Master Thesis

Applied Design Research of the Operator-Machine Interaction of ASML's Extreme Ultraviolet Lithography Systems

B.D. Bootsma
Integrated Product Design
June 2024

Applied Design Research of the Operator-Machine Interaction

of ASML's Extreme Ultraviolet Lithography Systems

June 2024

Master Thesis

Delft University of Technology

Faculty of Industrial Design Engineering

Integrated Product Design

Project Chair

Ir. R.J.H.G. van Heur

Project Mentor

Ir. Eur.Erg G.P.M. Hoekstra

ASML Mentors

Human Factors Engineer Eur.Erg M. Sunshine

Human Factors Engineer T. Yasar Yilmaz

Author

B.D. Bootsma

Acknowledgements

I would like to express my gratitude to all those who have contributed to the completion of this thesis.

I am thankful for everyone on the Human Safety team at ASML. I felt welcome from the start, which created a very pleasant work environment. I am especially grateful to my mentors, Megan Sunshine and Tolga Yasar Yilmaz, for your supportive mentorship, assistance and for always making time for me, even within busy schedules. Additionally, I want to express my appreciation to Jan Kokken, Ertan Zaferoglu, and Kees Broekmeulen for your support and valuable advice throughout this process.

I would like to acknowledge the participants of this study for sharing their experiences and insights, engage in brainstorming and co-creation sessions, and the large group of individuals who completed my survey. This research would not have been possible without their input. Furthermore, I want to thank the various experts from Mechanical System Layout, Computer Systems, UX Design, and other departments at ASML who took the time to share their expertise and advice with me.

The thesis would not have been the same without my supervisors, Gonny Hoekstra and Ruud van Heur. Thank you for your enthusiastic involvement, valuable inputs, and providing me with the right constructive feedback and guidance when I needed it.

Thank you all for your support!

Table of Contents

Executive Summary

Project Purpose

The purpose of this project is to conduct an applied human factors engineering research on the operator interface unit to reimagine the human-machine interaction of EUV lithography machines.

User Research

The user research consists of interviews, observations, a survey, task analysis and incident report analysis. It highlights that the main OIU user groups are install engineers, field service engineers, upgrade engineers, and customer operators. The main differences between the user groups are that, from a machine perspective, the ASML users have infrequent, but long OIU-related use scenarios, and customer operators have more frequent, short OIU-related use scenarios. Additionally, the OIU use environment changes according to the type of user, the workspace around the OIU can be limiting, and the cleanroom can be a stressful environment to work in. Finally, results show that the majority of the users feel physical discomfort when using the OIU after a relatively short use duration.

Design Analysis

The design analysis presents a selection of key results that each impact the selection of the following set of design criteria for the future human-machine interaction:

- Provide textual & pointing input
- Space for input tools
- Provide visual output
- Optimize work posture
- Use all around machine
- Mobile device workflow
- Keep pathways clear
- Quickly accessible
- ASML aesthetics

Design Development

The outcomes of the user research and the design analysis are developed into a design proposal by conducting research into technology advancements, adjacent industries, organizing brainstorm and co-creation sessions, and finally developing and choosing one concept to proceed with.

Design Proposal

The proposal is a system applying AR headsets, customer control room advancements, and a new digital platform. It allows the OIU to be removed from the machine and allocates new employee tasks to enhance efficiency. AR headsets enable the engineer to access the machine directly, have real-time work procedures, hands-free gesture and voice control, and improved remote collaboration. The AR headsets and adapted user interface allow the user to access and execute software actions during hardware tasks in the cleanroom. Additionally, longer, software actions can effectively be performed from the control room. This new approach improves the employee work conditions, minimizes cleanroom presence, improves work efficiency, accuracy and safety.

Recommendations

The design proposal is a future vision and is expected to take about 10 years before fully developed. However, due to the urgent conclusions regarding current physical discomfort, it is recommended to pilot a short-term mobile workspace solution in addition to initiating research of the long-term vision.

CHAPTER 1

Project Introduction

Image obtained from open internet source (ASML, 2024)

The aim of this project is to propose concept design solutions according to an applied research the operator interface unit of ASML's extreme ultraviolet lithography systems through the application of human factors engineering and design methods. This first chapter provides an introduction to the project context, assignment and approach.

1.1 Project Context

ASML

ASML stands as an innovation leader in the semiconductor industry, providing chipmakers with everything they need - hardware, software, and services essential for the high-volume production of patterns on silicon via lithography. In confidential Appendix A, a more in-depth description can be read about ASML's products, services, departments and company structure.

"Together with our partners, we provide leading patterning solutions that drive the advancement of microchips."

– ASML's Mission (ASML, 2023a)

EUV Lithography Systems

ASML's NXE and EXE systems enable high-resolution lithography, to be used for the mass production of the world's most advanced microchips. In essence, an ASML lithography system functions as a projection system. In ASML's DUV systems, light passes through a pattern blueprint called a 'reticle,' while in ASML's EUV systems, light is reflected by the reticle. The pattern is encoded in the light and then reduced and focused onto a photosensitive silicon wafer using the system's optics, see Figure 1.

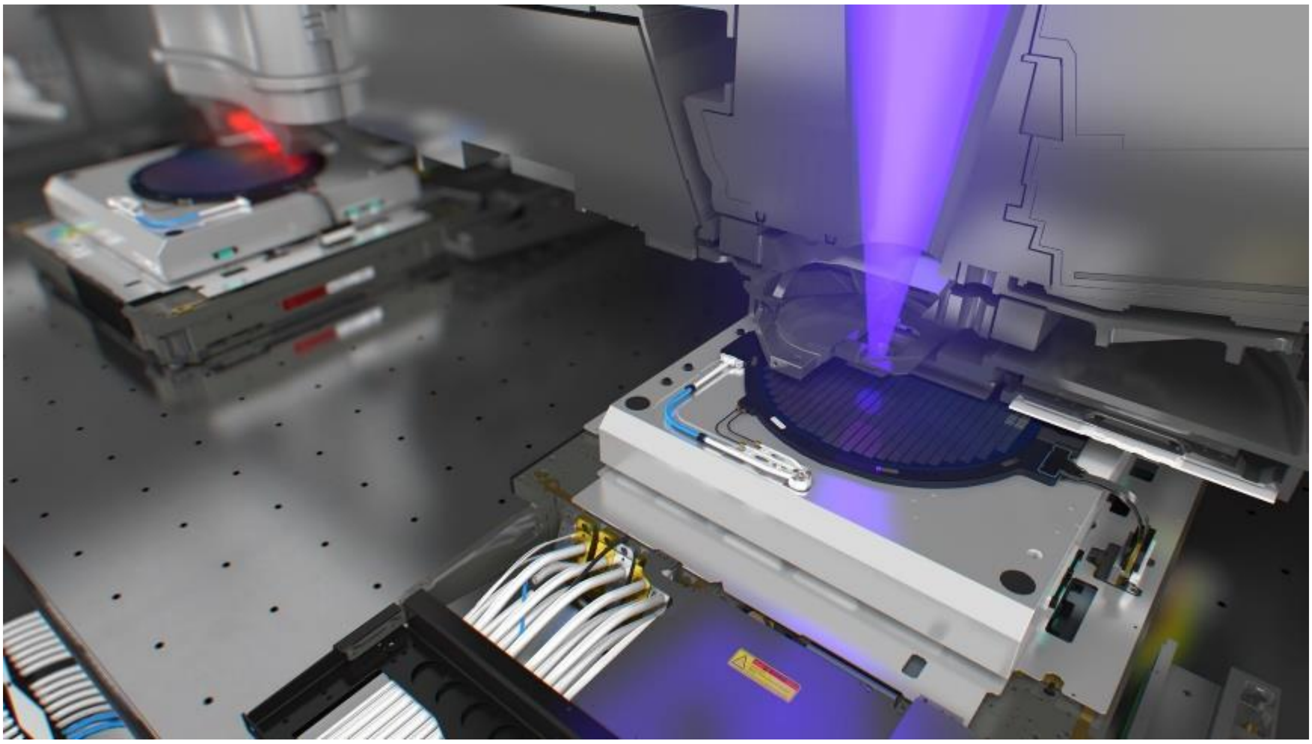


Figure 1: EUV light is focused onto a silicon wafer (ASML, 2023a)

The process continues, with slight wafer movements, until the entire wafer is covered in patterns, resulting in one layer of the chip. To create a complete microchip, this layering process repeats, stacking patterns to form an integrated circuit. The number of layers varies, with simpler chips having around 40 layers and more complex ones exceeding 150 (ASML, 2023a).

Figure 2: ASML's EXE:5000 high-NA EUV lithography machine (ASML, n.d.)

Figure 2 shows a render of ASML's latest high-NA EUV lithography machine, called the EXE:5000. Confidential appendix B presents more information about EUV lithography.

The Operator Interface Unit

To install, operate and maintain these EUV lithography systems, human interaction is required. The ASML scanner and source are components of the machine that are integrated in the manufacturing process of the customer. Both of these components should currently be able to be operated locally using the Operator Interface Units (OIU). Therefore, two OIU's are integrated in the design. The main function of an OIU is to provide a human-machine interface. However, this component currently has several issues. The motivation behind this project stems from both a direct cause and a collection of additional raised concerns related to this OIU design. In Figure 2 both the scanner and the source OIU can be seen on the same side of the latest machine design.


Figure 3: OIU Render, Closed Keyboard Tray (ASML, 2021)


Figure 4: OIU Render, Open Keyboard Tray (ASML, 2021)

Figure 3 and Figure 4 show the current outer body design of the OIU with an open and closed keyboard tray. The main components of the OIU are the screen, foldable keyboard tray, keyboard, mouse, and a storage for the keyboard and mouse. Confidential Appendix C presents more information about the OIU.

Human Factors Engineering

ASML's Definition

According the ASML's Human Factors Engineering (HFE) department, HFE is a multidisciplinary science that focuses on the interaction between the human and the work system in order to design human-machine interactions that optimize human and system performance (ASML, 2023c).

> *"Proactive incorporation of Human Factors Engineering scientific methods throughout the design lifecycle to ensure the delivery of efficient, effective, safe, sustainable and compliant systems."*
>
> *- ASML HFE Department Vision (ASML, 2023c)*

HFE Significance for the OIU

HFE is a general engineering discipline applied to design many complex human-machine systems, such as aircrafts, military systems, computer systems, and medical devices. It is most prominently applied in systems requiring high reliability where failures can have significant consequences (Fink et al., 2004). Therefore, HFE is also relevant for EUV lithography machines. By integrating HFE research into the design process, design requirements can be formulated accordingly, which will result in a more user-centered design. Finally, HFE ensures that the product will meet the ergonomic industry guidelines.

1.2 Assignment

Problem Definition

See confidential appendix D for a description of the problem definition.

Assignment Description

Because of the variety of identified limitations presented in the problem statement, it is valuable for ASML to move beyond the scope of only addressing the single, height-related issue. The human-machine interaction requires an applied research to be able to find different design solutions. These solutions will therefore not only be redesigns, but also new design approaches to address the core challenges. Accordingly, the assignment of this project is formulated as follows:

“Propose concept design solutions according to an applied research of the operator interface unit of ASML's extreme ultraviolet lithography systems through the application of human factors engineering and design methods.”

Scope

In Scope

A project scope has been formulated and visualised in Figure 5. Design criteria are at the core of the project, because they are formulated according to the design analysis, user research, task analysis outcomes. As well as the insights from the use environment and procedure research.

Out of Scope

The detailing of redesign embodiment is less valuable use of the project time. Because, the technical constraints will overshadow the subjects that are more in line with the project purpose. The design solutions will not include detailed materialization or product embodiment. The development of an embodied design is limited by many requirements and technical limitations. Using the time assigned to this project for this would miss the point of the unique advantages of the setup of this project. In addition, employee trainings and software improvements are not part of the scope.

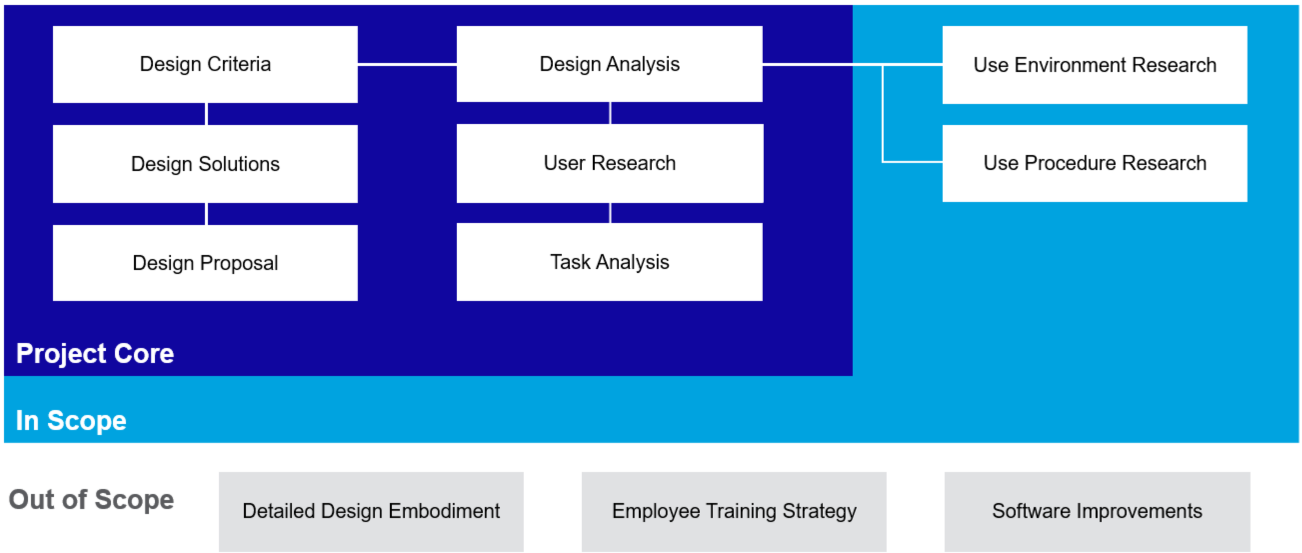


Figure 5: Scope Visual

Product focus

The product focus will be the EUV Lithography systems. This contains the NXE and EXE machines. But ideally, the outcome will also benefit other future products, or products already at the customer.

Project Limitations

The project will be limited by the existing mechanical system layout of the machine. The physical diversity of the end-users and their training and familiarity with the current design can also constrain the results. Design adjustments are expected to mostly be subject to time and regulatory constraints, but also budget constraints. Also, the limitations will be different for products of which the production has already started.

Project Timeframe & Planning

A Gantt-chart planning has been made at the start of the project to guide the project's progress. The full chart can be found in appendix B.

Stakeholders and Stakeholder Value

The project holds value for various stakeholders within the semiconductor manufacturing domain. Especially, the OIU users, ASML's customers, ASML, ASML Development & Engineering, and ASML's HFE Team. The project's success will be measured by the extent to which the deliverables contribute to all of the stakeholder values.

OIU Users

The OIU users are crucial stakeholders that consist of engineers and operators responsible for a diverse selection of tasks. For them, the project aims to enhance the safety, comfort, efficiency and ease of operation of the OIU. The result of the project should improve the work environment and job satisfaction for the users of the OIU.

ASML

ASML holds a reputation for quality products and customer satisfaction. Compliance with HFE standards, addressing customer complaints, and overall product quality improvements contribute to maintaining this image. Safety is the number one priority at ASML. This project will contribute to the improved safety of employees and customer employees. Therefore, ASML requests human-centric design. Additionally, the machines are positioned as luxury items, being the most advanced machines available in the industry. The OIU should live up to this luxury standard.

ASML's Customers

For the customer, a redesigned OIU should improve operational efficiency. It should reduce the risk of downtime because of less human error, and faster downtime recovery because of more efficient service and maintenance procedures. A reduced risk of downtime and faster downtime recovery can save costs for the customer. Additionally, the company will benefit from improved employee safety and satisfaction.

ASML's Development & Engineering, Human Factors Engineering

The ASML D&E department and specifically the HFE team, are important stakeholders of the project. The HFE team is a part of the Human Safety Competences Department, which also includes Machine Safety and Work at Height. This project will contribute new insights and a propose concept design solutions to the HFE team. The project contributes to the team's knowledge, offering fresh perspectives on the ergonomic qualities of the design, which can be applied to this OIU and likely to other ASML products in the future.

TU Delft, Faculty of Industrial Design Engineering

The TU Delft is a stakeholder of the project, since this project initiated as graduation project at the faculty of Industrial Design Engineering. The project and gained knowledge, excluding confidential information, will be included in the TU Delft repository.

1.3 Approach

The project approach includes HFE research and design methods aimed at delivering an overview of new requirements, resulting in design criteria and finally, a design proposal.
User research methods includes interviews, observations, a survey, analysis incident reports, and speaking to experts. In the design phase, technologies and human-machine interaction advancements are researched. To ideate, brainstorm and co-creation sessions are organized, making mind maps, and completing a morphological chart. From this, four concepts were selected and assessed with a Harris profile. The selected concept is further developed into a design proposal. More information on the chosen methodologies and the field visits descriptions and preparations can be found in appendix C, D, and 0.

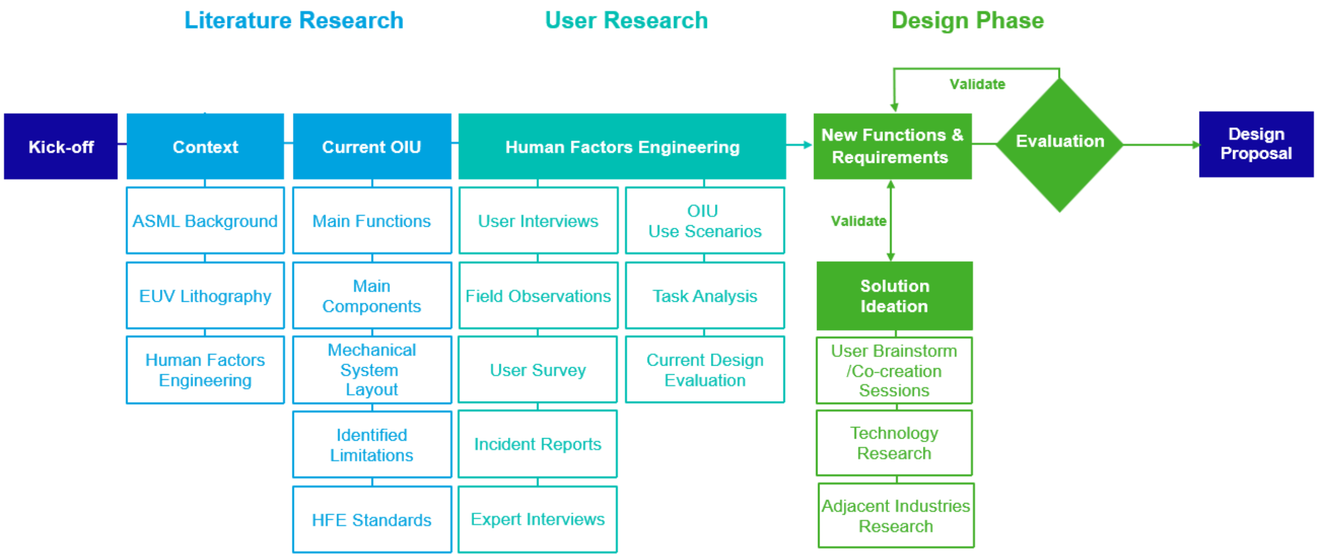


Figure 6: Approach Flowchart

The approach is based on the selection of books and papers about HFE and ergonomic research (Fink et al., 2004; Roozenburg & Eekels, 1995; Sauro & Lewis, 2016). For example, Stanton and Young (1999) underline the value of interviews and task analysis in the concept creation phase. Additionally, Wickens (1997) recommends user analysis, environment analysis, function analysis, and task analysis to be part of the front-end analysis.

CHAPTER 2

User Research

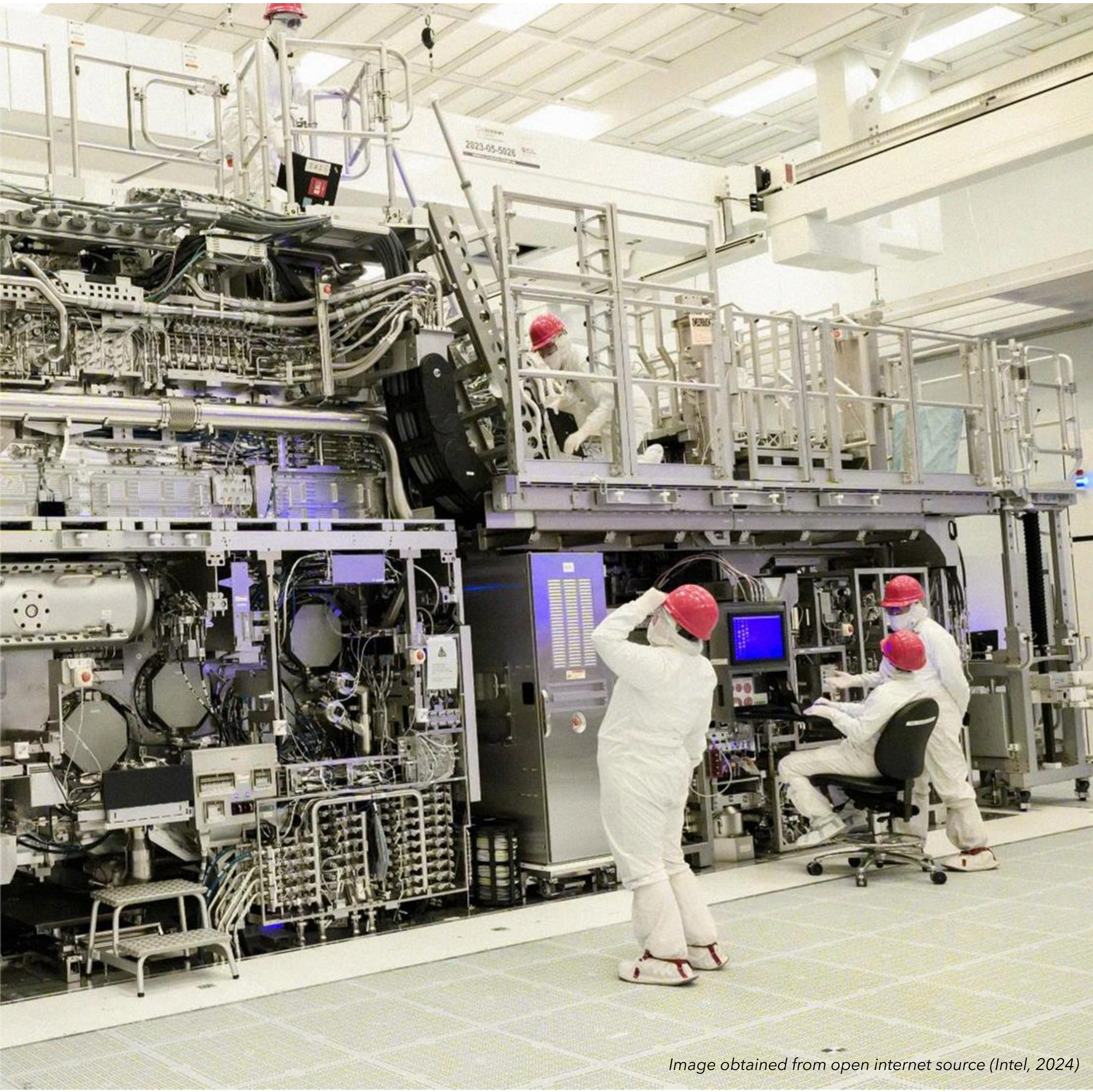


Image obtained from open internet source (Intel, 2024)

This chapter focuses on the end-users of the OIU, who are key stakeholders in this project. These users are separated into four groups and analysed to understand each of their unique requirements. Furthermore, the use procedures, use environment, and their differences for each user group are presented. Finally, this chapter examines the occurrence and consequences of physical discomfort among these users.

