and having meetings with the local project group, the design variables of the case study were defined. Additionally, a meeting with the design project manager of DC2023 was setup to define the variable values as a result of the current design practice, known as the standard design. These standard design values are used as a reference point to compare the design solutions found after optimization. The selected design variables with their boundaries are:

1. **Height of the datacenter**
   The height of the datacenter was discussed multiple times during the meetings. While the zoning allows a 16 height of some teams prefer to have a higher datacenter, to increase capacity. Other teams do not want to build higher then 16 meters due to a risk of permitting delays. The lower bound is set at 15 meters, while that is allowed by the zoning and the authorities. The upper bound is set to 30 meters, the highest multi-story datacenter design.

2. **Location of second access route to the site**
   The location of the second access was still unclear, while some teams wanted this location at 180 degrees, other teams preferred it around 270 degrees and the AHJ recommended it at around 350 degrees. See Figure **redacted due to confidentiality** for an overview of the site plan of DC2023 and the corresponding degrees. The bounds for this design variable are set between 180 and 360 degrees, since there is no road from 0 to 75 degrees and there is already an entrance between 90 and 180 degrees.

3. **Amount of PV panels on the roof**
   PV panels are also a topic of discussion within the different teams of Microsoft. Some teams are in favour of placing a lot of PV panels, some are against this and some teams only want the datacenter building partly covered with PV panels. The lower bound of this variable is set at 0. The upper bound of this variable is set at around 73.000 square meter, while this is the total surface of the whole datacenter DC2023.

4. **Amount of green walls**[1].

5. **Amount of ecosystem enhancements**
   Ecosystem enhancements contains enhancements that fit the design into the ecosystem of the location of the datacenter site. These can be native landscaping, tree scaping, placing green walls, storm water run-off etc. The lower bound is set at 0, if there will not be an ecosystem enhancement applied. The upper bound is set at 8, since that is the current maximum that they are using. Figure 5.1a shows a datacenter with only a few ecosystem enhancements. Figure 5.1b shows a possible future example of including a lot of different ecosystem enhancements in the datacenter design.

(a) Datacenter design with no ecosystem enhancements

(b) Datacenter design with a lot of ecosystem enhancements

[1] This variable has been removed after the first iteration, since green walls are part of the ecosystem enhancements, and therefore left out

The values for the standard design are:

1. **Height of the datacenter** The standard height that is used for the datacenter is **15 meter**. This contains two floors, without taking into account the height of chimneys.
2. **Location of second access route to the site** For the location of the second access route, there is no standard location. This differs per site. The established location in the first design of DC2023 was to have the access route at **187 degrees**. However, this was still under discussion in the SDD.
3. **Amount of PV panels on the roof** Microsoft uses in the standard design only PV panels on the roof on the admin blocks. These are only a small part of the whole datacenter block. For this case, it means that there would be **3408 square meters** of PV panels on the roof.
4. **Amount of ecosystem enhancement** The standard amount of ecosystem enhancements used by Microsoft is **2**. In most projects some landscaping is done by planting some trees for example and some other minor enhancements when not specifically requested by the AHJ. However more ecosystem enhancements as part of the biomimicry package require significant investments.

6

Iteration 1: Design and Performance

This chapter describes the first iteration for the Social Cycle, Technical Cycle and the first DCW. The methods, design and performance of the Social Cycle is elaborated in Section 6.1. Then the methods, design and performance of the Technical Cycle are discussed in Section 6.2. Section 6.3 delves into the first development and performance of the DCW. As explained in Section 3.3, this thesis contains two iterations in total. Figure 6.1 schematically shows this process. During the coming two chapters this schematic will gradually be filled in corresponding sections.

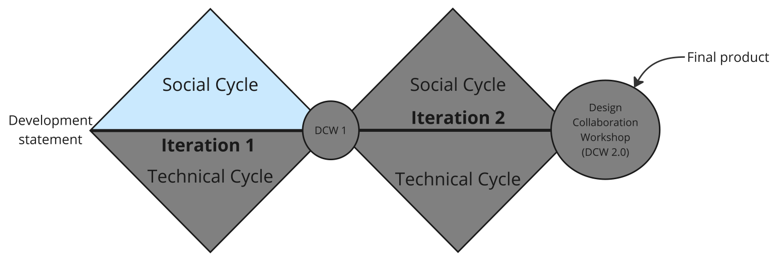


Figure 6.1: Iterations process overview

6.1. Social Cycle development

The key objective of the Social Cycle is to enhance the representation of human preferences in the preference curves and explore more deeply how to improve this, including considering stakeholder engagement. The reason for this is that previous research about the Odesys methodology and MODO did not adequately investigate on stakeholder engagement, and in particular there was no focus on how the stakeholder preferences are reflected. Furthermore, it is stated that this reflection of human objectives and preferences requires improvement (Wolfert, 2023). First, the methods that are used in order to reflect these human preferences in the preference curves are explained in Section 6.1.1. Then the design of the Social Cycle approach is described in Section 6.1.2. Accordingly, the performance of the Social Cycle is discussed in Section 6.1.3. Then the verification and the validation have been executed and can be found in Section 6.1.4 and Section 6.1.5. Based on all this information, an improvement suggestiona are made in Section 6.1.6.

6.1.1. Methods Social Cycle

In order to collect the preference curves that are reflecting good human preferences, 1-on-1 meetings have been held, and deviations from the former PAS method to collect preference curves has been made. Figure 6.2 gives an overview of the approach to collect the preference curves during the Social Cycle. This approach will be explained in this section. Before diving deeper into the methods used, an explanation will first be given on what a preference function is, in Section 6.1.1.1. In Section 6.1.1.2 a more detailed description of the current PAS method and Odesys methodology is given, regarding preference functions. That Section also contains the deviations made in this study from the PAS method and the Odesys method. Section 6.1.1.3 discusses the method on how to collect these preference functions from the participants.

Approach preference curves

- Collect preference curves on direct design variables
- Participant can fill in a preference curve for every design variable
- Participants can draw their preference curves freely in an online board
- Use 1-on-1 meetings to collect the preference curves
- Use Thinking-Out-Loud method while the preference curves are drawn

Figure 6.2: Overview of used methods and approach

6.1.1.1 Preference function example

Before diving deeper into the methods used, first a simple example of a preference curve is given, to understand how a preference curve looks like. Figure 6.3 shows a straightforward preference curve. It shows a preference for the height of a building. On the x-axis the design variable is stated; the height in meters. The lower bound is set at 2.5. This means that the building must be at least 2.5 meters high. The upper bound is set at 20, that implies that the building can have a maximum height of 20 meters. On the y-axis the preference is stated. Zero signifies that this is the least favorable option and hundred signifies the most favorable option. According to the preference curve shown, it can be concluded that this person prefers a taller building.

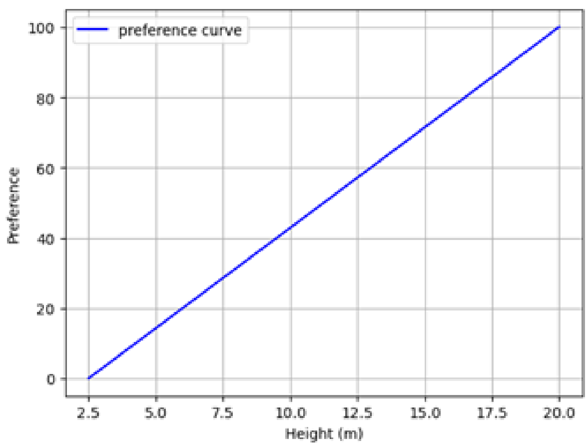


Figure 6.3: Example preference curve

6.1.1.2 Deviations former method

In order to improve human reflection in the preference curves and to fulfill the needs for the process to be understandable for also non experienced MODO and Odesys users. There have been deviations from the PAS method from Arkesteijn and Binnekamp, 2013 and the Odesys methodology for defining and collecting the preference curves.

The original Odesys methodology uses objective functions to define capable object performance, based on a set of controllable variables. For example consider a bridge design with two stakeholders: 1) the municipality concerned about the costs, and 2) waterway concerned about the waiting time when the bridge is closed. Two design variables are taking for this example: X1) span of the bridge, and X2) clearance height of the bridge. The municipality wants the costs as low as possible, which becomes the first objective function. The costs are determined by the span and the clearance height. The higher the span and clearance height, the higher the costs. The waterway wants to have the waiting time as low as possible. Both span and the clearance height have an influence on this. The waiting time will decrease, when the span and the clearance height are bigger. The objective for the municipality will be to minimize costs, and the objective for the waterway will be minimizing the waiting time. When those objectives are defined, the preferences for these different objective functions can be collected. In previous literature from Arkesteijn and Binnekamp (2013), Arkesteijn et al. (2015), Arkesteijn (2019), a preference-based accommodation strategy (PAS) was used to execute this. The second step of the PAS method involves rating the decision maker's preference for the objective function. This defines a curve based on three points. They define a bottom preference, for the value that is least value and a top preference, for the value that is most valued. Additionally, the stakeholder rates an alternative relative to the bottom and top points.

This development examines how to enhance this method to better reflect human preferences. Several different methods were explored to determine if alternative approaches could be used to collect participants' preferences. One of them was a quantitative method; q-methodology. Which is a method to determine common perspectives from people instead of variables (Watts and Stenner, 2012).This will also automatically identify the different viewpoints among the participants. Diving deeper into this method, reading the guidelines to execute this method (Kroesen and Cuppen, 2012) and discussing this with the author and associate professor, it has been decided that this method is not entirely suitable for the purpose of identifying the preferences of the participants and fitting them in into the needed preference curves. After all, it was decided to stay closer to the original methods and make adjustments on the original PAS procedure. To improve the reflection of a good human preferences, there have been three significantly deviations from the above mentioned methods.

The first deviation is using **direct preferences on design variables** to define stakeholders preferences. While the original methodology uses objective functions to define capable object performance, based on a set of controllable variables, in this study it has been chosen not to. As in the bridge example, it is clear how the span and clearance height are influencing the objectives of the two stakeholders. In the problem related to this study this is unclear. Therefore, the first version of the DCT directly maps these variables in the desirability domain as preference functions. How this mathematically influences the model can be found in Section 6.2.1. This deviation is necessary because the impact of the variables on the objective functions are unclear. There is a lack of consensus among the various teams within Microsoft regarding the effects of some variables, such as installing pv panels, on the objective time. While some teams argue that this increases the time required, others contend that it reduces the community's opposition and hence avoids delays. Therefore, they view it as a positive influence on time. Collecting preferences directly on the variables overcomes the mathematical problem in the original method when the sign of a variable's influence is uncertain. Additionally, this direct preference curves on design variables can contribute to stimulate the talk on how the design variables influences certain objectives. This is done during the DCW.

The second deviation from the PAS method is the possibility for the participant to **fill in a curve for each variable** and not only for one or a few. The reason for this is that the interviews revealed that the participants had strong opinions on many variables. However, they were free to not fill in a preference curve on a variable, if they did not wanted to.

The third deviation is the use of the **free drawing method**. Where the PAS method uses three point system, as explained in the first paragraph. In this study, each participant has to draw their own preference curve for each variable by hand in an online environment. A benefit of allowing the participants to draw a curve themselves is that they can express their preferences without any constraints and create a curve that matches their desires the best. Moreover, this makes the curves easier to comprehend because they can draw them as they wish, and not have to conform to a specific format. This allows for more flexibility and more specific curves. These three deviations will be implemented when the preference functions are collected from the participant.

6.1.1.3 Method 1-on-1 meeting

The 1-on-1 meeting is a method that involves a meeting containing two individuals. In this case the meeting contains an individual session between the participant and the one who is collecting the preference curves. The selection of the participants is explained in Section 5.2. Every 1-on-1 meeting took half an hour, and all 1-on-1 meetings have been scheduled in the same week. There were five participants, so there have been five 1-on-1 meetings held. The meetings were held online via Microsoft Teams, since a lot of participants are based in separate countries. The meetings have all been recorded. The 1-on-1 meeting does not only include the collections of the preference curves, but also includes two built-up exercises. These are elaborated in the next Section 6.1.2. The exercises were executed using an online Miro board, while the participants took over the control of the shared screen during the meeting. The "Thinking-Out-Loud" method, which has been widely researched and applied by psychologists and educators, will be used during the 1-on-1 meeting. Participants are being asked to think out loud and speak their mind while executing the different exercises during the 1-on-1 meeting. In case the participants have a real difficulty to speak out loud, a discussion guide has been drawn up which includes stimulated questions, see Appendix C. During the 1-on-1 meeting, the most important exercise was the exercise were the participants needed to draw their preference curves for the different design variables. This preferences curves are the focus of the Social Cycle. These collected curves will be further used in this study as input for the DCT and DCW. An example of these collected preference curves can be found in Figure 6.4. Section 6.1.1.2 will elaborate on the collection of these curves. After the 1-on-1 meeting, the participants received an online feedback form with some open and closed (5-point Likert scale) questions about the 1-on-1 meeting, to see whether the meeting has achieved its goals.

As a result of these 1-on-1 meetings, there were recordings of the meetings available where the participants thought out loud while executing the exercises. Furthermore, the preference curves of the participants had been established for the different design variables. The preference curves will be validated by analysing participants thoughts and expressing during the 1-on-1 meeting using the recorded meetings. Looking at the preference curves to see whether the preference curves are reflecting these thoughts and expressions, by looking at the top, bottom and turning points of the curves. This will be done in Section 6.1.5. The results of the feedback forms were filled in by every participant. The questions and the feedback can be found in Appendix E. These results will be used to verify to what extent the 1-on-1 meetings have achieved its goals, in Section 6.1.4.

The reason for choosing the 1-on-1 meeting is because a lot of attention and time can be devoted to the participant and this can bring out detailed information (Sleeswijk Visser et al., 2005). A further advantage of this set up is that the participants are not together during the meeting, so they cannot sway or pressure one another. They have a "safe space" to express their views freely. However, a disadvantage is that it is more time-consuming for the ones who are facilitating all the 1-on-1 meetings, while more meetings need to be hosted, then collecting them during one collective session.

The reason for choosing the Thinking-Out-Loud method during the 1-on-1 meetings, is to gain more than explicit knowledge. Four types of knowledge about experience can be distinguished, as shown in Figure 6.5 (Sleeswijk Visser et al., 2005). This research aims to get good insights into the preferences of the participants which means that obtaining tacit knowledge of the participants will be very helpful to

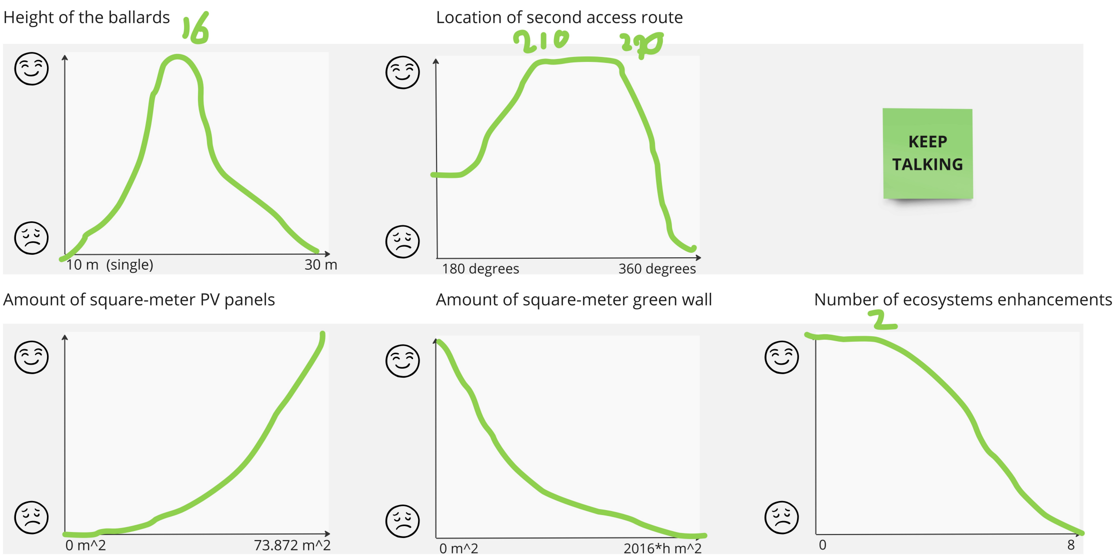


Figure 6.4: Example of input collection, *drawing preference curves*

get insight in unmet needs, aspirations, and dreams for the future. Olson et al. (2018) stated that using the Thinking-Out-Loud method is one of the most effective ways to access a higher-level thinking processes. This can be used to get a better understanding of participants' views, but also participants are more aware of their own thinking and trade-offs, which can improve the reflection on their preferences. Therefore, the 1-on-1 meetings have used the Thinking-Out-Loud method.

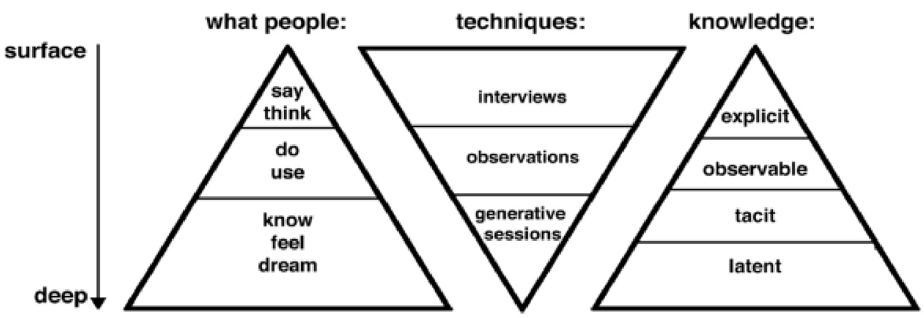


Figure 6.5: Different levels of knowledge about experience (Sleeswijk Visser et al., 2005)

6.1.2. Design Social Cycle

The Social Cycle does not only contains the 1-on-1 meetings. The Social Cycle already started right after the participant selection, to make sure the participants were willing to participate during the whole process. During the whole Social Cycle, there were multiple contact moments with the participants through mails and Microsoft Teams to keep them updated and engaged during the whole process. Not every mail or text will be described in the design of the Social Cycle. This would be too time consuming and too detailed. The design of the two main elements of the Social cycle will be discussed in this Section. An overview of this can be found in Figure 6.6. In Section 6.1.2.1, the content of a video that was sent to the participants will be explained together with the reason why this was made. In Section 6.1.2 the design of the 1-on-1 meetings is described. During the design of these elements the Social Cycle Principles as stated in Section 4.2.1 are kept in mind to make sure these principles are used in the design.

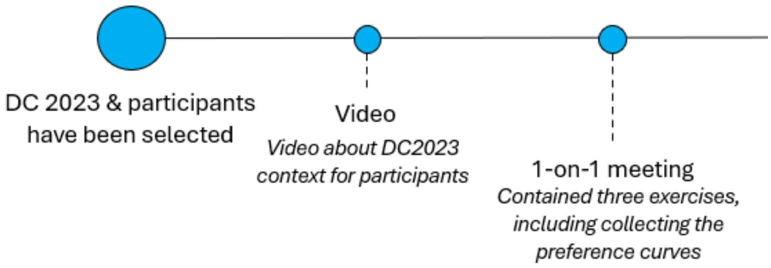


Figure 6.6: Overview Social Cycle iteration 1

6.1.2.1 Design of the video

In order to collect the preference in the 1-on-1 meeting, first the participants are needing a context to be able to actually define their preferences. As described in Chapter 5, a case study was selected including the design variables, where the participants needed to draw a preference curve for. The collection of the preference curves are partly depending on how well the participants are informed and communicated with about this case study context. Therefore, the Social Cycle included a video to inform the participants about the selected case study.

The participants are going to be asked about their team's preferences regarding the selected design variables. The participants' preferences depend on the location and the case, so they need context related to the case study before they can define them. The participants are not directly involved in this specific project, but they are the leaders of the teams across the EMEA region, so they may not know all the site details. Therefore, it is important to have them well informed on the context, so they can define their preferences on the design variables in this specific case. The most accurate input can be collected when the context will be explained clearly. An investigation has been done, by going through all the related case documents within Microsoft and interviewing the people on this specific project. This information is filtered and the most important information has been selected to use as context for the participants. The selection of the most important information on this DC2023 context can be found in the classified appendix CD.

The format of this information exchange that has been chosen is a video format. The participants can view this video get the contextual information on the selected case study. Opting for a video format had multiple reasons. The participants have the flexibility to watch the video at their convenience without the need to attend a meeting. Using this format, all the participants receive the same information. Additionally, they can also re-watch the video, when needed. Furthermore, presenting information through a video adds enjoyable and unique elements to the process and the footage can also contribute to illustrate context better.

Setting the context was not the only goal of the video. The video needed to contribute to the expectations of the participants on what they could expect during the upcoming 1-on-1 meeting as well. Furthermore, the video was also used to motivate the participants to participate, by using a format what was not common practice in their current way of working. The video was sent to the participants one week before the meeting was scheduled to collect the input, so they had enough time to watch the video.

The video was edited with Microsoft Clipchamp Pro and the TU Delft NewMedia Centre podcast room was used to record the audio. The video began by thanking the viewers for their time and interest, and then stated the goal of the video. After the introduction, a description is given of the video's content. The participants are also informed on what to expect from the upcoming 1-on-1 meetings and how this video will help them prepare for those. Then the most important part of the video follows, with the case DC2023 related information. The participants are shown the location and some footage that explain its background. Next, the legal process and the rules for obtaining permission are presented. Sequentially the risks of DC2023 are discussed including permitting, community, design and environmental risks. Then the design variables are introduced to the participants. The video ends with a summary and a description of the further thesis process. The video story line can be found in figure 6.7. The whole script with substantive information can be found in the classified Section 5.3.

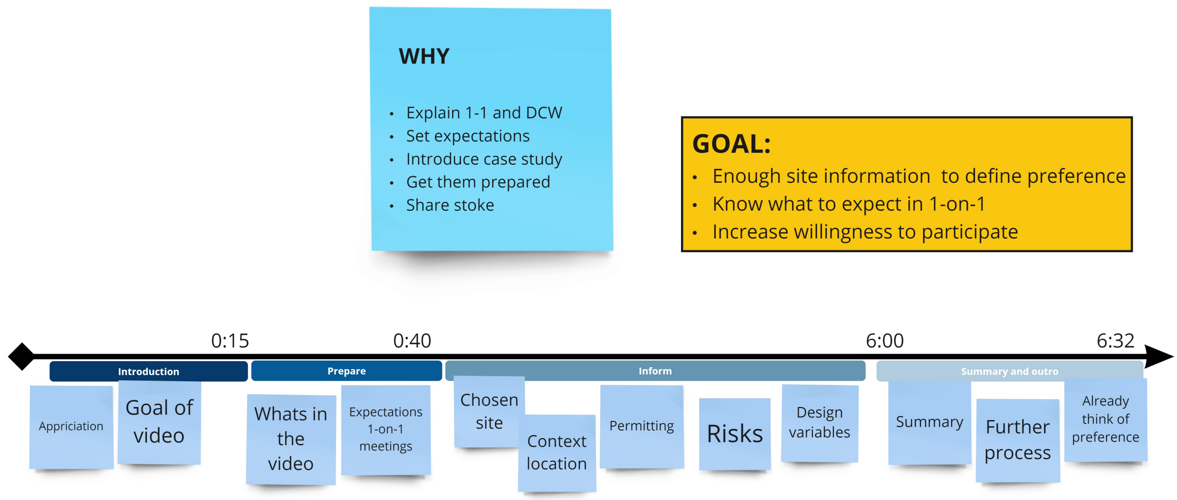


Figure 6.7: Video story line overview

6.1.2.2 Design 1-on-1 meeting

The 1-on-1 meeting contained a brief introduction, three exercises and a closing part. The outline of the meeting can be found in Figure 6.8. During the meeting the Thinking-Out-Loud method was used. A keep talking sign in the exercises was used to remind them to verbalize all thoughts (Sugirin, 1998). Charters (2003) recommends to use an intermediate level of difficulty for the participants, because it requires more than an automatic response, but it should also not be cognitively overwhelming. Furthermore, a task which can be broken into shorter tasks is also recommended so that it can be worked on one unit at a time. That is the reason multiple exercises are used during the 1-on-1 meeting and the level of these exercises was tried to be at an intermediate level of difficulty. The exercises were executed in the online 1-on-1 meeting by the participants, while using an online Miro board, where the participants could take control over the screen and fill in the exercises.

At the start of the meeting the participants received information on why and how to use the Thinking-Out-Loud method. The participants were instructed to verbalize their thoughts as they performed the various tasks. The facilitator did not engage in any dialogue about their mental processes during the exercises, to avoid any interference. The participants were the sole speakers during the exercises. In case the participants have a real difficulty to speak out loud, a discussion guide has been drawn up which includes stimulated questions so the participants are stimulated to share their thoughts. The discussion guide can be found in Appendix C. In this case the meeting facilitator is not entirely quiet and tries to help the participant by asking stimulating questions. The discussion guide includes more than only the help question for the Thinking-Out-Loud method. It also was used as a foothold for the introduction and the end of the conversation to ensure some consistency in all the different 1-on-1 meetings.