2.1 User Research Methods

User Interviews & Observations

The aim of conducting the interviews and observations is to understand the current user experiences with the OIU and to uncover the fundamental reasons behind them. Additionally, it helps gather all crucial information that should be covered in the survey and task analysis. The semi-structured interview method was chosen because it allows for flexibility in exploring the individual perspectives of each user. 22 of these interviews have been conducted.

User Survey

The user survey uses all findings from the user interviews and aims to gather a large collection of quantitative data based on the topics discussed in the interviews. The survey consists of 47 questions and takes around 15-20 minutes to complete. It gathered 130 responses from mixed user types of the OIU. Survey participant characteristics can be found in confidential Appendix E.

Task Analysis

The OIU serves multiple purposes for various user groups. To design a product that effectively meets all intended applications, it is essential to map the range of tasks involving the use of the OIU. Therefore, a task analysis was developed (Kirwan & Ainsworth, 1992). In this task analysis, approximately 50 different tasks are analyzed according to 11 different aspects. These results were gathered through a combination of user interviews and field observations. The full overview of this analysis can be found in confidential Appendix F.

2.2 User Groups

As a result of the interviews, observations, survey, and company analyses, the following four different types of OIU users are identified in Figure 7. ASML and customer operators mainly differ in OIU use durations and occurrences, resulting in their own unique preferences. These preferences are also summarized below.

	Install Engineer *ASML*	**Field Service Engineer** *ASML*	**Upgrade Engineer** *ASML*	**Customer Operator** *Customer*
	"Responsible to deliver a qualified system to the customer."	*"Performs scheduled maintenance or unscheduled machine repairs."*	*"Performs similar work as install engineers, but works on more software-related tasks."*	*"Mainly monitors and retrieves data from the OIU."*
Challenges	• Frequently walking back and forth between OIU and another machine part for mechanical work. • Procedure durations can take weeks and are different each time. • Procedures can include waiting at the OIU.	• Work durations and the type of work is highly unpredictable. • Keep the machines up to the latest hard- and software standards. • These engineers are in close communication with the customer.	• Standard long use procedures and OIU use durations.	• Could work on multiple systems within a shift. • Most often connected to the OIU remotely.
OIU-related task occurrence per machine	• Procedures should occur only once when installing the machine.	• Periodic maintenance occurs about once every 1 to 3 months • The occurrence of machine down service is highly variable.	• Occurrence differs per machine, but could happen once of twice.	• A short (<10 min) use could occur about weekly.
Maximum continuous OIU usage	• Up to 8 hours.			• Up to 1 hour.
Maximum procedure durations	• Up to 3 weeks.			• Procedures do not take multiple shifts.
Unique preferences	• The workspace should be comfortable for long working hours. • A mobile (part of) the workspace would improve the workflow. • The workspace should be suitable for combined laptop use.			• The OIU should be quickly accessible. • Pathways should not be permanently obstructed.

Figure 7: OIU User Groups (Images obtained from open internet sources)

2.3 ASML Use Procedures

Install OIU Use Procedures

Install engineers are responsible for delivering a qualified system to the customer.
The detailed install OIU use procedures can be found in confidential appendix G.

Key takeaways of the install use procedures

- *Once the machine is powered on, almost all install procedures often result in OIU usage for the full shift duration.*
- *OIU use can vary from long (entire shift) to short (5 minutes).*
- *OIU use can sometimes include waiting at the OIU for commands to finish.*
- *The use of the OIU is often combined with mechanical work that can be in any other part of the machine.*
- *During almost all tasks, the install engineer requires using a laptop or fabtop.*

Field Service OIU Use Procedures

Once the system is handed over to the customer by the install engineers, the field service engineers become responsible for maximizing the availability and performance of the machine. This includes fixing unscheduled machine downs, which can include diagnostics, repair or recovery tasks. Because their work is often a reaction to these unpredictable downs, the service tasks are even less predictable in comparison to all other tasks. In the task analysis, the service tasks are separated into two types of procedures: periodic maintenance and unscheduled down service.

The detailed service OIU use procedures for both periodic maintenance and unscheduled down service can be found in confidential appendix G.

Key takeaways of the service use procedures

- *Service tasks can vary greatly in duration, frequency, and type of work.*
- *For almost all tasks, the OIU is required.*
- *It is rare for operators to work in parallel on both the scanner and source OIU.*

Upgrade Engineer & Upgrade Procedures (ASML)

The tasks of the upgrade engineers are almost identical to install engineers. However, the upgrade engineers have less mechanical work, but more software-related work. This means on average, higher intensity and longer duration use of the OIU. However, in user interviews it has been confirmed that the user scenarios presented in the Install Engineer OIU Use Procedures heading, can be assumed almost identical to the tasks of an upgrade engineer.

Key takeaway of the upgrade use procedures

- *OIU-related upgrade tasks can be assumed to be identical to install tasks.*

2.4 Use Environment

Cleanroom at ASML in Veldhoven

EUV Lithography machines are located and operated within cleanrooms to prevent contamination. These are controlled environments in which the concentration of particles is kept below strict limits. The air quality, temperature and other environmental factors are controlled. Personnel must wear cleanroom suits, gloves, hoods, face masks and shoes. Due to strict rules and safety measures, training is required before someone is allowed to enter the cleanroom.

Customer Fabrication Environment

User interviews revealed that in the ASML cleanroom, the system is often operated from a connected laptop, or from a connected desk setup. The OIU is therefore mostly used at the customer fabrication (fab) environment. These environments also maintain strict confidentiality rules. In some cases, ASML employees are not allowed to enter with their laptop. In these cases, they are often provided with a 'fabtop' by the customer. This is a laptop that is not allowed to leave the cleanroom.
Figure 8, Figure 9, and Figure 10 give an impression of these customer cleanroom environments, combined with frequently mentioned user comments.

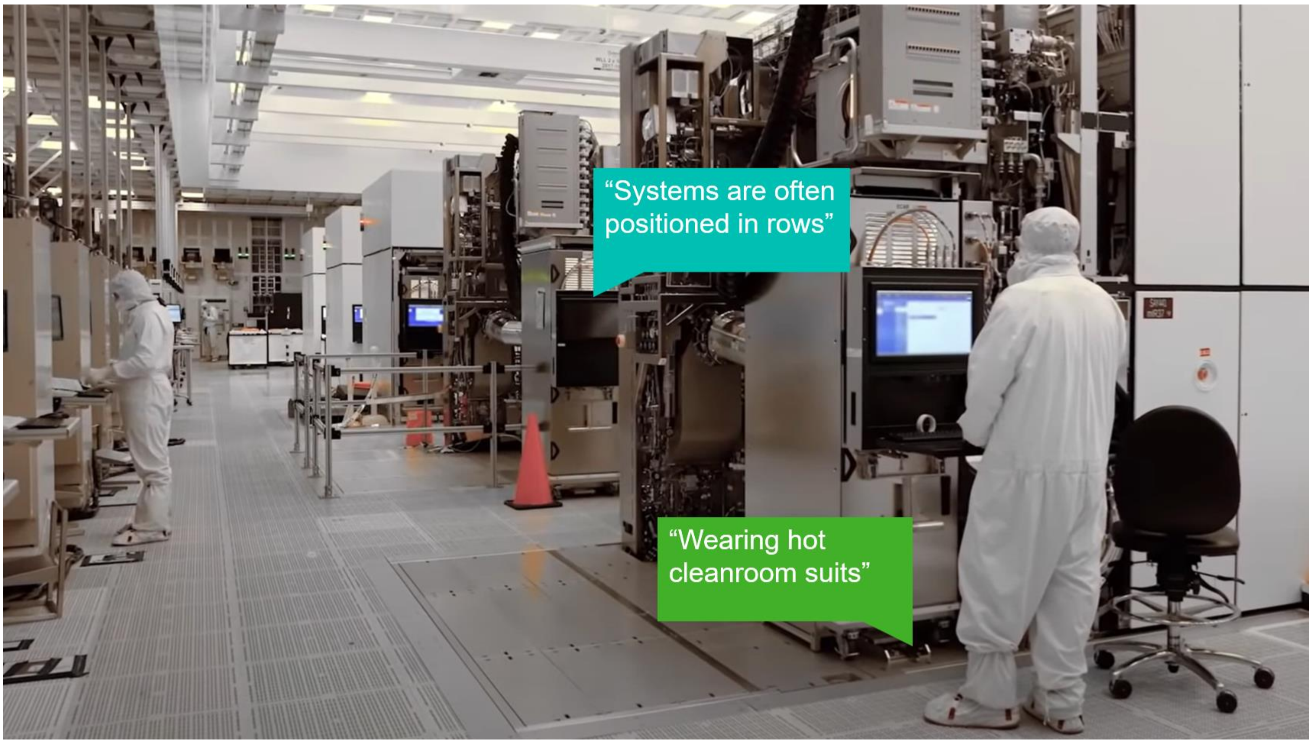


Figure 8: Customer Cleanroom (Intel Newsroom, 2022) - obtained from open internet source

Figure 9: Customer Cleanroom (Intel Newsroom, 2022) - obtained from open internet source

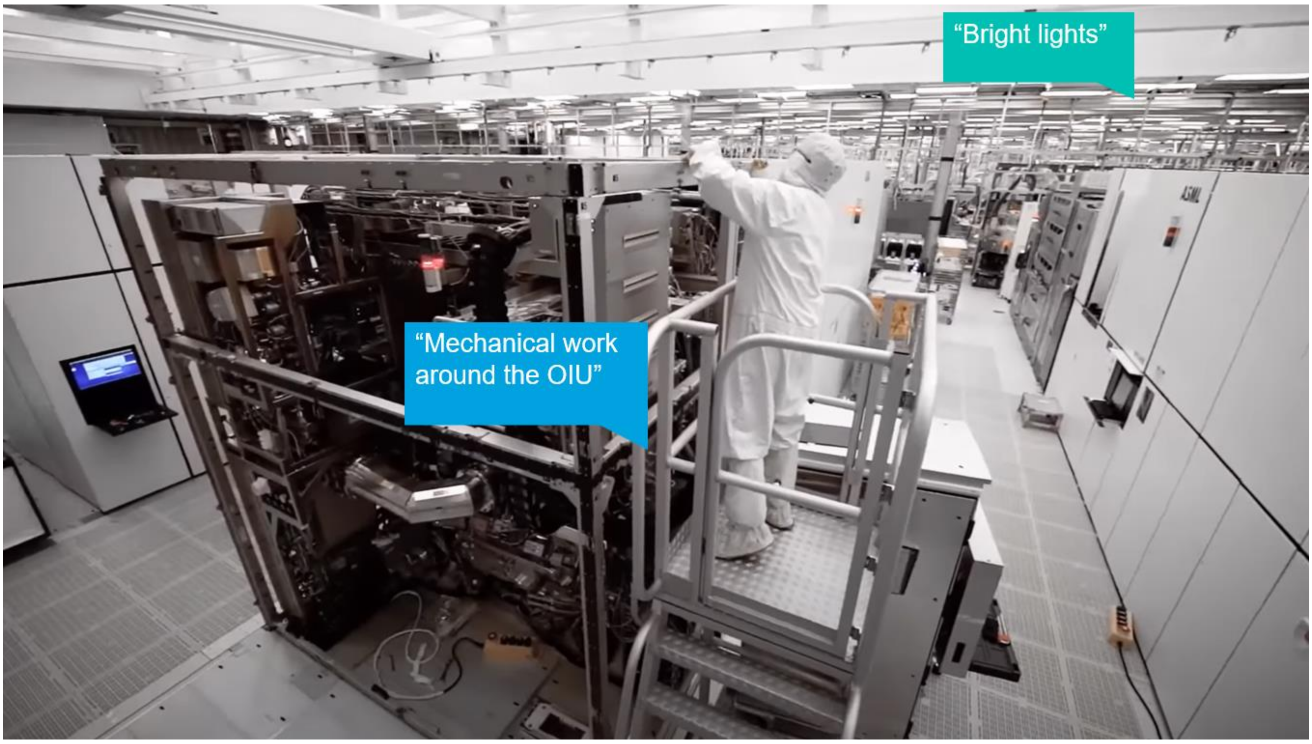


Figure 10: Customer Cleanroom (Intel Newsroom, 2022) - obtained from open internet source

Control Room

Control rooms at the customer site are mostly used to check the status of the machines. They show if a machine is down and can give an error code. When this occurs, an operator can go to the machine's OIU to see what's wrong. However, increasingly more remote operation can be done from the control room, reducing the need to go to the system. These control rooms are not designed by ASML.

Comparing Use Environment of ASML and Customer Users

The use environment changes during ASML and customer use. Figure 11 presents the key differences.

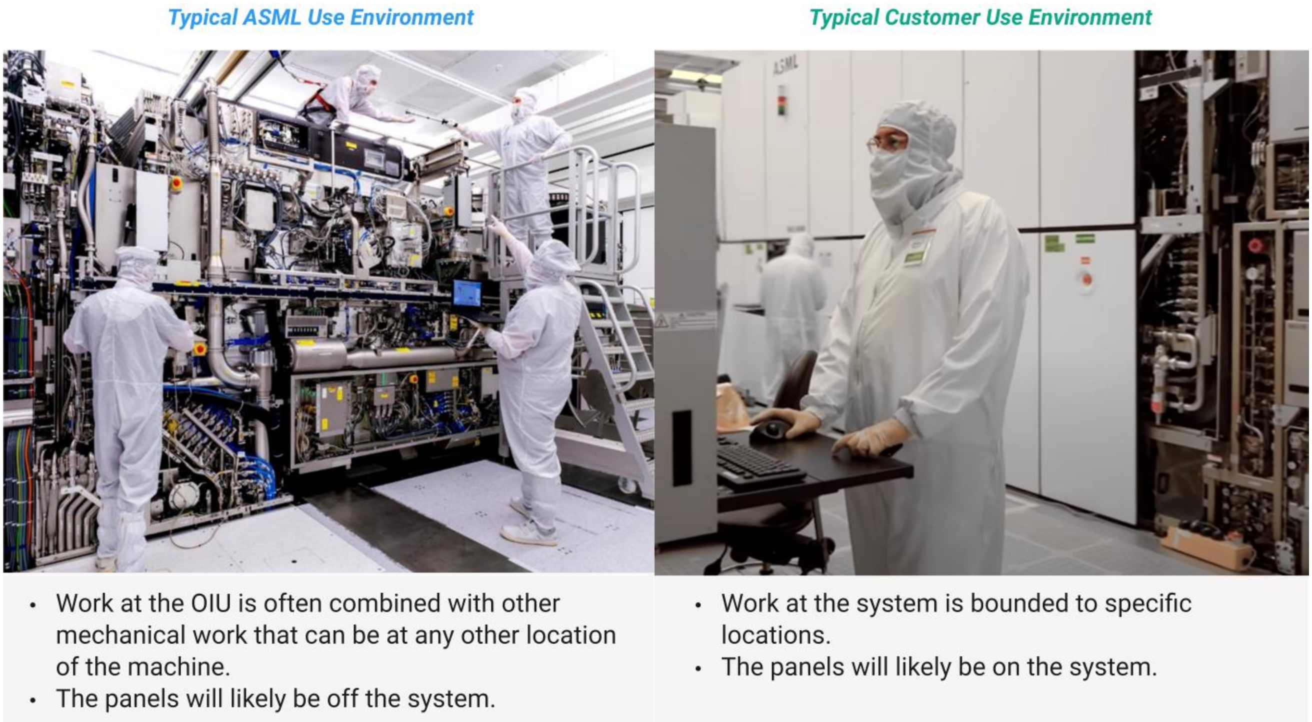


Figure 11: Typical ASML and Customer Use Environment Comparison
(Left image: ASML, n.d. - obtained from open internet source)
(Right image: (Intel Newsroom, 2022) - obtained from open internet source)

User Interactions in EUV Lithography

Typical customer user interactions at the system include wafer or reticle loading. To load wafers, the operator opens the door of the wafer dock and loads the machine by placing a box with wafers. When loading reticles, the machine operator moves the reticle box from a cabin or rack to the loading box of the machine. Handling the reticles requires extremely careful handling.

2.5 Physical Discomfort

Physical Discomfort Analysis

Physical Discomfort Occurrence

In the interviews, the most frequently discussed limitation of the design is that it is fully fixed in place. It does not allow height adjustments of any of the features. Also, the angular adjustments of the features are limited. The lack of adjustability results in physical health complaints for the majority of the interviewed users in this research. Some operators who use the OIU for extended periods of time have reported that they prefer to work at a separate desk whenever they can. Additionally, the current height of the OIU makes it challenging for the user to assume an ergonomic work posture.
The survey results reinforce these user complaints. A significant number of users (95 out of 128) report that they experience physical discomfort caused by using the OIU (see the graph in confidential appendix H). Eighty-eight users report that they already start feeling this discomfort when they use the OIU for three hours or less. Nearly half of the respondents for this question (62 users) start to feel discomfort within the first hour of use.

The graph on occurrence of physical discomfort can be found in confidential appendix H.

OIU Use Durations

Additionally, survey respondents have estimated their average minimum cumulative duration of OIU usage within a shift to range from 3.2 to 9.0 hours (see Table 1). Furthermore, the survey results show that one continuous operation of the OIU typically ranges from 1.5 to 5.3 hours. Finally, the short (<15 min) use ranges from 7 to 29 times per shift.

Table 1: OIU Use Durations (Survey, 2024)

	Average Minimum	Average Maximum
Cumulative duration of all OIU usage within a shift	3.2 hours	9.0 hours
Duration of one continuous operation of the OIU	1.5 hours	5.3 hours
Frequency of short (<15 min) use of the OIU per shift	7 times	29 times

Physical Discomfort Discussion

When these OIU usage durations shown in Table 1 are combined with the results in the graph in confidential appendix H, it presents a concerning scenario. Most alarming is that 74% (95 out of 130) of the survey respondents feel physical discomfort due to the current design. Of these people, 72% (68 out of 95) already feel this discomfort within just 1.5 hours of OIU usage, which is the average minimum continuous use of the OIU.

Additionally, the average total duration of using the OIU within a shift is 9.0 hours, and 20 people indicate that sometimes they use the OIU for an entire shift. From these results it can therefore be concluded that a significant number of OIU users are struggling with discomfort during their typical work tasks.

2.6 The Impact of Physical Discomfort

Impact on Employee Productivity and Job Satisfaction

The users that experience physical discomfort were asked if, when they feel physical discomfort caused by using the OIU, they notice a decrease in productivity or job satisfaction. As shown in Figure 12, the majority agrees with both statements. 63.1% of the users that feel physical discomfort caused by using the OIU notice a decrease in productivity because of this. Of these users, 46.3% agree with the presented statement, and 16.8% strongly agree. Also, 71.6% of the users experiencing physical discomfort notice a decrease in job satisfaction because of this.

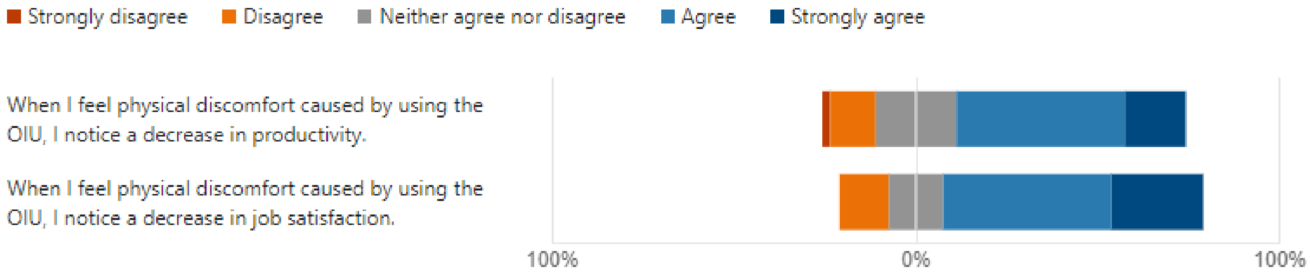


Figure 12: Users' agreement with the presented statements (Survey, 2024).

Impact on Work Results

The group of users that experience physical discomfort caused by using the OIU were also asked if their discomfort led to (temporary) absence from work because they were/are unable to perform duties. Five out of these 96 users responded 'yes,' and 24 responded 'No, but I switched tasks with a colleague.' These results show that about a quarter of the users that feel physical discomfort because of the OIU design are impacted in performing their work.

Figure 13: Has your physical discomfort caused by using the OIU led to (temporary) absence at work because you were/are unable to perform duties? (Survey, 2024)

Impact on Customer and ASML

The sections on the impact on the customer and ASML can be read in confidential appendix I.

2.7 User Research Conclusion

To conclude, the OIU is used by a variety of users, each requiring its functionalities for different use scenarios. The main OIU user groups are, install engineers, field service engineers, upgrade engineers, and customer operators. The main differences between the user groups are that the ASML users have (from a machine perspective) infrequent, but long OIU-related use scenarios, and customer operators have more frequent, but short OIU-related use scenarios. In some cases, the OIU usage duration can take up the entire shift of the user. The interviews and survey results reveal that a significant amount of users experience physical discomfort from using the OIU, often within the average minimum use duration. This discomfort affects their productivity, job satisfaction, and work performance, posing risks to the customer and ASML's responsibility for employee wellbeing. The following chapter aims to find the root causes of these complaints, along with other issues, and derive a selection of design criteria from these results.

CHAPTER 3

Design Analysis

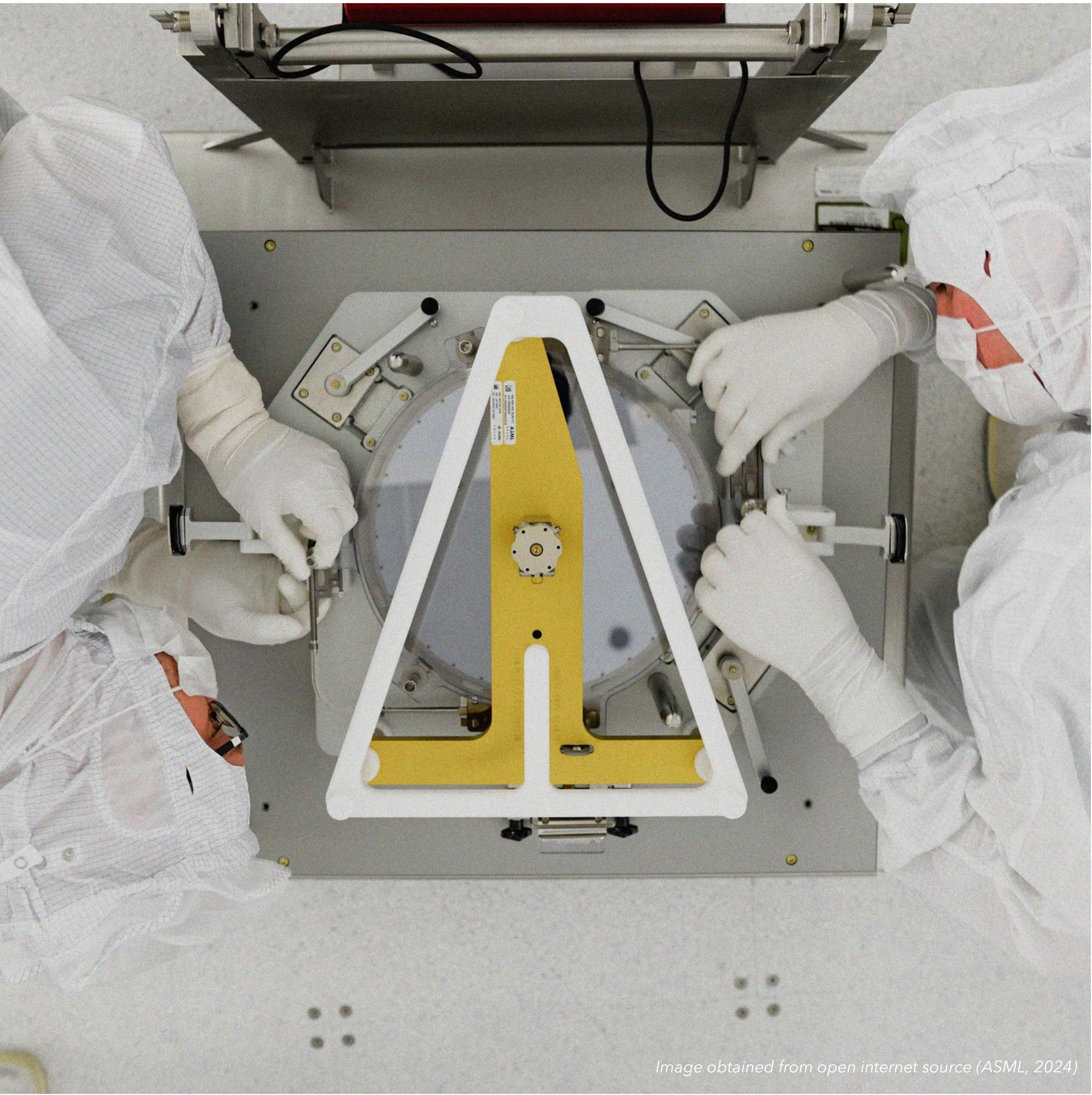


Image obtained from open internet source (ASML, 2024)

In this chapter, aspects of the current design are discussed according to the results from the user research. For each topic, a key result is presented. The purpose of these results is to learn from the limitations currently present in the OIU and to formulate the core 'design criteria' from a user perspective.

3.1 Work Posture

The current design of the OIU is mounted on the side of the machine and is fully fixed in place. Therefore, users cannot adjust it to their personal body measurements or work posture preferences. In Chapter 2, it was concluded that many OIU users regularly experience physical discomfort. In this chapter, the current work posture of the user is analyzed to find the root causes of this discomfort. Accordingly, recommendations for future requirements will be presented.

Work Posture Analysis Results

The most frequent work postures were gathered through a survey. These results were assessed according to the work posture guidelines from the "Main Human Factors Engineering Requirements" document (ASMLc, n.d.). These guidelines specify which angles of certain body parts are acceptable and how long these angles should be maintained daily.

The angle displacements of the body parts shown in Figure 14 indicate movements that occur too frequently. Detailed results can be read in Appendix F.

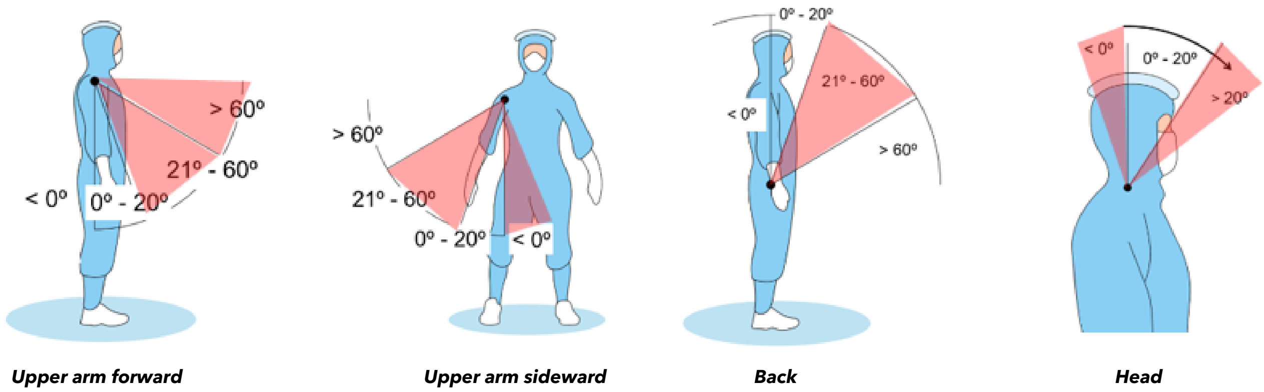


Figure 14: Frequently Occurring Unacceptable Work Postures Indicated in Red

The work posture of the user was observed during a customer field visit. At the customer location, operators frequently adjusted their posture to find a comfortable viewing angle at the screen.

See confidential Appendix J for images of the standing work posture observations in the customer cleanroom.

The photographs taken at the customer site in confidential Appendix J show four different, relatively tall (175+ cm) users working in the customer location cleanroom. The operators are seen hunching over when standing at the OIU, mostly looking down at the screen. This suggests that the screen is too low for these users. However, because the height between the desk and screen is fixed, their upper arm is frequently positioned forward instead of alongside their body. This is likely a consequence of the scanner OIU screen being directly positioned above the keyboard tray.

KEY RESULT

OIU users frequently assume work postures that are unacceptable according to ASML's HFE requirements.

Areas of Physical Discomfort

Users who indicated experiencing physical discomfort due to the OIU in the survey were asked to indicate the location of this discomfort on a map of the human body. As shown in Figure 15, the most frequent areas of discomfort are the shoulders, neck, lower arms, lower back, and feet. The discomfort in the feet is possibly a consequence of prolonged standing.

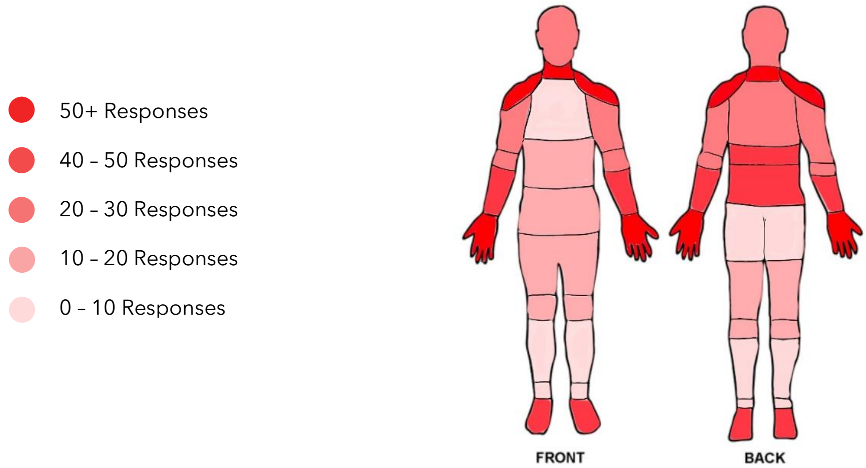


Figure 15: Please indicate the zone(s) of your personal physical discomfort caused by using the OIU with the corresponding number(s).

KEY RESULT

Unacceptable work postures result in related physical discomfort.

Work Posture Analysis Conclusion

From these results, it can be concluded that the inability to adjust the OIU prevents users from assuming a sustainable work posture that corresponds to their specific body measurements. The frequently occurring unacceptable work postures retrieved through the user survey align with the field observations. Additionally, the areas of physical discomfort complaints correspond to these postures.

Therefore, it is likely that the fixed nature of the current OIU design causes the physical discomfort presented in Chapter 2. As a result, the following design criterion is formulated:

DESIGN CRITERION

The interface must allow users to assume a correct working posture.

It must allow users with varying personal body measurements to assume work postures that correspond to the HFE guidelines. This either means that the interface and its features should be adjustable in height and angles or that the interface provides a new type of interaction to improve work posture.

Standing or Seated Work Posture

Currently, the OIU is designed to be used with a standing work posture. However, the use durations are too long to only be standing.

Figure 16: Operator working standing behind the OIU (Intel Newsroom, 2022) - obtained from open internet source

As shown in Figure 17, 62 out of 128 respondents indicate that they would often (~75% of the time using the OIU) rather sit than stand, if sitting is possible. Twenty-four users would (almost) always (~100% of the time using the OIU) prefer to sit. Only three users would (almost) never (~0% of the time using the OIU) rather sit than stand.

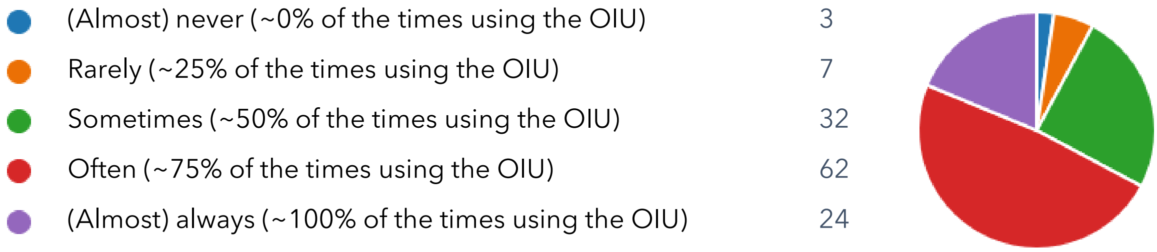


Figure 17: When using the OIU, how frequently (estimate) would you sit rather than stand, if sitting is possible? (Survey, 2024)

KEY RESULT

The majority of the OIU users most frequently prefer to sit at the OIU.

Sitting, Standing or Adjustable for Both

As shown in Figure 18, 105 out of 128 users report that they would prefer the OIU to be designed for both sitting and standing use. Sixteen out of 128 would prefer it to be designed for seated use only. Only four out of the 128 users would like to see the OIU designed for standing use only, which corresponds to the current design. In interviews, it was indicated that most often, and in the most critical times, users need to be at the OIU for several hours uninterrupted. In these cases, a seated work posture is preferred.

Figure 18: Would you personally prefer the OIU to be designed for seated use, standing use or adjustable for both? (Survey, 2024)

KEY RESULT

The large majority of the OIU users want the interface to be adjustable for both seated and standing use.

Chair Suitability & Availability

If a chair is provided at the customer site, interviewees explain that these are often unsuitable for the OIU design and its use scenarios, resulting in ergonomic challenges. Interviews indicate that most frequently, the operator is provided with a standard office chair, as shown in Figures 19 and 20.

Figure 19: Office Chair in Front of the OIU at the customer location Customer Location (Intel Newsroom, 2022) - obtained from open internet source

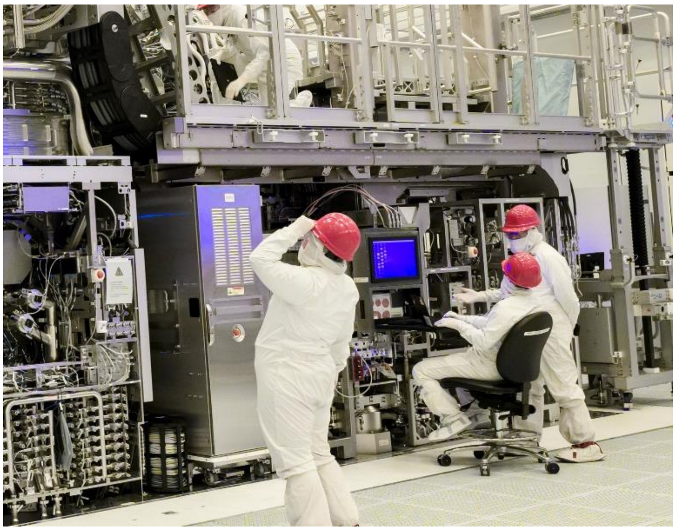


Figure 20: Operator work on the OIU on a low office chair (Intel, 2024) - obtained from open internet source

KEY RESULT

Most common provided chairs do not fit the use scenario of the OIU.

Additionally, user interviews frequently mentioned that the user is currently not provided with a standard seating solution. In some cases, the customer location does not provide a chair at all.

KEY RESULT

Many customer operator cleanroom environments do not provide a chair.

Most Common Seated Work Posture

The low chair seated image in confidential Appendix J shows the best possible posture with this low office chair at the OIU. It is not possible to sit comfortably with this setup. For example, the user needs to reach up to the tools, and there is no leg space.

See confidential appendix J for seated posture image.

KEY RESULT

It is impossible to maintain a correct seated posture with the current most common seated work setup.

High Chair Work Posture

See confidential appendix J for the images of the seated work posture observation in the customer cleanroom visited for this research.

At the customer location visited for this research, the operators are provided with a high chair, as shown in confidential Appendix J. According to the interviews, this is already a better solution than the 'regular' office chairs. However, this setup still leads to ergonomic challenges. Images in confidential Appendix J show operators at the customer location using the OIU on this high chair. The operators are bending forward to look at the screen while reaching up to use the keyboard and mouse. At the customer site, it can be seen that users awkwardly elevate their shoulders when using the tools. This will result in discomfort in long-term use. Additionally, the extended reach of certain users to the trackball mouse can also result in excessive strain on the arm, shoulder, and neck muscles. Furthermore, the users did not have enough space for their legs underneath the keyboard tray.

KEY RESULT

Some operator cleanrooms provide a high chair, which still does not provide a sufficiently correct seating posture.

Task-Dependency of Work Posture

The preference to sit or stand is dependent on the type of task that needs to be performed at the OIU. As concluded in the use scenarios described in Chapter 2, tasks that involve using the OIU vary highly in durations and frequencies. Often, the OIU is used for short actions (<30 seconds) where it is convenient to stand. However, it also frequently occurs that the OIU needs to be used for extended periods, for which it is preferred to sit down.
For example, users prefer to sit during tasks like 'module adjustment & qualification' or 'OIU usage for long recoveries involving exposures'. On the other hand, users would rather stand during tasks like 'mechanical install', 'hardware tasks', 'check reticle inventory', 'check test reports', 'driver startup', or 'logbook updates' (Survey, 2024).

KEY RESULT

The preference to sit or stand is task-dependent.

Take a Break at the OIU

In discussion with users, another insightful perspective came forward regarding sitting at the OIU. Many tasks in the cleanroom involve standing and moving around, making the OIU one of the rare occasions where sitting is feasible. Therefore, to include a seated option at the OIU, would expand its purpose to an area that not only serves its primary functions, but simultaneously offers some much-needed rest. This allows the user to maintain productivity while also resting, which in turn could increase productivity when performing the next task.

KEY RESULT

A chair at the OIU is the only option to rest the legs and feet while staying productive in the cleanroom environment.

Additionally, another survey respondent indicates that sitting can improve their focus. Sitting down can reduce fatigue, more energy could be channelled into mental tasks. Providing the user with the option to rest is another argument to adjust the OIU design to provide a seated option.

KEY RESULT

Sitting at the OIU can improve focus, for the current and the next task.

Alternating Users' Impact on Work Posture

If this results in a design becoming adjustable for both, it should be noted that users will alternate frequently. Therefore, the ease of adjustments needs to be designed accordingly. Frequently alternating users could mean that operators might not take the time to adjust the OIU to their personal body dimensions each time they use it. Additionally, the moving parts of the OIU must meet sufficient durability standards to withstand frequent adjustments.
In the survey, most users (50 out of 125 responses) indicated that 'Sometimes (~50% of the time using the OIU)' they would alternate using the same OIU with another user within 2 hours (see Figure 21). 25 users indicated that this happens often, and 18 people responded that it occurs (almost) never.

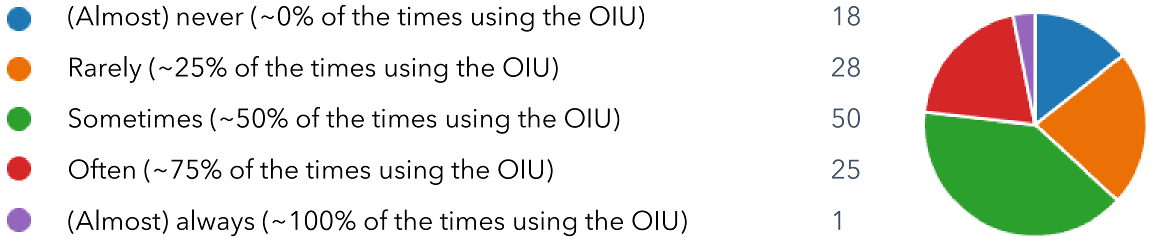


Figure 21: Survey Question: How frequently would you alternate using the same OIU with another user within a 2-hour time period?

KEY RESULT

Users often alternate using the same OIU within a 2-hour period.

Work Posture Flexibility Conclusion

The key results presented in this chapter result in the following design criterion:

DESIGN CRITERION

Provide flexibility to adapt work posture.

The interface must provide the user with the flexibility to adapt their work posture to the type of tasks they are working on and their personal preferences.

3.2 Workspace and Tools

The foldable keyboard tray includes one or two surfaces with hinges that can be folded out of the machine. The surface provided is meant for a keyboard and mouse. There is a section behind this tray to store these tools.

Keyboard Tray Workspace Dissatisfaction

69% of the respondents are dissatisfied with the keyboard tray workspace, with 33% being very dissatisfied. Only 7% of the respondents indicated satisfaction, and not a single user is very satisfied with this feature of the OIU.

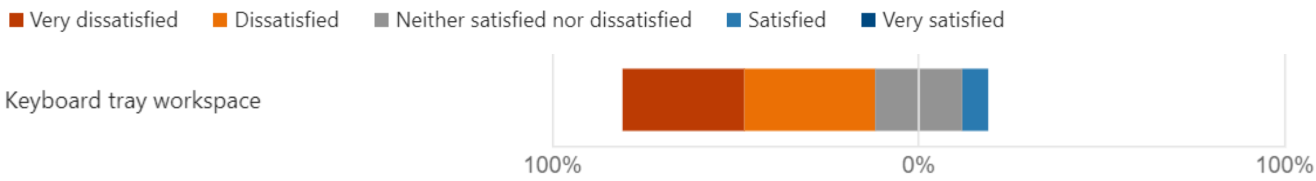


Figure 22: Please indicate your satisfaction of the following OIU features.

KEY RESULT

The majority of the users is dissatisfied with the keyboard tray workspace.

Keyboard Tray Workspace Size

The most frequently mentioned limitation of the keyboard tray is its insufficient surface area. The tray is too small to comfortably use both the mouse and keyboard. Observations at the customer location cleanroom visit confirmed this lack of space. When arriving at the source OIU, an optical mouse was connected and placed on a high table next to the chair (see confidential appendix J). As seen in these images, the user's upper arm is slightly behind them, an unacceptable posture according to the HFE requirements for upper arm position, as presented in chapter 3.1. Additionally, the user is unable to sit straight at the OIU. This unergonomic work posture results from the lack of space on the keyboard tray.

KEY RESULT

The keyboard tray's insufficient surface area leads to unergonomic work posture.

Storing Tools

Behind the keyboard tray, there is a section to store the keyboard and mouse, as shown in confidential appendix J. The storage space is small and sometimes results in accidental key presses. Multiple ASML employees have described this as a common issue that can cause significant delays.

See confidential appendix J for images of the process of storing tools behind the keyboard tray, observed in the customer cleanroom visited for this research.

KEY RESULT

Accidental inputs when storing input devices behind the tray block remote connection.

Workspace Analysis Conclusion

Enhancing the keyboard tray size would prevent ergonomic issues and contribute to a more user-friendly experience, especially in environments where prolonged use is common. Additionally, the keyboard tray folds to keep pathways clear when required. Therefore, this analysis results in the following two design criteria.

DESIGN CRITERION

Space for input tools.

The interface must provide space to use the optimal input tools.

DESIGN CRITERION

Keep pathways clear.

The interface must keep pathways clear when needed.