The meeting started with a short introduction. After a bit of small talk, to stimulate the emotional connection, they were asked if they want to say anything about the video. This way the participant can

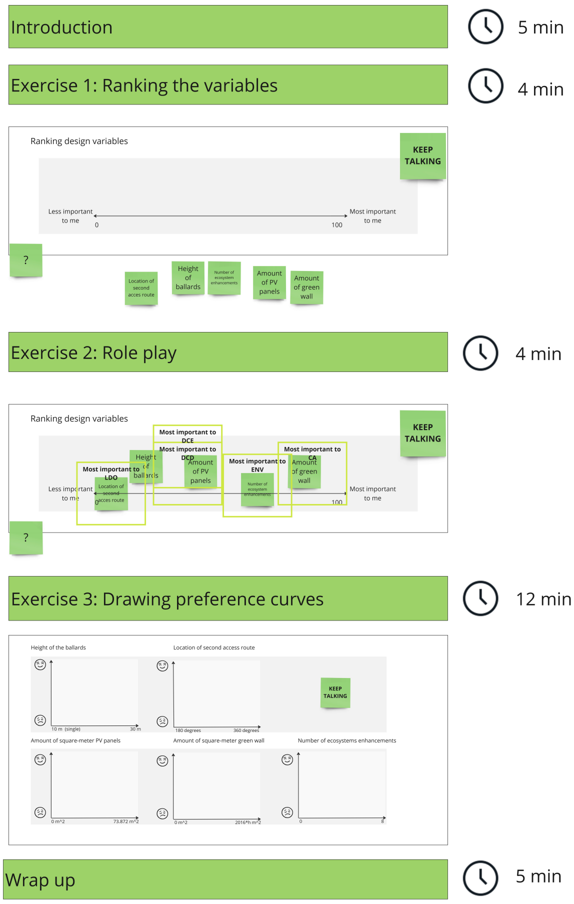


Figure 6.8: Outline 1-on-1 meting

clear their mind and can ask questions if things were still unclear. Furthermore, they were asked when this study would be successful for them. With the help of these answers the DCW could be developed. Sequentially the outline of the meeting is given to the participant, together with the goals of the meeting.

The first exercise was to rank the selected design variables from important to less important for their team on this specific case DC2023. See Figure 6.9, for the exercise. There is one empty post-it, so they could write down missing important variables. This is to get a good insight into whether there were things overlooked or missed during the selection of the design variables. During this exercise participants were asked to place post-its with the design variables in their correct order. In Figure 6.10 an example of a completed exercise can be found. The reason behind this first exercise is to see if there is a variable that is ranked as less important for every team or whether there is a variable that is the most important for everyone.

It must be noted that this first exercise was intended to directly yield results for the definition of the optimisation model. The variables for each stakeholder were scaled between the lowest and highest. The initial idea was that these scaled values represented the weights a stakeholder would give to a variable. These weights would be used as starting point for the DCW after which stakeholders through communication would decide on changing certain weights to fit a simulated project environment. The tool used during the DCW would display these weights as dynamic parameters that can be changed to optimise the design for different scenarios. This method, to indirectly quantify the weights, proved inconsistent and resulted in a strongly shifted starting point. Therefore, it was decided to abandon this starting point and rather use an equal weight distribution as starting point. In hindsight this undermined the quantitative purpose of this exercise but nevertheless it was considered very insightful to see each other's ranked variables, participants noted. Additionally, this was a good built up exercise to get familiar with the use of Miro and the Thinking-Out-Loud method.

The second exercise was a role play exercise. The participants received four box frames with the

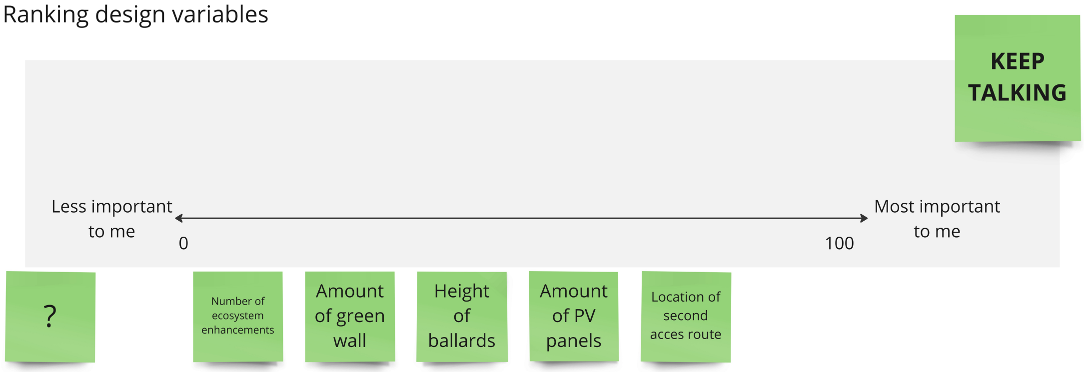


Figure 6.9: Miro exercise 1, *ranking the variables*

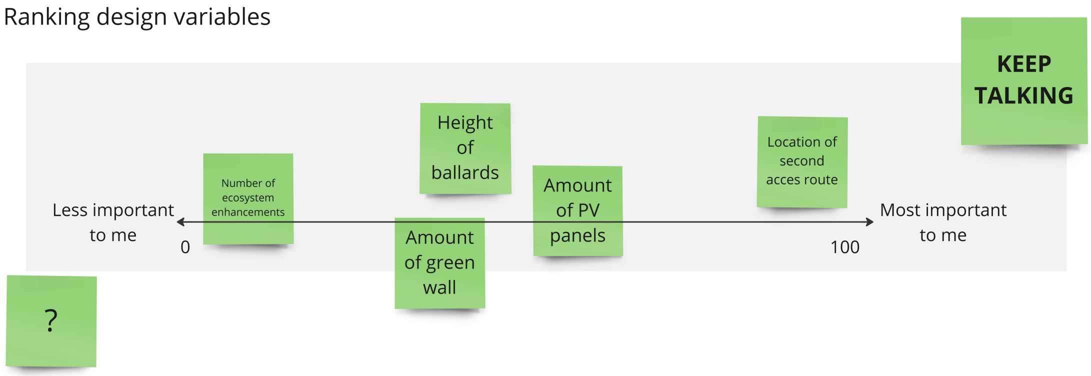


Figure 6.10: Miro exercise 1, *completed example*

names of the other teams on it. They were asked to place the box over the variable that they think would be the most important variable for that team. They were still asked to continue using the Thinking-Out-Loud method, to share their thoughts and reasoning. The reason to execute this exercise was to get them already in the right collaborative mindset and create awareness of other teams' preferences. Figure 6.11 shows an example of a completed exercise 2.

After being more familiar with Miro, the design variables, the Thinking-Out-Loud method and defining preferences, they were asked to define their preference functions for every design variable. These functions were needed for the DCT to run the optimisation. First, an example of several different curves were given and explained. PowerPoint slides with design variables references have been created and were held next to the Miro board, so the participants had a reference on the bounds and on the different variables to stimulate comprehensibility of the preference curves. This reference PowerPoint can be found in the classified Appendix CE and CF. After they understood the format of the preference curves, the participant was instructed to draw any curves they wanted, using the free drawing format as explain in section 6.1.1.2. They were explained that they also could draw a horizontal line if they had no strong preference for the design variable. They had to sketch their own lines, in the format as shown in Figure 6.12. They were still being asked to think out loud, so the researcher could gain insight into the trade-offs they made by drawing these lines. Figure 6.13 shows an example of a completed set of drawn preference curves.

The meeting ended with a wrap up, where the participants had to share their key takeaways from the meeting and give a one-minute summary. This gives insights into how the participants look back

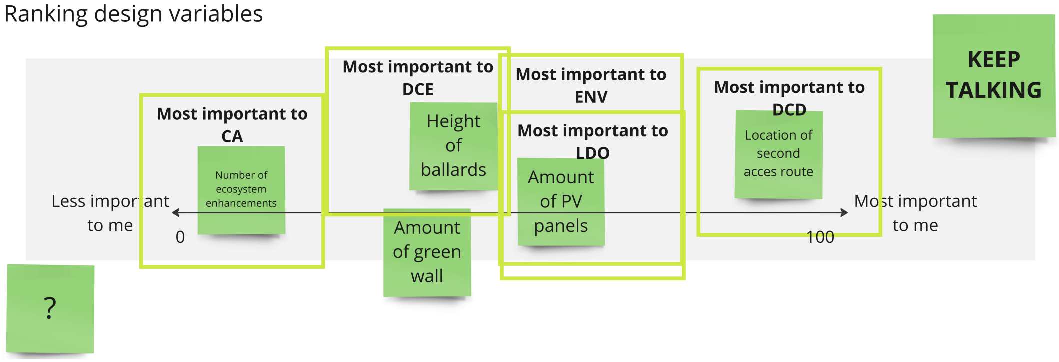


Figure 6.11: Miro exercise 2, *role play*

at what they have done themselves. The session ended with questions about if there is anything else they want to share, add, or ask. They were also reminded that the DCW was in a week from the 1-on-1 meeting. The participants were thanked for their time and contribution. Later, they received a feedback form to give feedback on the video and the 1-on-1 meetings.

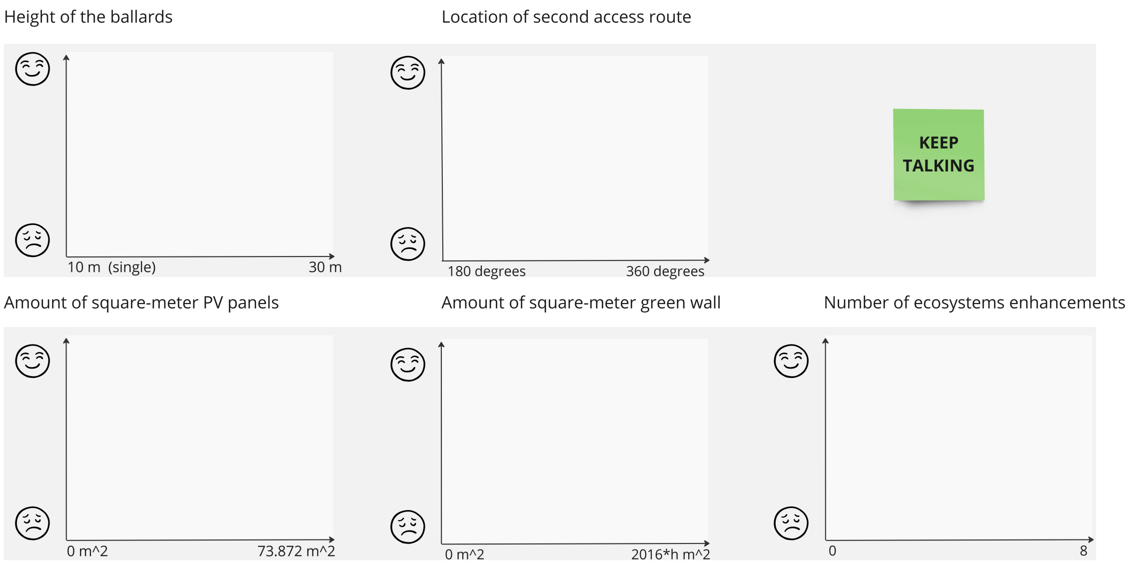


Figure 6.12: Miro exercise 3, *drawing preference curves*

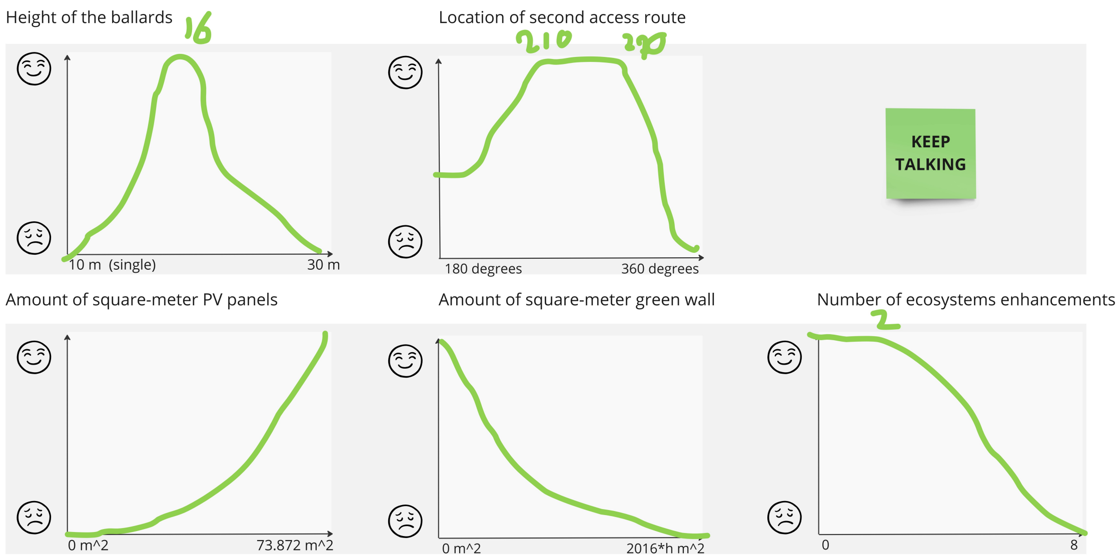


Figure 6.13: Miro exercise 3, *example*

6.1.3. Performance Social Cycle

All the participants showed up on time to the 1-on-1 meeting. Some of the participants had not seen the video, so they were given some time at the start of the meeting to watch the video. The exercises were achievable in the allotted half hour and if there was some time left, that was used for personal conversation with the participants. As results of the 1-on-1 meetings, all the exercises were filled in, and there were five times four[1] preference curves. The results of the first two exercises were noteworthy, as they showed that the participants often failed to guess the most important variable of other teams in the DC2023 case correctly. This implies that there is a lack of clarity about teams' key preferences in the DC2023 case among the different teams. As a result of this, it has been decided that these results would be very interesting for the participants, and would be shown and discussed during the DCW. Furthermore, there were no design variables, for which all the different teams filled in the same preference curve. This means that the selected teams have different preferences of the selected design variables on the same case. These different preference curves will be further discussed in Section 6.1.5. The collected results from the first two exercises can be found in the Classified Appendix CJ, The collected preference curves can be found in Classified Appendix CG.

6.1.4. Verification Social Cycle

> *I really liked all of it. I really value the improvements and the additional question to get a better perspective. Well done!*
>
> Participant at Microsoft

The absence of prior research on stakeholder involvement in the specific MODO and Odesys context led to the creation of the approach that was developed during the Social Cycle. In order to stimulate the willingness to participate and to guard the understandability of the process for the participants, a set of principles had been drawn up in the Section 4.2.1. To assess if the Social Cycle approach adhered to these principles, a table was drawn to check how these principles were integrated in the Social Cycle in Table 6.1. All identified principles were successfully incorporated into the Social Cycle approach.

Apart from the successfully integrated principles, the video and the 1-on-1 meetings were also designed with certain goals. The video served the goals to be an information source to prepare the participants

[1]The green walls preference curves have been removed after the first iteration, since green walls are part of the ecosystem enhancements, and therefore left out

and make them feel excited for the upcoming 1-on-1 meeting, including giving them the context on the case study so they could define their preferences. The feedback of the participants using the results of the feedback form (see Appendix E) highlighted the success of the video in providing context, setting the expectations right and generated excitement for the 1-on-1 meetings and the DCW. That fulfilled the goals of the video, mentioned earlier in this paragraph.

The primary goal of the 1-on-1 meetings was to collect the preference curves as input for the DCT, reflecting good human preferences, but it was also used to guide the participants into the right collaborative mindset. To verify the understandability of the 1-on-1 meetings, the feedback form was used to gain insights in how the participants experienced the 1-on-1 meeting. The executed exercised were experienced as well focused, to the point and were not found to be overly challenging. The participants indicated that they were well informed and knew what was expected of them during the meeting. All the participants fostered the meeting as a positive experience and was in total rated 5 out of 5. The use of the Thinking-Out-Loud method during the meetings served not only as observation tool to use in the validation process, but also contributed to the participants own understanding in their own trade-offs and thought, improving their reflection of their preferences. In addition, the participants indicated that they understood the preference curves without difficulty and they faced no issues in creating them or interpreting the design variables. Participants feedback details can be found in Appendix C.

To conclude, the Social Cycle principles established in the requirements (4.2.1) were fully integrated into the Social Cycle approach, successfully achieving the intended goals of the video and the 1-on-1 meeting. Throughout the process, the participants engaged actively and understood how to provide input (the preference curves) for the DCT.

Table 6.1: Social Cycle principles linked to activities

PRINCIPLES SOCIAL CYCLE	SUB-PRINCIPLES	SUBSUB-PRINCIPLES	HOW
Emphasize their importance	Listen to their experience		During the 1-on-1 meetings the facilitator was listening carefully to their thoughts on the different design variables connecting to the DC2023 case.
	Use their information and show		The results of their exercises of the 1-on-1 meeting were shown and discussed during the DCW.
Add value for them	Takes all their interest into account		While the participants fill in a preference curve for every design variable and is being used as input for the DCT, their interests are taken into account.
	When is it successful for the participants		During the 1-on-1 meetings and the feedback form participants are asked when this study would be successful for them. This is used in the design of the DCW.
Keep them engaged	Keep them involved and informed		During the whole process the participants are informed and involved by sending them thesis updates, invitation to meetings etc.
	Foster a positive experience while performing a task	The feeling of control of the situation	Participants are prepared by the video that also explains what is expected of them. At the start of the 1-on-1 meeting the participants also get an overview of the meeting.
		Set clear goals	The goals of the video and 1-on-1 meetings are explained at the start of the video or meeting.
		The feeling a task can be completed	The exercises were split up into three smaller exercises to maintain the overview for the participants.
		A clear vision	Video and 1-on-1 meeting are aligned and are clearly explaining the goals of this.
		A challenging task	The exercises are at intermediate level.
		Participants skills are fully utilized	The participant can use their full experience and expertise to execute the exercises.
		Receiving immediate feedback	While they are executing the exercises they immediately see the exercises being completed.
		Participants are able to concentrate	During the exercises the facilitator is quiet and lets the participant take control over the screen and let them do the exercise.
	Emotional connection	Ice breakers	Start the meeting with a joke about the video.
		Trust, do what is promised	Facilitator was on time and did not postpone meetings etc.
		Personal conversation	During the 1-on-1 meetings there was some time calculated for personal conversation.

6.1.5. Validation Social Cycle

The need, as stated in Section 4.1.1, to improve human reflection in the preference curves will be validated in this section. There have been looked at the collected preference curves and how they are reflecting the preferences of the different participants. The recorded meetings of the 1-on-1 meetings were analysed, where the thoughts and expressions of the participants can be watched back during the execution of drawing the preference curves. The collected preference curves were compared to these thought and interests of the participants by looking at the top, bottom and turning points in their curves. These were examined whether the curves match the thoughts and expressions of the participants. Moreover, there have been looked at if these preference curves, also are showing the expected conflicts of the teams different preferences, as investigated in Chapter 2.

The drawn preference curves directly collected from the participants have been programmed with the cubic Hermite interpolation to get the final input for the DCT. In Section 6.2.1 this is explained in more detail. The collected preference curves will be discussed per team[2]. The preference curves after the interpolation are shown in Figure 6.14.

The first discussed preference curves are from the Datacenter Design (DCD) team, which is respon-

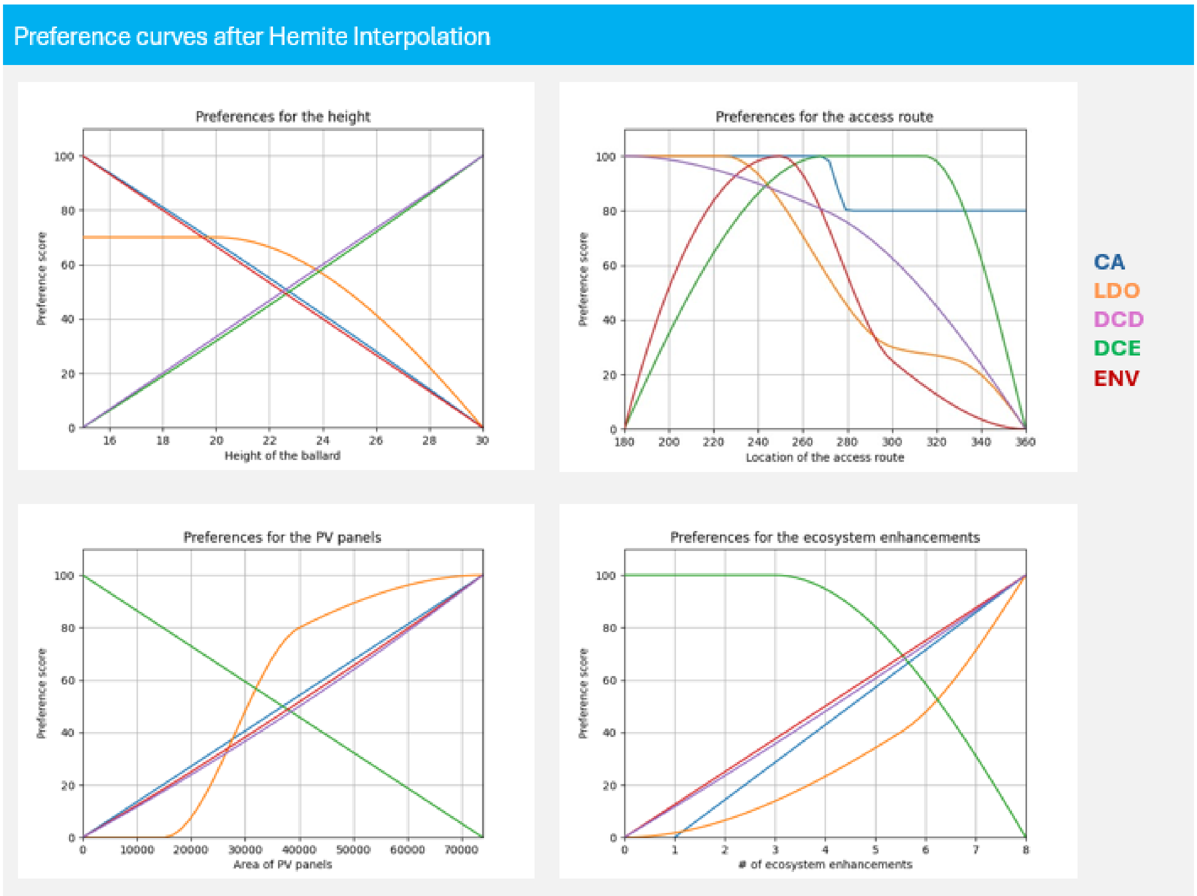


Figure 6.14: Preference curves after Hermite Interpolation

sible for the construction of the datacenters and the datacenter demand. The DCD team wants to build the datacenter as high as possible to increase the capacity, since they are responsible for meeting the demand. This expectation matches with the drawn preference curve. The optimal location for the secondary access route is at 180 degrees, near the main road. The further away from that point the less preferred it is. This meets the expectations as well. A surprising preference of the DCD team is the amount of PV panels. Contrary to other teams' assumptions that DCD would not want many

[2]Note that the variable green wall has been removed after the first iteration, and therefore not discussed here

PV panels because they complicate the construction, DCD actually prefers to have them. They justify this by saying that it is the right thing to do and that it makes use of the available space. The DCD team also favors ecosystem enhancement, as long as it does not interfere with the fiber cables or other infrastructure. However, this still has a significant impact on the design that needs to be considered. The drawn curves are aligned with the thoughts of the participant of DCD.

The second team discussed is the Datacenter Engineering (DCE) team, which is responsible for the engineering part of the datacenter and wants to stay close to the standard design in order to make use of the repetition effect to save time and money. All their drawn curves were aligned with their thoughts of staying close to the standard design. The higher the building the more preferred to optimize time and capacity. The location of the second access route should be across the other road, for the best accessibility for the site and the most flexibility of coming from other directions. PV panels and ecosystems are not preferred, because it impacts the standard design.

The third team is the Community Affairs (CA) team, which is engaged in community affairs and wants to improve the license to operate and minimize community push backs. The currently allowed height coming from the zoning is 16 meters. CA wants to respect this, in order to be compliant with the current zoning, so higher than 16m will be less preferred. This is reflected in their graphs. The location of the secondary access route is set on 100 from 180 until 250, since only one road needs to be taken to use that entrance. From 270 until 360 degrees it is a bit less preferred since people have to take an extra route, which is not beneficial for the neighborhood. Because the neighborhood is a bit further away and it is not a crowed location, it only drops until 80. For the PV panels and the ecosystem enhancements applies the more the better. Often, the push backs arises of sustainability concerns including energy and water consumption. Including more PV panels and ecosystems this can be a mitigation to decrease the push backs and take sustainability more into account.

The fourth results came from the Land Development Organisation (LDO). They are accountable for starting the construction as soon as possible, without cost escalation. Zoning plans and the wishes of the authorities are important for them to have minimised resistance so they can start the construction of the datacenter early as possible. The drawn preferences curves are showing these thoughts as well. Looking at the height of the building, the most preferred value is the one that is allowed by the zoning. The location of the second access route is preferred just as the way it was already on the early design plans. For the PV panels and the ecosystem enhancements applies that green washing plays an important part.Doing the bare minimum is seen as green washing to LDO, so they have to do more. Furthermore, these subjects were already discussed by the local authority and therefore important to comply with.

The fifth team was the Environmental team. They are accountable for the sustainability within the company and are also looking if the datacenter fits into the environment. Furthermore they are responsible for obtaining the environmental permits in the datacenter development. This can be also seen by looking at the preference curves that were drawn and the thought they had while drawing these curves. The higher the building, the less preferred it is. The location of the secondary access route is not preferred to be near the pond due to contamination dangers. Additionally it is not preferred to have it after the 270 degrees, since it further away from the main road and then the community will experience more nuisance of the traffic . A higher number of PV panels and ecosystem enhancements would increase the sustainability and the compatibility of the datacenter with the environment, and therefore are rated the participant as the more the better. The interest of the Environmental team are well reflected in their preference curves.