One Visible Screen

Most complaints related to the screen concern having only one screen available, which allows only one window to be visible. 93 out of the 125 responses indicate that the ideal number of software displays/windows that the OIU screen would allow to be seen at the same time would be more than ~3.

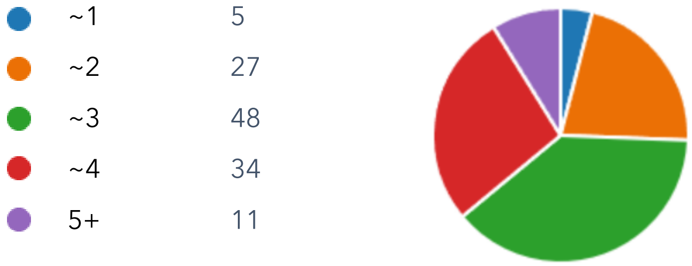


Figure 23: How many different software displays/windows do you typically use at the same time or switch between on the OIU screen?

> ***KEY RESULT***
>
> *Most of the users use about three software windows at the same time on the same OIU screen.*

Ideal Number of Software Displays

However, when asked what the ideal number of software displays/windows the OIU screen should allow at the same time, 43 out of 126 chose 2 displays/windows. Only 7 people chose to see one OIU display/window at a time. The majority preferred more than 3 screens: 66 people out of 126. In interviews, users additionally indicated a desire for an increase in visible displays.

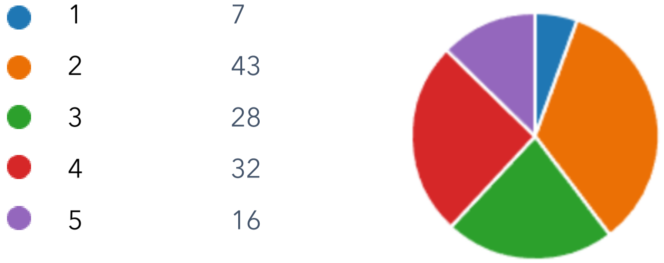


Figure 24: In your opinion, what would be the ideal number of software displays/windows that the OIU screen would allow you to see at the same time?

> ***KEY RESULT***
>
> *The majority of users prefer more than three software displays/windows on the OIU screen.*

Limited Screen Workspace

Comments in user interviews identify, that increasing the size could help in some tasks. It is easier for more people to watch along on a bigger screen. Also, during a brainstorming session with multiple users, it was indicated that sometimes four people need to see the screen at the same time, for example during training. With the current fixed location and screen size, this is challenging.

KEY RESULT

Increasing the screen size would enhance visibility for multiple users, facilitating group tasks and training sessions.

Angle of the Screen

Additionally, for work productivity, and collaboration purposes it has been requested to give the user the option to pull the screen outwards. Some users note that making the angle of the OIU screen adjustable can also improve productivity during some tasks. Currently, when choosing to operate the OIU from a seated position, the user often has to look up at the screen.

KEY RESULT

Users have expressed a need for an adjustable screen angle on the OIU to enhance productivity and comfort, particularly when operating from a seated position.

Input Tools' Satisfaction

As shown in Figure 25, 38.6% of the survey respondents are dissatisfied with the keyboard, with 18.9% being very dissatisfied. 38.1% of the responses are satisfied or very satisfied with the keyboard.

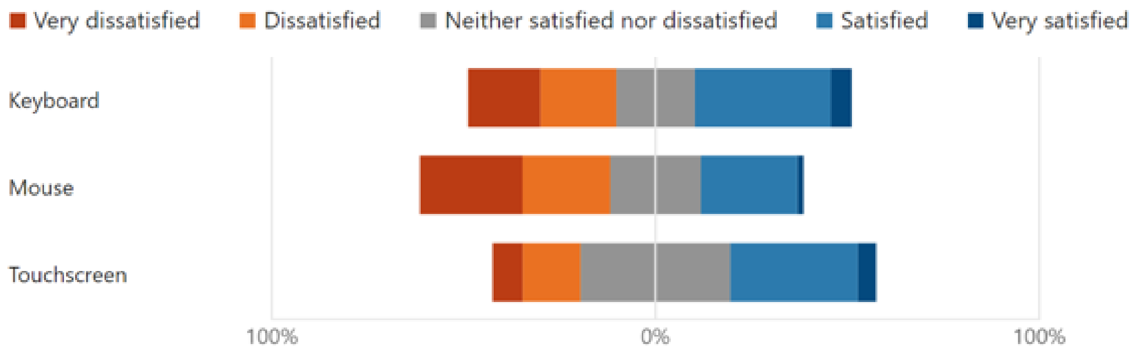


Figure 25: Survey Responses Keyboard Satisfaction

KEY RESULT

People have mixed opinions on the keyboard, mouse, and touchscreen.

Keyboard Complaint

Some of this dissatisfaction stems from the keyboard being broken. The industrial cleanroom is a relatively rough use environment for keyboards. Multiple users have identified that tools are often broken because of this.

KEY RESULT

The keyboard often breaks in the rough conditions of the industrial cleanroom.

Mice Complaints

From the research, users indicated a range of complaints regarding the mice used at the OIU. Some of these complaints are selected and listed in the confidential Appendix M. Users notes that mice are often broken, unavailable, and should preferably be wired.

KEY RESULT

Mice are often broken, unavailable, and should preferably be wired.

Optimal Keyboard and Mouse within Current Context

From survey results, the optimal keyboard and mouse were identified within the current use context. The detailed analysis and argumentation behind these results can be read in Appendix G.

KEY RESULTS

- *A full-size mechanical keyboard with number pad is the most reliable text input tool for the OIU user.*
- *The majority of the users prefer an optical mouse over a trackball mouse.*

Touchscreen Use is not Linked to Specific Tasks

When completing the task analysis, users indicated that using the touchscreen is not linked to a specific task; however, it is mostly considered a quick and easy option to use whenever the user feels like it. On the other hand, designing a UX for both mouse and touchscreen results in design concessions that could possibly be optimized when designing for only one pointing device input.

KEY RESULT

Users find the touchscreen convenient for spontaneous use, but designing for both mouse and touchscreen often requires compromises that could be avoided by focusing on just one input method.

Touchscreen Complaints

In the survey, some users expressed dissatisfaction with the touchscreen. Selected complaints are listed in the confidential Appendix M. The primary issues raised include calibration and accuracy. In some instances, the touchscreen can register accidental inputs, and it does not function effectively with cleanroom gloves for some users.

KEY RESULT

Some users are dissatisfied with the touchscreen due to issues with calibration, accuracy, accidental inputs, and compatibility with cleanroom gloves.

Workspace and Tools Conclusion

The workspace analysis results in the following design criteria.

DESIGN CRITERION

Provide textual and pointing input

The human-machine should allow the user to provide textual and pointing input.

DESIGN CRITERION

Provide visual output

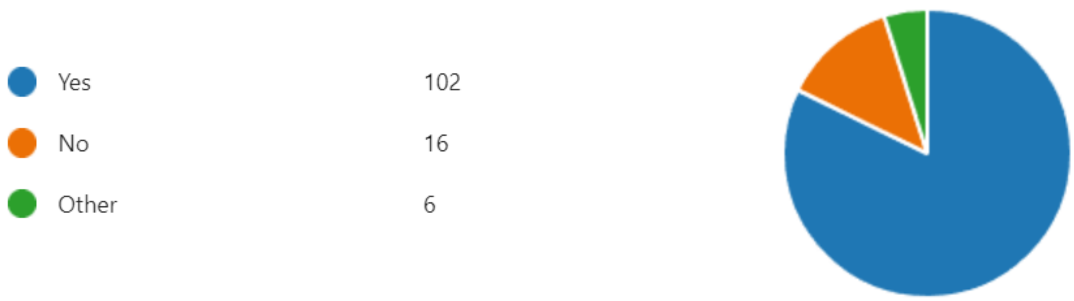
The human-machine should allow the user to provide textual and pointing input.

3.3 Work Mobility and Flexibility

This chapter explores the user's mobility around the machine and the flexibility to choose their workspace. Additionally, it researches the use of laptops in parallel. Interviews have shown that these topics are important for users' work comfort and efficiency.

Portable Device

Out of 124 respondents, 102 indicated that having an available portable device that duplicates or extends the OIU screen would increase their work productivity. Five out of the six "other" responses indicated that their laptop or fabtop already provides them with sufficient portable options.



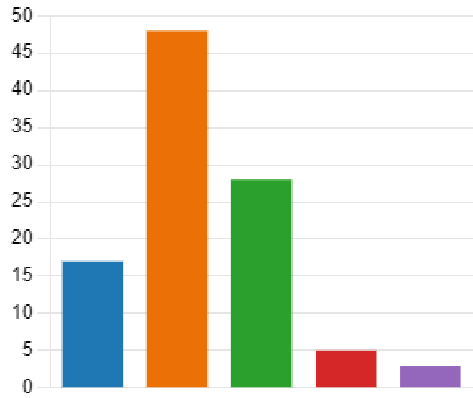
KEY RESULT:

Users indicate that a portable device that duplicates or extends the OIU screen could significantly increase work productivity, although some users feel their current laptops or fabtops already meet their portability needs.

Frequency Requiring OIU at Another Machine Location

The majority, 48 out of 101 users, indicated that they require the use of the OIU while simultaneously working on a component or area of the system located more than one meter away from the OIU, 2-4 times per hour.

0 – 1 times per hour of using the OIU	17
2 - 4 times per hour of using the OIU	48
5 - 14 times per hour of using the OIU	28
15 - 29 times per hour of using the OIU	5
30+ times per hour of using the OIU	3



KEY RESULT

The majority of users, need to use the OIU while working on parts of the system more than a meter away several times an hour.

Reduce Walking Back and Forth

As presented in the task analysis and Chapter 2, some tasks are almost always combined with work at another location on the machine. These tasks often involve mechanical procedures that can occur at any part of the machine. According to a user, removing and then putting back on the working-at-height gear to check the OIU can take up to 10 minutes, whereas this could take only 10 seconds with a portable device.

Figure 26: Engineer Working on System with Safety Harness (ASML, n.d.) – Obtained from open internet source

KEY RESULT

A portable device can save a significant amount of time and effort that would otherwise be spent walking back and forth between the OIU and other machine locations.

Work Location Flexibility

In some cases, the limited workspace around the OIU is a reason for users to look for another space to work. Sometimes, there are space restrictions around the OIU due to other work being performed in the area.

KEY RESULT

Portable device can provide flexibility when the workspace around the OIU is restricted.

Portable Device Requirements

In the survey, users were asked to identify important requirements for a portable device, resulting in 75 responses. The topics are listed below along with the frequency of mentions. An optimized laptop workflow is the most frequently mentioned requirement. Other features that were frequently mentioned include wireless capabilities, a long-lasting battery, durability/robustness/reliability, and docking stations. Some requirements were mentioned only once or twice, but they are still included because they have been highlighted in previous interviews. Additionally, it should be noted that the portable device should be able to connect to the main OIU without hindering its use.

Table 2: Portable Device Requirement Topics

Portable Device Requirement topic	Mentioned frequency in survey
Optimize laptop workflow	**12**
Wireless	**10**
Touchscreen	**8**
Tablet	**6**
Long-lasting battery	**5**
Durable/robust/reliant	**4**
Docking station/storage place	**4**
Combined with additional table	**3**
Power connection/no battery	**2**
Ethernet connection	**2**
Allow simultaneous OIU usage	**2**
Easy setup	**2**
Responsiveness/low latency	**2**

Source: Survey (2024) Results

12 survey respondents have indicated that they would prefer the current situation with the laptop to be improved, instead of adding a different portable device. This is the most frequently mentioned solution a portable solution in the survey. Also, in user interviews a laptop solution is most popular. First of all, the user is not only reliant on a touchscreen, like a tablet. However, the laptop can still have a touchscreen, but also still have a keyboard and mousepad. In the interviews, these are judged as being more reliable compared to other input methods, like a touchscreen. Additionally, a laptop is relatively easy to use when operating it from improvised surfaces, like a lap, the floor, or other. These are not preferred use-cases but should be prepared for if the device is taken to work locations that can be anywhere at the machine. However, a tablet could resolve this issue with a well-designed support or stand. From the interviews, it is derived that the work culture is currently built around laptop work. Users are very familiar with using laptops in their professional lives. Maintaining familiarity can work well for efficiency, and reduce the learning curve when users are confronted with a new design.

KEY RESULT

Users indicate a preference for optimizing the laptop workflow and also highlight important requirements for portable devices, such as wireless capability, touchscreen functionality, tablet integration, and a long-lasting battery.

Using a Non-connected Laptop to the OIU

More than half of the respondents, 65 out of 124, indicated that they (almost) always use a laptop in parallel with the OIU that is not directly linked/connected to the OIU. Only 14 out of 124 (almost) never use a laptop in this manner. The 14 people who (almost) never use a laptop next to the OIU was unexpected, as every interviewed person reported doing so.

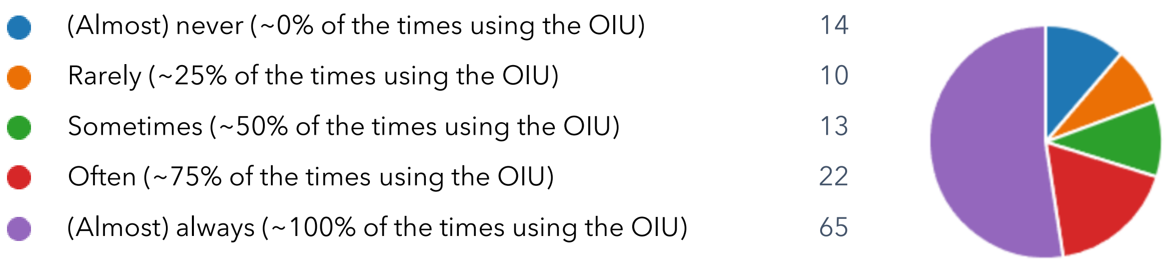


*Figure 27: For each time using the OIU, how frequently do you require parallel use of a laptop that is **not** directly linked/ connected to the OIU?*

In most cases, a laptop is used for ‘Coach’ (a program with work procedures), communication via ‘Teams’, support line communication, PDF readers for action plans, and checklists.

KEY RESULT

Most users often or always use a non-connected laptop with the OIU, primarily for work procedures and remote communication.

No Place to Put Laptop (Or Other Reference Material)

Another frequently occurring topic in the research has been the inability to place the laptop at the OIU, or anywhere else at the workspace. During observations at the customer location, OIU operators were seen operating the OIU while having their laptops on a table next to them. Resulting in working back and forth between the laptop and OIU, being unable to find an ergonomically correct position, and ending in bad posture.
An upgrade engineer said that when he needed the laptop to work at a certain part of the machine, it very often had to be placed on the ground because there was no other place to put it. Confidential appendix L shows a relatively recent OIU design that already provides some additional surface to place a laptop. However, the workflow is still limited as operating the laptop from this position remains challenging.

KEY RESULT

OIU users lack adequate space to position their laptops.

High Desk Next to OIU

At the customer location, OIU operators have a better workspace setup than usual, with high chairs and a high table next to the OIU. Table 3 in confidential appendix J separates the workspace observations into 4-second intervals to illustrate the work posture of a customer operator. As seen in the frames, the operator switches between two screens. Sometimes, he looks forward at the screen while his chair and upper body remain turned to the left. At 4-second intervals, he looks over to the laptop using only his neck.

In the survey, 27 users indicated that they frequently rotate their head sideways, exceeding 45 degrees. According to HFE requirements, this should occur less than once a minute.

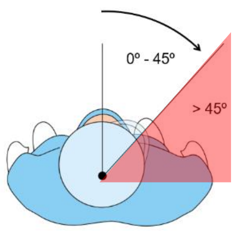


Figure 28: Rotation of Head (to the left, and/or to the right)

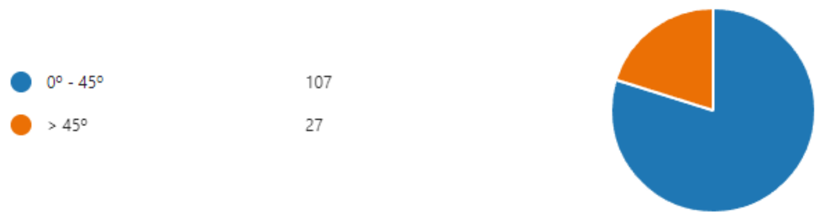


Figure 29: When working at the OIU while standing, which zone(s) would best describe the rotation of your head (to the left, and/or to the right)? Take into consideration combined laptop use.

KEY RESULT

Work posture for parallel laptop use is unacceptable according to ASML's HFE requirements.

These outcomes result in the following design criteria:

DESIGN CRITERION

Use all around machine

The user should be able to interact with the machine at as many locations around the machine as possible.

DESIGN CRITERION

Mobile device workflow

The human-machine interaction should support a workflow with a mobile device.

3.4 Machine Integration

Mechanical Work Combined with OIU Usage

In the task analysis, for many tasks, the work at the OIU is combined with other (mechanical) work at another part of the machine. Also, for some tasks, it is essential to hear the sounds that the machine produces as a result of the actions at the OIU. The final important reason is to ensure the safety of other engineers working at the system while the OIU is being operated. The OIU operator could activate something that could have dangerous results on a person working on mechanics. Possibly, future scenarios could solve these challenges by integrating mechanical stops when maintenance is performed and integrating sensors to remain connected to the machine. However, for now, the user requests to keep the interface close to the machine.

KEY RESULT

For ASML users, mechanical work is often combined with OIU use.

Separation of Scanner and Source OIU

In user interviews, it has been requested to keep the scanner and source OIU as separate workspaces. This allows users to work in parallel and prevents any confusion that might occur if the two interfaces are combined into one. The source OIU is rarely used when the machine is up and running.

KEY RESULT

Users prefer the scanner and source OIU to be separate workspaces.

OIU Accessibility

Another important requirement that the majority of users agree on is that a backup interface should always remain quickly accessible. In some cases, an action needs to be performed quickly and unexpectedly.

KEY RESULT

Most user want the interface to be quickly accessible at all times.

OIU-Machine Proximity Conclusion

In customer fab cleanrooms, tools that are not fixed can unexpectedly change places. However, in some cases, it is critical that the OIU is quickly accessible in emergencies. Even when brainstorming out-of-the-box future scenarios with users, they request to always maintain an attached OIU that provides all core functions, with standard features such as a keyboard, mouse, and screen. This does not mean the main workspace must be designed this way. However, if it is not, there should still be an additional interface designed as a backup. This backup should be close to the machine and locked in place.

DESIGN CRITERION

Quickly accessible

The interface must be quickly accessible at all times and must inform the user about the machine status in detail.

Machine Aesthetics

The design visions presented in this chapter impact the outer appearance of the machine. Therefore, ASML's vision related to the aesthetics and brand identity should be applied. The outer panel's appearance has been designed by the npk design firm according to their created design vision for ASML: 'Clean Machine'. The Clean Machine concept embodies cleanliness, modularity, and functionality to correspond with the cleanroom environment. Their design features modular panels and frames with integrated elements like handles, locks, and hinges. Over the years, this machine appearance has become closely connected with ASML's brand identity. This Clean Machine vision should therefore be respected maintain this recognizable appearance.

Figure 30: Collection of ASML machines to convey the outer machine aesthetics (npk, n.d.)

DESIGN CRITERION:

ASML Aesthetics

Parts of the interface that impact the outer appearance of the machine should align with npk's 'Clean Machine' design vision.

3.5 Conclusion - Defined Design Criteria

The analysis presented in this chapter results in the following design criteria. These criteria will be used in the design development chapter to ideate solutions and validate concepts.

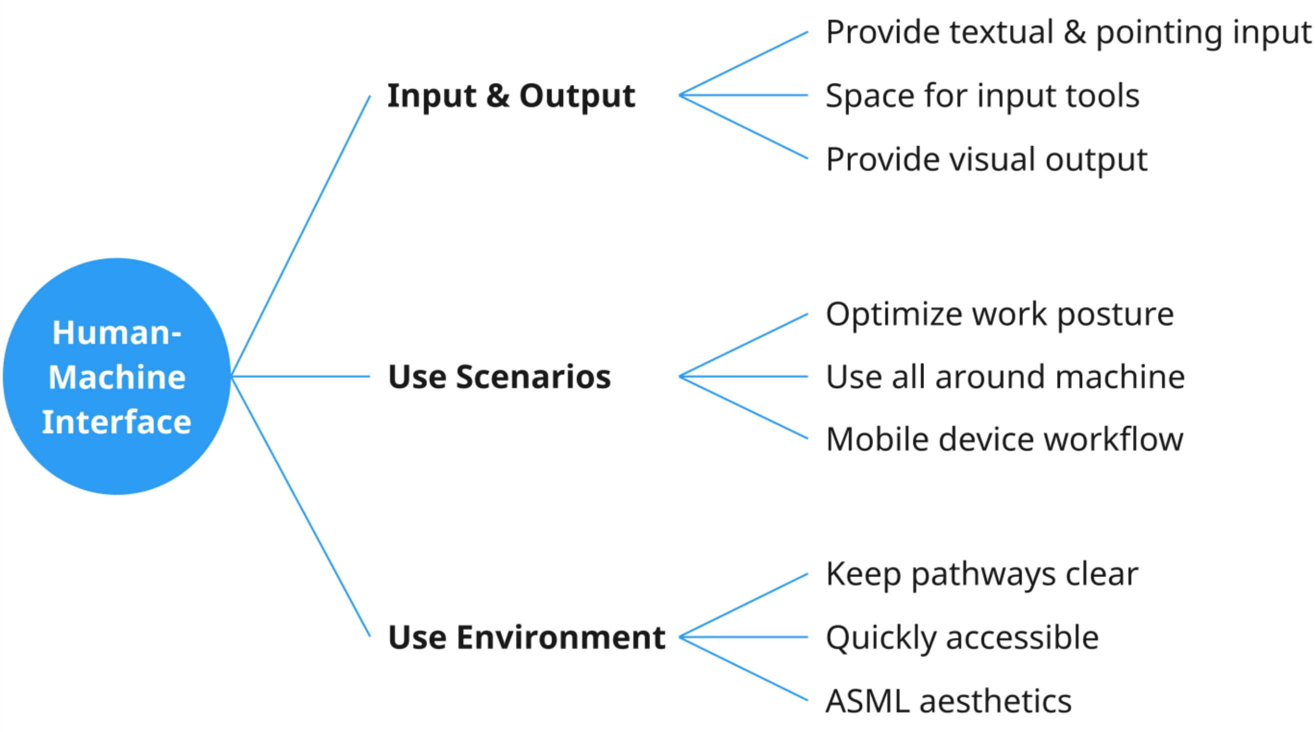
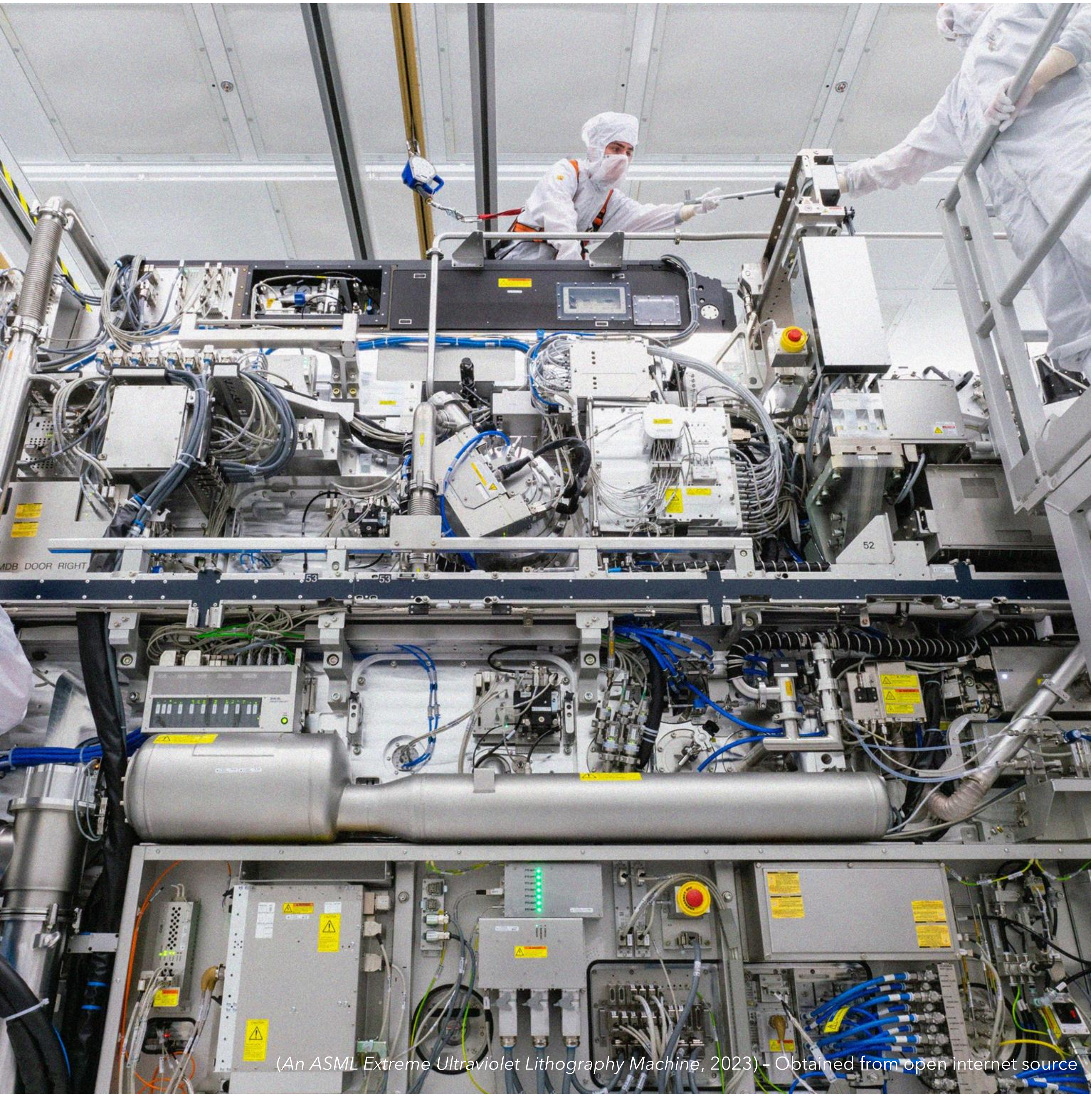


Figure 31: Design Criteria

CHAPTER 4

Design Development



(*An ASML Extreme Ultraviolet Lithography Machine*, 2023) – Obtained from open internet source

In this chapter, the design criteria are taken as a starting point to ideate and create concepts. After conducting technology research, holding brainstorming sessions, mapping ideas within a morphological chart, considering different future scenarios, and co-creating with OIU users, four concepts are selected. From these, one concept is chosen according to a weighted assessment with the design criteria, using a Harris Profile.

4.1 Ideation and Concept Creation

Adjacent Industry and Technology Research

Trends in the human-machine interaction industry are mapped and analyzed. Additionally, other relevant technologies, such as future data output, input, or portability methods, are researched. Mind maps can be found in Appendix J, and additional technology research can be found in Appendix K. The resulting relevant ideas from this research are categorized in a morphological chart that will be presented later in this chapter.

Figure 32: Adjacent industry research and technology mind map

Grouping Future Scenarios

The interpretation of the mobile device criterium is dependent on different possible futures.

Laptop-centered

Currently, laptops are the primary tool of people in a professional environment. In one possible future, laptops will continue with this status. Some key laptop benefits are that they are versatile, reliable, and familiar. With future developments these laptops will have even more integrated features and advanced processing capabilities.

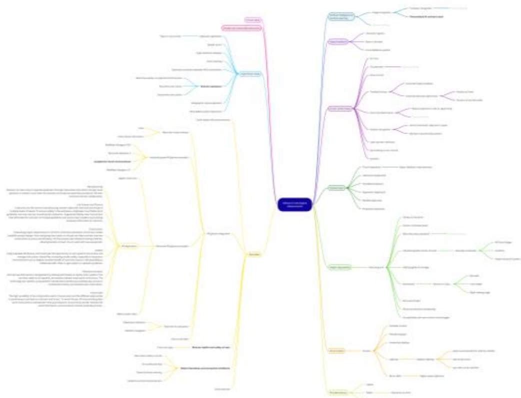


Figure 33: Mapping future technologies for different possible futures

Wearable-centered

In a different future scenario, wearable smart devices like advanced smartwatches and AR headsets become central tools in most professional environments. The wearable technology will allow the user to be constantly connected, and will improve remote communication possibilities.

Separating these different futures of mobile devices supported the selection of certain concepts. As will be presented in the concept presentation in Chapter 4.2, concepts are selected to respond to both possible future scenarios regarding portable devices.

Generating Ideas - Brainstorm Sessions

This brainstorming session with four employees from the HFE department at ASML took the design criteria as a starting point and aimed to generate as many ideas as possible.

Figure 34: Brainstorm session

Categorizing Ideas - Morphological Chart

A morphological chart (Figure 34) is created to stimulate the generation of ideas and combine them into concepts using a morphological chart design method. Combined ideas are highlighted in green and were further used in the user co-creation session to develop into concepts. The full chart can be found in Appendix K.

Functions															
Seated and standing work position	Mounted fully adjustable	Ergonomic high chair setup	Adjustable on rails mounted on machine	Separate standing and seated workspace	Fully adjustable trolley with monitor	Slide along pilar attached to machine	Slide along pilar separate from machine	Integrate 'control pocket' in machine	Stool with screen	Hand-held terminal	Panels fold out to adjustable desk	Adjustable suspension from ceiling	Only backup/status OIU on machine & separate workspace next to machine		
Working in parallel with laptop	Laptop tray on machine	Adjustable trolley for laptop	Fixed monitor to connect laptop to	Laptop tray on mounted arm	Large enough desk space	Eliminate need for laptop	Multiple docking stations around machine	Tray to insert laptop, to connect automatically to desk setups							
Use at multiple locations	Laptop workflow optimization	Tablet	Smart watches	Rotate screens or mounts	Additional screens	Wireless control options	AR Glasses	Additional projections	On wheels	Transparent screens	Large overhead displays	Interface can move along track of the machine	Voice control/ audio feedback		
Pointing input	Optical mouse	Trackball mouse	Touchscreen	Hand gesture input	Joystick	Laser pointer interfaces	Voice control	Foot controlled	Air mice	Eye-tracking control					
Textual input	Mechanical keyboards	Ergonomic Keyboards	Handheld keyboard	Touch keyboards	Projection keyboards	Flexible keyboards	Neurolink	Voice control	Use mobile input device	AI typing assistance					
Visual output	Monitor	Ultra wide monitor	Multiple monitors	Foldable screens	Flexible screens	Rotatable monitor	Micro LED screens	Transparent micro LED	Projection on panel or floor	Adaptive lightning	AR Glasses	Smart watch	Connected tablet as screen	Enclosure panels made of LED screen	Large screen with 2-4 quadrants
Don't obstruct pathways	Foldable	Extractable	Telescopic	On wheels	On rails	Attached to the ceiling	Insert into cavity in machine	Wide enough pathways	Work-pocket in machine	Foldable within enclosure	Mobile workstation	Mobile work option all around the machine	Separate workspace for OIU		
Posture support	Palm rests	Elbow rests	Motorized adjustability	Encourage enough breaks	Monitor user health/posture	Exoskeleton support	Foot rests	Know the users' body dimensions, and adjust automatically							

Figure 35: Morphological chart

Developing Concepts - User Co-Creation Session

The co-creation session involved five ASML users of the OIU. During this session, the overview of criteria and the ideas in the morphological chart were used as a starting point to develop concept directions and design criteria. Mind maps were created while brainstorming both on a short-term solution and their ideal human-machine interaction. This resulted in several concept directions presented later in this chapter.

Figure 36: User Co-Creation Session

4.2 Concept Presentations

Concept 1: Integrated Workspace

User comfort – Clean machine appearance – Customizable

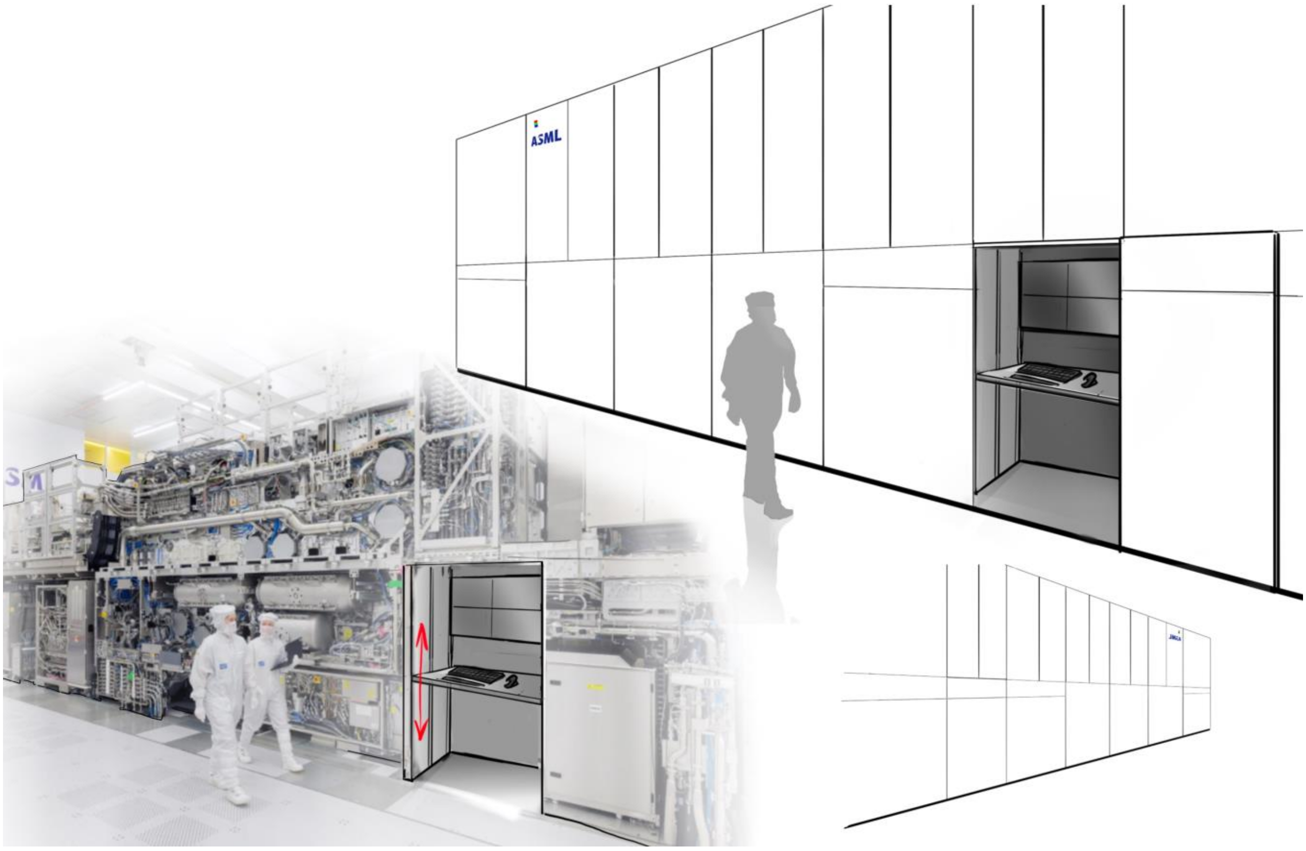
The integrated workspace is a module designed by ASML that is fully integrated into the system to improve accessibility and usability. Based on user research insights, it has been shown that the panels are often removed from the machine during most tasks performed by ASML users. In these situations, the workspace becomes visible and accessible, while maintaining a clean, minimal appearance when not in use.

Accessibility and visibility

- The workspace is naturally revealed when the panels are removed but also remains quickly accessible when the panels are on the system with a sliding door solution.
- When not in use, the workspace is fully hidden, enhancing npk's 'clean machine' vision.

User adjustability

- This interface is adjustable in height and allows angular adjustments to accommodate different users, enabling them to work seated or standing.



Concept 2: Fixed Backup Interface

Minimal structural changes – Quick accessibility – Integrated design

The fixed backup interface concept focused on keeping an integrated solution at the system, but also minimizing the machine volume occupation. The compact design can take up similar volume as the current OIU, but still it fulfills all essential functionalities. It can quickly provide the user with all of the essential tools.

Motorized and automatic adjustments

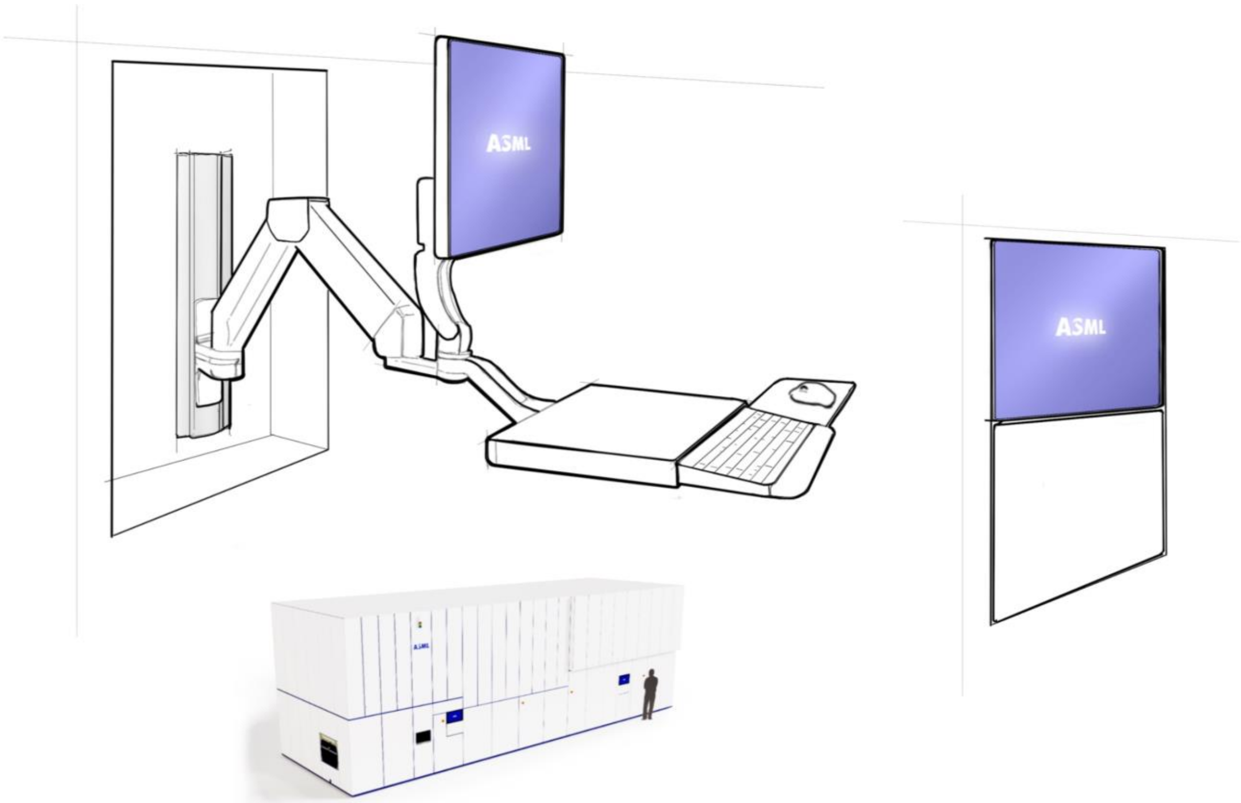
- The motorized arm automatically adjusts to the user's body dimensions through its four pivot points. The integrated cable management ensures a clean and efficient setup.
- The interface can automatically retract and store itself within the machine, keeping pathways clear and maintaining the system's clean appearance.

Touchscreen interface

- The display is a high-definition, anti-glare touchscreen, selected for optimized readability in bright cleanroom environments. The screen supports accurate input from users wearing gloves.

Machine integration & minimal structural changes

- The arm is fixed within the machine volume that is currently reserved for the OIU, therefore requiring minimal structural changes.
- Constructed from aluminum and other cleanroom-suitable materials, the design is durable and lightweight.



Concept 3: Mobile Workspace

User flexibility – Personalization - Versatile

The mobile workspace concept focusses the rare, but longer use scenarios of ASML users. In these scenarios, the workspace can connect to the system and moved around the machine to the user's task location. The workspace is customizable to the specific user needs and tasks.

Mobility and wireless connectivity

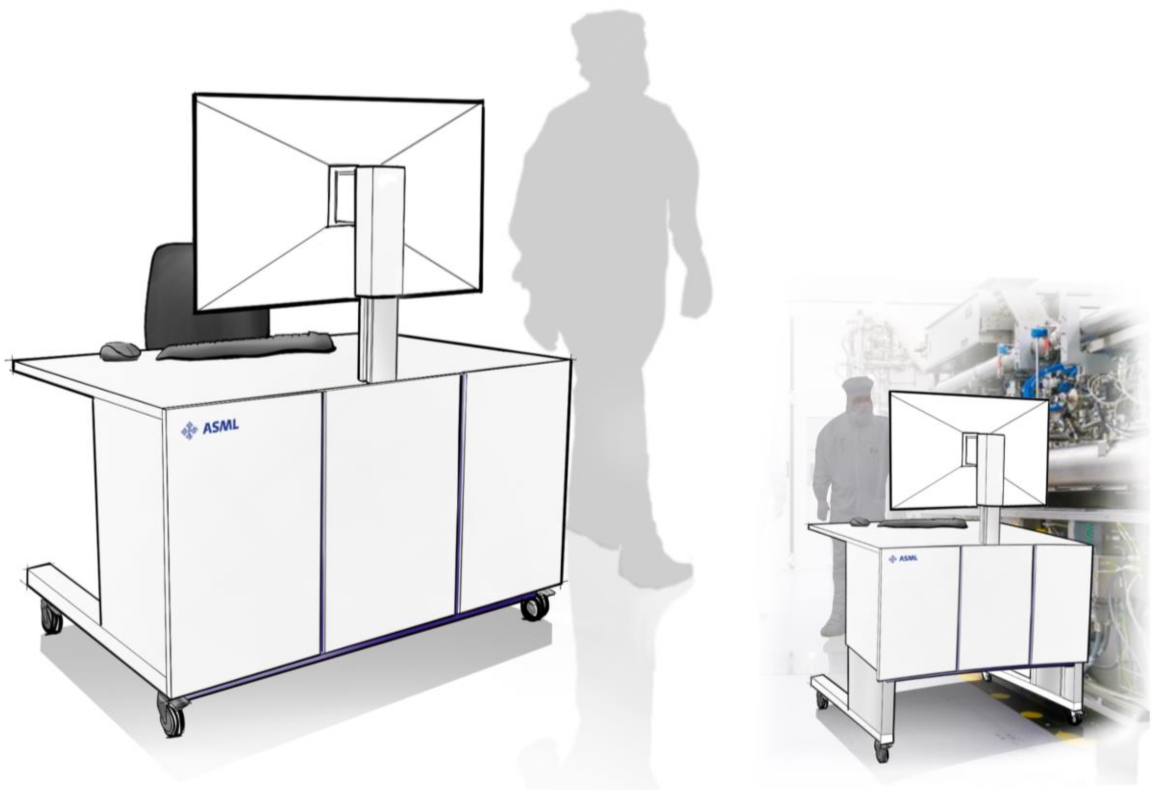
- The workspace can connect wirelessly to the system and can be moved around on wheels. This introduces the freedom to choose the work location around the cleanroom according to user preference.

Workspace tools and visual output

- Large desk space for all essential input tools.
- Has docking station for laptop and supports wireless laptop connection.
- 4-split screen to for using multiple screens for improve efficiency.

Height adjustable mechanism

- Height adjustable and suitable for both sitting and standing with an hydraulic lift.
- The workspace can identify the user with an integrated camera and automatically adjusts to their preferred height and device settings.



Concept 4: AR Headset Workflow

Improved collaboration - Accessible – Space efficient

This concept applies AR headsets to improve operator work efficiency. These advanced wearables, combined with advanced sensor technologies, can provide real-time remote assistance, intuitive control of an AR interface, and can eventually allow the elimination of the OIU from the system.

Real-time remote assistance

- The headsets allow support with optional annotations directly in the operator's field of view, improving communication and speeding up the problem-solving process.

Accessibility in extreme work locations

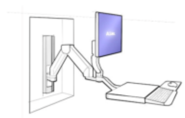
- The user can stay connected with the system in limited work locations, such as on top of or underneath the machine.
- The headsets can be controlled with gestures and voice commands, allowing for a natural body posture and hands-free operation when required.