To conclude, the interests of the different teams are well reflected in their preference curves. The preference curves per design variable for the different teams are directly showing the conflicts by the preference curves that differ from team to team. The conflicts that the preference curves are showing are aligned with the conflicts found in earlier interviews and observations at the beginning of this study. The main conflict is to what extent should the standard design be adapted in order to be more sustainable and to consider the community. This is reflected by some preference curves that are inversely related to each other, as could been seen in Figure 6.14.

6.1.6. Improvements Social Cycle

The main objective of the Social Cycle was to collect the preference curves from the participants, reflecting their preferences accurately on the design variables. An approach had been developed to improve this, including informing the participants about the case study context and a 1-on-1 meeting to collect the preference curves. This approach achieved its goals compared to the established needs and requirements in Chapter 4. The use of the free drawing format and the Thinking-Out-Loud method to establish the preferences curves have contributed to an accurate reflection of the participants' preferences. The drawn lines were checked by using the thoughts and expressions coming from Thinking-Out-Loud method as validation tool, to see if the curves matched the participants thoughts. It can be stated that the curves are aligned with their thoughts and do reflect the participants' preference and their team interests.

While from the verification and the validation it can be stated that the approach achieved its goals and the use of the Thinking-Out-Loud method and the free drawing principle contributed to a good reflection of the participant preference. The question arises how this new approach relates to the former approach, the PAS-method developed by Arkesteijn and Binnekamp (2013). Therefore, instead of using the second iteration to improve the new developed approach, the focus for the new 1-on-1 meetings is on the comparison of the former PAS-method to the new approach, including focusing on the contribution of the Thinking-Out-Loud method and the free drawing method.

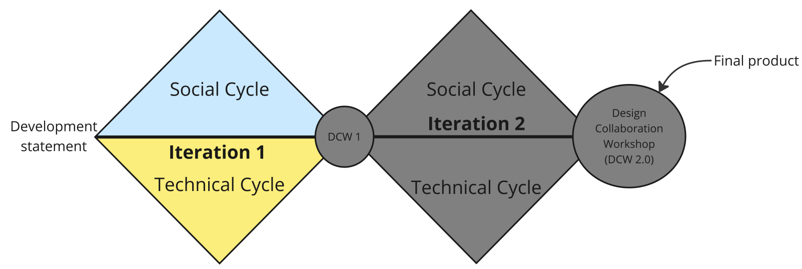


Figure 6.15: Iterations process overview

6.2. Technical Cycle development

This section describes the development of the Technical Cycle for the first iteration. The Technical Cycle aimed to develop a interactive digital tool that can be used to facilitate a design conversation in a multi-stakeholder setting. The Design Collaboration Tool (DCT) as it was called is build up of three different components namely; the back-end optimization model, the Application Programming Interface (API) and the front-end Graphic User Interface (GUI). Firstly, the methods used for this development are described in Section 6.2.1 for each of the three main components. Secondly, based on these methods a design is proposed for the first iteration in Section 6.2.2. Thirdly, an evaluation of the performance of the designed DCT with respect to the defined needs and requirements is performed in Section 6.2.3. This section concludes by proposing some improvements for the second iteration in Section 6.2.4.

6.2.1. Methods Technical Cycle

6.2.1.1 Back-end

The back-end of the DCT contains the optimisation method developed in the Odesys methodology by Wolfert (2023) and Van Heukelum, Binnekamp, and Wolfert (2023). This method combines this preference domain, through stakeholder desirability, with the performance domain as the datacenter capability. The Odesys methodology uses objective functions to define capable object performance, based on a set of controllable variables. Figure 6.16 visualizes a simplified version of the Odesys method. On the left it shows the preferences of two stakeholders. These stakeholders express their preference for an objective function. This objective function is based on some set of controllable variables, in this example two variables. More complex variations can be made such as one stakeholder expressing a preference for multiple objectives or the addition of constraints among others. The graphs on the right visualize this Odesys setup. It can be seen that the preference curves map preference on the vertical axes and an objective function on the horizontal axes. These objective functions depend om some quantification of the controllable variables shown in the graphs below.

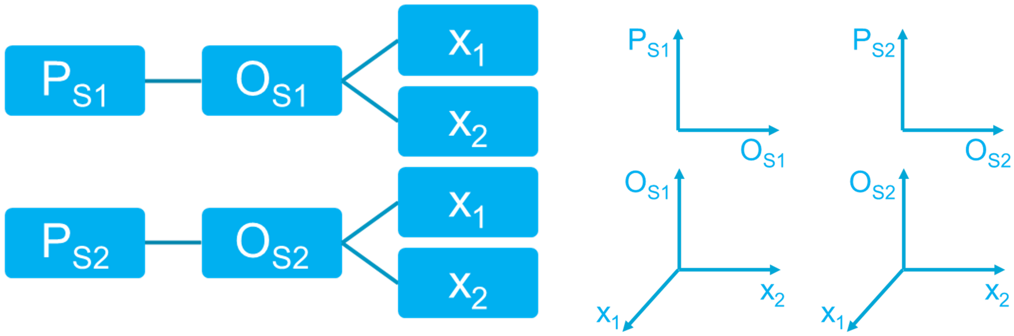


Figure 6.16: Visualization of a simple optimization model according to the Odesys methodology

The example described above can also be translated into a mathematical equation. The mathematical formulation of this example is given by Equation 6.1:

$$Maximise\ U \ = \ T[P_k(O_k(\mathbf{x})), w_k] \ \ for\ k = 1,\ 2,\ ...,\ 5 \tag{6.1}$$

Where:

- T: The aggregated preference score determined using the PFM theory principles (Barzilai, 2022).
- $P_k(O_k(\mathbf{x}))$: The preference functions that describe the preference that each stakeholder k towards their objective function. The preference functions are scaled between 0 and 100, where 0 is the worst performing and 100 the best performing. This scaling adheres to the work of Barzilai (2022) to correctly solve for the optimal aggregated group preference score T.
- $\mathbf{x}$: A vector containing the controllable design variables x_1 and x_2. These variables are boundes such that lb_n < x_n < ub_n, where $lb_n$is the lower bound, ub_n is the upper bound and n = 1, 2, ..., 5.
- w_k: Weights for each of the stakeholders. The weights for all stakeholders combines is such that $\sum w_k = 1$.

The method and example described above formed the basis for the back-end of the DCT. Next to this main method, another method was used to parameterize the preference curves that were inputted by the participants. It is worth mentioning how the drawn preference functions are parameterised as mathematical input for the optimization model. Especially since the work of Binnekamp (2010) , Arkesteijn et al. (2015) and Van Heukelum, Steenbrink, et al. (2023), whose work narrowly aligns with the research performed here, show some differences with regard to this preference parameterisation. Binnekamp (2010) uses Bézier curves, while Arkesteijn et al. (2015) opts for Lagrange interpolation and Van Heukelum, Steenbrink, et al. (2023) utilises cubic hermite interpolation. Even though the differences are subtle it is worth noting for this research since the model depends heavily on the preference functions. For this research, the use of cubic hermite interpolation has been chosen coinciding with the most recent work presented above. The main disadvantage of regular Lagrange interpolation is the phenomenon of excessive oscillation of the polynomial between points, known as Runge's phenomenon. This phenomenon is especially the case with higher order polynomials which could be used in this research since participants are free to draw whatever preference curve they seem fit. This oscillation hampers the smoothness of the preference functions. Given the importance of the preference functions Lagrange interpolation was deemed less suitable. The Bézier curves perform better with regard to this smoothness. Within its graphical fields its main purpose is to look smooth. This purpose has a downside, namely that the Bézier curves are not very controllable to fit a specific drawing effectively. Therefore, also the Bézier curves were deemed less suitable for this research which evolves around transforming drawn preference functions into smooth curves with control over the curve. The cubic hermite interpolation does not only fit a polynomial to the data entry points but also matches the first derivative (slope) to the data. This means that the cubic hermite interpolation does not experience Runge's phenomenon. Therefore, it provides the intended smoothness and controllability, which also improves due to the use of the first derivative, needed for this research. The parameterised versions of the preference curves for each variable are shown i Figure 6.14. Next to the interpolation method there are also multiple alternatives for the type of aggregation method used to calculate the optimal group preference score.

For the type of aggregation method there are two available alternatives; Integrative Maximised Aggregated Preferences (IMAP) and Min-max goal attainment (Marler and Arora, 2004). These differ quite fundamentally. For either method first the individual preference scores are determined but they differ in how these individual preferences are aggregated into one group preference. Note that also both methods align with the Preference Function Modeling (PFM) principles of Barzilai (2022). This is because the algorithms apply a scale to ensure correct relative alternative evaluation is performed. Without this any solution can be considered an arbitrary solution. The IMAP allows for a single stakeholder preference to be lower in order to increase the group preference, while the min-max method keeps all the individual preference scores (Wolfert, 2023). The two methods most often yield very different results. The work of Eijck and Nannes (2022) compared the results of both methods in an urban planning context. They concluded that the IMAP outperformed the min-max based on expert evaluation of the results. During the development of DCT during this research, another major difference became apparent. The computation time of min-max outperformed the IMAP by a factor 60 in this iteration. The average computation time of the min-max was less than half a second while the average computation time of the IMAP exceeded thirty seconds. This was not further researched for this first iteration but to enhance interactive use for the stakeholders a decision was made to use the min-max method during the Design Collaboration Workshop (DCW).

Lastly, a tailor made Genetic Algorithm (GA) was used that connects with software to calculate the aggregated preference scores based on PFM, which is called Tetra. The development of this GA had already been conducted and tested by Van Heukelum, Binnekamp, and Wolfert (2023) and there was no need to implement further adaptations and was kept as is.

6.2.1.2 API

The API functions as the communicator between the back-end and the front-end. It serves as the backbone of the DCT. For this API a framework had to be chosen. Currently, there are three generally used alternatives which are Django, Flask and FastAPI. Each framework brings its unique approach to web development, catering to different needs for software developers.

Django, adopts a 'batteries-included' philosophy. It is a high-level framework that encourages rapid development and clean, pragmatic design. Django comes equipped with a many built-in features, including an Object-Relational Mapping (ORM) layer, forms, authentication mechanisms, and a powerful admin interface for managing database records. This makes Django particularly well-suited for developers who prefer to have a solid foundation from which they can develop. It's ideal for larger applications or projects where the built-in features align well with robust project's requirements. The latter can also be considered a major downside of Django since it might not be applicable for some projects. Also, the learning curve for beginners to get acquainted with Django was considered steeper than with the other alternatives. Especially this steep learning curve daunted the developers during this research and Django was not selected for the first iteration. Its robust principles and solid foundation might however be suitable for the DCT in a later stage especially considering its abilities to use an admin interface and manage large amount of data that can be stored for further development of the DCT.

Flask emerges as the minimalist choice among the three. It is mostly known for its lightweight and flexible nature. It follows a micro framework approach, providing developers with the essential tools to get a web application up and running, but leaving much of the decision-making and configuration to the developer. This flexibility allows for a high degree of customization and is particularly appealing for smaller projects or when a project's requirements are not well-suited to the more opinionated structure of Django. However, this comes at the cost of having to manually set up various components which might be readily available in more comprehensive frameworks such as Django. Additionally, the Flask community is almost as big as the Django community, while FastAPI s relatively new resulting in a smaller community. This can be beneficial to use for back-up research and referencing during the development. Especially for beginners learning software development from scratch. Because of its above mentioned flexibility and freedom for developer creativity in combination with the widely available resources Flask was chosen for the first iteration of this research, as shown in Figure 6.17.

FastAPI as mentioned is a relatively new alternative in the field of web frameworks but it has quickly gained popularity due to its performance and ease of use for building APIs. It is built on more modern Python features such as type hints and asynchronous programming. Therefore, it provides a fast, efficient way to develop APIs with automatic data validation and interactive documentation. FastAPI allows for high performance and scalable APIs, and its design is particularly aligned with the needs of modern web applications that heavily rely on asynchronous data handling. The latter is an important element of the DCT use but asynchronous data handling has been implemented using a different protocol, which will be explained shortly. FastAPI showed great potential and could in theory be very suitable to develop the DCT given its modern take on web developing. Since it is relatively new it was not chosen for the first iteration of this research.

To conclude, Flask was chosen as the API of interest for this iteration. This decision was made on the basis of well researched arguments as described above, but can still be considered somewhat trivial especially for a beginner. Therefore, it is worth depicting this comparison in this report and re-evaluating the decision for the second iteration and future developments of the DCT.

6.2.1.3 Front-end

For the front-end there had to be a strong focus on user experience which aligns with the principles to enhance collaboration set out in Section 4.2.2 . The front-end development employs relatively standard HTML, CSS, and JavaScript to create an intuitive interface. Even though the use of these programming language is relatively standard they were learned from scratch, since no prior knowledge was existing with the development of such a Graphical User Interface (GUI) in a web application. This emphasizes the use of iterations to gradually develop the GUI based on the purposes of this study. The initial layout when starting the application can be seen in Figure 6.24. It shows the defined and parameterised preference curves of all the stakeholder for each of the variables, larger images of these curves are shown in Confidential Appendix CH.

6.2.2. Design Technical Cycle

The design of the first iteration of the the Design Collaboration Tool (DCT) consists of three parts as previously mentioned. Figure 6.17 shows the main architecture of the DCT. It displays the three different parts including the framework or programming language that was used for each. The coming subsections will elaborate on these. Figure 6.17 also shows the data format JSON that was used to communicate between the three parts. Additionally, two protocols that were used to improve performance are visualized. It's functionalities, performance and design were developed from scratch without prior knowledge of digital application developments of GUI's and API's. However, the main setup and architecture that was designed has been verified during an expert consultation with a software developer within Microsoft.

6.2.2.1 Back-end

The Odesys method directly used the direct preference curves that were drawn by the participants as mentioned in Section 6.1.1.2. The Odesys methodology was adapted for this study to mainly test the

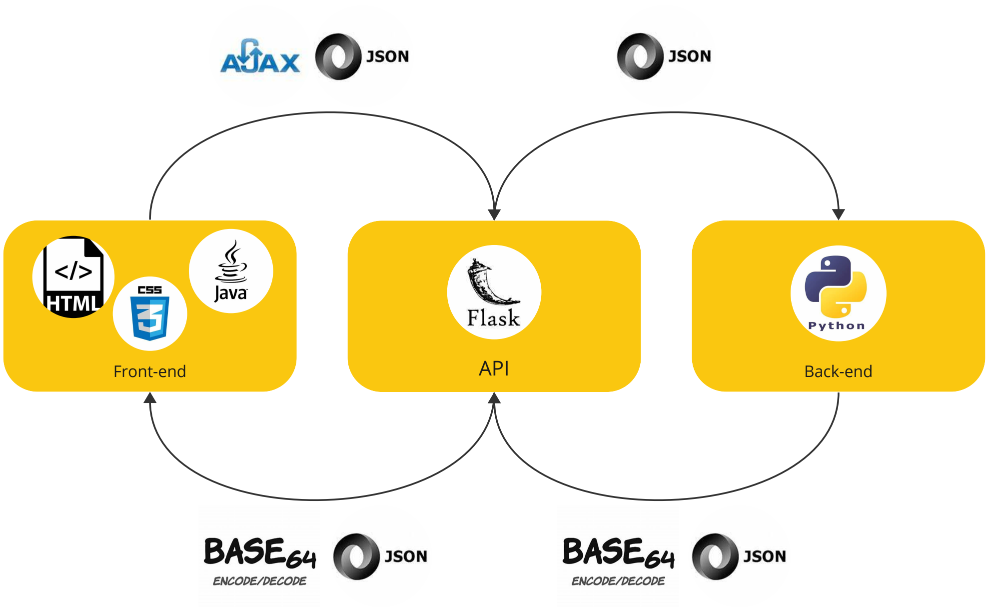


Figure 6.17: DCT main architecture

potential of purely preference based design to enhance collaboration. During initial presentations of the Odesys methodology it became clear that to enhance collaboration at Microsoft the DCT had to be understandable to enable the participatory process, following the principles defined in Section 4.1.2. This primary focus on preference based collaboration, as brand new intervention in current practices at Microsoft, and the need for simplicity during the initial development iteration led to the decision to simplify the Odesys methodology. While the Odesys methodology uses objective functions to define capable object performance, based on a set of controllable variables, the first version of the DCT directly maps these variables in the desirability domain as preference functions based on their shape from the 1-on-1 meetings as explained in Section 6.1.2.2. Figure 6.18 visualizes the optimization model that was adapted in this study based on the Odesys methodology. On the left it shows the preferences of all (five) stakeholders for each variable. So each stakeholder had a preference function for each variable resulting in 20 preference functions since there were 5 stakeholders and 4 variables. Each preference function was connected to an objective function which was based on one variable. This way the direct preferences implemented by the stakeholder directly mapped the preference for that stakeholder to one of the variables. The graphs on the right show this direct preferences where the preference on the vertical axes is mapped on the variable on the horizontal axes between its lower and upper bound.

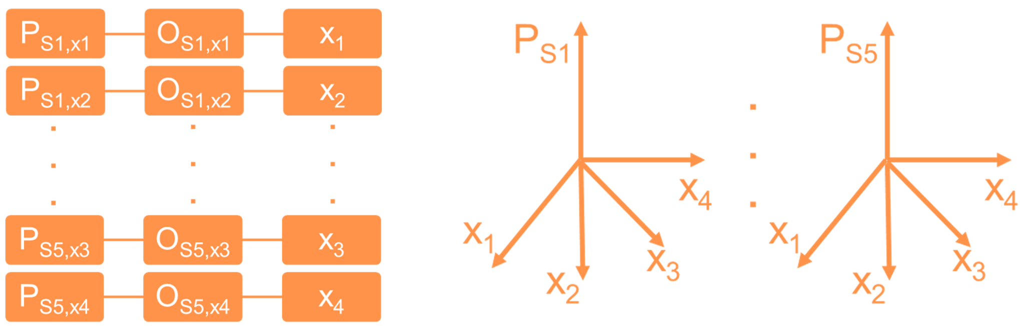


Figure 6.18: Visualization of the optimization model setup based on the Odesys methodology

Given the setup described above, also the mathematical formulation for the optimisation model used in this research was adjusted from its full definition (Van Heukelum, Binnekamp, and Wolfert, 2023).

This resulted in the mathematical Equation 6.2 below:

$$Maximise\ U = T[P_{k,i}(\mathbf{x}), w_{k,i}]\ \ for\ k = 1,\ 2,\ ...,\ 5\ and\ i = 1,\ 2,\ ...,\ 4 \tag{6.2}$$

Where:

- T: The aggregated preference score determined using the PFM theory principles (Barzilai, 2022).
- $P_{k,i}(\mathbf{x})$: The preference functions that describe the preference that each stakeholder k has towards the design variables. The preference functions are scalled between 0 and 100, where 0 is the worst performing and 100 the best performing. This scaling adheres to the work of Barzilai (2022) to correctly solve for the optimal aggregated group preference score T.
- $\mathbf{x}$: A vector containing the controllable design variables $x_1,\ x_2,\ \ldots,\ x_4$. These variables are boundes such that lb_n < x_n < ub_n, where $lb_n$is the lower bound, ub_n is the upper bound and n = 1, 2, …, 4.
- $w_{k,i}$: Weights for each of the preference functions. These weights represent the weight stakeholder k gives to variable I given that $\sum w_{k_i} = 1$.

6.2.2.2 API

As the backbone of the the DCT application Python's Flask framework handles a requests initiated by the front-end, where the user-defined input is received in JSON format as mentioned before. This means that Flask receives a piece of JSON data, commonly used to transfer data between application layers, that is forwarded to the optimisation model in the back-end. This Python model calculates the optimal design solution with the highest group preference score, given the pre-defined min-max aggregation method (for this iteration). These binary results are encoded into an ASCII string and send as JSON data to the Flask again which updates the front-end based on the new results.

As mentioned above some form of asynchronous data handling is required to enhance usability by the users. In the context of this particular application, an Asynchronous JavaScript and XML (AJAX) call is utilized to submit user-input data from the front-end (JavaScript) to the Flask back-end. This asynchronous data handling allows the participants to continue using the front-end without reloading the web page. This approach was especially beneficial for the DCT's applications since it required real-time data processing and immediate feedback based on user inputs. This way some technical considerations were made during the development to enhance eventual in game use. However, the main element that stimulates the DCT's usability is of course the front-end.

6.2.2.3 Front-end

Underneath the preference curves Figure 6.24 shows card like boxes with sliders. These sliders can be used to change the weight of a stakeholder for a certain design variable. Note that these cards are only colour coded and are therefore anonymous for the participants. Then the figure displays a big play button indicating it can be clicked to start the app based on the weight setting of the sliders. These weight setting from the input for the optimisation model in the back-end. To the right of the play button some spots are reserved for the resulting preference curves but nothing is displayed here as of yet. Then a table is displayed which is still empty. These cells will be filled when the optimized results are calculated and sent to the front-end. Finally, two visual 3D schematic representations of a datacenter design have been depicted.

Figure 6.20 displays the layout of the DCT when a model run has been performed. It shows the additional resulting preference curves with the optimal solution represented in the graphs. Also the table now displays the found optimal values of the design. Note that also the preference curves without the solutions are still shown at the top but these are not visible in the snapshot shown in Figure 6.20. An additional feature added to the front-end that is currently not visible is a pup-up notification window when the weights on one card to not add up to 100%. The Java script in the front-end checks each of the cards and if this constraint is not satisfied it will show a notification that could for example say *"The* *weights in box ... do not add up to 100. The current value is 113"*. Then the participants know how much weight should be changed in order to satisfy the constraint and run the model successfully. This finalises the description of the three main components of the DCT. Next the performance of the DCT during the Design Collaboration Workshop will shortly be verified and validated. The performance of the DCT is entirely connected to the use of the DCT in the DCW. Therefore, the performance of the DCT will be explained during the performance of the DCW.

Figure 6.19: Layout of the empty DCT when started for the first time

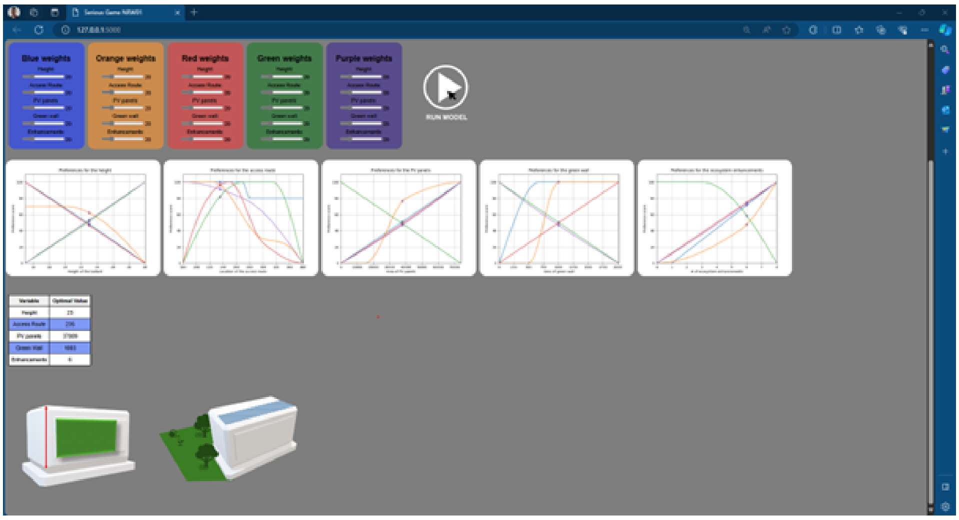


Figure 6.20: Layout of DCT after a model run

6.2.3. Verification & Validation Technical Cycle

In general it can be concluded that the first version of the DCT clearly showed its limitations with respect to the understandability and utility needs.

The back-end showed some flaws. Particularly due to the choice of aggregation method, the min-max. This decision was consciously made but the use of the participants showed that speed was not the primary concern. The use of only the min-max also resulted in several things. Mainly, the results were consistent but can also be characterised as too consistent. During the game it proved difficult to arrive at strikingly different results. This can to some extend be attributed to the min-max method. In order to arrive at different solutions, rigorous changes had to be made to the weights, which participants were slightly reluctant to do voluntarily. Their reasoning that even less crucial variables deserved some weight indicated this. Also, the selection of only the min-max method made it difficult to compare results to something else. Incorporating both the IMAP and the min-max could have made this much easier.

Next to this, the decision of simplifying the optimisation model to be purely preference based also showed a limitation. The link between mere preferences and a task to change weights to solve a simulated project scenario proved difficult for the participants. Nevertheless, the back-end proved to work to some extent in an interactive digital tool.

The API on the other hand worked well but could also be improved. Since much in dept knowledge about the use of different API's is missing a critical evaluation is difficult. The learning curve to get acquainted with Flask was challenging but doable. The RESTful principles made many intermediate steps easier and the flexibility of Flask proved functional to relatively quickly develop a first working prototype.

The front-end also showed some limitations. Due to the fact that the tool was ran locally it was difficult to use for online participants. The sliders were small and therefore sensitive and in combination with the 100% weight constraint it proved difficult to control. Next to this, the understandability of the DCT was limited. This was partly caused by the fact that the weight cards were anonymised. Participants found it challenging to know which sliders to adjust. Also, the DCT portrayed only the results of the most recent run. There was no back-logging of previous runs or secondary visualisations to display this. This proved comparing scenario's difficult. These were the main issues caused by the front-end. All in all, there is plenty of room for improvements of the DCT.

6.2.4. Improvements Technical Cycle

The second iteration for the technical cycle will consist of both a re-evaluation of the decisions made during this iteration as well as added functionalities to the DCT. Some proposed improvements for each of the three main elements will be discussed.