Removal of current OIU

- With a combination of the AR headsets and advanced sensors around the system it is possible to remove the current OIU from the machine, resulting in reduced machine volume occupation.

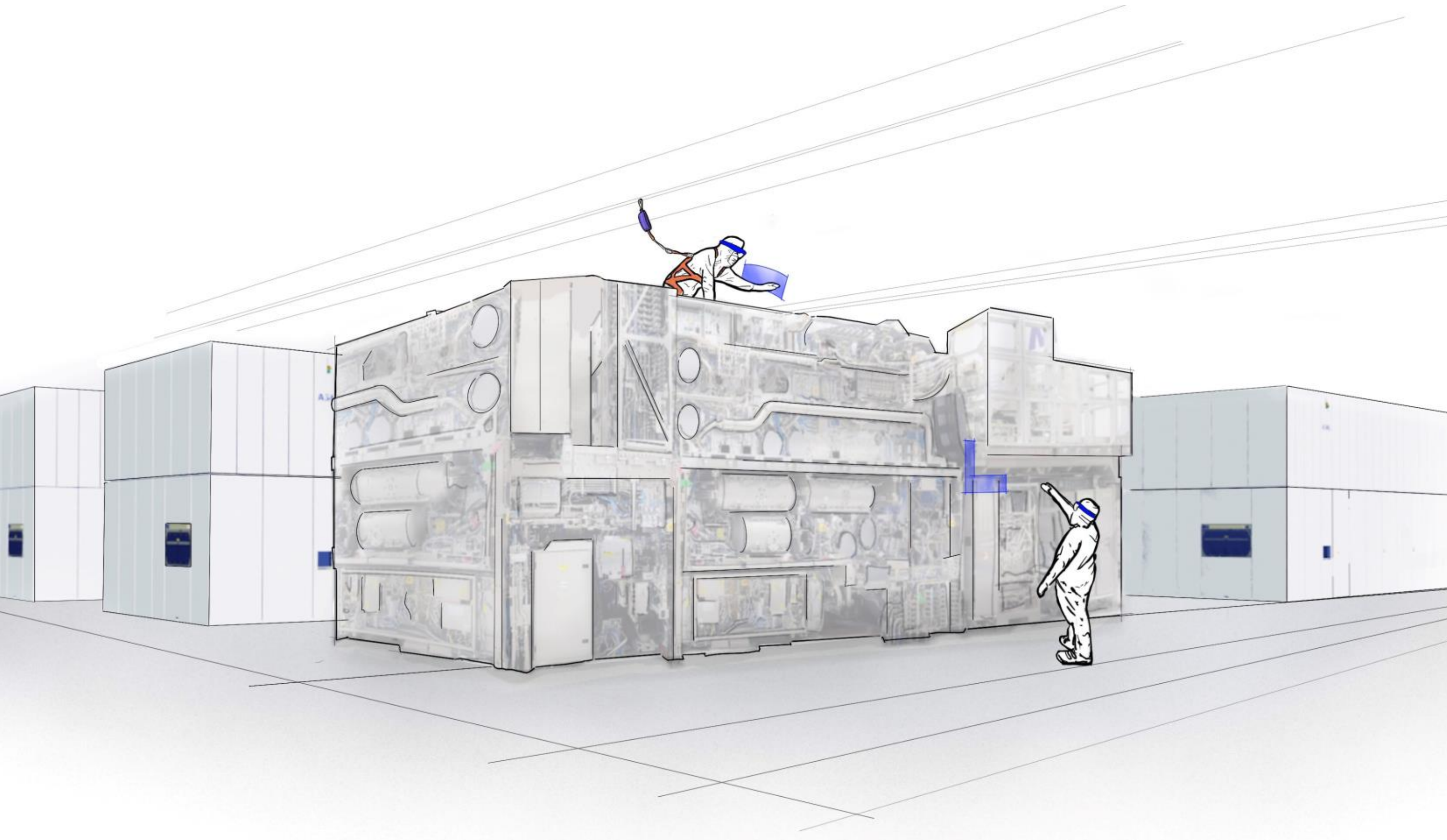
4.3 Concept Selection

A Harris Profile uses design criteria to create a graphic overview of the strengths and weaknesses of design concepts. The top criteria are weighted more heavily than the bottom criteria (Roozenburg, 1995). The AR headset workflow and removed OIU scores perform the best in this overview. Therefore, this concept is chosen to be developed further into a design proposal, which is presented in the next chapter.

	Concept 1: Integrated Workspace	**Concept 2:** Fixed Backup Interface	**Concept 3:** Mobile Workspace	**Concept 4:** AR Headset Workflow
				
Data output	1	-1	1	2
Data input	2	-1	2	1
Use all around machine	-2	-2	1	2
Seated and standing work posture	2	-1	2	2
Mobile device workflow	-1	-1	1	2
Cleanroom suitability	-1	1	1	-1
ASML aesthetics	-1	-2	1	2
Feasibility	1	2	1	-1
Viability	-1	2	1	1

CHAPTER 5

Design Proposal



The chosen concept from the previous chapter is further developed into a design proposal and presented in this chapter. First, a general description is provided, and the envisioned use scenario is described. Then, the proposal is presented in more detail, covering the new responsibilities and tasks it involves, how it will change the use environment, the AR headset features, and an impression of the user interface.

5.1 Design Proposal

All scenarios in this design proposal are fictional.

The proposal is a new system that applies AR headsets, an advanced control room, and a platform designed for the cleanroom environment. It aims to significantly improve the current system by removing the OIU and reallocating employee tasks and responsibilities.

AR Headsets

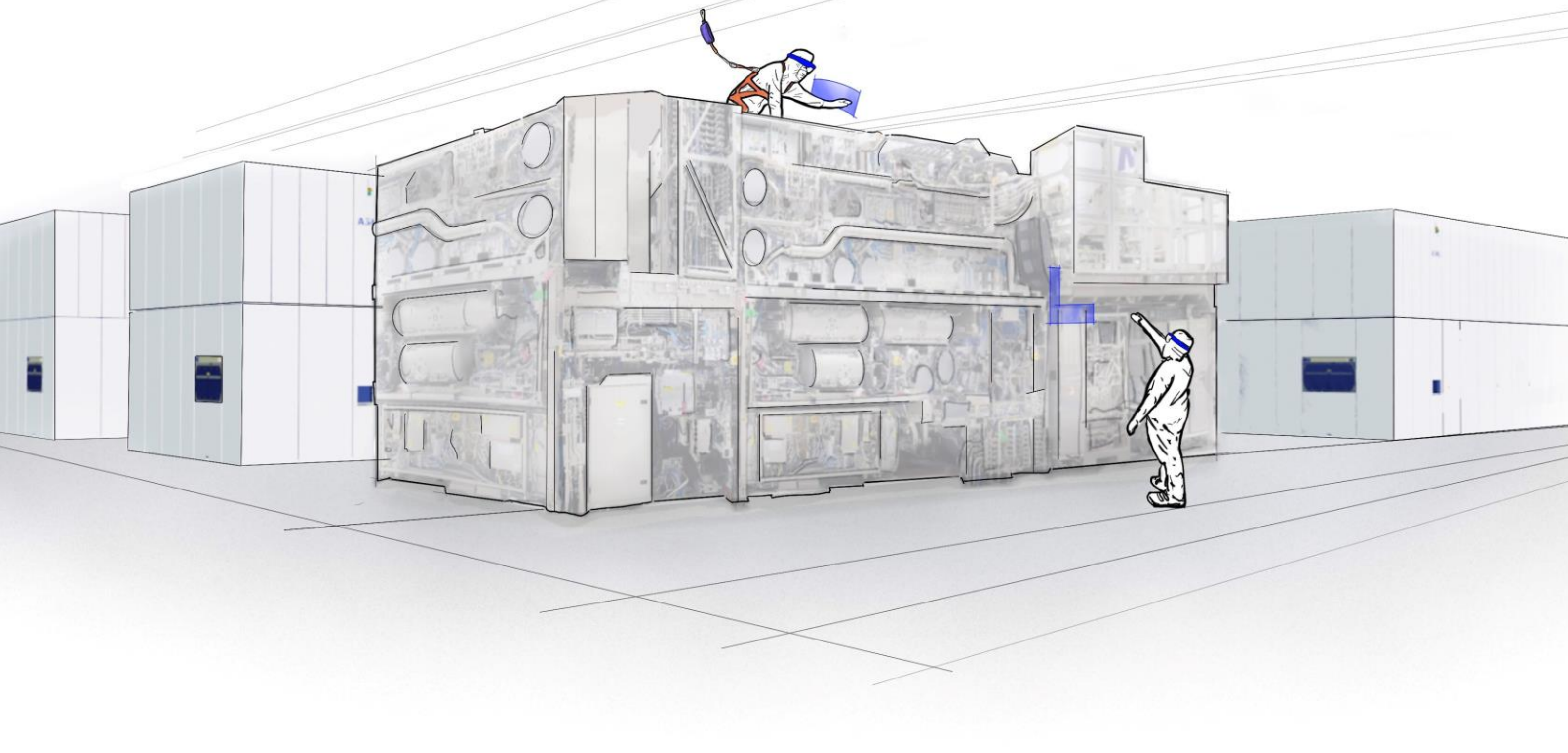
The AR headsets will project an intuitive user interface in the users' field of vision, controlled through gestures and voice commands. This allows the user to access the system from any location around the system. This is especially beneficial for installation and service engineers who have to perform work all around, on top of, and underneath the machine.

Removal of the OIU

Additionally, the development of AR technology will impact remote work by providing visual and sound inputs similar to being physically present. Combining this with strategically placed smart sensors around the machine will eventually allow the removal of the OIU workspace.

Advanced Control Room & System Platform

The system platform enables smooth collaboration between the cleanroom and control room. The AR headsets, with their user interface adapted to the cleanroom work environment and specific tasks, enable the user to access and execute relevant software actions whenever required during hardware tasks in the cleanroom. Additionally, longer software-related actions can effectively be performed from the control room. This minimizes the user's presence in the cleanroom, eliminates the need to wait at the OIU within the cleanroom, and allows them to work more efficiently when working in the cleanroom is inevitable. AR-driven software and real-time collaboration tools in the cleanroom will improve efficiency, accuracy, and safety.



5.2 Envisioned Use Scenario

Character Introduction

Chris
Customer Operator
Customer

Jim
Service Support Engineer
ASML

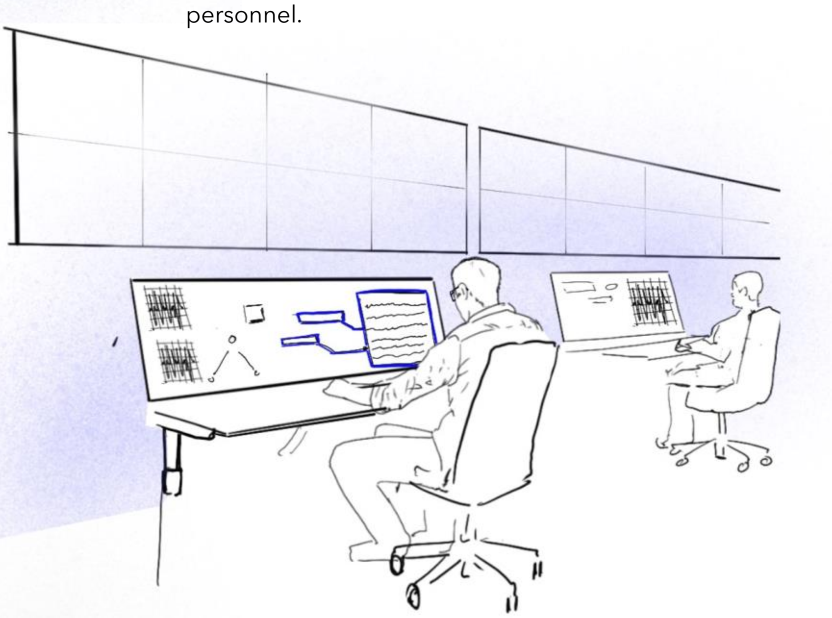
Alice
Service Field Engineer
ASML

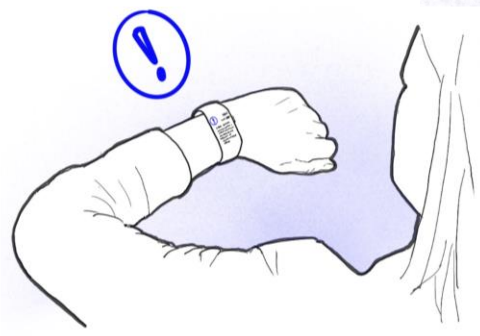
Chris receives issue detection

- Chris is stationed in the customer's control room, equipped with multiple screens displaying real-time data and system health statuses.
- The AI system analyzes data from various machines and predicts a potential fault in one of the EUV systems.
- The system sends a warning to Chris's workstation in the control room.
- He receives a report of the issue and a recommendation for preemptive maintenance.
- Chris verifies the data, confirms the prediction, and shares the report with the on-site ASML service personnel.

Initial assessment and planning

- ASML's on-site service team receives the alert from Chris.
- Support engineer Jim is assigned to this task.
- Jim takes his place at a workstation in the customer control room.
- The workstation authenticates him through facial recognition and loads his user data and tasks.
- Jim reviews the technical details and decides to involve Alice to handle the hands-on adjustments.



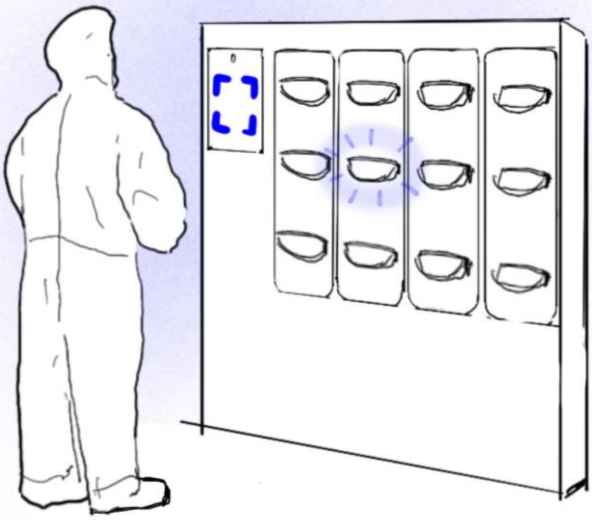


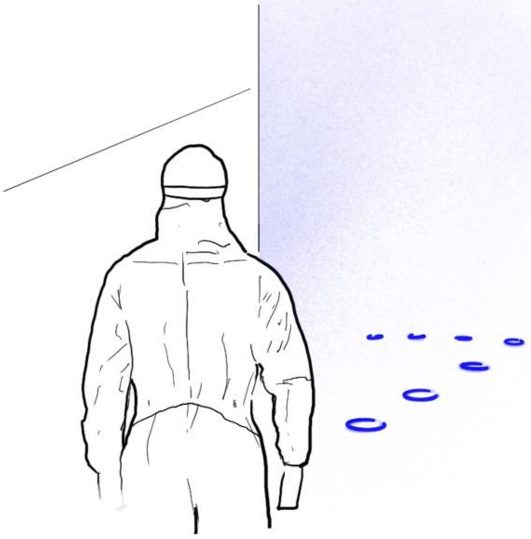
Alice gets notified

- Alice is part of the on-site ASML team and she receives a notification on her smartwatch.
- Accordingly, she moves to the customer cleanroom.

Alice enters cleanroom

- Alice puts on her cleanroom suit and approaches the docking station wall.
- The integrated camera system in the docking station authenticates Alice as a user using facial recognition.
- Once Alice is authenticated, the system looks up her user profile.
- This profile contains her personal settings, visual preferences, and specific data access permissions.
- The headset automatically adjusts display settings, updates the latest software, and syncs relevant data for Alice's tasks for the day.
- After a few seconds, the assigned AR headset is ready and unlocked with a physical unlocking system.
- Alice takes this headset, which is now fully charged and ready for use.



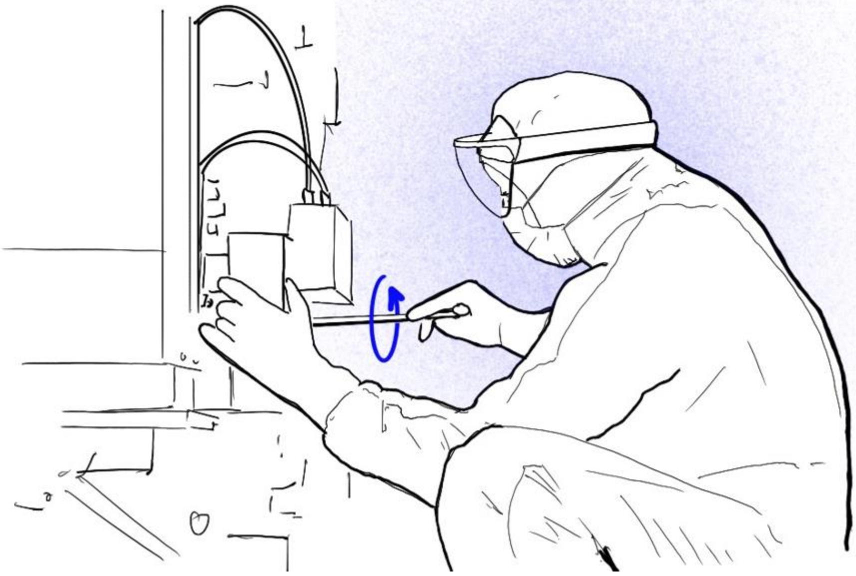


Walking to the machine

- Guided by her headset, Alice navigates through the customer cleanroom towards the corresponding system.
- When approaching the systems, Alice sees the systems' history, sensor readings, and highlighted areas based on Jim's analysis.

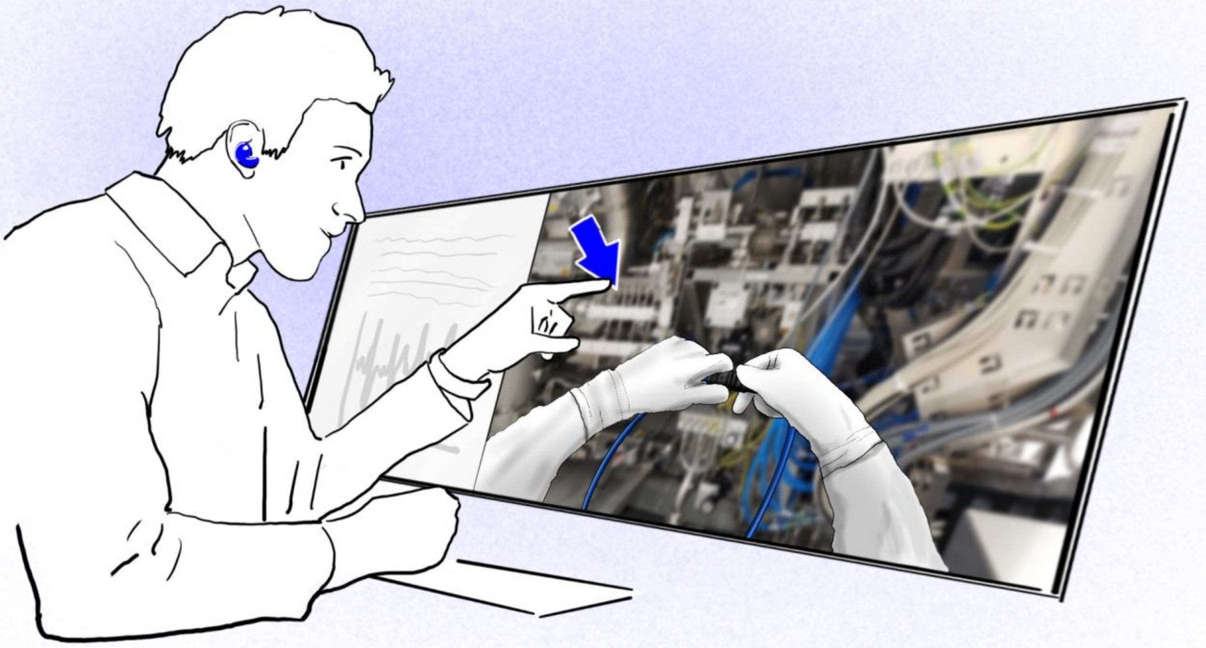
On-site inspection by Alice

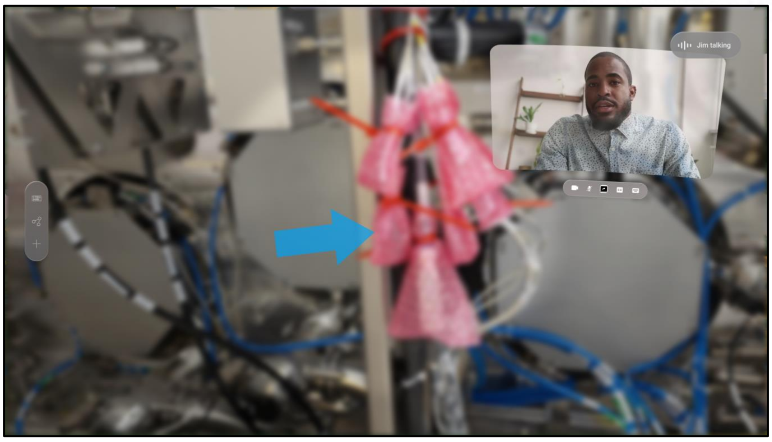
- Alice inspects the area following AR instructions in her field of view.
- She checks and calibrates the area according to the work instructions.
- Alice can work hands-free while accessing live data and reading work procedures.



AR collaboration

- When Alice encounters a more complex issue, she activates the AR collaboration feature. This allows her visual field to be shared directly with Jim in the control room.
- Jim, now seeing what Alice sees, can conduct more in-depth research into the issue from the control room.





AR headset point-of-view

- Jim makes annotations in her field of view with overlays to guide her through the adjustment process.
- Following the real-time guidance, Alice makes the precise adjustments needed.

Finishing up

- Jim in the control room reviews the machine and confirms that all components are correctly aligned and operational.
- The data is logged by the system, and Jim runs a diagnostics test from the cleanroom to ensure that no further issues are present.

5.3 New Responsibilities and Task Allocation

According to the new workflow, new responsibilities and task are defined as follows:

Field Engineer
Install/Service/Upgrade
ASML

"Responsible for mechanical work in the customer cleanroom environment"

- Operate directly in the cleanroom environment.
- Equipped with advanced AR headset.
- Communicate closely with the support engineers.
- Physically intense work that requires frequent breaks.

Support Engineer
Install/Service/Upgrade
ASML

"Provides support to the field engineer from the customer control room."

- Manage software tasks, monitor operations, and provide remote guidance.
- Performs longer software-related tasks with the system.
- Reponses to support calls from Field Engineers.

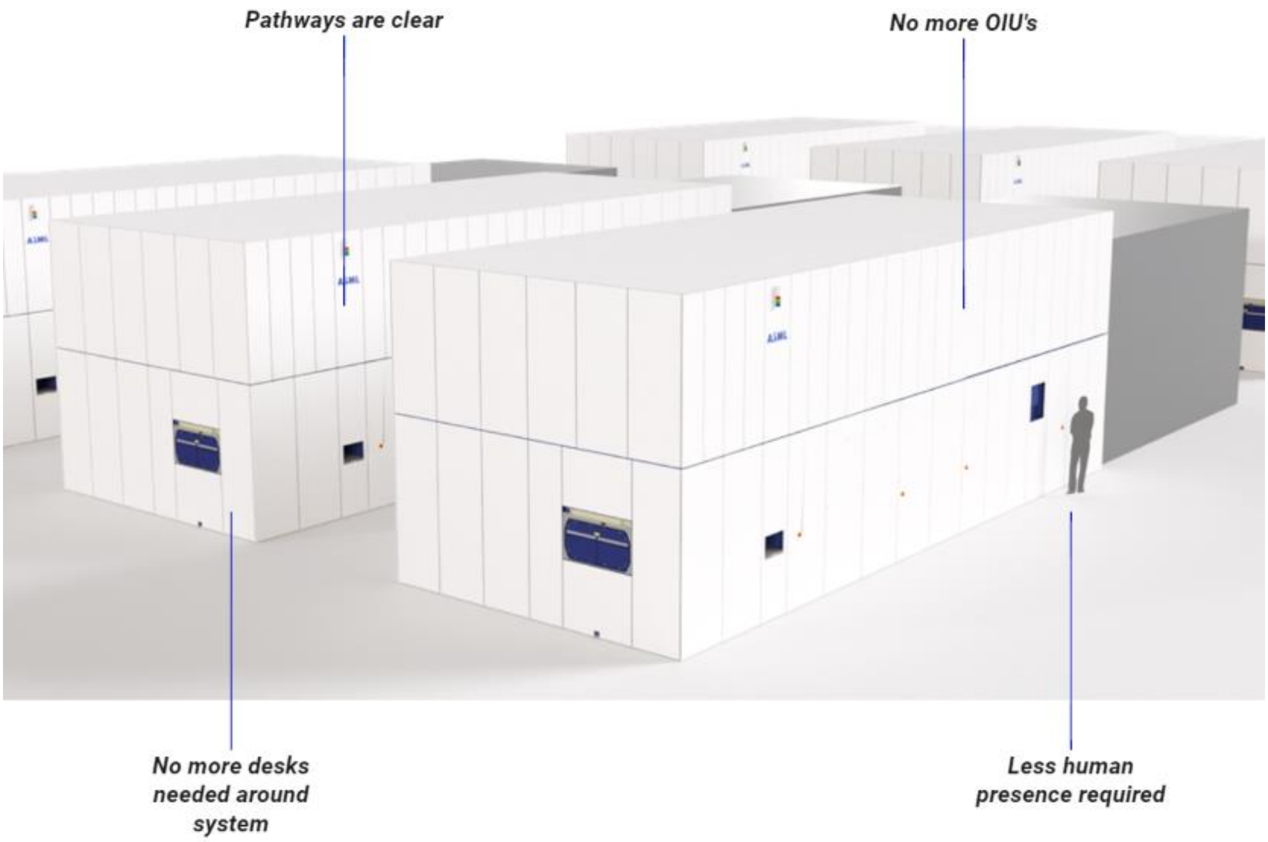
Customer Operator
Customer

"Monitors and retrieves data from from running systems the control room."

- Keeps track of all machines' statuses.
- Alarms ASML employees when service is required due to machine .

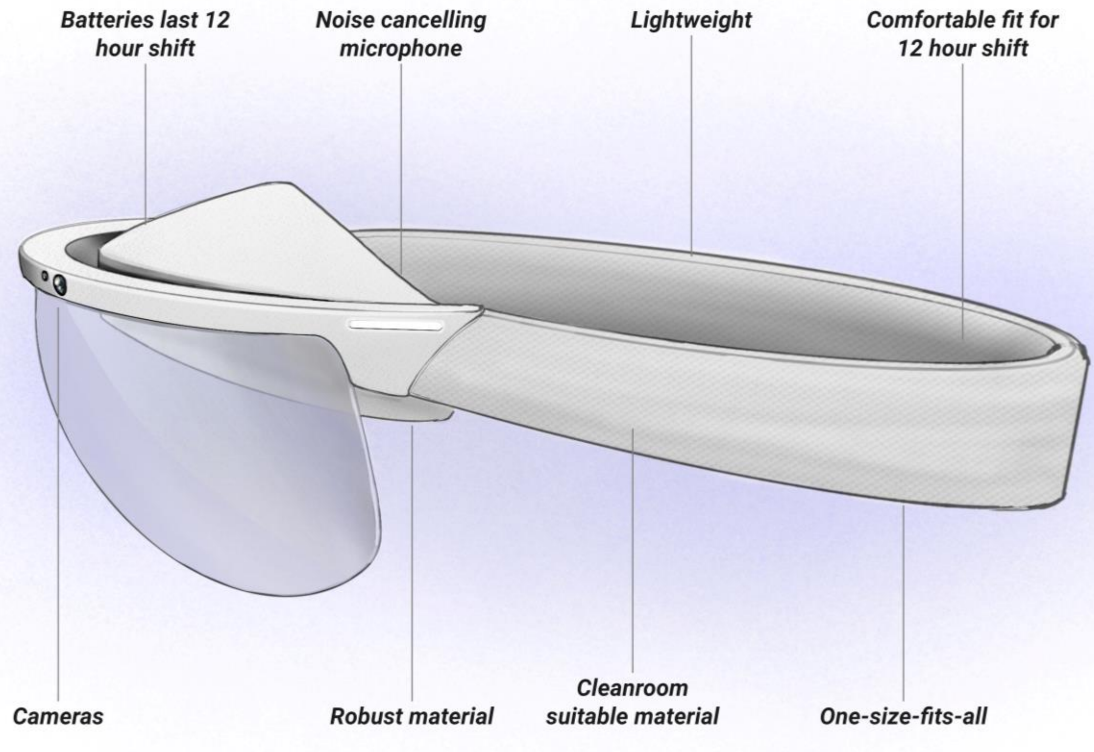
5.4 The Cleanroom Environment

By removing the OIU from this system and minimizing the human presence in the cleanroom, the user ergonomics will be improved. Additionally, humans are the biggest source of contamination, and this is now also minimized. Also, because of this, the cleanroom can become less cluttered and there is no more need to place desks around the machines. Smart sensors in the system will provide live updates in the control room, mimicking proximity to the machine.



5.5 AR Headset Features

The AR headset should feature several important requirements. Most importantly, is should optimize the comfort, durability, usability, and cleanroom suitability. They should be lightweight and suitable for 8 hour use without causing discomfort. The working condition in the cleanroom can be harsh, and sometimes products can fall from high heights. Therefore, the design should be prepared and tested on sufficient durability. The materials should be cleanroom suitable, and the additional features that it should contain are: cameras, depth sensors, a noise-canceling microphone, a 12-hour lasting battery, and motion trackers.

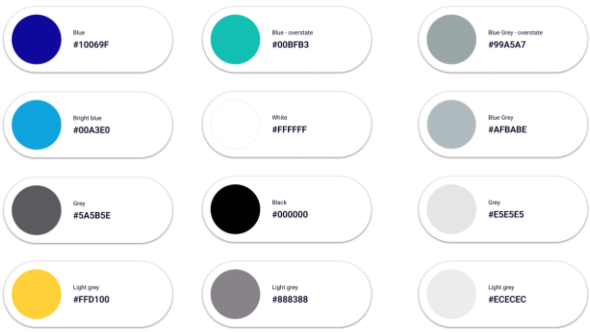


5.6 AR User Interface Impression

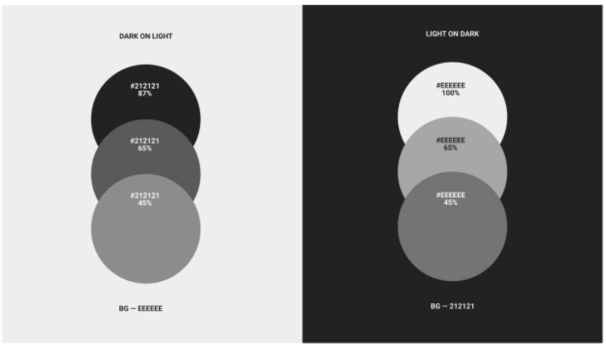
The aim of this user interface presentation is to provide an overview of how users might interact with the AR headset platform within the semiconductor fabrication environment.

Graphic Style

The graphic style of the interface is based on ASML's current brand identity. It applies the same colors and font. In the cleanroom use environment, comfortable readability is highly important, it all information should be visible in a bright, noisy, distracting, and sometimes stressful environment. Therefore, the content should be presented as simple, large information and with high contrast. However, the information should not be distracting and also maintain a calm appearance.



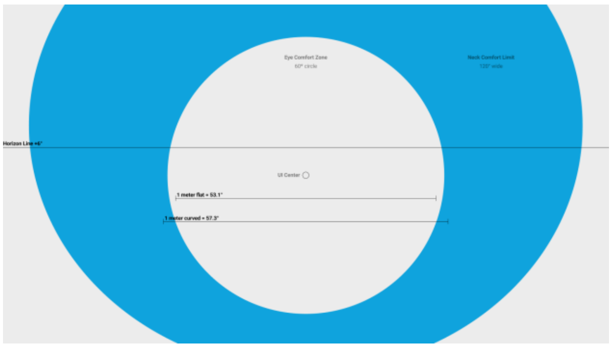
Color palette (ASML branding Inspired)



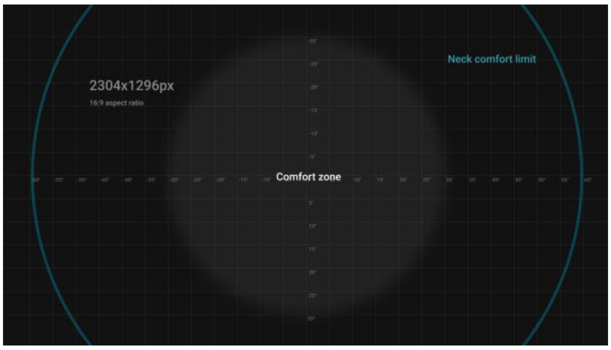
Light & dark mode

AR interface guidelines

AU user interface guidelines emphasize the importance of intuitive interaction within the use environment. The interface must be usable at different locations. Also, the physical limitation of the user must be considered in the design, mainly noting the limits of the eyes and neck.



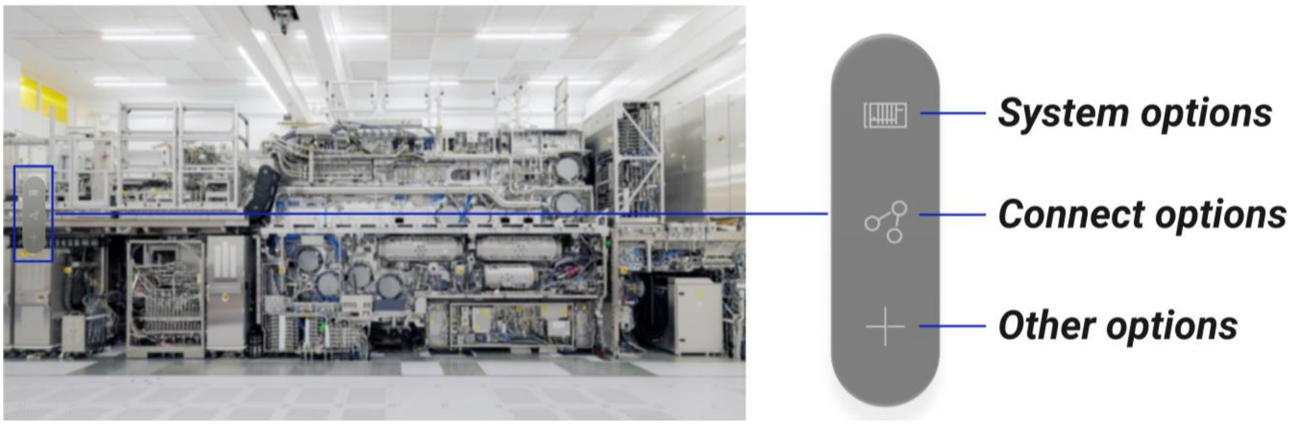
Eye comfort zone & neck comfort limit



Angular grid, focus area & aspect ratio

Navigation Menu

The navigation menu is always available for the user to access three key interface environments. These options include system-related functions, connecting with colleagues, and other features.



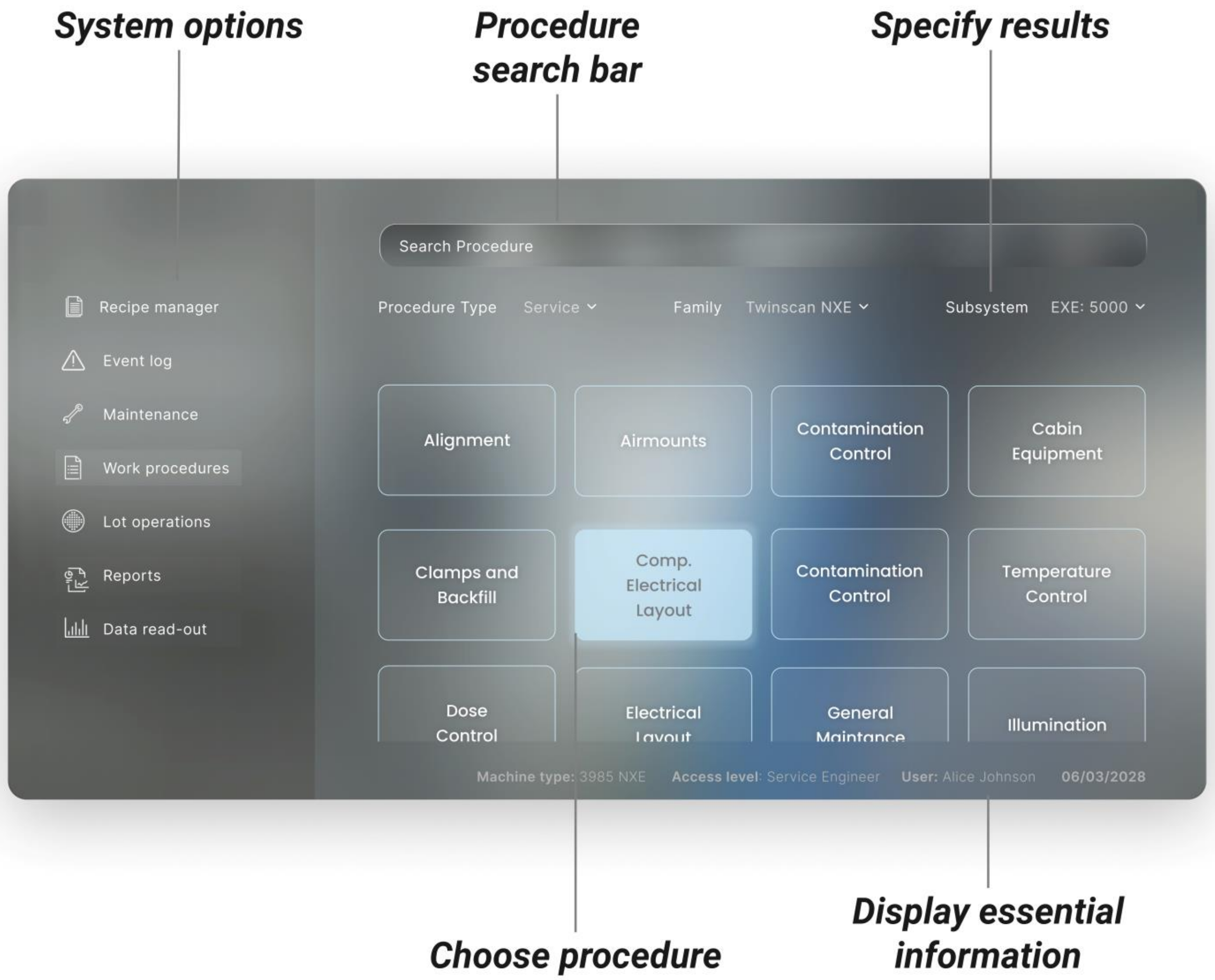
Icon Descriptions

Below, the options and icons related to this menu are displayed. These options correspond to the tasks that can be performed within the system. Additionally, features for connecting with colleagues and other useful functions are included.

System options	
Recipe manager	Reports
Event log	Work procedures
Maintenance	Data read-out
Lot operations	
Connect options	
Videocall	Mail
More options	
Translate	Settings/ User preferences
User profile	Camera

System Dashboard Overview – Work Procedure Page

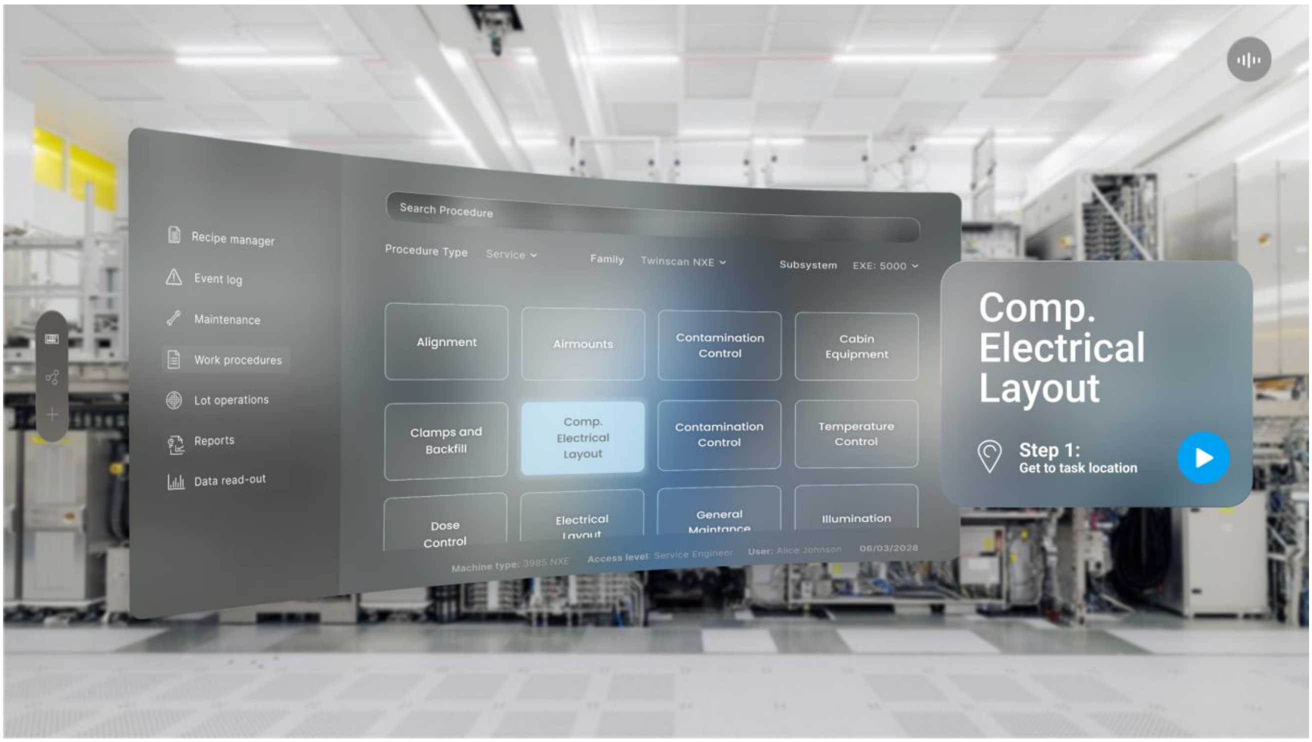
The system dashboard overview includes system options, a procedure search bar, a scrollable list of procedures, additional filters to refine search results, and essential information display. Essential information is shown that includes the machine type, in this case, it shows a screen of an EXE:5000 machine. It also informs the user of their authorization level. Accordingly, certain buttons or menu items are disabled for users lacking the authority to access them.