For the back-end an improvement for iteration two will be to re-evaluate the decisions made during iteration one. The decision to use only the direct preferences potentially needs alterations. The main advantage of applying only the preference domain still holds during iteration two, namely keeping the optimisation model as simple as possible to improve understandability and facilitate a conversation with the participants. However the feedback from the participants indicated that the gap between the task with regard to the Risk At Play and the changing of the weights might be to large. Datacenter performance equations in the form of objective functions, as defined by Van Heukelum, Binnekamp, and Wolfert (2023), between the preferences and the variables can potentially help bridge this gap. Additionally, the decision to only use the min-max needs to be re-evaluated. Studies performed by Eijck and Nannes (2022) and Van Heukelum, Steenbrink, et al. (2023) showed the potential of the IMAP to yield interesting design solutions. Moreover, a comparison between both the IMAP and the min-max can be particularly interesting within the DCT.

Concerning the API also several aspects can be improved. The main focus will be to add functionalities to the model. When additional functionalities will be added to the DCT during iteration two the decision for Flask might also need to be re-evaluated. Perhaps again in consultation with more expert software developers. This allows to strengthen the foundation underneath an interactive form of the DCT for future developments. Added functionalities such as, changeable preference curves, design solution back-logging and comparison and dynamic 3D visualisations based on the optimal solutions come to mind. To effectively prioritize these functionalities a priority vs. feasibility trade-off needs to be done.

Lastly, for the front-end also some improvements can already be suggested. Ideally all social cycle engagements are also included in the application. Then there is no need to change between collaboration software such as Miro, Powerpoint presentations to show the results and the web application of the DCT to play the game. A full integrated front-end would improve all aspects of this research. Furthermore, improvements can be made with regard to usability. By adding elements such as different input methods than the sliders, like a number box to type in, enlargement of the preference curves for improved readability, additional visualisations with respect to preference scores, clearly distinguish between the input from different teams by labeling and more intuitive flow of the DCT to allow for more immersed play.

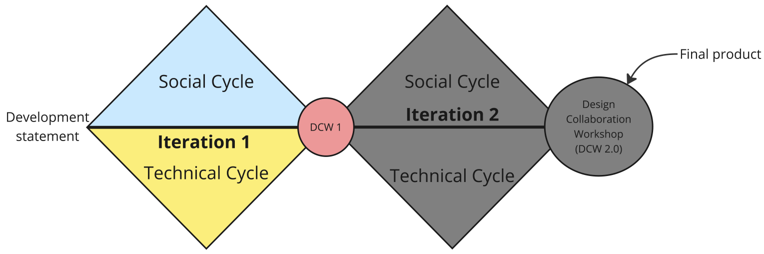


Figure 6.21: Iterations process overview

6.3. Design Collaboration Workshop development

The Design Collaboration Workshop is designed to simulate collaboration between teams within Microsoft in the datacenter development design process. Teams need to gain insights in each others preferences and find consensus on datacenter design solutions. In order to facilitate this, the Design Collaboration Workshop (DCW) is developed where the participants will be coming together. The method used for the DCW is already explained in Section 3.2.2 and uses a serious game set up. The design of the DCW is explained in Section 6.3.1. The DCW uses the preference curves, and the results of the first two exercises gathered in the Social Cycle as input. Furthermore the DCW uses the DCT, developed in the Technical Cycle, as conversation facilitator. The DCW performance is discussed in Section 6.3.2. The verification of the DCW can be found in Section 6.3.3 and the DCW is validated in Section 6.3.4. It ends with improvements for the second iteration. These improvements can be found in Section 6.3.5.

6.3.1. Design of the Design Collaboration Workshop

The design process of the DCW began with a few clear criteria that the DCW had to meet. The DCW needed to be held online since the participants are located all around Europe and it should not be taken more than one hour, due to time constraints of the participants. The DCW should be able to be executed with the five participants plus extra people form Microsoft who wanted to join as well. Furthermore, the information gathered during the 1-on-1 meetings needed to be somehow included as well. This information practically consisted of the ranked variables per team, the role play outcomes and the drawn preference curves. Before the outline and the content of the DCW was designed, first the decision was made on the main game element of the DCW, on what the participants could adjust, keeping in mind the requirements for the DCW established in Section 4.2.3.

Firstly, it was decided that during the DCW the preference curves would be fixed. During the DCW participants were not able to interactively adjust preference curves. There are two reasons for this. If they would have been able to, participants could have been inspired by the preference curves of other participants which could have contaminated the principle that this research strives to listen to each stakeholder individually to collect their core preferences. Also, stakeholders have been intensively involved when drawing the preference curves so making them dynamic could have influenced participants positive experience. Why would they have put effort into defining one curve prior to the DCW even though the curve could be adjusted in the DCW? This aligns with the metric ‘respect’ that is required to be protected.

Secondly, it was decided that the preference curves should be anonymous and only contained color coding. This was decided to stimulate communication without the chance of it getting personal during the discussion. This aligns with the metric ‘respect’.

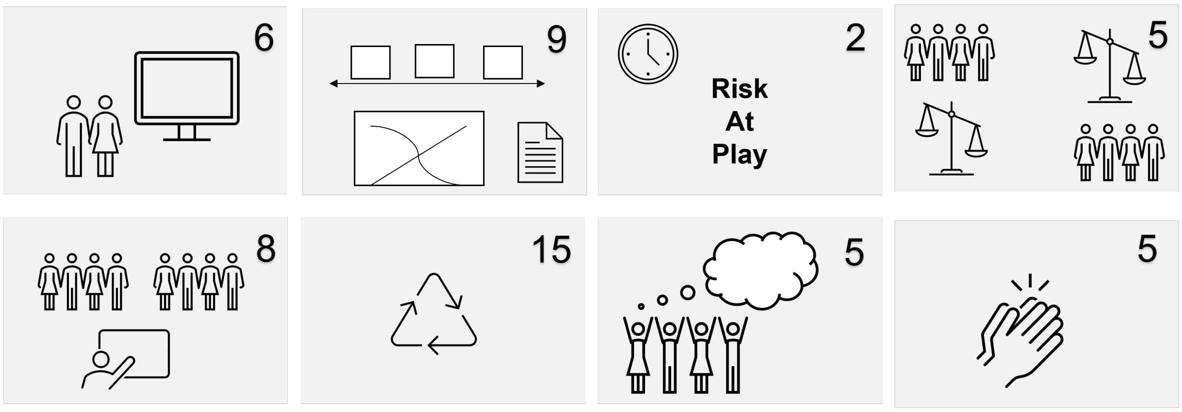


Figure 6.22: DCW timeline with elements

Thirdly, it was decided that the ranks of the variables would not play a role during play of the DCW, as described in Section 6.1.2.2. They do play a role in the first part where the results were shared to enhance mutual insights among participants' important design variables as described above.

Sequentially, it was decided to fix the set of variables and their bounds. This was done to improve the comprehensibility of the model and make it not too complex.
In the end it was decided that the dynamic feature that participants could play with, were the weights. Each stakeholder initially had an equal share of the total weight, which was 100%. During the game, they could change their share as they wished, as long as the total weight remained 100%.

After this was decided, brainstorm sessions were held to further develop the design and outline of the DCW. Visuals from the brainstorms around the DCW can be found in the Confidential Appendix CI. As in the beginning of this subsection was mentioned, an inventory was made of all the acquired information. This information has been considered by developing the design of the DCW.

The DCW consist of 8 parts, which can be seen in Figure 6.22. The DCW contained a PowerPoint as a basis (see Classified Appendix CJ), and a web application of the DCT, developed in the Technical Cycle.

Start (6 min)
Since the DCW contained an online meeting, there was some time reserved to let everyone install their microphone and camera. The moment all participants had joined and were ready, the purpose of the DCW was explained to them.

Showing the 1-on-1 results (9 min)
The first part of DCW concerned presenting and discussing the results from the 1-on-1 meetings to all the participants to enhance insights of each other's preferences. Figure 6.23 shows one of the slides used to discuss this. This conversation started with the outcomes of ranking the variables on importance per team and what other teams thought was the most important variable for that team. On the right side the ranking of the variables on importance were shown for the discussed team. On the left side, the variables were shown on what other teams thought were most important to that discussed team. The representation of these results can be viewed in Confidential Appendix CJ. Sequentially, the preference curves of all teams were shown per variable. This accurately displayed the conflicts, since some lines were right-angled to each other. This first part of the DCW did not contain any gaming elements but was still vital to foster a valuable experience during the rest of the game and motivate personal development with these new insights.

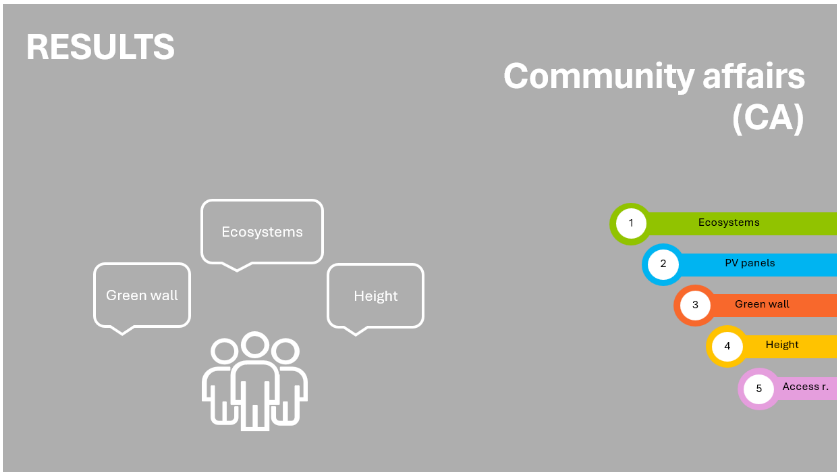


Figure 6.23: Example of the results from the 1-on-1 with the CA team

Explaining DCT and rules of the game (2 min)
In the second part an explanation was given to them on how the visualisations and workings of the DCT and how to interpret the outcomes. Figure 6.24 shows the DCT. At the top of the webpage of the DCT, the preference curves of the participants are visible per variable. The colored boxes underneath the graphs are the weight distribution boxes, where participants can adjust their weights. In the blue and white box, the optimized value per variable is shown. When the working of the DCT was clear to the participants the Risk At Play was introduced to the participants.

One of the participants was asked to randomly draw a Risk At Play (RaP) card, from the cards that were shown on a PowerPoint slide. This RaP is expected to influence the datacenter design. The RaP creates a simulated game setting about the case study, which can directly be linked to the serious game metric 'simulative'. It symbolises potential risks during later phases of the development that could in theory be impacted by different design choices. These risks could have been identified during due diligence studies but their effects are unknown during this design phase. This game element accurately aligns with current practice at Microsoft as mentioned in Chapter 4. Different teams identify risks but cannot show the expected effects and how design choices can assist to mitigate these effects. The

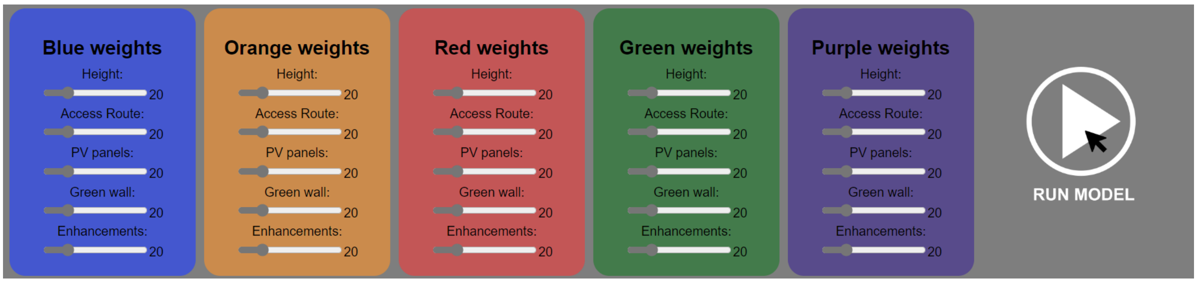


Figure 6.25: Weight sliders in the DCT GUI

DCW simulates this phenomenon and asks participants to change the weights to cope with the Risk At Play. The RaP in round one was:

”*The demand for DCs is growing due to AI. MS determined that DC2023 should be in operation in 3.5 years instead of the planned 4 years*.”

Figure 6.24: DCT GUI when initially loaded

Adjusting weights (5 min)
After the RaP had been drawn the participants were divided into two breakout rooms to discuss the effects of this risk and could collectively adjust the weights for each of the teams preference curves. Figure 6.25 zooms in on these weight sliders. Note that the cards are colour coded but not labeled. Each colour represented one team. The moment the participants agreed on the weight set they could run the model and watch the new datacenter design variable values. Then they could alter more weights until they were satisfied with the alternative design they created. Based on the two alternative designs from the two breakout rooms the participants were asked to use their shared insights to discuss the new found design configurations and determine if they preferred these over the standard design. This play of the serious game aims to fulfill the second part of the collaboration defined in the research goal namely to use the increased mutual insights to create new datacenter design configurations.

Play the second round (15 min)
Then a second cycle started were a different (conflicting) Risk At Play had been drawn. The RaP in round two was:

”*Due to the increased time pressure the projects sustainability is threatened. The AHJ thinks their design aspirations are not sufficiently met and there are voices of greenwashing by MS. Also, community objections grow since they believe MS powers their way through public permitting phases*.”

The teams were slightly changed to enable cross-contamination and a new design solution was sought in the break out rooms. The results of the second cycle were pitched and compared and the DCW concluded with a plenary discussion of the results.

Compare and discuss the solutions of the two teams (5 min)
When the two breakout rooms found their new datacenter design solutions all participants were brought back together in the central meeting and the two solutions were pitched and compared.

Reflection of the game (5 min)
Afterwards, the participants were again asked to fill in a questionnaire about their experience during the DCW and how they would like to see it improved.

6.3.2. Performance Design Collaboration Workshop

The first part of the DCW, discussing the 1-on-1 results went promisingly well. The participants clearly reviewed each other’s variable ranking and the results from the role play exercise. This provided them with new insights about each other, especially with regard to the role play. The participants had almost exclusively highlighted different variables as being most important than they ranked them themselves. For some teams the others were quite unanimous about which variable was the most important while for others the responses were more distributed indicating no limited mutual insights into each other’s preferences. All the results can be reviewed in Confidential Appendix CJ.

Then, the preference curves of the different teams were shown and discussed. The participants were able to see the preference curves as shown in Figure 6.14. The curves were purposefully not labeled, but the participants created a transparent conversation by verbally labeling the curves themselves to discuss them. They mentioned in the future labeling them is easier to read the graphs and the transparency it offers outweighs the anonymity. When the participants reviewed the graphs of the combined preference curves the conflicts in preferences became very apparent. Participants said that this was extremely insightful for them.

After discussing the results from the 1-on-1 meetings it was time to use the found insights to collaboratively develop new datacenter design solutions. The participants were split into two groups in different break-out rooms. In the break-out rooms the participants started to discuss the Risk at Play while also getting used to the Design Collaboration Tool and the Graphical User Interface (GUI). There was intentionally no real steering by the moderators to test intuitive and independent play. Quickly this raised questions with the participants in both break-out rooms. Repeating the intention of the game and the task at hand helped but still participants seemed flustered on what to do. Getting used to and playing the game demanded most of the time but eventually two design solutions were found. The results of the two break-out rooms were very similar which was mostly caused by robustness of the model and the algorithm used. Figure 6.26 shows the results for the solution of one of the break-out rooms in a table. Figure 6.27 shows the same result but plotted on the preference curves. The absence of numeric preference scores and labels in the graphs made interpreting and comparing these results challenging. In addition, the participants felt that the results were not developed through understood and confident play of the game. Despite providing some initial insights into new design solutions the quality of the solutions were not extensively discussed.

Next to this, the results were overly robust. The number of weights that could be assigned resulted in more or less distributed weight sets while completely different design solutions required harsh weight changes. This was induced due to the nature of the algorithm and the number of weights used. For the participants this meant that they did not feel they could influence the design since the same configuration kept reappearing. This undermined the purpose of exploring different design solutions and evaluating their effects on the preference scores.

Variable	Optimal Value
Height	23
Access Route	256
PV panels	37407
Green Wall	966
Enhancements	6

Figure 6.26: New design configuration found in one of the break-out rooms

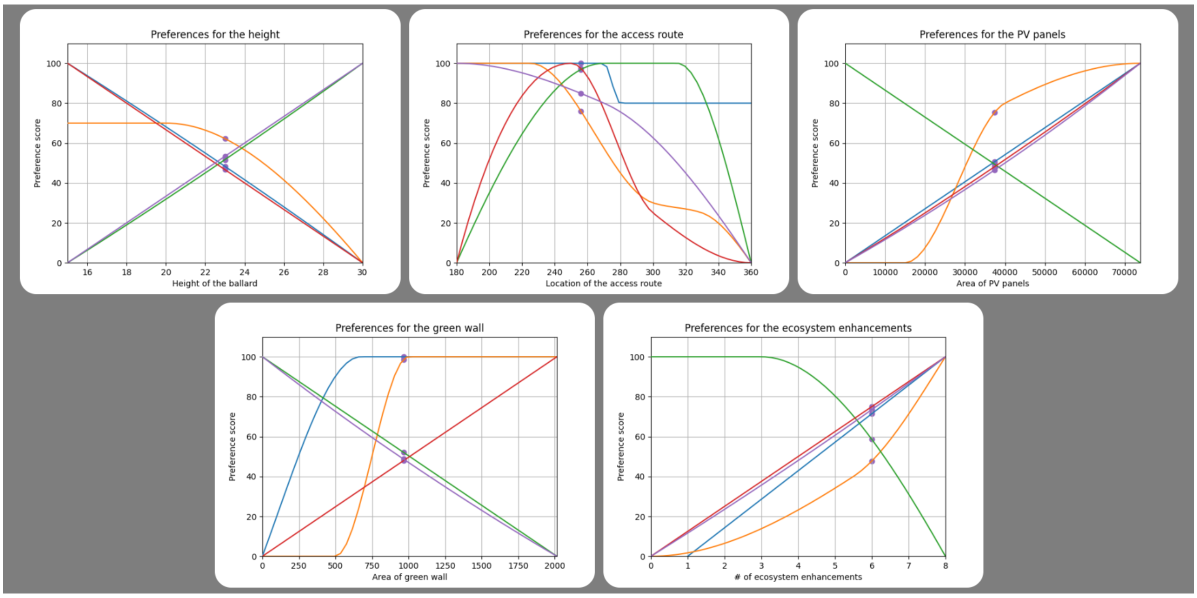


Figure 6.27: New design solution plotted on the preference curves found in one of the break-out rooms

All in all, playing the first round demanded almost all of the time. The second round was omitted and DCW was shortly evaluated with all the participants. They acknowledged the added value of the first part where the 1-on-1 meeting results were collaboratively discussed. Also they saw the potential of interesting new design solutions as fruits of the increased mutual insights but in the current form of the DCT were unable to adequately review this.

6.3.3. Verification Design Collaboration Workshop

Looking at the performance of the first DCW, it meets the criteria for being valuable, simulative, and respectful. This was also confirmed by the feedback forms that were filled in by the participants after the DCW. The participants were enthusiastic about gaining insight in each other's preferences and the reasoning behind this. This contributed to the participants' daily practice within Microsoft, and therefore was **valuable**. The RaP made sure there was a **simulative** effect. It contained a time pressure risk, what represents an accurate depiction of reality. Furthermore, participants did not have the feeling that they were personally attacked and had the control over their individual decisions. Therefore, the metric **respect** had been successfully met. Noticeable was that the participants asked to not use the colour coding, but wanted to have the teams stated. The extensive feedback can be found in Appendix G.

However, some criteria could also be improved for the new DCW, since it was noticed that the use of the DCT and the interpretation of the solutions were found difficult. The **collaborative** metric has to be improved since the understanding of the tool hampered deep involvement. The general goal of the DCW was clear, but the specific task during the game, finding the best optimal design considering the Risk At Play (RaP), was not fully understood. This was also mentioned in the feedback from the questionnaire. Next to this, the **feedback** metric needs to be improved. The DCT focused only on computation speed while this proved to be a less important attribute. Ease of use, and comparable results were the main missing elements and these need to be changed in further development. Lastly, also the **scalable** metric demands additional attention. The tool was not sufficiently understood, especially if the developers were not there to insist. This version of the DCW limits intuitive use. This was shown in the fact that the 100% weight constraint was not clear and the effect of the changed weights was limited. It was unclear to some participants which weights had to add up to 100%. Some recognized that the weights of one team had to add up while others thought the weights of one variable should add up. Given the fact that this was a 5x5 model this was particularly confusing because the starting point of all equal weights added up to 100% in both directions.

6.3.4. Validation Design Collaboration Workshop

The needs of the DCW, as stated in Section 4.1.3, is to improve the collaboration between different teams within Microsoft, to find new datacenter design solutions, that are considering teams preferences that covers different socio-technical aspects. Teams need to gain insight in each other's preferences on the design variables. In the end this needs to lead to find new datacenter design solutions collectively containing socio-technical aspects.

During the DCW it was achieved to gain better insight in each other's preferences. This was primarily due to showing the results of the ranked variables that were gathered during the 1-on-1 meeting and letting the participants explain why. This was done central at the beginning of the DCW. The participants indicated that the DCW contributed to gain more understanding for each other's preferences. However, two different breakout rooms were used during the game after the RaP was drawn. This limited gaining insights what happened to teams preferences when the RaP was drawn, because they were only with the half of the participants in the break out room. Unfortunately, due to the difficulty of the tool, a lot of time was lost by explaining the tool and explaining the weight distribution. Therefore, there was no time to extensively discuss the new design solutions, coming from the tool. So the goal of finding new datacenter design solutions had not been achieved.

6.3.5. Improvements Design Collaboration Workshop

In conclusion, the DCW demonstrated success in the requirement metrics such as **valuable**, **simulative**, and **respect**. It consisted of certain limitations, particularly in the **collaborative**, **feedback**, and **scalable** aspects. These aspects are needed to be taken into account for the second iteration. Showing and discussing the results with the participants contributed to gaining insights in each other's preferences. However, the use of breakout rooms during the weight distribution contributed to a lack of gaining insights, since only half of the teams are in one breakout room. It would be better to not use two breakout rooms, but instead keeping it central. The time management needed to be improved since the participants were not able to find and discuss the new design solutions that were found by the tool. A more intuitive tool and a simplified exercise of the weight distribution, needs to be included as well in the next iteration. This way, there is no time needed for additional explanations. The most important improvement for the second iteration would be to really focus on discussing the new found design solutions, since that is a prominent part of the study.

7

Iteration 2: Design and Performance

After the first iteration, a second iteration is executed in order to improve the cycles and the DCW. The second iteration of the Social Cycle is discussed in Section 7.1. The second iteration of the Technical Cycle can be found in 7.2. The second iteration of the DCW is discussed in Section 7.3.

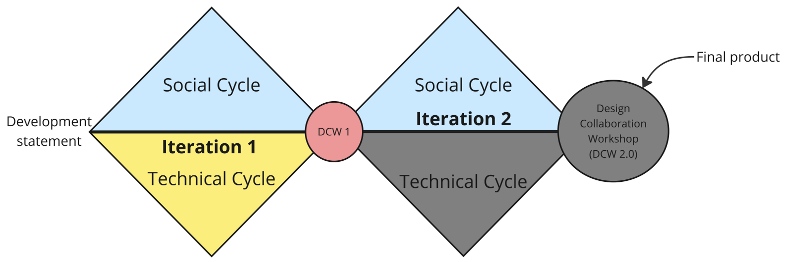


Figure 7.1: Iterations process overview

7.1. Social Cycle development

Concluding the first iteration of the Social Cycle in Section 6.1.6, the focus for the second iteration will not be on the improvement of the approach of collecting the preference curves. However, the focus will be on testing if the human reflection is really improved comparing to the former PAS method. First the method on how this will be done is discussed in Section 6.1.1. Then the design of this is described in Section 7.1.2. In Section 7.1.3, the performance is discussed. The verification can be found in Section 7.1.4 and the validation in Section 7.1.5.

7.1.1. Methods Social Cycle

While from the verification and the validation in the first iteration can be stated that the Thinking-Out-Loud method and the free drawing principle contributed to a good reflection of the participant preference in the preference curve. The question arises how this new approach relates to the former approach; the PAS-method developed by Arkesteijn and Binnekamp (2013). Therefore, instead of using the second iteration to improve the new developed approach, a comparative analysis will be executed.

In the second iteration, a second 1-on-1 meeting is held with the same participants. In this meeting the participants are being asked to draw their preference curves according to the former PAS method. These meetings are taking again half an hour and will be held online via Microsoft Teams and will be recorded. The PAS method contains a three point preference curve, where the participant is being asked to define a bottom and top value and an intermediate value. The participant is being asked to give a value for the green boxes, that can be seen in Figure 7.2. The facilitator enters the values while sharing their screen, and the preference curve is displayed with the help of Excel. Contrary to the first 1-on-1 meeting, the Thinking-Out-Loud method was not used while executing the second 1-on-1 meeting, because this was also not used in the original PAS method. After these new preference curves were filled in, these new preference curves were held next to preference curves drawn in iteration 1, as shown in Figure 7.3. The old preference curves were in advance already copied in the Excel, but hidden for the participants until now, so they were not influenced by their old curves. These different curves were displayed next to each other to the participant. The participant was asked to compare the two different curves by answering the following questions:

- Which curve reflects your preference better and why?
- What did you notice for differences using the Thinking-Out-Loud method during the first 1-on-1 and not have been using it for this meeting?
- What specific element or features made it easier or more challenging to express your preferences, looking at both methods?
- Was it clear what was being asked by defining the preferences? Were the bounds and variables clear?
- How have you experienced the level of difficulty with drawing a preference curve in general?
- In the future if this process is used in the datacenter development process within Microsoft, which method of drawing the preference curves would you prefer if the main focus is to reflect your preference and why?

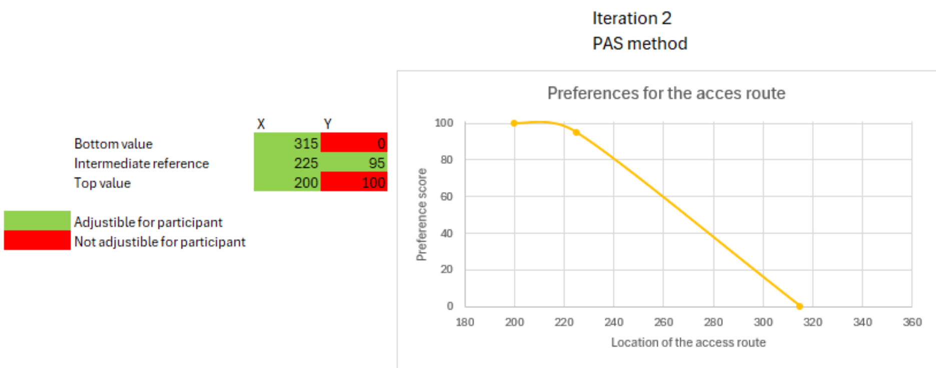


Figure 7.2: Using PAS-method to define preference curves

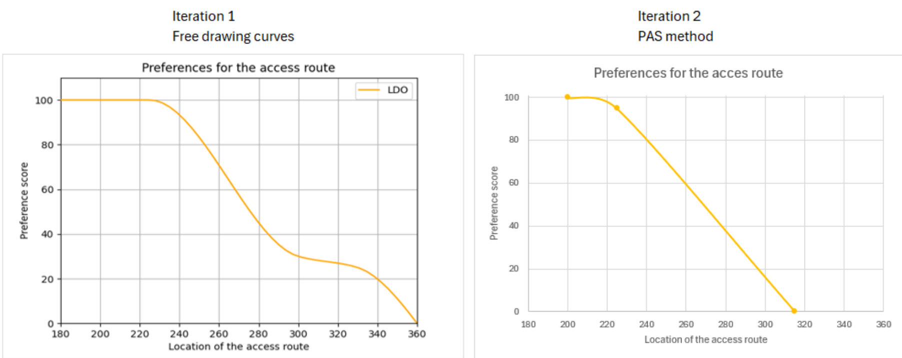


Figure 7.3: Showing the participant their two different curves

In the end of the meeting, the participant was told that the curves from iteration 1 would be used as input for the DCT 2, and not the ones that were established in this second 1-on-1 meeting. However, they were asked if there were preference curves they wanted to adjust or replace by the curves established in this second meeting were the PAS method was used. The meeting was recorded, so the answers to these questions could be watched back and the interviewer did not have to write along these answers.

As a result of the two different 1-on-1 meetings, two different preference curves of the same design variables in the same case were collected from the participants. The difference of these preference curves could be analysed by looking at the lines how these curves differed from each other, and how the participants answered the questions during the 1-on-1 meeting, that compared these methods. This will be discussed in Section 7.1.5.

This comparative analysis was chosen to compare two different methods and evaluate the different preference curves, to be able to see if the method of iteration 1 was an improvement comparing to the PAS method. It enabled examination to see if the free drawing method and the Thinking-Out-Loud technique helped to better reflect human preferences than the former PAS method.

7.1.2. Design Social Cycle

The meeting started by some small talk. Then the purpose of the meeting was explained including the difference of this meeting compared to the first 1-on-1 meeting. The explanation included the introduction of the former PAS method and an explanation that this meeting was needed to investigate the academic relevance. They have been reminded that the same case study is used (DC2023), with the same related context as explained in the video that they received before the first 1-on-1 meeting. The design variables are again shortly discussed and they are told that the design variable ”green walls” have been removed. The PAS method was then explained to the participant. They needed to define a bottom value, a top value and an intermediate value. For the intermediate value the participant had to fill in the X and the Y values. This was described in Arkesteijn and Binnekamp (2013), Arkesteijn et al. (2015) and Arkesteijn (2019). The participant was being asked to give the values for these three different points. The values were filled in by the interviewer in Excel, while sharing their screen during the meeting. Simultaneously the participants were able to see the actual preference curves arises. The participant needed to fill in the green boxes as shown and explained in Section 7.1.1. After defining these curves, the participants were asked to compare their free drawing preference curves to the ones that were made using the PAS method and answer some questions, as described in Section 7.1.1. They also got a chance to adjust their curves from iteration 1, that will be used for the DCT and the DCW 2. In the end of the meeting a short summary of the meeting was given and they were thanked for participating in this second 1-on-1 meeting. Furthermore, they were reminded that the DCW 2 was taking place next week Monday.

7.1.3. Performance Social Cycle

All the meetings were executed in time, and often there even were 5 of 10 minutes left. These were filled in with personal conversations. The Excel graphs were easy to use and the participants could understand this easily, by watching the shared screen during the meeting of the interviewer and seeing their preference curves arise. Some participants had difficulty in remembering the case context of DC2023. When this happened, there was a short summary given of the case.

7.1.4. Verification Social Cycle

For the verification of this second 1-on-1 meeting, the same principles can be used as stated in the requirements of Section 4.2.1. The first principle is emphasizing their importance, by listening to their experience and to show that their information is actually used. During the meeting, there was a lot of time reserved to listen to the participants’ experience and how they have encountered using the PAS-method. Furthermore, the information they gave, by defining the new preference curves, were directly used to compare those curves to their old curves. By letting them define their preference curves, their interests are seriously taken into account. During the meeting but also during the second iteration, participants have been actively involved by getting updated on the development of the thesis and how their input is used. Using the second 1-on-1 meeting as extra validation, kept the participants involved on the process. The sub-principles of fostering a positive experience were considered as well by outlining the meeting. The goal and the purpose of the meeting were clearly explained and the participants received immediate feedback while directly seeing their new defined preference curves.

Noteworthy was the principle emotional connection. The small talk and the personal conversations at the beginning of the second 1-on-1 meeting, were more personal and took longer. The logical explanation for this, is that over time, the contact moments with the participants have been increasing while the emotional connection is getting stronger. This was strongly seen in the second 1-on-1 meetings.

The meeting did not fully emphasize the principle of knowing when the meeting will be successful for the participant. Since the focus was more on comparing the two methods for academical reasons.

To conclude almost all the principles as stated in Section 4.2.1 have been met except the principle of knowing when the thesis will be successful for them. However, this was already identified during the first iteration.

7.1.5. Validation Social Cycle

The need for the Social Cycle that was stated in Section 4.1.1, was to improve human reflection of the preference curves. The new method developed in this thesis was compared to the former PAS-method, to validate whether the new method improves human reflection of the preference curves. The preference curves of both methods and the answers of the participants have been compared after the second 1-on-1 meeting. There was no black and white answer to the question of which method contributed better to a human reflection of the curves. However, the new method used in iteration 1, did increase the level of human reflection by being more flexible in the preference curves and the use of the Thinking-Out-Loud method. An overview of the observations is given in Figure 7.4.

The curves that have been drawn according to the free drawing method, allowed participants to be

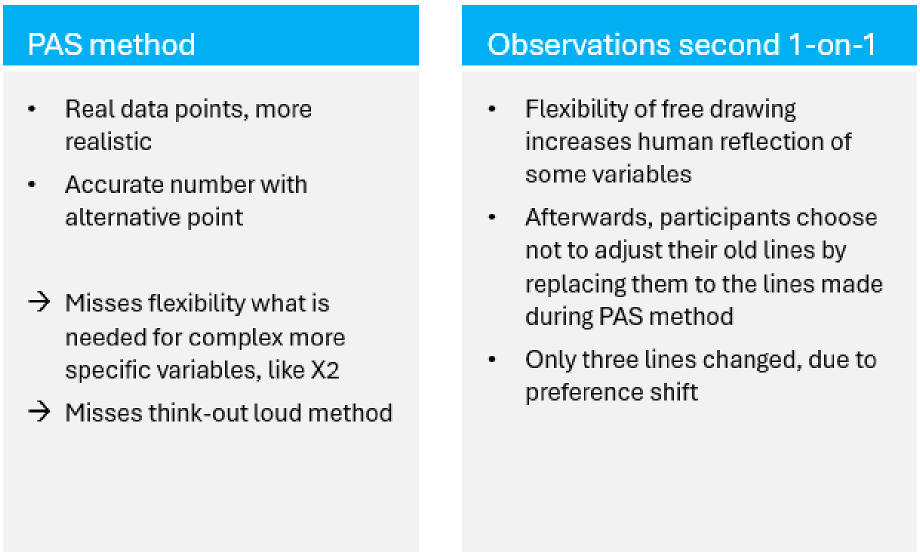


Figure 7.4: Overview comparing the two methods

more flexible in their preferences. The flexibility of this free drawing was indicated and mentioned by every participant. The need for flexibility was mostly seen by more complex specific variables, such as the location of the second access route. The curves that have been drawn there, could not have been established using the PAS-method, Figure 7.5 shows such a drawn preference curve from a participant. Having more flexibility gives increases the reflection on the preferences with more complex specific variables like the location of the second access route.

Furthermore, using the free drawing method allowed participants to not have a bottom or top preference. This was used by participants during the first iteration. A participant indicated that the location of the second access route did not really have a big negative preference. At one side it was set as

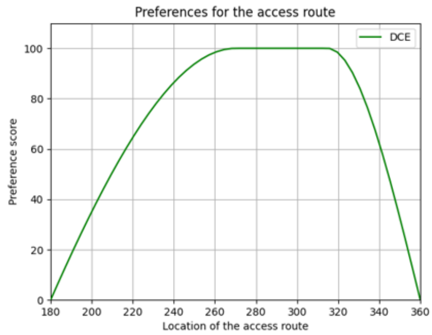


Figure 7.5: Example 1 of a participants' preference curve using free drawing

most preferred (to 100), but if the road would be on the other side, this would not be preferred, but just a bit less (set at 80). The PAS method does not allow this since a bottom and top value is being asked. This preference curve is shown in Figure 7.6.

However, the tested PAS method also received positive feedback and had its advantage compared

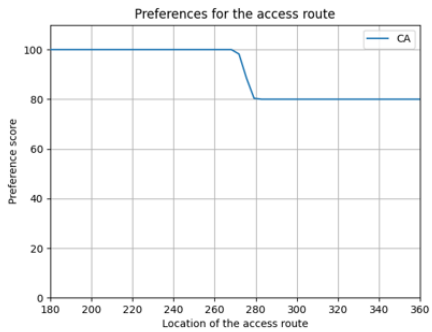


Figure 7.6: Example 2 of a participants' preference curve using free drawing

to the free drawing method. The participants indicated that using real data points and seeing the preference curves arises was more realistic. Having to indicate these specific point and actual numbers made it more accurate, which also contributes to the level of reflection of the preferences. But still, almost every participant mentioned the lack of flexibility and the decrease of the level of good reflection on the variable location of the second access route using the PAS method. The preference curves were hard to define with only three points. Additionally, no participants have changed their preference curves from iteration 1 into a preference curves established in iteration 2.

All participants indicated that the use of the Thinking-Out-Loud method during the executing of defining the preference curves, really helped them by reflecting and defining their preferences. This is an improvement on the former PAS method where they did not use this. Using the free drawing principles improves flexibility in curves, which increases the level of reflection of human preferences. However using realistic data points and seeing the preference curves arise in Excel was an element of the PAS method in iteration 2, that participants indicated to miss using the free drawing method. In Section 8.2 a recommendation will be made combining the more realistic data points of the PAS method, with the flexibility of the new method and the use of the Thinking-Out-Loud method.

7.2. Technical Cycle development

Based on the improvements defined for the technical cycle the DCT underwent rigorous alterations. Basically, all three aspects, the optimization back-end, backbone API and GUI front-end were redesigned. The final design will be described in the sections below and its performance will be verified.

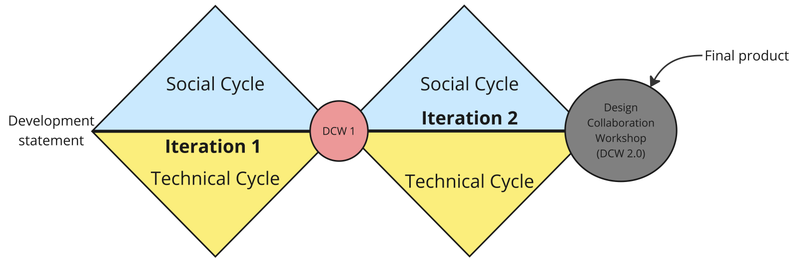


Figure 7.7: Iterations process overview

7.2.1. Methods Technical Cycle

7.2.1.1 Back-end

As described in the improvements in iteration one the main issue concerning the back-end was the choice of aggregation algorithm. This choice was made based on computation time and the quality of the solutions. In iteration one therefore only the minmax algorithm was applied. A faster aggregation algorithm was applied for the IMAP which made sure it is now as fast as the minmax to calculate an optimal solution. This way both the minmax and the IMAP solutions can be considered and reflected upon during the Design Collaboration Workshop.

7.2.1.2 API

The API underwent a rigorous change. While in iteration one the Flask framework was used as the backbone of the DCT due to its relatively easy use and flexibility, iteration two is build using the more robust Django framework. There are several reason for this decision. Most importantly, the improvements from iteration one stated that an integration of the 1-1 results and the DCT was useful to disable switching between interfaces during the DCW. This meant that the DCT should be able to handle different inputs from different stakeholders. Also, the ranking of the variables and the drawing of the preference curves would ideally be played in the DCT as well. For the development of the DCT this means that tracking of different data structures was necessary to correctly link the input to a stakeholder and allow for possible changes in their input and save this input data within the DCT. Moreover, the improvements of iteration one mentioned that is would be useful if model runs and their solutions would be logged and saved for future evaluation. Also here the DCT was required to save and handle this data.

7.2.1.3 Front-end

For the front-end no real new methods were adopted. The front-end of the DCT still contained HTML, CSS and Java coding. All of these codes needed to be adopted to suit the Django framework which works on significantly diffent protocols than Flask.

7.2.2. Design Technical Cycle

From the outset of iteration two, the architecture of the DCT changed. The new architecture can be seen in Figure 7.8 below. The only difference can be observed in the API where it now says Django instead of Flask in iteration 1. More information on changing the framework will follow.

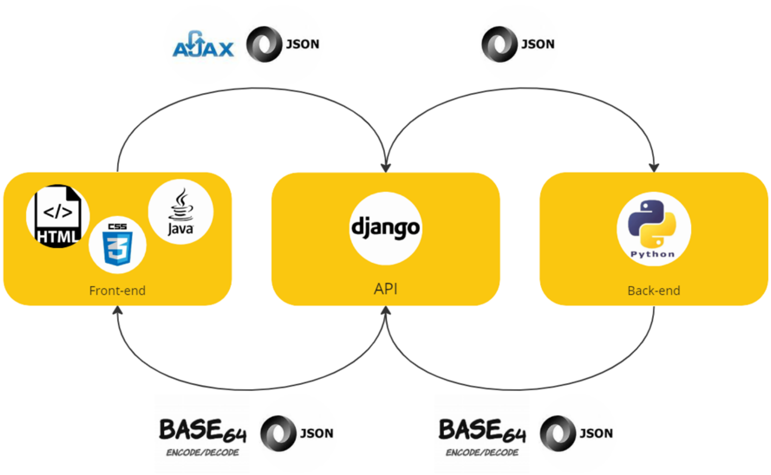


Figure 7.8: DCT main architecture for iteration 2

7.2.2.1 Back-end

The final design of the DCT incorporates both the minmax and the IMAP results. Next, the results generated by the algorithm were extended. During the first iteration merely a plot with the most recent minmax solution was shown and the values of the variables for this optimal solution. For iteration two also the IMAP solution was provided, so were all the resulting prefernce scores for these points in order to allow participants to evaluate the quality of the solutions better. Also, an 'as-built' solution or standard design solution was implemented in collaboration with the design manager for this particular case study, based on the standard design and provisional site test fits. This way the participants could reflect on the differences between the found optimal solutions and the current/ standard design solution.

7.2.2.2 API

Django provided robust protocols to create different profiles, a login authentication and store data such as input data and model run back-logging. Figure 7.9 below shows the view of the login place. In future versions of the DCT a profile can be created for each of the participants, they can enter and save their input data in the app which will then be used during the DCW. This switch from Flask to Django did however require the researcher to start from scratch and build the DCT given all the Django protocols which are completely different than Flask.

7.2.2.3 Front-end

The front-end GUI underwent the most changes compared to iteration one. The fact that the 1-1 results are now also displayed in the DCT in combination with improvements to the GUI of the serious game elements resulted in a completely different interface. Figure 7.10 below shows the view for the input data of the participants. In this view each participant had their own card showing their input data, the ranks of the variables with the amount of time others mentioned a variable as being the most important and their preference curves. The variable sticky notes can be dragged on the screen allowing interactive play and reconsideration of the rankings. This functionality anticipates a future version of the DCT where participants can input their data individually and save it in the app. So no other software such as Miro is required for this. The preference curves can appear rather small, but these can be enlarged by clicking on them which enlarges them in the middle of the screen. Note the icon menu on the left. This dynamic menu allows participants to navigate wherever they want in the DCT. Other views are used for playing the game, voting on found design solutions or provide help in using the app with a tutorial. Next to this menu to navigate participants can also use the continue and previous buttons to adhere to the natural flow of the DCT.

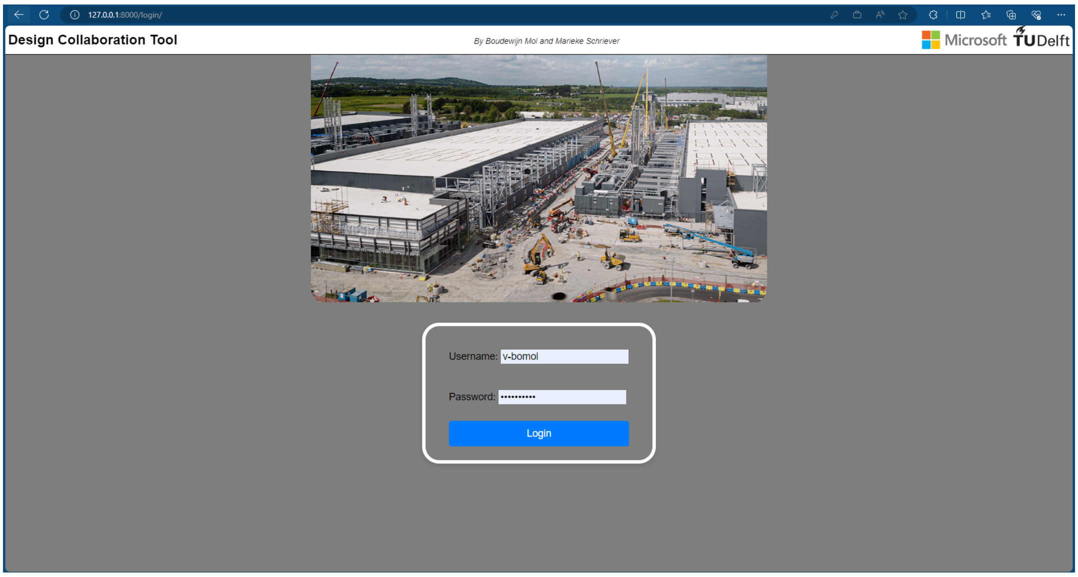


Figure 7.9: Login view of the DCT

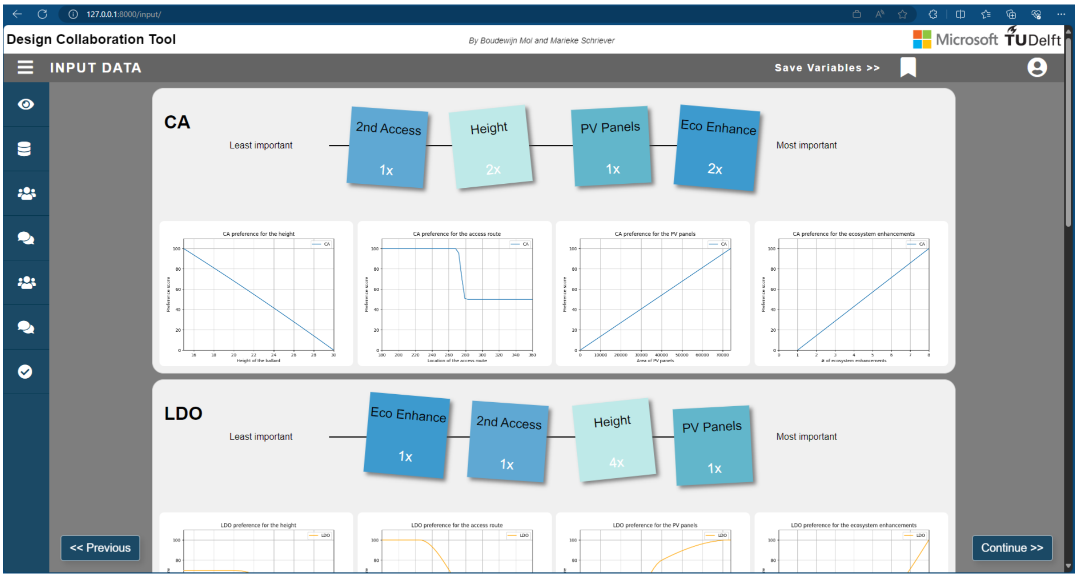


Figure 7.10: Input Data view of the DCT

After the input data page can be discussed between the participants they start to play the game in the next view. Figure 7.11 below shows the view for the this. Note that each of the participants again have a personal and scrolling down would show the resulting cards. In comparison to iteration one all the preference curves are now labeled and colour-labeled. The participants mentioned that there is no need for anonymous data and that labeling would allow for a more transparent shared conversation. The weights for each stakeholder was changed from a slider to a textbox to enhance ease of use. Also the sum is immediately calculated and shows on the bottom of the weights panel. This way participants can immediately see how much weight they still need to add or subtract rather than waiting for an error message. Still, similar to iteration one, this error message would appear when a simulation is started without all the weights adding up to 100. The tables are just to display the results of the found solutions, which are the values of the variables as well as the preference scores and the right shows the preference curves which would be updated after a model run. This way the participants can review their individual results as well as the aggregated results at the bottom of the view. Note that also these preference curves can be enlarged to improve readability and that these already portay the standard design solution as a starting point/ point of reference. The natural flow of this view is to scroll down. This way each stakeholder can personally express their views on the Risk at Play (RAP) with respect to the variables. When scrolling down the RAP stays in the top spot for reference for all of the stakeholders.

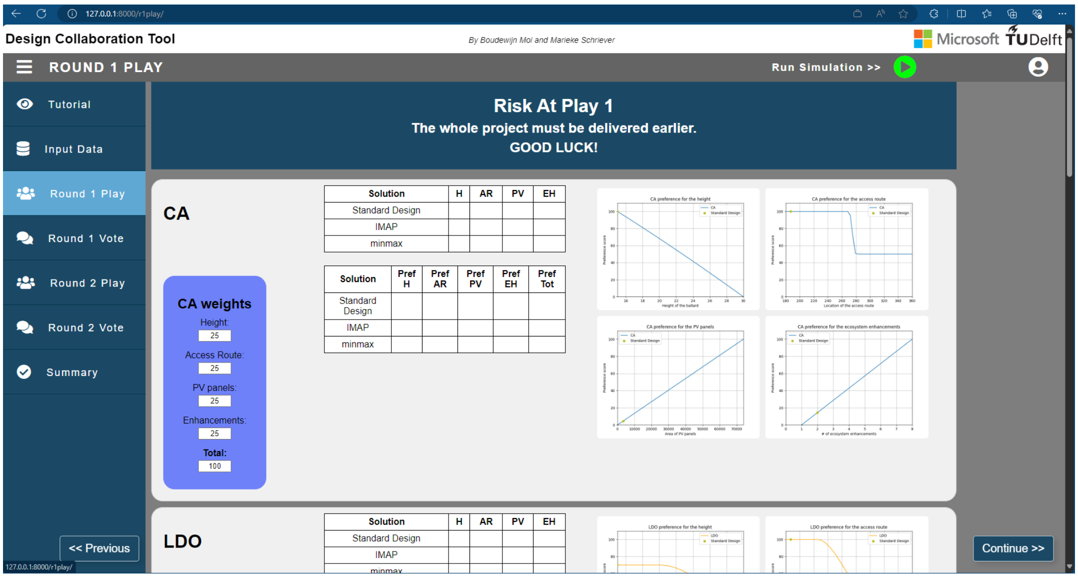


Figure 7.11: Play view of the DCT

Figure 7.12 below shows the aggregated preference curves and tables. Note that the bottom table here does not portray the preference score of a stakeholder per variable but instead shows the prefernence scores per team and an aggregated total preference score. This results card is also shown on the next view which is the voting view. The idea is that based on a model run the participants reflect on the quality of the found optimal solutions compared to the standard design by voting on whether the design is improved or not. The other icons (as shown in Figure 7.11) in the menu indicate that a second round could be played if another design decision should be discussed and visualized.

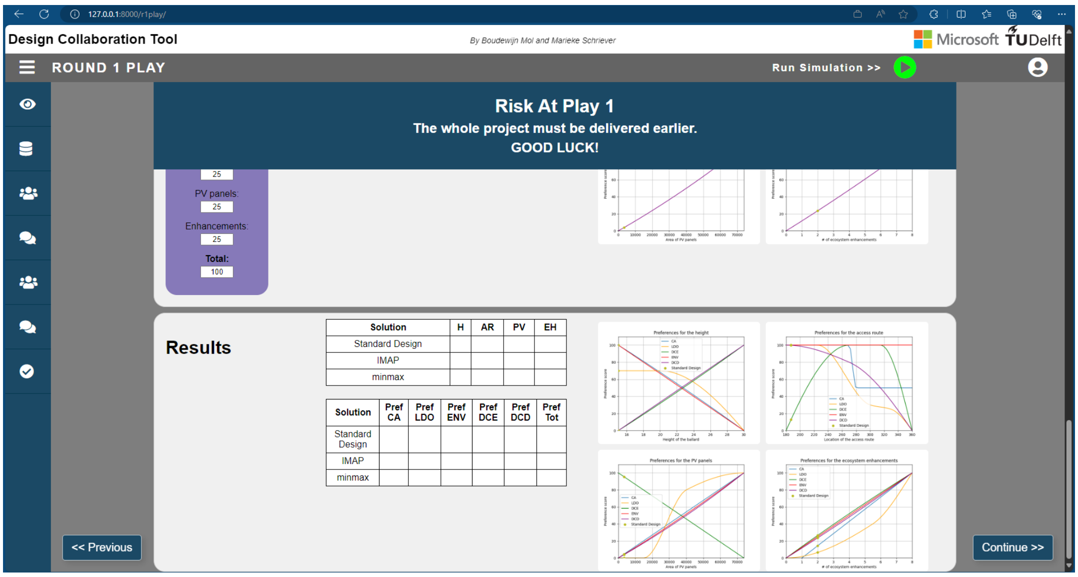


Figure 7.12: Results card in the DCT

7.2.3. Verification & Validation Technical Cycle

The performance of the DCT was greatly improved between iteration one and iteration two. The final design is easier to use and understand, but more on this in the next chapter. Moreover, it provides a more robust framework for further development. It showed a glimpse of the anticipated possibilities by introducing the variable ranking exercise in the DCT and allowed for better play and reflection on the outcomes, which was one of the main concerns. During the DCW the conversation was more calm and relaxed since it was easier to understand and the flow of the DCT facilitated this conversation in a centralised way. Therefore, the requirements immersion and feedback were greatly improved. The enhanced speed of both the algorithms allowed for faster feedback and strategy adaptation and the centralised information allowed for deeper immersion into the DCT. The participants expressed more control during play. For example the ranking of the variables allowed for reconsideration because the notes were draggable and the textboxes for the weights with the provided dynamic sum allowed for more controlled play.

The scalable metric was still insufficiently incorporated. The defined variables and bounds were fixed in the back-end of the DCT. During play this proved problematic when participants proposed to change the bounds of a variable. This shows that greater flexibility to change the definitions of the model would allow better play. This also ties in with the increasable metric, where adding variables or constraints would make the game more difficult whenever the participants feel comfortable in doing so.

7.3. Design Collaboration Workshop development

Based on the first iteration, the DCW requires improvements, as specified in Section 6.3.5. The improved design is described in Section 7.3.1. Afterwards, the executed DCW is discussed in Section 7.3.2. Then the DCW will be verified in Section 7.3.3 and validated in Section 7.3.4.

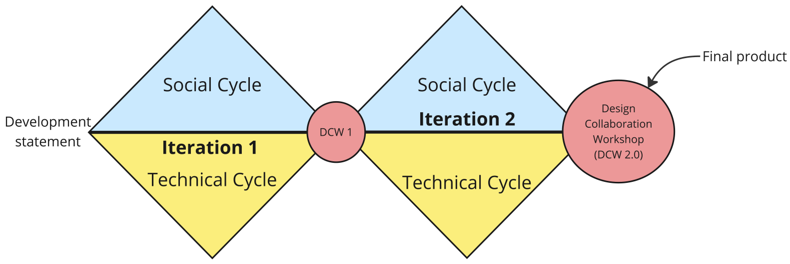


Figure 7.13: Iterations process overview

7.3.1. Design of the Collaboration Workshop Development

Considering the feedback and the reflection of the executed first DCW, the improved DCW has been developed. In Figure 7.14, the outline of the improved DCW can be found.

Welcome (5 min)

The initial minutes are used for casual conversation and for allowing everyone to join and adjust their video and audio settings. If some participants are a little delayed, then this will not affect the further time schedule.

Discussing DCW 1 (5 min)

First of all, the DCW started with a reflection on the first DCW. The improvements have been discussed to show the participants what is improved and what is different compared to the first DCW. The main objective of the improved DCW is to really focus on discussing the new datacenter design solutions by means of the DCT outcomes. Furthermore, it is important to show the participants that there has been an improvement on the distribution of the weights, which was unclear to the participants the last time.

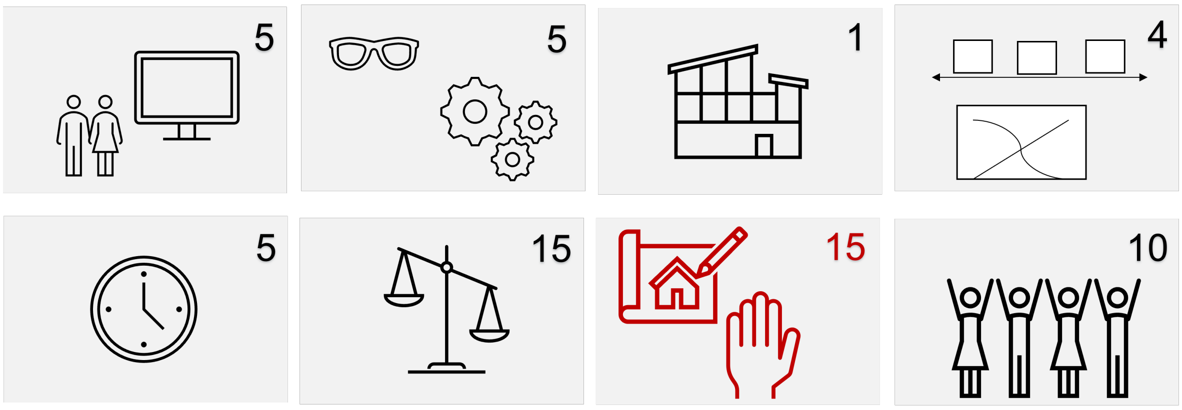


Figure 7.14: DCW 2 timeline with elements

Explaining context (1 min)
As a reminder to the participants, it has been emphasized that the same case context has been used for this DCW. The only thing that has been changed comparing to the last DCW, is that the green walls variable is removed, since this was part of the ecosystem enhancements. Furthermore, it is noted that some participants have adjusted their preference curves, so some curves differ from the last time.The layouts of the DCT that were used for this can be seen in Section 7.2.2, see Figure 7.10 and 7.11. This way the DCT was explained to improve the understanding of the participants.

Gaining insight in each other (4 min)
This part of the DCW consist of gaining insights in each others most important variables and preference functions, that was collected during the first 1-on-1 meetings as input. The first screen of the DCT displays the input of the participants, as shown in Figure 7.15. Then the design of the DCT and the interpretation of the design solutions are explained to the participants.

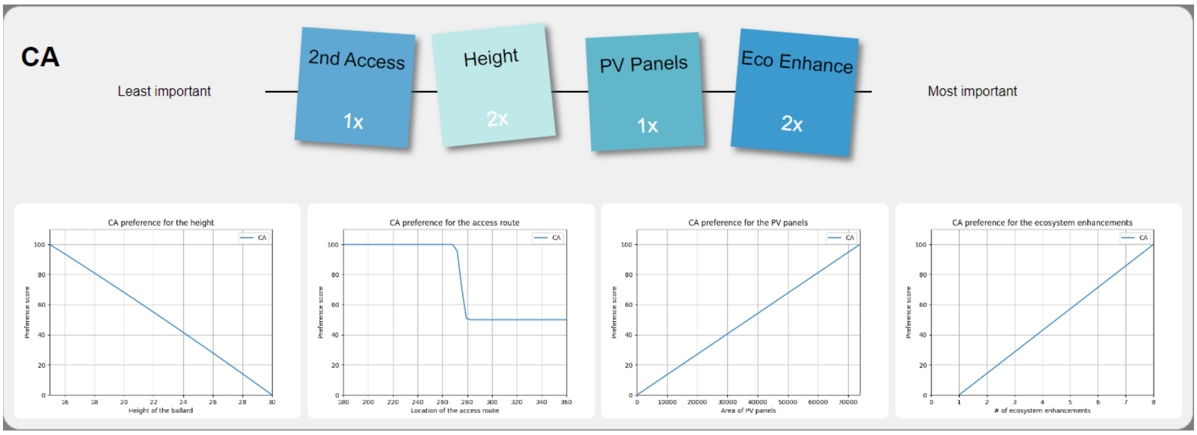


Figure 7.15: DCW 2 timeline with elements

Risk at Play (RaP) (5 min)
Due to the uncertainty that was found during prior meetings about the influence of time on design variables. Therefore, a focus on this time aspect was chosen as Risk at Play (RaP) and the RaP was simplified compared to iteration one. The RaP in round one was:

"The whole project must be delivered earlier."

The focus has been set on time minimisation, which raises the question of how variables affect time. For one stakeholder a higher value can minimize time while for another this is the opposite. For ex-

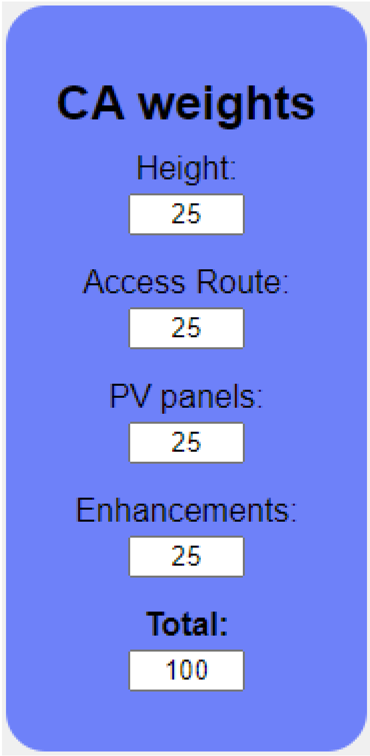


Figure 7.16: Weight input field for the CA team

ample, one team might say installing more PV panels will result in less delays during the permitting process while another says installing more PV panels will cost more time which both affect the time to market. Since teams have a different point of view on this, time was chosen as RaP.

Weight distribution (15 min)
Every team has to take a turn, to explain what happens with their weight distribution if time minimisation becomes the main focus of the project. They have been asked to divide their total 100% weight over the four variables. Furthermore, while they are doing this, they have to think-out loud so other teams are understanding why these trade-offs are made to gain better insights. There is room for the other participants to ask questions to the participant that is distributing the weights.

Discussing solutions (15 min)
After every team has distributed their weights, the DCT will produce two solutions. One is calculated with the minmax method and the other one with the IMAP method, as explained in Section 6.2.1. Additionally, together with the design project manager of DC2023[1], a standard design as a result of the current practice was determined as reference point, as described in Section 5.4. The values of the standard design are used to compare the new found design solutions of the DCT. Three solutions were shown to the participants, after each run; 1) The standard design values, determined with the design project manager 2) The min max solution 3) The IMAP solution. Next to this, also the preference scores are shown. After showing these solutions to the participants the solutions have been compared and discussed. If participants are not satisfied with the new design solutions, they can adjust their weight distribution and rerun the model. The new found design solutions were discussed. The design outcomes of the DCT that were shown to the participants looked like Figure 7.17.

Closing and wrap up (10 min)
To wrap up, every participant got the chance to give feedback and was asked to tell how the DCW had

[1]Confidential name of the selected case study

Results

Solution	H	AR	PV	EH
Standard Design	15	187	3408	2
IMAP	15	232	73635	8
minmax	23	245	38579	8

Solution	Pref CA	Pref LDO	Pref ENV	Pref DCE	Pref DCD	Pref Tot
Standard Design	54.7	44.1	57.3	33.7	31.8	44.3
IMAP	99.9	92.1	99.9	44.8	73	82
minmax	75.1	82.2	74.1	72.5	72.5	75.3

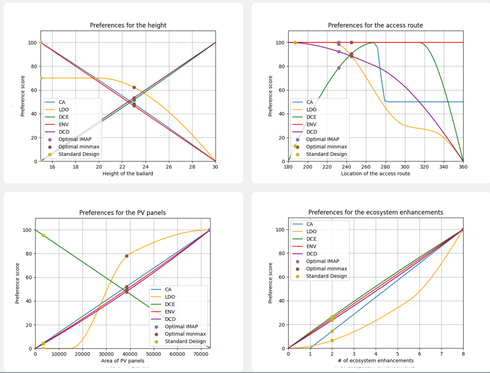


Figure 7.17: Results from a model run

contributed to their daily practise. Collectively they looked back at what they had done and what they had learned.

In order to enhance better time management and a clearer explanation to overcome the problems of the first DCW. A script was written, including the timing, for executing the second DCW. This can be found in Classified Appendix CL.

After the second DCW, individual meetings with participants were held, to collect feedback on the improved DCW.

7.3.2. Performance Design Collaboration Workshop

Compared to the first DCW, this DCW has significantly improved. The improved DCW was more structured and better understandable for the participants. First the participants were able to see in the DCT the ranking of their design variables on importance, and how this was guessed by other participants. There was a structured round where every participant could explain their ranking and other participants were able to ask questions to the explaining participants if they wanted to know more about the reasoning. This facilitated interesting conversations between the participants about the reasoning why certain design variables were so important to them.

After these rankings were discussed, the RaP was explained to the participants together with the assignment on how they had to adjust the weights. This was more clear than the last time, by noticing less chaos and less questions. This time, the participants took rounds on adjusting their weights for the different design variables, when time minimisation becomes more prominent. They were asked to share their thoughts when they were distributing their weights. Again, other participants were able to ask questions about this and that let to substantive conversations between the participants. After all participants took turn, the DCT was run. It was explained to the participants how to interpret these new found design solution outcomes. Figure 7.18a and 7.18b show the results of two scenarios. Figure 7.18a shows the results for the variables with equal weight and Figure 7.18b shows the results based on the weights how these were inputted by the participants during the DCW. Note that it also incorporates the standard design solution. Figure 7.19a and 7.19b show the preference scores for all the teams for each of the solutions. Figure 7.19a shows the scores for the equal weight scenario and Figure 7.19b shows the results for the weights from the DCW. It can be observed that both the minmax and the IMAP solution have a significantly improved group preference score compared to the standard design.
Figure 7.20 shows the preference scores with the found optimal solutions plotted in them for the equal weight scenario. Subsequently, Figure 7.21 shows the preference curves with the weights from the participants in the DCW.

Solution	H	AR	PV	EH
Standard Design	15	187	3408	2
IMAP	15	245	38579	8
minmax	23	232	73635	8

(a) Variable results with equal weights

Solution	H	AR	PV	EH
Standard Design	15	187	3408	2
IMAP	30	228	72438	8
minmax	26	245	56356	6

(b) Variable results with weights from the DCW

Solution	Pref CA	Pref LDO	Pref ENV	Pref DCE	Pref DCD	Pref Tot
Standard Design	54.7	44.1	57.3	33.7	31.8	44.3
IMAP	99.9	92.1	99.9	44.8	73	82
minmax	75.1	82.2	74.1	72.5	72.5	75.3

(a) Preference scores with equal weights

Solution	Pref CA	Pref LDO	Pref ENV	Pref DCE	Pref DCD	Pref Tot
Standard Design	54.7	44.1	57.3	33.7	31.8	44.3
IMAP	74.5	74.9	74.5	96.1	97.7	78.1
minmax	68.9	68	69	65.7	77.1	69.7

(b) Preference scores with weights from the DCW

The participants discussed these new design solutions values. As outcome of the conversation the participants agreed that the new found design variable values found with the minmax and the IMAP were an improvement of the standard design. Moreover, the new found design variable values of the minmax method, for the location of the second access route, amount of PV panels and the amount of ecosystem enhancements, were more preferred than the outcomes of the variables values of the standard design and the IMAP method. The new found values of the IMAP method were more extreme as can be seen in in the figures above, both in the tables as well as the graphs. The participants noted that the values of the IMAP gave a feeling of an unfeasible solution because of its tendency to maximize all the values. Given the preference curves it does however make sense the IMAP arrives at this point since quite some stakeholders drew similar curves.

7.3.3. Verification Design Collaboration Workshop

In Chapter 4.2.3 a seven metrics with their definition has been drawn up, to verify if the DCW was built right. These seven taxonomies are the basis of the verification of the DCW.

The first metric was valuable. This was covered by the RaP that has been used with respect to the objective time. As mentioned before there can be a lot of uncertainty about the influence of the design variables on time. By using this RaP, and having conversations about the reasoning of the weight distribution per participant. The participants gained insights into each other's motives and preferences. This contributes to a better understanding of each other's perspective in the daily practice, since they are all busy with the datacenter development.

The second metric was collaboration. The participant needed to recognise goals that only could be achieved in a group. As they cannot decide in daily practise on the design of the datacenter individually, they had to find and discuss the design solutions together. It was clearly communicated and mentioned a couple of times during the DCW, they had to evaluate the optimized design solutions together and determine whether there was a design solution that they collectively more preferred.

The third metric was feedback. During the DCW, participants needed to see interactive feedback based on their decisions. Participants were asked to explain their variable rankings and other participants could respond to that. After the Risk at Play was explained, participants were asked to adjust their weights and explain them again. There was room for other participants to react and ask questions about this. Changing the weights also affected the outcomes of design solutions generated by the DCT. These were visually displayed, and therefore a form of feedback.

The fourth metric was simulative. The game selectively represented an accurate depiction of reality. By using a Risk at Play for the objective time, this was covered, since it is unclear within Microsoft how time influences design choices. The Risk at Play was after discussing clear to the participants and they were actively involved in defining this, so that they all had the same understanding of the Risk at

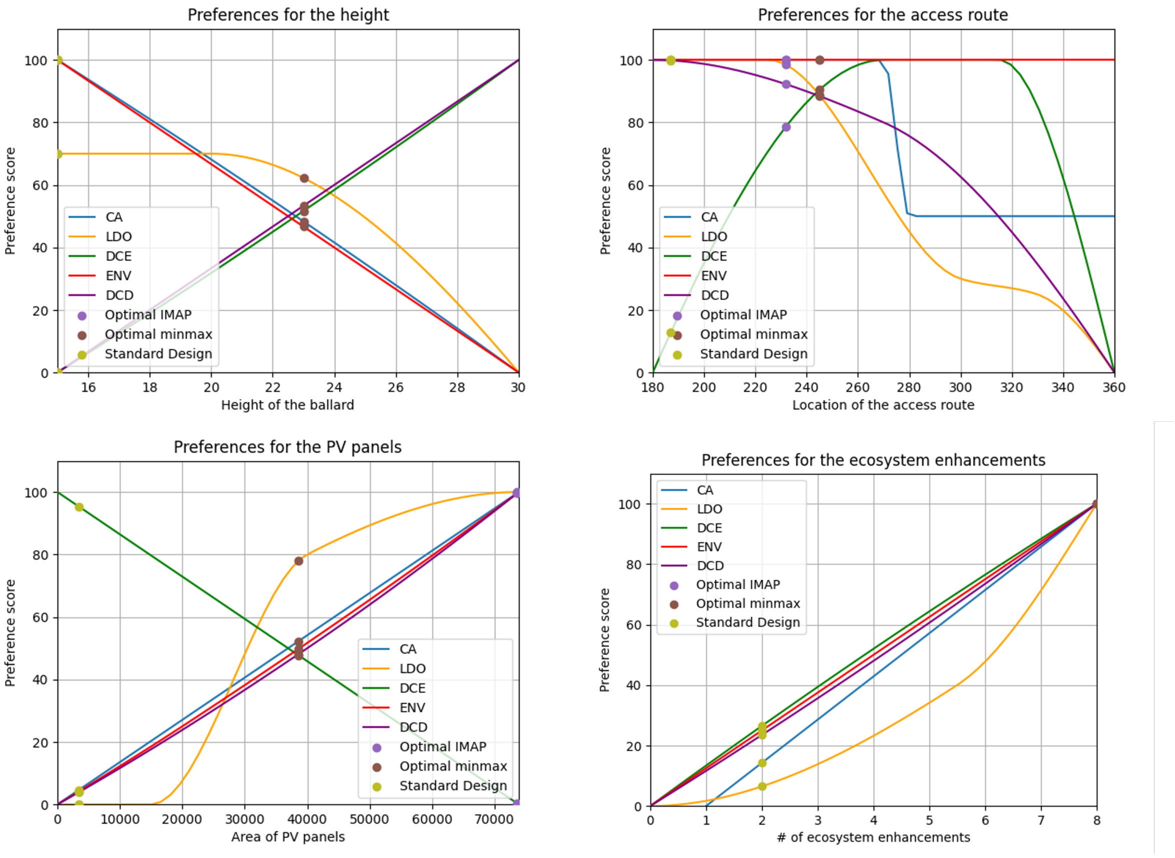


Figure 7.20: Results on preference curves with equal weights

Play.

The fifth metric was respect. The participants could not have the feeling there were personally attacked. The previous design used colour coding to overcome this. The participants then indicated that they wanted to use the real teams instead of colour coding. Using the real teams names instead of colours. However, this did luckily not contributed to an unsafe environment and all the participants were still treating each other with respect and interesting conversations were held. They all got a chance to individual explain their thoughts and decisions and were able to decide individually their weight distribution.

The sixth metric was challenge. The teams had to face a problem that matched their collective knowledge and skills. The teams were instructed to apply their knowledge from their team perspective, and to explain their choices and weight distribution with reasoning. Furthermore, they were challenged to find new design solutions and give their opinion about it.

The seventh metric was scalable. The DCW needed to be scalable when it is widely accessible, implementable and easy to moderate. However, the current final design of the DCW fell a bit short on this. Since the design was geared to give participants time to share their thought and react on each other, this would be too time consuming if there were a lot more participants.

To conclude, the DCW design succeeded in the key metrics such as valuable, collaboration, feedback, simulative and respect. However, the scalability of this design has its limitations and need further development to accommodate a larger audience. Also the metric challenge could be improved, since some participants had still difficulty in understanding the outcomes of the DCT.

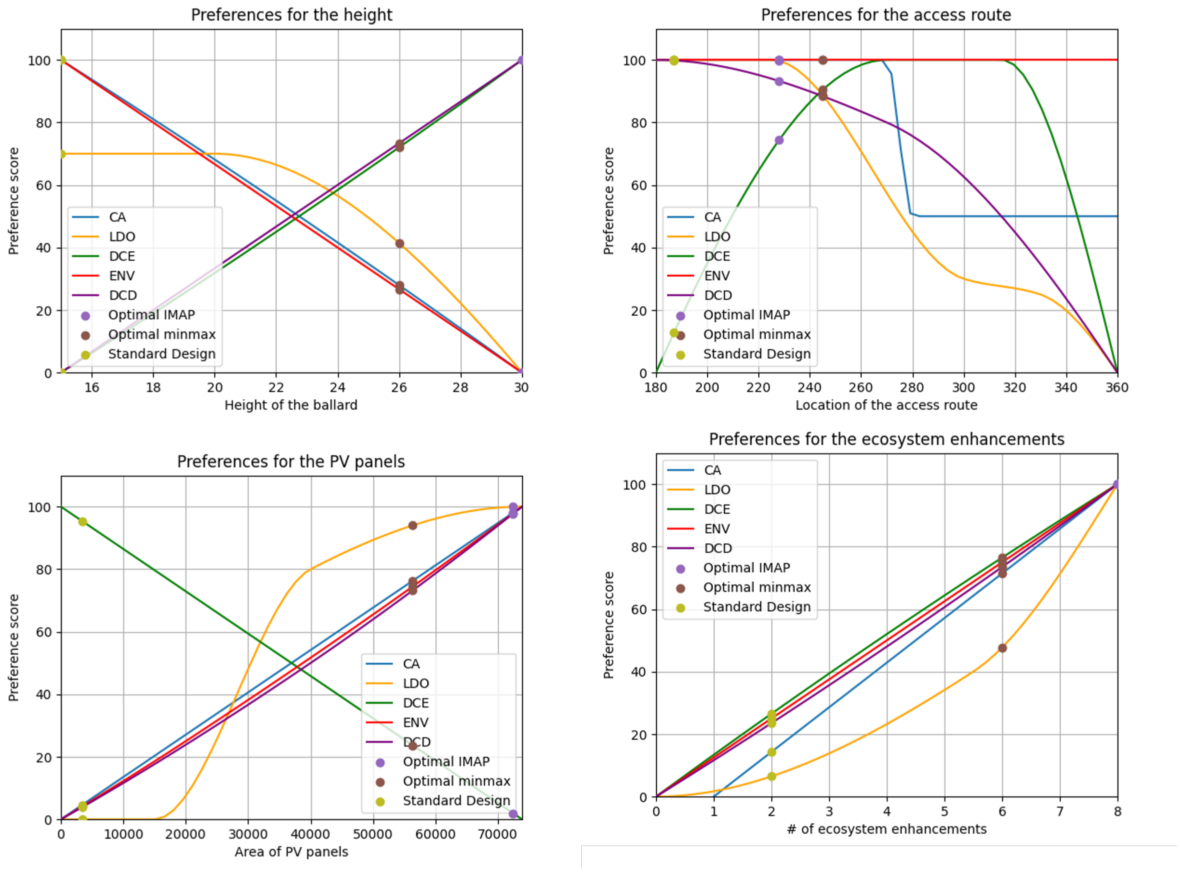


Figure 7.21: Results on preference curves with weights from the DCW

According to individual feedback meetings with the participants after the improved DCW. It could be stated that the DCW 2.0 was significantly improved and much clearer than the last time. They had a better understanding of the RaP and knew what was meant by changing the weights of the design variables. Furthermore, there was more structure during the DCW, which allowed for more room to explain their decisions better and listening to each other. Additionally, there was enough time to delve deeper into the new found design solutions and extensively discuss this.

7.3.4. Validation Design Collaboration Workshop

The needs of the DCW, as stated in Section 4.1.3, is to improve the collaboration between different teams within Microsoft, to find better datacenter design solutions, that are considering teams KPI that covers different socio-technical aspects. Teams need to gain insight in each other's preference and how these can change over time. In the end this needs to lead to find better datacenter design solutions together.

Compared to iteration 1 the DCW improved greatly. The workshop was way calmer inducing better performance of the DCT and the DCW. Participants felt at ease and the flow of DCW allowed for a strong focus on creating mutual insights. Additionally, the found solutions were clear and insightful. It helped participants to start talking about the different configurations and they expressed a sense of learning when asking more and more complex questions about the workings of the tool and how they could use this.

8
Conclusions and recommendations

I was thinking very much as a civil engineer and I think my thinking has moved even in the short time to the bigger picture.

Participant Microsoft

8.1. Conclusions

The main goal of this study was to develop an interactive tool that facilitates collaboration between Microsoft's teams in the datacenter development design process. The newly developed process, containing the Social Cycle, Technical Cycle and Design Collaboration Workshop (DCW) successfully contributes to collaboration in the datacenter design process. It does so by incorporating socio-technical aspects and visualizing the preferences associated with these aspects among the participants. A visualisation of the need, the new approach and the outcomes are given in Figure 8.1. Participants acknowledged to have gained insights in each other's most important design variables and are now aware of each other's different preferences and drivers. This can be viewed as an immense success given their disconnected and independent way of working before this study. Participants mentioned that they experienced something completely new and felt like a collaborative team due to learning about each other's motivations and needs. All participants endorse further development of this tool and anticipate its use in their future projects. They specifically foresee a role for the DCW during the early design process to gain relevant information about governing design variables and align the preferences among the teams. This also indicates that the scope of this study was well chosen from the outset. The principles underlying this study concerning the incorporation of socio-technical aspects have already been further deployed at Microsoft. Two initiatives are currently being drafted to incorporate socio-technical aspects through 'Good Neighbour Principles' and 'Datacenter Design Principles'. It highlights the essential role of taking into account socio-technical aspects and their role in a design process which validates the importance of an approach such as the Odesys methodology.

Apart from the practical conclusions concerning the process that was applied in this study something can be concluded about the design solutions that were found. By using the DCT during the DCW, new design solutions were found which were significantly different than the standard design solution. Participants concluded that the newly found design solutions incorporated more socio-technical aspects represented by increased preference scores. Additionally, participants preferred the newly found design solutions over the standard design because of the incorporation of the socio-technical aspects. The visualizations clearly helped to understand the differences with respect to the standard design. Also, the DCT helped to have a conversation about these differences which further amplified the collaboration among the participants. The participants felt increasingly comfortable with the workings of the tool and eventually indicated they would like to change the bounds of one variable. This illustrates the potential of the tool to iterative improve the model of the case study and therefore improve the optimal design solutions.

The added value of the approach in this study as stated by Microsoft, is the increased reliability of costs and time of the datacenter development while having the conversation about the datacenter design and considering relevant socio-technical aspects earlier in the development process. This is aligned with the theory as described in Section 3.3 that co-design decisions can reduce time and costs while it decreases the amount of controversy and objections. Also, this approach explicitly showed that teams currently working within their own silo can recognize the benefits of approaching a datacenter design from a broader perspective. During this study, a participant was observed switching literally 180 degrees in their preference. From first looking only from their own point of view to look at time and cost and not considering socio-technical aspects. The participants now preferred to integrate socio-technical aspects into the design.

Next to the practical conclusions and their implications at Microsoft some things can be concluded about the methods used during the different parts of this study. The study was split up in three parts: the Social Cycle, the Technical Cycle and the Design Collaboration Workshop (DCW). The Social Cycle is accountable for the participant engagement and collecting the needed preference curves for the Technical Cycle. The Technical Cycle developed the interactive Design Collaboration Tool (DCT) that is used to facilitate the conversation during the DCW. The DCW is the workshop were the DCT is used and the participants are playing a serious game in order to enhance mutual insights between the participants and find new datacenter design solutions. To develop these elements an iterative approach was used. The iterative approach created a benchmark after the first iteration to evaluate the improvements made in the second iteration. This benchmark was necessary because there was no approach prior to this study to stimulate collaboration. This also enabled adequate verification and validation according to the needs and requirements observed after the second iteration, as they differed from the first iteration. Next to this, the iterative approach exemplifies the purpose of the tool and the workshop that were developed. Namely, the purpose of the tool is to stimulate co-design in an interactive conversation. A core attribute of the tool and the workshop is to iterative converge towards new design solutions that incorporate socio-technical aspects. The iterative approach of developing this tool therefore aligns with it's purpose.

By applying the Social Cycle principles to the process, positive stakeholder engagement was achieved. They can be kept being engaged by keeping them informed, adding value for them, emphasizing their importance, letting them foster a positive experience and building an emotional connection with them. Additionally, during the Social Cycle the preference curves were collected. A 1-on-1 meeting was a suited method to gather these curves and understand the participants' preferences and motivations better. The level of human reflection in these curves was improved by using the Thinking-Out-Loud method during the 1-on-1 meetings and using free drawing curves. This allowed for more flexibility in the preference curves, which lets to a better reflection of their preferences.

The Technical Cycle as it was developed during this study showed the potential of the Odesys methodology to facilitate collaboration, connecting to sub-question four from the research questions. In essence the method entails the right ingredients to do this. It is however, essential to slowly build a confident relationship between the model and the participants. At every step there is a looming danger to advance too rapid which can result in participants losing interest and motivation to understand and use the DCT. For the future this should always be protected when trying to implement the DCT in a practical setting. The model performance criteria the were used to determine collaboration were established in the requirements of the Technical Cycle. These incorporated metrics from literature surrounding creative collaboration and using them to evaluate the DCT. More importantly the use of the DCT in the DCW helped to iteratively improve the Technical Cycle. The last sub-question on how Odesys can be connected to a Graphical User Interface (GUI) has been sufficiently answered in this thesis. The two iterations showed different approaches to effectively do so. There should be no obstacles as to investigate the decision made in this study further to develop improved version of the DCT connecting Odesys to a GUI.

Looking from a broader perspective the approach from this study can be used broader then only in the datacenter development within Microsoft. When there is a need for new design solutions that considers different preferences or interests of different teams, this approach can be of use. This study can be applied to other design problems besides datacenters, if the design variables are changed. Design projects that have a need for pro-active decision-making including stimulating collaboration between different teams, can benefit from this study. Also, this study can be used to communicate to external stakeholders. This study showed that the representative teams tried to incorporate socio-technical aspects that pertained to their external stakeholder. This relation could be deepened or a more direct influence of external stakeholder can be developed. This study does however provide Microsoft teams with a tangible approach to say to external stakeholders that their relevant socio-technical aspects are considered during the datacenter design. In short it can be said that the approach of this thesis is applicable in situations where the following is needed:

- early collaboration on design across multidisciplinary teams
- a proactive attitude considering different design preferences in a conflict situation
- finding new design solutions taking into account different design preferences and socio-technical aspects

8.2. Recommendations

8.2.1. Practical recommendations

From the practical side some recommendations can be defined for Microsoft. The first practical recommendation concerns use of the DCT and the DCW in future projects. From the outset of this study the focus was on collaboration during the early design phase. This moment proved to be suitable for the application due to the fact that teams gain insights into each other and learn about the relevant information of that specific project. In the future we would advise Microsoft to apply the DCT and DCW during the 'Design Kick-off'. This meeting is part of Microsoft's current datacenter development process and it's goal aligns with the purposes of the DCT and DCW. To stimulate more collaboration during the Design Kick-off and align the goals of the different teams, the DCT and DCW could be used in an interactive setting during the Design Kick-off. This can be achieved using a future version of the DCT.

The second practical recommendation elaborates on this future version of the DCT. We would recommend to further develop the DCT as an empty, blank canvas version that can be used in any datacenter project. To acquire this the Social Cycle needs to be further integrated into the DCT, a first step was made during iteration two where participants could perform the exercise of ranking the variables in the DCT. More importantly, the mathematical representation of the model, which are the variables, bounds and preference curves, should be available in the GUI. This enables participants can change bounds, add or remove variables and change preference curves which would change the definition of the model and the new design solutions. Such a version of DCT also aims to allow for independent, so without a moderator, use during the Design Kick-off.

The third practical recommendation describes this independence further. Given the initial purpose of this thesis and to continuously keep the participants engaged there has been a strong focus on understandability throughout this study. The mathematical model of the Odesys method was simplified since the goal was to stimulate collaboration and give relevant insights and the tasks during the DCW were kept simple to stimulate this. We would recommend to maintain this focus on simplicity for this purpose and during the Design Kick-off. While the Odesys methodology and the model defined here allow for more complex situations, such as constraints, physical attributes and meta or surrogate models, the goal in this study is not to directly deplot a new design solution. The focus is on the conversation about design solutions that incorporate socio-technical aspects. To succesfully have this conversation the DCT does not need to be overly complex. On a longer term, if desired more and more complex can be developed. More on this will be described below in the scientific recommendations.

8.2.2. Scientific recommendations

Also from an scientific perspective several recommendations can be defined. The first scientific recommendation for future research pertains an element of the Social Cycle. During the second iteration of this research the Social Cycle tested and compared the existing PAS method, described by Arkesteijn and Binnekamp (2013), with the proposed free drawing and Think-Out-Loud method. The Think-Out-Loud method and the free drawing method improved the human reflection in the preference curves, however this approach still misses realistic data points that are used in the PAS method, as mentioned by the participants. In further research there should be looked into how to implement these missing realistic data points, in this new proposed approach developed in this study. Additionally, if preference curves needed to be collected from many more participants using this approach, there should be looked into if using individual 1-on-1 meetings with every participant is still a lucrative method. If not, there should be looked into a more effective way of collecting these preference curves, rather than conducting individual 1-on-1 meetings with every participant.

The second scientific recommendation for future research pertains the Technical Cycle. The final version of the Design Collaboration Tool showed a true potential as a central conversation facilitator regarding the Odesys methodology in combination with the Social Cycle. The design of the GUI allowed for sufficient understanding with the participants which triggered more complex questions exceeding current functionalities of the DCT. All of these questions concerned enhanced interactiveness and flexibility of the DCT. The next generation of the DCT should provide the functions to incorporate these interactions with participants. This entails functions such as:

- Changing variable bounds in the DCT.
- Adding or removing variables.
- Adding or removing participants.
- Adding constraints.
- Adding objective functions and/or physical performance function.
- Connect to relevant meta and/or surrogate models to interact with the GUI.

In essence a next generation of the DCT should be an general model that functions as an empty canvas for any design optimization problem. Then the problem at hand can be mathematically formulated and implemented within the GUI.

For future research it would be recommended to look into the integration of the Social and the Technical Cycles. It would be beneficial to have one system that contains the two cycles, so the data collection of the Social Cycle can be immediately used and displayed in the DCT and DCW. To facilitate this integration, it would be helpful if participants could log into an application and are able to modify their preferences or weights on example their phone. This would directly affect the design outcomes in the centralized DCT and DCW. This increases the active involvement of the participants. A possible other feature of this integration would be that this app allows participants or facilitators to adjust bounds and remove or add other design variables easily in the app. This way, participants have the ability to adjust these design variables during the DCW. If an integrated app allows these adjustments, the tool can also be more easily used for other projects.

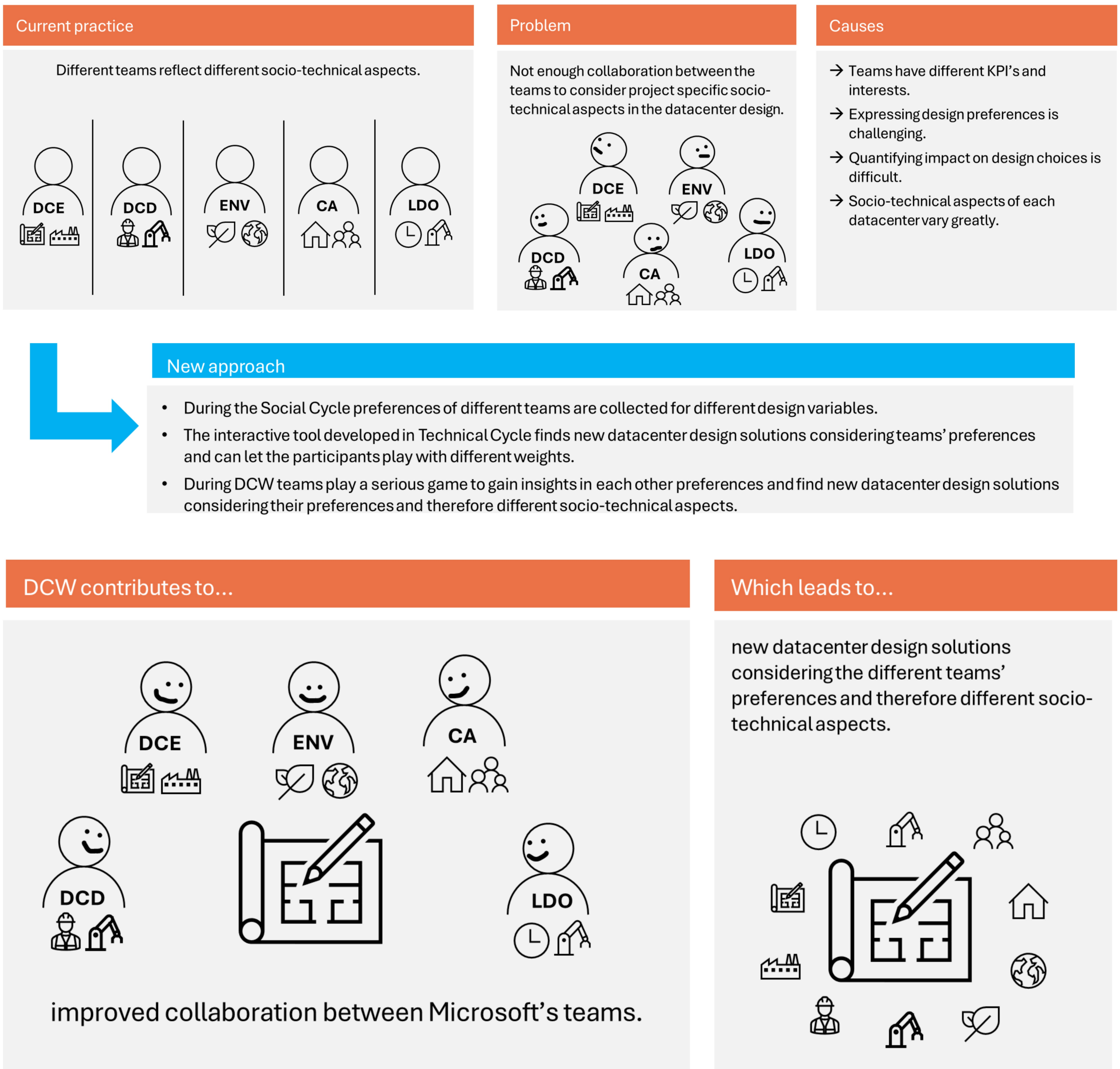


Figure 8.1: Overview of the problem, new approach and the outcome

Bibliography

Abt, C. (1970). Serious Games. New York: Viking, 1970, 176 pp., $5.95, L.C.79 - 83234$. *American Behavioral Scientist*, *14*(1), 129. https://doi.org/10.1177/000276427001400113

Arkesteijn, M., & Binnekamp, R. (2013). Real estate portfolio decision making. *Infranomics: Sustainability, Engineering Design and Governance, Springer, Dordrecht*, pp. 89–99.

Arkesteijn, M. (2019, December). *Corporate Real Estate alignment a preference-based design and decision approach* (No. 12). https://doi.org/10.7480/abe.2019.12

Arkesteijn, M., Valks, B., Binnekamp, R., Barendse, P., & De Jonge, H. (2015). Designing a preference-based accommodation strategy. *Journal of Corporate Real Estate*, *17*(2), 98–121. https://doi.org/10.1108/jcre-12-2014-0031

Avila-Pesantez, D. (2017, November). Approaches for Serious Game Design: A Systematic Literature review. https://www.semanticscholar.org/paper/Approaches-for-Serious-Game-Design:-A-Systematic-Avila-Pesantez-Escriba/1f6d2b032c98de3e9faf51be861d9168cd2963cd

Bachen, C. M., & Raphael, C. (2011). Social Flow and Learning in Digital Games:A Conceptual Model and research Agenda, 61–84. https://doi.org/10.1007/978-1-4471-2161-9\{_}5

Barzilai, J. (2006). Preference modeling in engineering design, 43–47. https://doi.org/10.1115/1.802469.ch6

Barzilai, J. (2010, January). *Preference Function Modelling: The Mathematical Foundations of Decision Theory*. https://doi.org/10.1007/978-1-4419-5904-1\{_}3

Barzilai, J. (2022, April). *Pure economics*. Friesenpress.

Bekebrede, G. (2010). Experiencing Complexity: A gaming approach for understanding infrastructure systems. *Next Generation Infrastructures Foundation*.

Bellotti, F., Berta, R., & De Gloria, A. (2010). Designing effective Serious Games: Opportunities and Challenges for research. *International Journal of Emerging Technologies in Learning (ijet)*, *5*(SI3), 22. https://doi.org/10.3991/ijet.v5s3.1500

Binnekamp, R. (2010). *Preference-based design in architecture* [Doctoral dissertation, Technische Universiteit Delft]. Delft University Press.

Brown, N. C., & Mueller, C. (2016). Design for structural and energy performance of long span buildings using geometric multi-objective optimization. *Energy and Buildings*, *127*, 748–761. https://doi.org/10.1016/j.enbuild.2016.05.090

Chance, C. (2023). Data Centre Trends in 2023. https://www.cliffordchance.com/content/dam/cliffordchance/briefings/2023/02/data-centre-trends-in-2023.pdf

Charters, E. (2003). The use of think-aloud methods in Qualitative research An introduction to think-aloud methods. *Brock Education Journal*, *12*(2). https://doi.org/10.26522/brocked.v12i2.38

Chen, L., & Bai, Q. (2019). Optimization in decision making in Infrastructure Asset Management: A review. *Applied sciences*, *9*(7), 1380. https://doi.org/10.3390/app9071380

Csikszentmihalyi, M. (1990). Flow: the psychology of optimal experience. *Choice Reviews Online*, *28*(01), 28–0597. https://doi.org/10.5860/choice.28-0597

De Koning, J., Crul, M., & Wever, R. (2016, May). Models of co-creation.

Diepersloot, B. (2019). Exploring the use of agile project management for infrastructure projects: Creating and using a serious research game to test the use of agile project management for infrastructure projects. *Engineering, Computer Science, Business*. https://api.semanticscholar.org/CorpusID:213718755

Duke, R. D., & Geurts, J. (2004). Policy games for strategic management. *Rozenberg Publishers*. https://www.narcis.nl/publication/RecordID/oai%3Atilburguniversity.edu%3Apublications%2F001d325e-b766-4fe1-8aef-bf560f72be0e

Eijck, S. V., & Nannes, R. (2022). Preference based decision support system for waelpolder: An a priori design optimization approach (pdoa) as decision support system, applied to the urban development of waelpolder. https://repository.tudelft.nl/islandora/object/uuid%3A36146902-4c0c-4d50-8643-59c067008978

Ferrera, J. (2011, April). The elements of player experience. https://uxmag.com/articles/the-elements-of-player-experience

Fu, F.-L., Su, R.-C., & Yu, S.-C. (2009). EGameFlow: A scale to measure learners' enjoyment of e-learning games. *Computers Education*, *52*(1), 101–112. https://doi.org/10.1016/j.compedu.2008.07.004

Haan, R.-J. D., Arevalo, V. J. C., Van Der Voort, M. C., & Hulscher, S. J. (2016, January). *Designing Virtual River: a serious gaming environment to collaboratively explore management strategies in river and floodplain maintenance*. https://doi.org/10.1007/978-3-319-50182-6\{_}3

Harteveld, C. (2011). Triadic game design: balancing reality, meaning and play. *Choice Reviews Online*, *48*(12), 48–6954. https://doi.org/10.5860/choice.48-6954

Heijer, F. D., Podt, M., Bosch□Rekveldt, M., De Leeuw, A., & Rijke, J. (2023). Serious gaming for better cooperation in flood defence asset management. *Journal of Flood Risk Management*, *16*(3). https://doi.org/10.1111/jfr3.12910

Heijne, K., van der Meer, H., Stelzle, B., Pump, M., Klamert, K., Wilde, A., Siarheyeva, A., & Jannack, A. (2018). *Survey on co-design methodologies in urban design* (Report No. D2.3 (D17)) (WP2: Media and Methodology for Massive Participatory Processes. Dissemination level: Public. Due date: 31 January 2018.). TU Delft. Delft, Netherlands.

Hickey, G., McGilloway, S., O'Brien, M., Leckey, Y., Devlin, M., & Donnelly, M. (2018). Strengthening stakeholder buy-in and engagement for successful exploration and installation: A case study of the development of an area-wide, evidence-based prevention and early intervention strategy. *Children and Youth Services Review*, *91*, 185–195. https://doi.org/10.1016/j.childyouth.2018.06.008

Ho-Huu, V., Nguyen-Thoi, T., Nguyen-Thoi, M. H., & Le-Anh, L. (2015). An improved constrained differential evolution using discrete variables (D-ICDE) for layout optimization of truss structures. *Expert Systems with Applications*, *42*(20), 7057–7069. https://doi.org/10.1016/j.eswa.2015.04.072

JRC. (2023, September). The EU Code of Conduct for Data Centres – towards more innovative, sustainable and secure data centre facilities. https://joint-research-centre.ec.europa.eu/jrc-news-and-updates/eu-code-conduct-data-centres-towards-more-innovative-sustainable-and-secure-data-centre-facilities-2023-09-05_en

Kasteleijn, N. (2022). Hyperscale-datacenters in Nederland? Nog maar op twee plekken welkom. https://nos.nl/artikel/2432219-hyperscale-datacenters-in-nederland-nog-maar-op-twee-plekken-welkom

Kroesen, M., & Cuppen, E. (2012). Richtlijnen voor Q-methodologie voor BEP (stappenplan uitvoering Q).

Le, H. (2012). *A transformation-based model integration framework to support iteration management in engineering design* [Doctoral dissertation, University of Cambridge].

Lin, J. H., Y, W., & Yu, Y. (1982). Structural optimization on geometrical configuration and element sizing with statical and dynamical constraints. *Computers Structures*, *15*(5), 507–515. https://doi.org/10.1016/0045-7949(82)90002-5

Liu, Y., Van Nederveen, S., & Hertogh, M. (2017). Understanding effects of BIM on collaborative design and construction: an empirical study in China. *International Journal of Project Management*, *35*(4), 686–698. https://doi.org/10.1016/j.ijproman.2016.06.007

Marler, R. T., & Arora, J. S. (2004). Survey of Multi-objective Optimization Methods for Engineering. *Structural and Multidisciplinary Optimization*, *26*(6), 369–395. https://doi.org/10.1007/s00158-003-0368-6

Martins, J. R. R. A., & Ning, A. (2021, November). *Engineering Design Optimization*. https://doi.org/10.1017/9781108980647

Mattelmäki, T., & Sleeswijk Visser, F. S. (2011). Lost in CO-X - Interpretations of Co-Design and Co-Creation. *Proceedings of the IASDR 2011, the 4th World Conference on Design Research*. https://research.aalto.fi/en/publications/lost-in-co-x-interpretations-of-co-design-and-co-creation

Mei, L., & Wang, Q. (2021). Structural Optimization in Civil Engineering: A literature review. *Buildings*, *11*(2), 66. https://doi.org/10.3390/buildings11020066

Meijer, S. (2012, April). *Gaming Simulations for Railways: Lessons Learned from Modeling Six Games for the Dutch Infrastructure Management*. https://doi.org/10.5772/35864

Mueller, C., & Ochsendorf, J. (2015). Combining structural performance and designer preferences in evolutionary design space exploratio. *Automation in Construction*, *52*, 70–82. https://doi.org/10.1016/j.autcon.2015.02.011

Nieuws, R. (2022, August). Nederlands datacenter Microsoft verbruikte vier keer meer water dan gedacht. https://www.rtlnieuws.nl/tech/artikel/5326566/datacenter-microsoft-hoger-verbruik-drinkwater-84-miljoen-liter

NOS. (2020). Onrust in lokale politiek Noord-Holland door bouw twee mega-datacenters. https://nos.nl/artikel/2359419-onrust-in-lokale-politiek-noord-holland-door-bouw-twee-mega-datacenters

Oh, M., Lee, J., Hong, S. W., & Jeong, Y. S. (2015). Integrated system for BIM-based collaborative design. *Automation in Construction*, *58*, 196–206. https://doi.org/10.1016/j.autcon.2015.07.015

Olson, G. M., Duffy, S. A., & Mack, R. L. (2018, April). *Thinking-Out-Loud as a method for studying Real-Time Comprehension processes*. https://doi.org/10.4324/9780429505379-11

Pavlas, D., Heyne, K., Bedwell, W. L., Lazzara, E. H., & Salas, E. (2010). Game-based learning: The impact of flow state and videogame self-efficacy. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *54*, 2398–2402. https://api.semanticscholar.org/CorpusID:34944772

Penadés-Plà, V., García-Segura, T., & Piqueras, V. Y. (2019). Accelerated optimization method for low-embodied energy concrete box-girder bridge design. *Engineering Structures*, *179*, 556–565. https://doi.org/10.1016/j.engstruct.2018.11.015

Rajput, S. P. S., & Datta, S. (2020). A review on optimization techniques used in civil engineering material and structure design. *Materials Today: Proceedings*, *26*, 1482–1491. https://doi.org/10.1016/j.matpr.2020.02.305

Rengers, M., & Houtekamer, C. (2023). Microsoft bouwt al een jaar aan een datacentrum zonder bouw- en stikstofvergunningen. https://www.nrc.nl/nieuws/2023/02/27/vergunning-microsoft-bouwt-al-a4158232

Sackey, E., Tuuli, M. M., & Dainty, A. R. (2015). Sociotechnical Systems Approach to BIM implementation in a multidisciplinary construction context. *Journal of Management in Engineering*, *31*(1). https://doi.org/10.1061/(asce)me.1943-5479.0000303

Sanders, E., & Stappers, P. J. (2008). Co-creation and the new landscapes of design. *CoDesign*, *4*(1), 5–18. https://doi.org/10.1080/15710880701875068

Sleeswijk Visser, F., Stappers, P. J., Van Der Lugt, R., & Sanders, E. (2005). Contextmapping: experiences from practice. *CoDesign*, *1*(2), 119–149. https://doi.org/10.1080/15710880500135987

Stappers, P., Sleeswijk Visser, F., & Kistemaker, S. (2011). Creation and co: User participation in design. In B. van Abel, L. Evers, R. Klaassen, & P. Troxler (Eds.), *Open design now: Why design cannot remain exclusive* (pp. 140–151). BIS Publishers.

Statista. (2023, September). Number of data centers worldwide 2023, by country. https://www.statista.com/statistics/1228433/data-centers-worldwide-by-country/

Sugirin, S. (1998). Exploring the Comprehension Strategies of EFL Readers: A Multi-Method Study. *an International Workshop on Written Language Processing at the University of New South Wales, Sydney*. https://files.eric.ed.gov/fulltext/ED428548.pdf

Sweetser, P., & Wyeth, P. (2005). GameFlow. *Computers in Entertainment*, *3*(3), 3. https://doi.org/10.1145/1077246.1077253

Tsiptsis, I. N., Liimatainen, L., Kotnik, T., & Niiranen, J. (2019). Structural optimization employing isogeometric tools in Particle Swarm Optimizer. *Journal of Building Engineering*, *24*, 100761. https://doi.org/10.1016/j.jobe.2019.100761

Van Heukelum, H., Binnekamp, R., & Wolfert, R. (2023). Human preference and asset performance systems design integration. https://arxiv.org/abs/2304.07168

Van Heukelum, H., Steenbrink, A., Colomés, O., Binnekamp, R., & Wolfert, A. (2023). Preference-based service life design of floating wind structures, 957–964. https://doi.org/10.1201/9781003323020-116

Van Nederveen, S., & Tolman, F. (1992). Modelling multiple views on buildings. *Automation in Construction*, *1*(3), 215–224. https://doi.org/10.1016/0926-5805(92)90014-b

van Wijnen, J. F., & van Gils, S. (2023, December). Na boeren en bouwers lopen nu ook datacenters tegen een grens aan. https://fd.nl/economie/1500098/na-boeren-en-bouwers-lopen-nu-ook-datacenters-tegen-een-grens-aan

Vardhman, R. (2023). 15 Crucial Data Center Statistics to Know in 2023. https://techjury.net/blog/data-center-statistics/

Verhagen, L., Frijters, S., & Sabel, P. (2024, January). Hoeveel water en energie gebruikt uw favoriete chatbot? https://www.volkskrant.nl/kijkverder/v/2023/hoeveel-water-en-energie-gebruikt-uw-favoriete-chatbot~v974828/?referrer=https%3A%2F%2Fwww.google.com%2F

Watts, S., & Stenner, P. (2012, January). *Doing Q Methodological research: theory, method and interpretation*. https://doi.org/10.4135/9781446251911

Wolfert, A. (2023, August). Open Design systems. https://books.open.tudelft.nl/home/catalog/book/78

Xia, W., Zhao, P., Wen, Y., & Xie, H. (2017). A survey on data center networking (dcn): Infrastructure and operations. *IEEE Communications Surveys Tutorials*, *19*(1), 640–656. https://doi.org/10.1109/COMST.2016.2626784

Xu, G., & Wang, W. (2020). China's energy consumption in construction and building sectors: An outlook to 2100. *Energy*, *195*, 117045. https://doi.org/10.1016/j.energy.2020.117045

Zhang, Q., Lü, C., & Boutaba, R. (2010). Cloud computing: state-of-the-art and research challenges. *Journal of Internet Services and Applications*, *1*(1), 7–18. https://doi.org/10.1007/s13174-010-0007-6

Zhao, L., Xu, B., Han, Y., & Rong, J. (2020). Continuum structural topological optimization with dynamic stress response constraints. *Advances in Engineering Software*, *148*, 102834. https://doi.org/10.1016/j.advengsoft.2020.102834

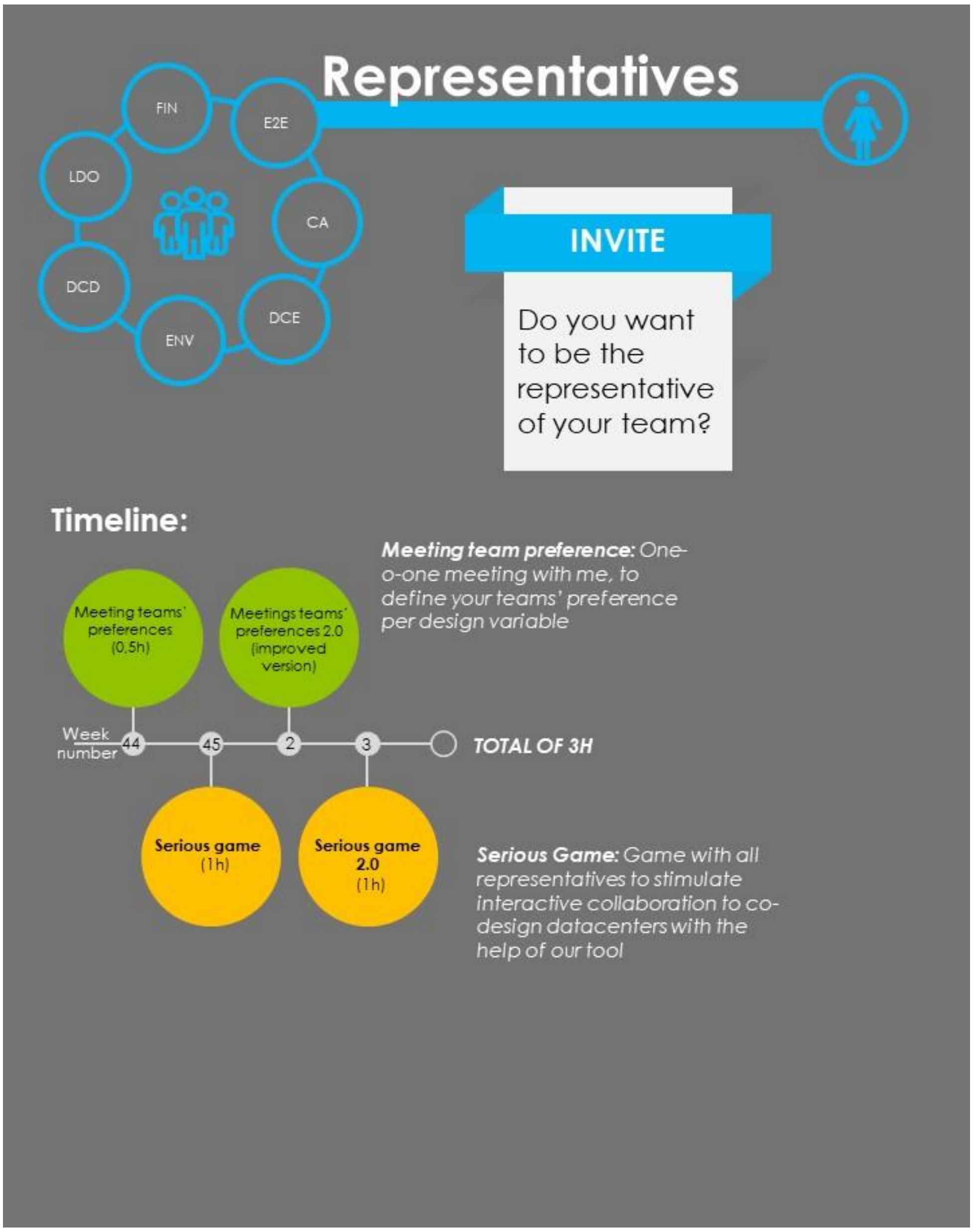
Zhilyaev, D. I., Binnekamp, R., & Wolfert, A. M. R. (2022). Best fit for common Purpose: a Multi-Stakeholder Design Optimization Methodology for construction management. *Buildings*, *12*(5), 527. https://doi.org/10.3390/buildings12050527

Zhou, Q., Bekebrede, G., Mayer, I., Warmerdam, J., & Knepflé, M. (2016). The climate game: Connecting water management and spatial planning through simulation gaming? https://doi.org/10.4324/9781315547626-6

Appendix A

Update from the interns
Teams involved:
We ask one representative per team, they get an invitation next week
FIN
E2E
LDO
CA
DCD
DCE
ENV
RESEARCH GOAL
Create a tool to stimulate interactive collaboration to co-design datacenters
Tool involved:
The tool must enable to give teams insights in the effects of the design choices on the preferences of different teams.
Process and planning:
Research & development
Research on serious gaming, creating preference functions developing and programming tool
Defining preference functions
Defining objectives per team per design variable to use as input for the tool
Collecting feedback after the serious games to improve model and tool
Collecting feedback
Interactive collaboration session between teams to co-design datacenters
Serious gaming
Meetings teams' preferences (improved version, 0,5h)
Meetings teams' preferences 2.0 (improved version, 0,5h)
Week number
45
46
3
4
Serious game (1h)
Serious game 2.0 (improved version 1h)
Thank you for sharing your experiences and kickstarting our internship journey! We believe in the potential of your and our ideas. Looking forward we are curious and driven to pursue realizing those ideas and develop our tool together. If you have any questions or ideas feel free to reach out to one of us!
Kind regards,
Marieke Schriever and Boudewijn Mol
(v-mschriever@microsoft.com) (v-bomol@microsoft.com)

Appendix B


Representatives
FIN
E2E
LDO
CA
DCD
DCE
ENV
INVITE
Do you want to be the representative of your team?
Timeline:
Meeting team preference: One-o-one meeting with me, to define your teams' preference per design variable
Meeting teams' preferences (0,5h)
Meetings teams' preferences 2.0 (improved version)
Week number
44
45
2
3
TOTAL OF 3H
Serious game (1h)
Serious game 2.0 (1h)
Serious Game: Game with all representatives to stimulate interactive collaboration to co-design datacenters with the help of our tool

Appendix C

Discussion guide

Introductie conversation - 5 min

Note: This is a qualitative contextual interview. This means that we let ourselves be guided by the interaction with the participant, and we don't necessarily have to ask every question. This guide is the foundation and a guideline, not a checklist.

Goal: know participant preferences on design variables and make them feel comfortable.

First contact
- Hi! How are you? thank you for making time. First of all I wanted to know if there is something on your mind about the video you like to share.
- Goal: The goal of the meeting is define your preferences on design variables. It can be divided into 4 parts:

1. Rank design var
2. Other team perspective
3. Define preference curves
4. Wrap up/ reflection

We are going to use the think-out-loud method during the session. See we can also hear the thoughts about the topics. Okay if we record this session? .

Form of this conversation:
- We are having a conversation together. It's not a standard question-and-answer session but informal. -
- We will record this meeting and do exercises on Miro.
- We are here without our 'own agenda.' Feel free to share; we would like to learn from you! We are particularly interested in your opinion. Therefore, speak from your perspective; we also speak with many others. •
- We don't want to take up too much of your time, so we may probe deeper at times, or cut things short. This is not due to lack of interest. Expect it to take about 1 hour - do you have a hard stop?
- Where possible, we will capture information while maintaining anonymity as much as we can.

Part 2 - Ranking decision variables

Questions that can help during the think out loud method when participant does not think out loud

1. *"Can you tell me what factors you considered when deciding to rank this variable higher or lower?"*
2. *"What information or attributes are most important to you when making this ranking decision?"*
3. *"What kind of trade-offs are you making when deciding on the position of this variable in your ranking?"*
4. *"Can you describe any challenges or uncertainties you encountered while making this ranking?"*
5. *"Is there any additional information or data you wish you had to make this ranking decision more confidently?"*

What do you think would be the most important design variable for the other teams? We place this raster on that variable.

Part 3 - Defining preference curves

Now that we ranked the variables. We are going to define our preference curves. Gives one example.

Wrap up / reflection - 5 min

Goal: Allow the participant to reflect on the conversation and express gratitude.

Thank you very much for your time and all the new insights!
- What were the most important insights for you from this conversation?
- How would you summarize the conversation in 1 minute for those who weren't present?
- Do you have any further questions or final remarks?

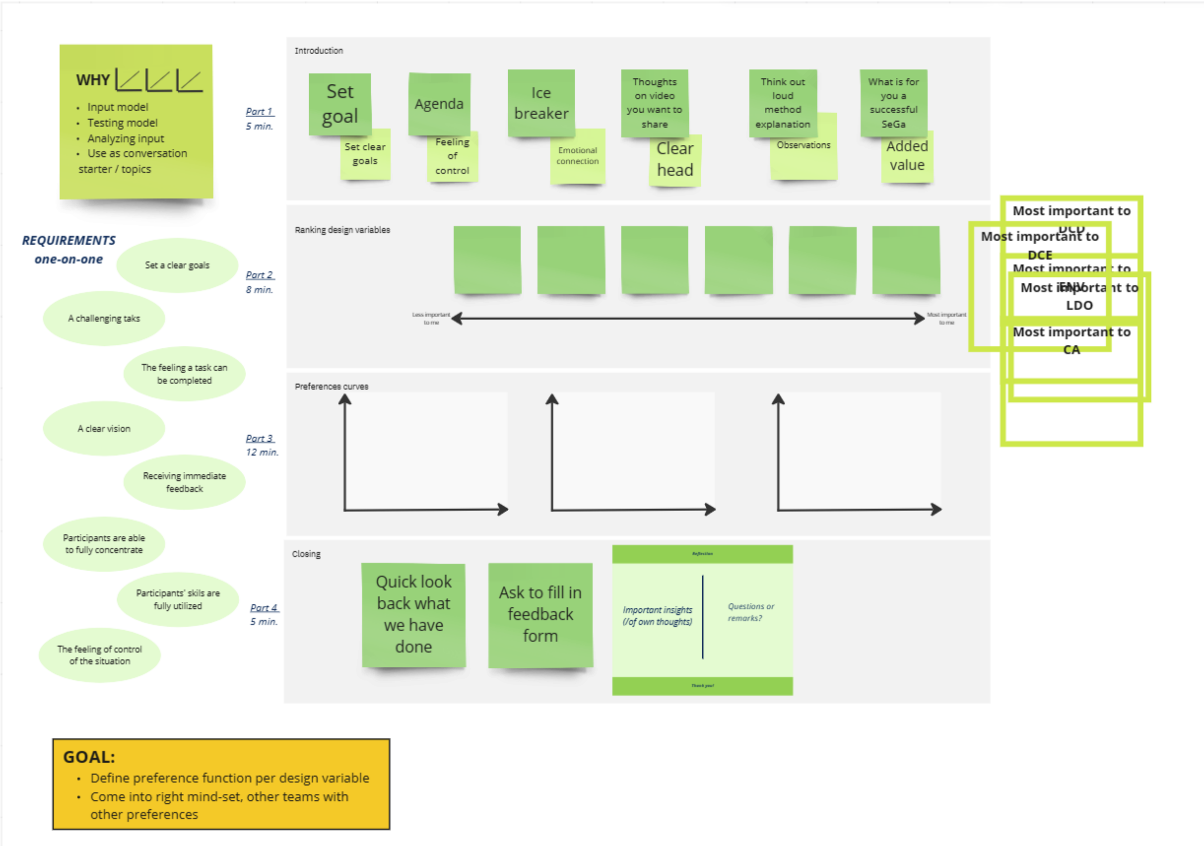
We will use this input for our model. The results we will use as conversation stater in the serious game. Please fill in the feedback form that I will send you afterwards. We can use this to improve our steps towards getting the best input as possible!

Trigger questions; where is the space

Why

Feelings

Appendix D



WHY
Input model
Testing model
Analyzing input
Use as conversation starter / topics
REQUIREMENTS one-on-one
Set a clear goals
A challenging taks
The feeling a task can be completed
A clear vision
Receiving immediate feedback
Participants are able to fully concentrate
Participants' skils are fully utilized
The feeling of control of the situation
Part 1 5 min.
Part 2 8 min.
Part 3 12 min.
Part 4 5 min.
Introduction
Set goal
Set clear goals
Agenda
Feeling of control
Ice breaker
Emotional connection
Thoughts on video you want to share
Clear head
Think out loud method explanation
Observations
What is for you a successful SeGa
Added value
Ranking design variables
Preferences curves
Closing
Quick look back what we have done
Ask to fill in feedback form
Important insights (/of own thoughts)
Questions or remarks?
Most important to DCD
Most important to DCE
Most important to ENV
Most important to LDO
Most important to CA
GOAL:
Define preference function per design variable
Come into right mind-set, other teams with other preferences

Appendix E

Feedback form filled in by all participants, with average ranking on a 5 point scale.

The video gave me enough context information to define my preferences on the design variables during the 1-on-1 meeting. **4,67**

I knew what I could expect during the 1-on-1 meeting because of the video. **4,4**

The goal of the video was clear. **4,67**

The video made me excited for the 1-on-1 meeting and the Serious Game. **4,5**

What did you like about the video and what could be done better?

It was short and to the point and it could be played at 1.5 times the speed. Perhaps the speaker background could be imaged?

The video was well presented, Marieke has great voice for video. Very clear and message relayed well.

Interesting approach, clear and time consize

Great production and got the point across quickly and clearly

I liked how you clearly explained the core items of the project.

Very professionally presented!

For the second iteration, would you again like a video, or do you preferer a different format to get site context (if yes, what)?

I like the video format.

Video works for me

Video was good

I really liked it, not sure if people prefer themselves for the meeting are watch the video upfront.

A video was great, easy to understand and visualise

I have fostered the 1-on-1 meeting as a positive experience. **5**

It was clear what was expected of me during the 1-on-1 meeting. **4,83**

I felt a bit awkward using the think out loud method. **2**

I feel like the thinking out loud method could contribute to a better understanding of my own trade-offs. **4,83**

What did you like about the 1-on-1 meeting, and what could be better for the second iteration?

it was fast and to the point; easy to do

Marieke's enthusiasm is infectious. She is very engaged with her topic and excited by the ongoing development and awaiting the outcomes. For next iteration, keep doing what you are doing

Your approach and overall experience, looking forward to outcomes

Expectations were clear, it was very well focused which is good when everyone is so busy!

I really liked all of it. Good to see you've made some small adjustments after the first. I really value it that you see yourself where to improve, or add some additional question to get a better perspective. Well done!

well organised and prepared

For me, the Serious Game is successful when (finish the sentence)

ive learned something new

I see the inputs from other stakeholders

the results of your study will find their implementation

we have a better understanding of the other teams' priorities and can use this to align on design issues early

I get better understanding of the priorities of others and reason behind it

All teams have a clear understanding of each others' priorities

Appendix F

Den Heijer (2023)	**Zhou et al. (2013)**	**Pavles et al. (2010) and Diepersloot (2019)**	**Ferrera (2011)**
	The serious game should ...		
1. Valuable: the process and outcomes provide guidance for the participant's daily practice.	... convey meaning and insight about the problem. ... react to the decision of participants.	... ensure deep involvement in the activity ... give a sense of control over participant's actions.	... be short-term interesting and long-term rewarding. ... attribute game effects to an understandable cause.
2. Simulative: game events selectively represent an accurate depiction of reality.	... incorporate analytical and political standards for useable outcomes. .. provide clear and understandable results for all participants.	... remove concern for oneself during immersion. ... alter the participant's sense of time.	
3. Interactive: the game gives interactive feedback based on decisions of participants so they can change tactics together.	... support negotiation between participants. ... react to the decisions of participants.	... give immediate feedback on the decisions of participants.	... stimulate the development of tactice and strategies to influence the outcome.
4. Increasable: the game increases in difficulty with participant's playing ability grows.	... consider different levels of design and decision making in a holistic and systematic way.	... be successfully completed.	... be equitably balanced to satisfy, not frustrate.
5. Unambiguous: the game is unambiguous when minimal sensory distraction causes full immersion.		... stimulate concentration so that the participants can immerse in the activity.	... set a tone through aesthetic choices.
6. Scalable: the game is scalable when it is widely accessible, implementable, and easy to moderate.	... be quickly applicable and usable for non-experts.		

Social GameFlow (Bachen and Raphael, 2011)	**GameFlow (Sweetser and Wyeth, 2005)**	**EGameFlow (Fu et al., 2009)**
Interdependent Goals and Rewards: Players recognize clear and authentic goals that can only be achieved by a group; players sense that goal interdependence is matched with reward interdependence	Clear Goals: Provide the player with clear goals at appropriate times.	Goal Clarity: Tasks in the game should be clearly explained at the beginning
Feedback: Players feel that they receive clear feedback at appropriate times to the group about its actions in the game and about individual members' contributions.	Feedback: Players must receive appropriate feedback at appropriate times	Feedback: Feedback allows a player to determine the gap between the current stage of knowledge and the knowledge required for ultimate completion of the game's task
Challenge: Players perceive challenges of different levels that match the group members' collective knowledge and skills, including their collaborative abilities	Challenge: Be sufficiently challenging and match the player's skill level	Challenge: Offer challenges that fit the player's level of skills; the difficulty of these challenges should change in accordance with the increase in the player's skill level.
Control: Players have a sense of control over their individual decisions, their groups' strategies and actions within the game, and their group's influence on the gameworld	Control: Players should feel a sense of control over their actions in the game	Autonomy: the learner should enjoy taking the initiative in game-playing and asserting total control over his or her choices in the game.
Concentration: Players are able to focus sustained attention and reflection on the group's interaction.	Concentration: Games should require concentration and the player should be able to concentrate on the game.	Concentration: Provide activities that encourage the player's concentration while minimizing stress from learning overload, which may lower the player's concentration on the game.
Immersion: Players experience periods of deep involvement in group play.	Immersion: Players should experience deep but effortless involvement in the game	Immersion: The game should lead the player into a state of immersion.
Intrinsic Reward: Players value social play and learning as worth doing for their own sakes.	Social Interaction: Games should support and create opportunities for social interaction.	Social Interaction: Tasks in the game should become a means for players to interact socially.
Achievement of Learning Goals: Players sense that they can achieve the game's learning goals	Player Skills: Games must support player skill development and mastery.	Knowledge Improvement: the game should increase the player's level of knowledge and skills while meeting the goal of the curriculum.

Appendix G

Feedback form filled in by all participants, with average ranking on a 5 point scale. Some questions were not filled in by every participant.

The rules of the Serious Game were clear to me. **3,8**

There was enough time to execute the exercises during the Serious Game. **2,8**

There was enough room for discussion. **4,25**

I had a good understanding of the results of the tool. **3,4**

What did you miss during the Serious Game.

More context around the ask. For example, if the ask is to accelerate the project, does it mean we can change the parameters of the project to deliver it earlier; or is it to be the same scope. In our exercise we looked at height being an important factor in accelerating the delivery - if the height is reduced (1 floor versus 2 floor) we can build the buildings quicker and deliver capacity quicker. If the ask is to maintain the same parameters, example the height can't be changed, then the priority of height is less relevant.

There was very good discussion which didn't allow for a second round. So not a bad thing as the conversations were very good

I don't think i fully understood the scoring, i.e. getting the scores to add to 100 both horizontally and vertically so perhaps clarity on this aspect
the biggest challenges was how the matrix should be made, it took our team quite some time to find out how it is working.

Unfortunately, as I joined late, I was unable to join the discussion on teams

What could potentially be omitted in the second iteration?

I think it's now clearer what is needed to be done so less need for introduction to the game

nothing, it was good exercise. it very well showed us where are the interests and needs of different teams and how much they can differ. This also explain why it is so hard to find out the infection point where all teams agree.

What could be improved (what would you add) for the second iteration?

We might want to look at the scenario upfront or have them checked by some of the team (people not part of the workshop) if the scenarios are easy to understand

If different players, perhaps need more clarity on scoring

The matrix could be a bit of easier for use. I am still not 100% sure if I fully got it.

There is always room for improvement with all tools and procedures. A pilot run will provide the most useful lessons learned

I think the tool has added value and can contribute to the current practice of MS. **4**

The tool contributed to collaboration between the different teams to have a better understanding of each other. **4,8**

Something else what you want to share- or add?

The tool was somewhat difficult to understand and to see the impact. Afterwards we realized we only moved 3 levers as not all teams were represented in our group

you are developing something what might be extremely important in the future. It would be great to streamline the model a little bit, that we do not need to search to reach 100% both horizontally and vertically.