User Interface Feature Impressions

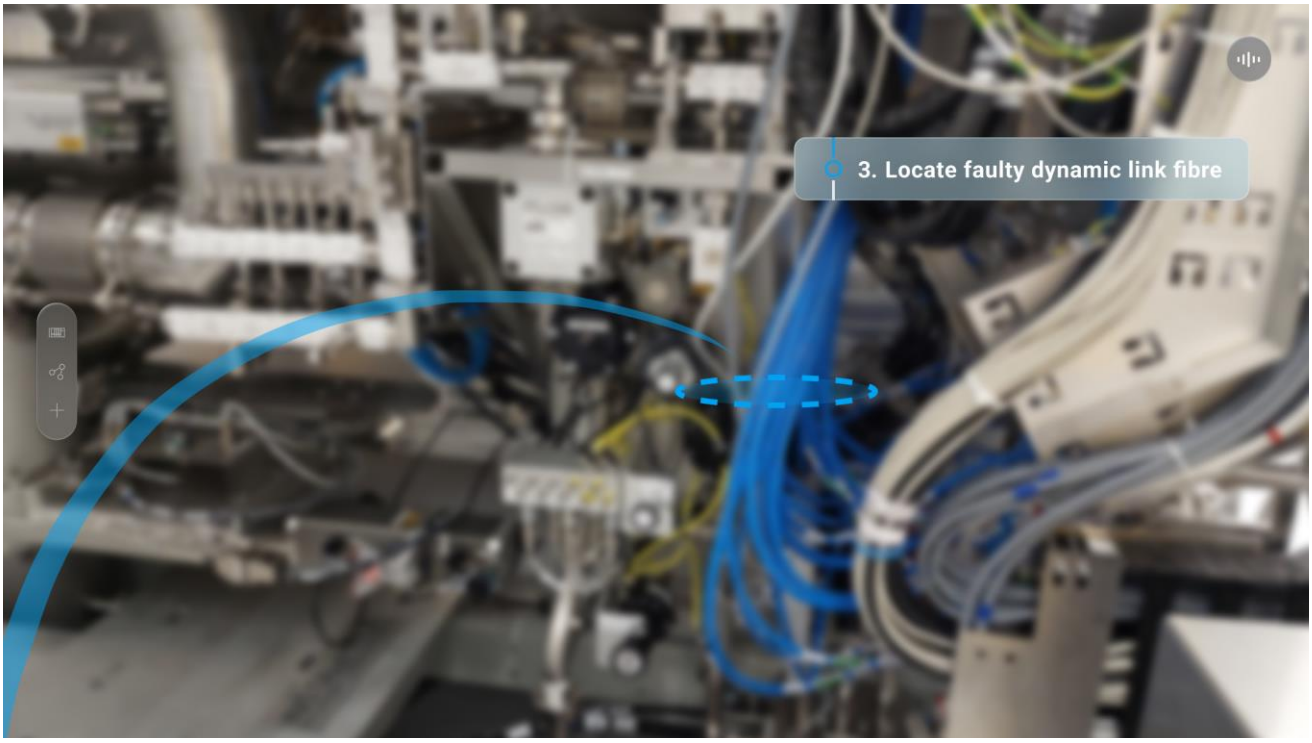
Select a procedure

Users can navigate the menu and select a procedure to work on.



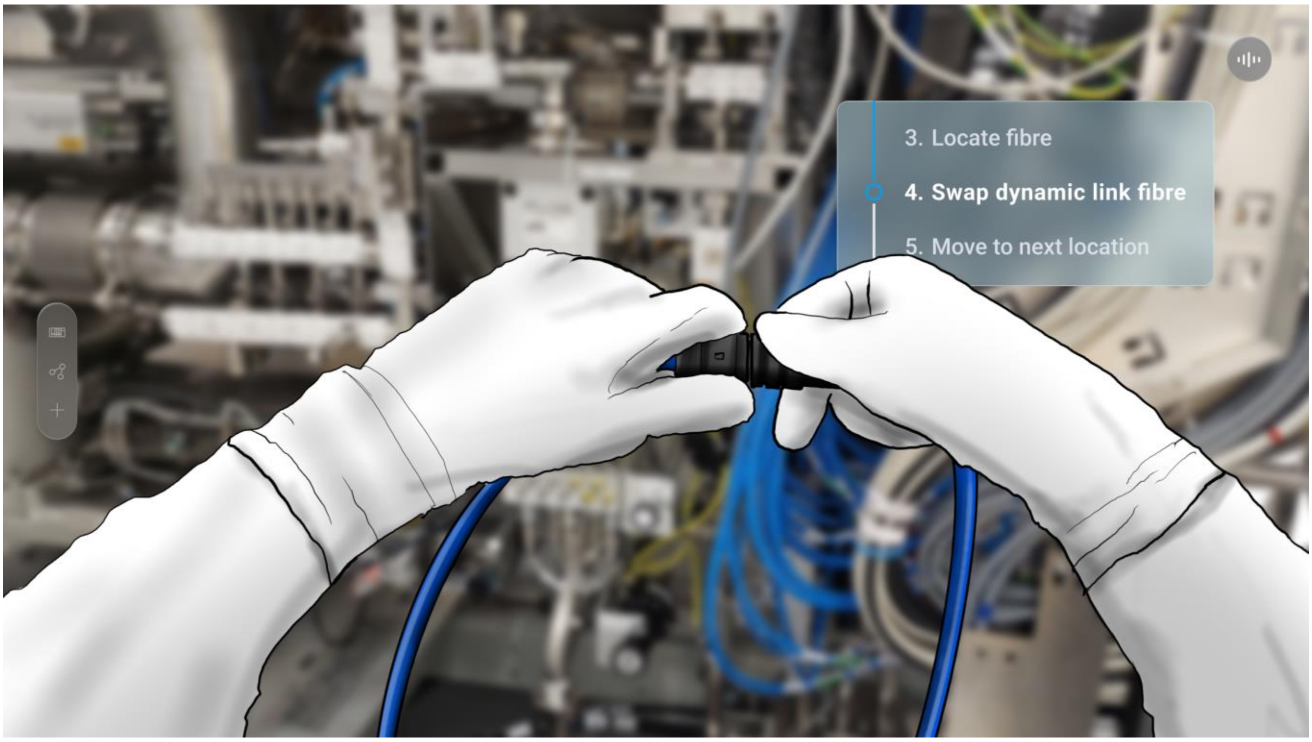
Guidance to locate object

The AR headset can identify the user's location and use integrated cameras to guide them to the correct machine part.



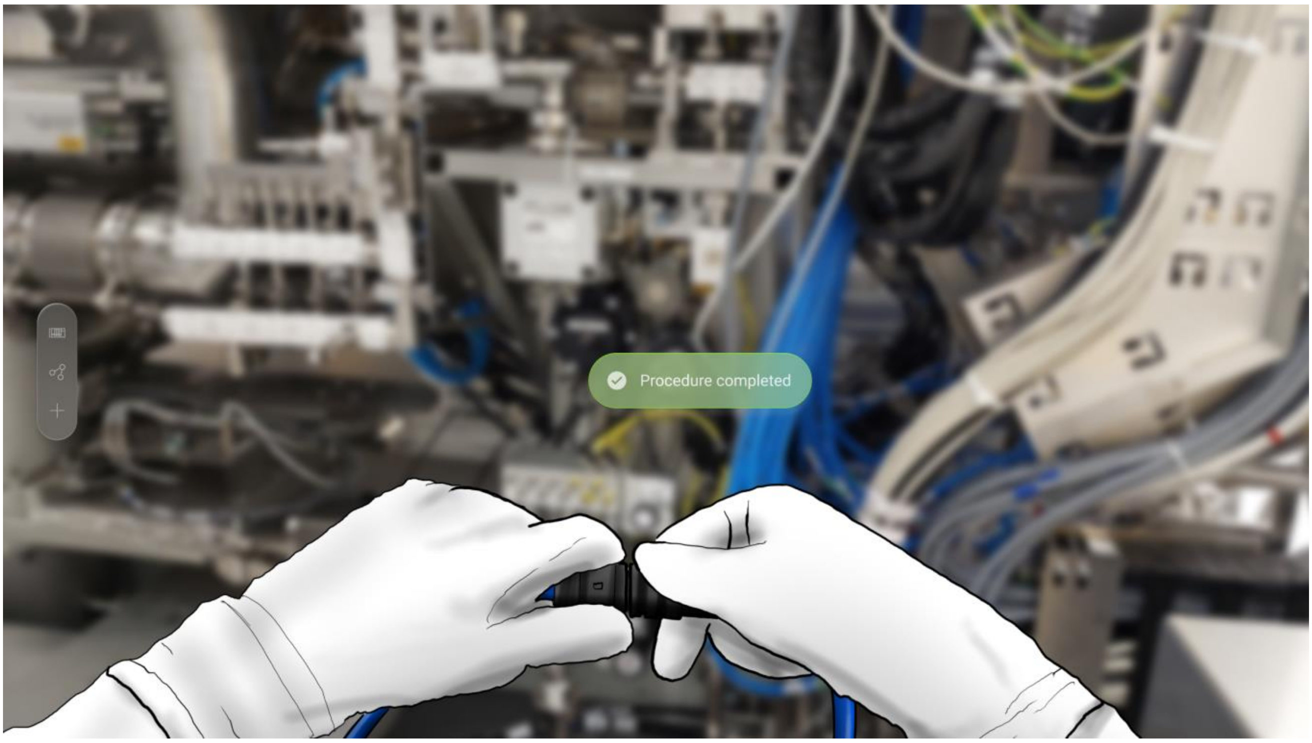
Step-by-step instructions

Clear step-by-step instructions can help the user work more efficiently in a stressful work environment.



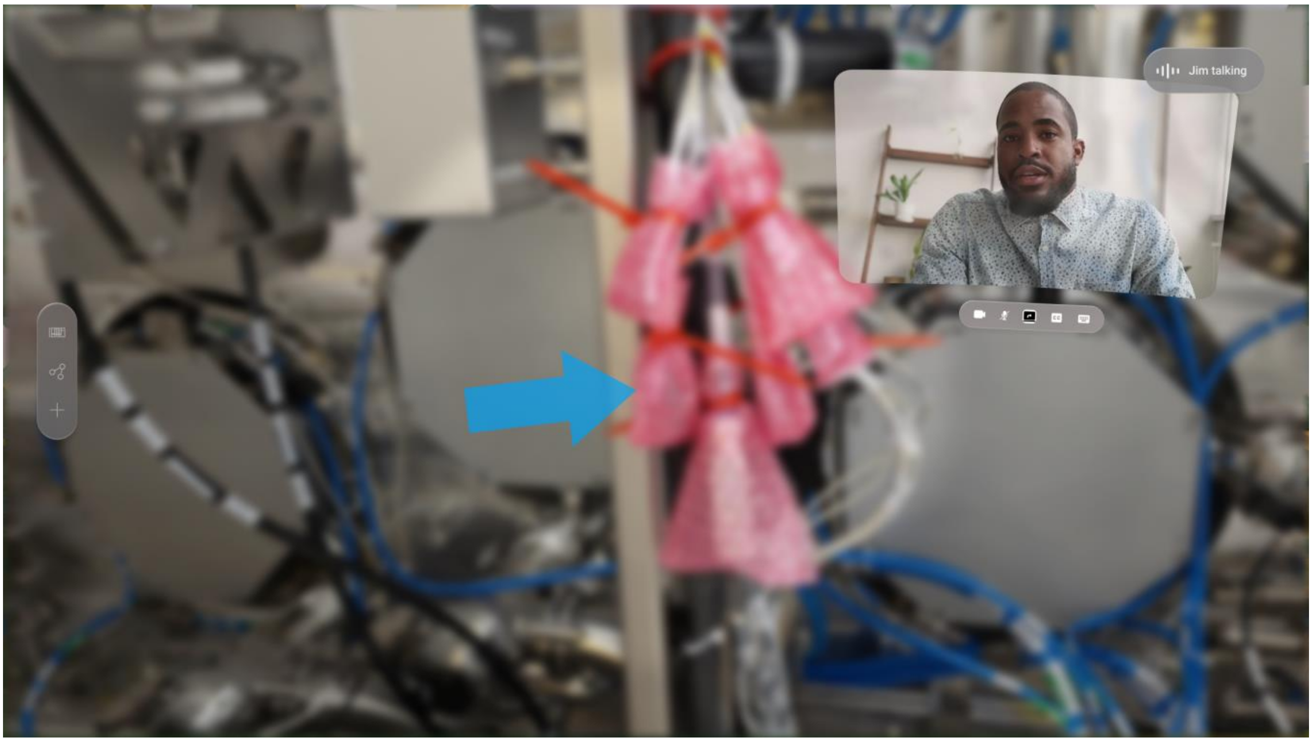
Successful completion confirmation

Users receive positive feedback upon successfully completing a procedure.



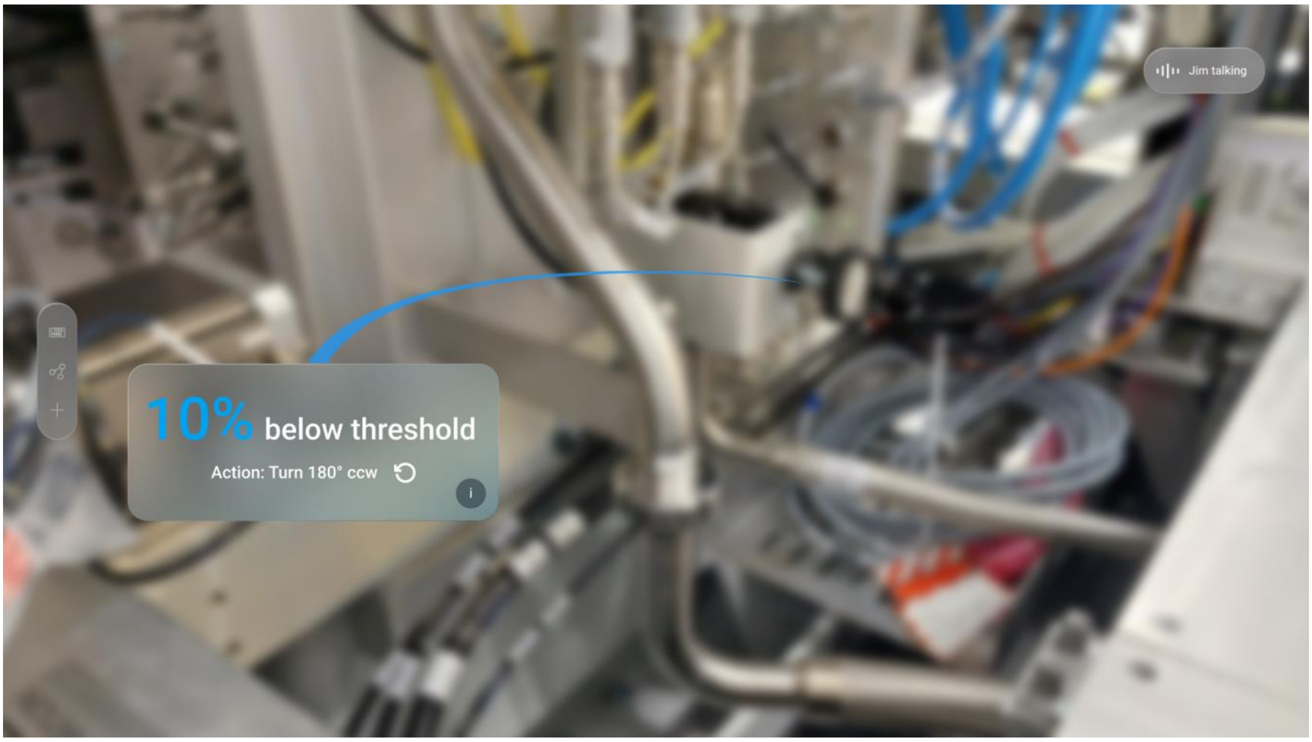
Video call to control room interface

In case of complex issues, users can initiate a video call with a support engineer stationed in the control room to receive live support.



Real-time sensor read-outs & tool recognition

AR headsets can display essential data, such as machine status and sensor readings, overlaying this information on the user's real view. This data corresponds to the specific part of the machine or sensor the operator is interacting with.

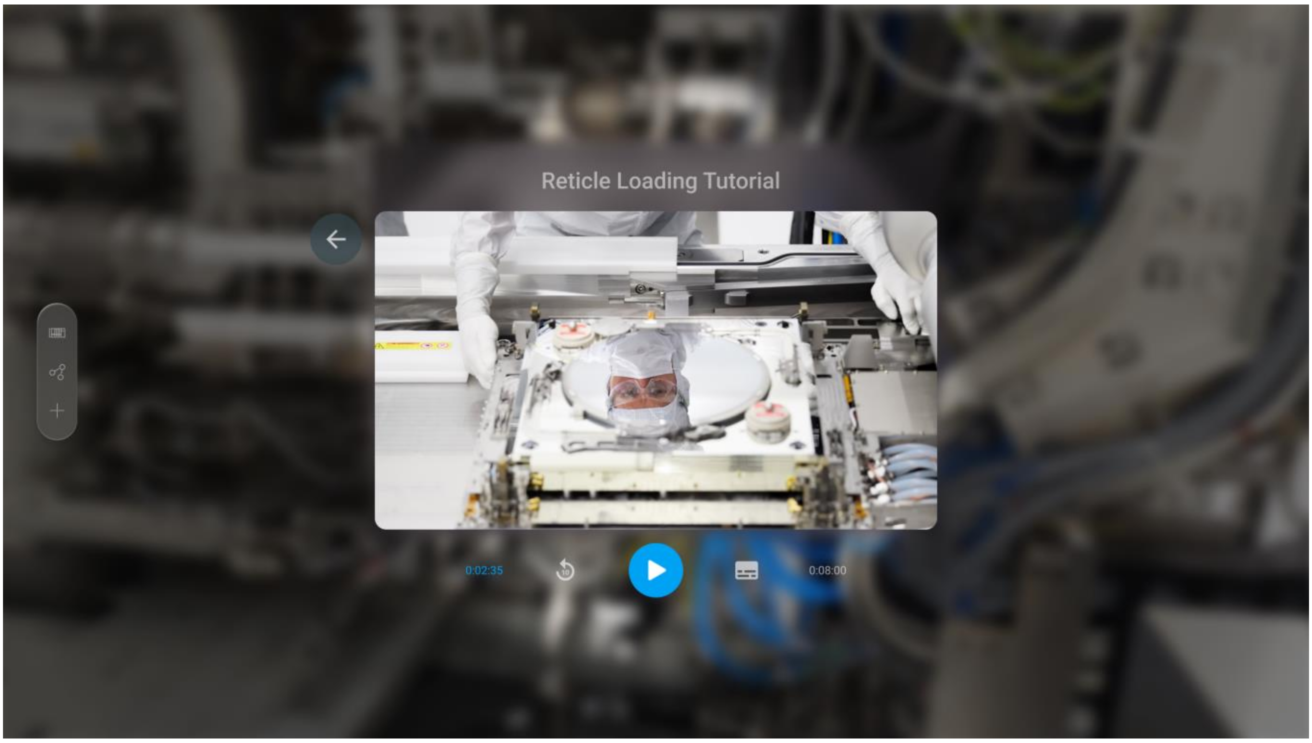


Receiving prioritized notifications

Users can receive important notifications directly in their field of view.

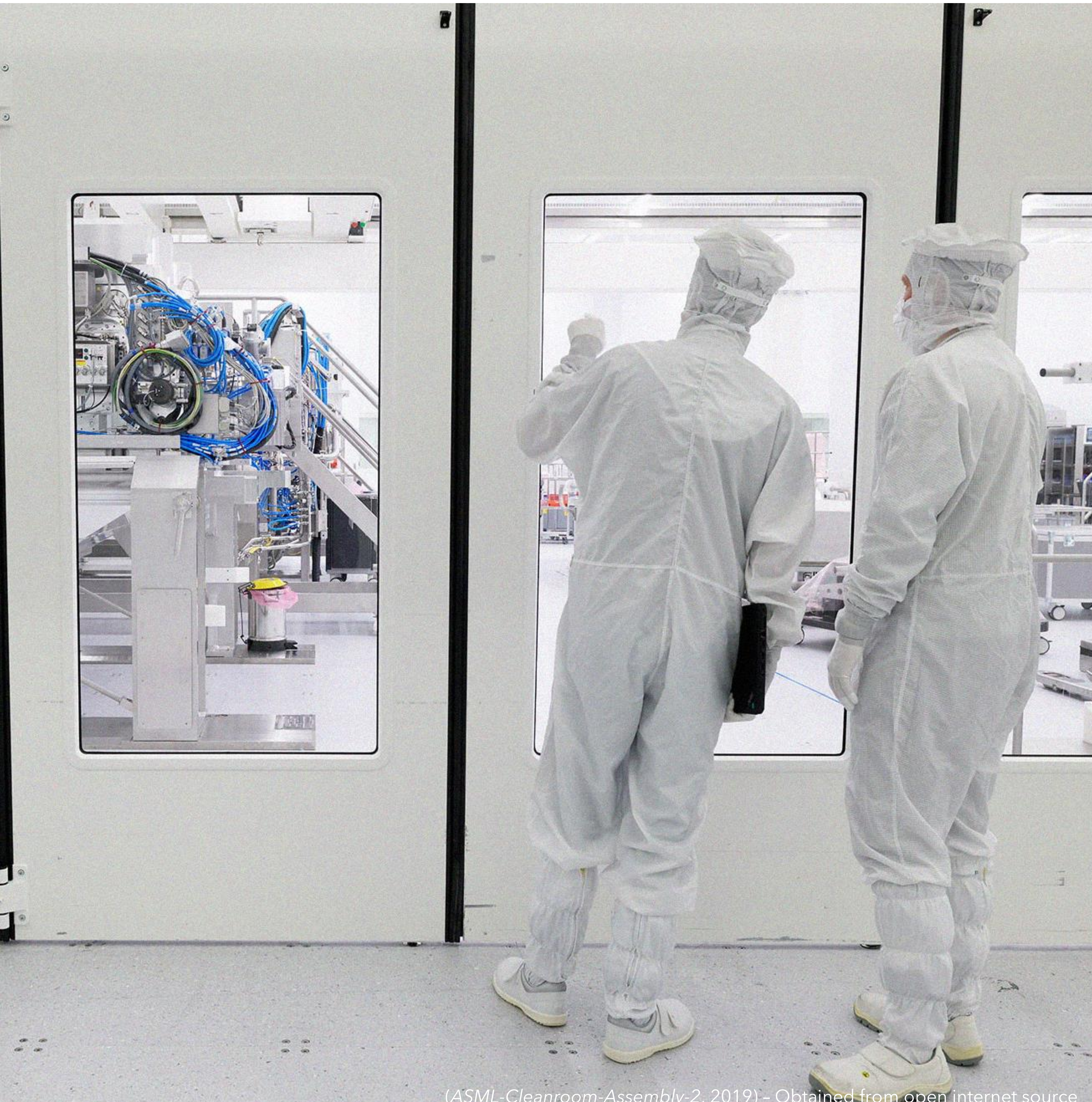
Watch tutorial videos

The interface offers additional features, such as watching tutorial videos for reference if needed.



CHAPTER 6

Recommendations and Discussion



(*ASML-Cleanroom-Assembly-2*, 2019) – Obtained from open internet source

6.1 Roadmap Proposition

This is an hypothetical roadmap proposition is created for this project.
This roadmap with description can be found in confidential appendix K.

6.2 Short-term: Pilot Mobile Workspace

The best short-term solution is a mobile and adjustable workspace. It is recommended to immediately pilot a minimal version of this concept. By using tools that have already been cleanroom-approved in the past, a minimal version of this desk concept could be realized quickly. It will greatly improve the ergonomics and workflow of the users. Figure 36 shows an impression of what this workspace can look like. Keep in mind that this is meant as an impression; however, the exact specifications should still be defined.

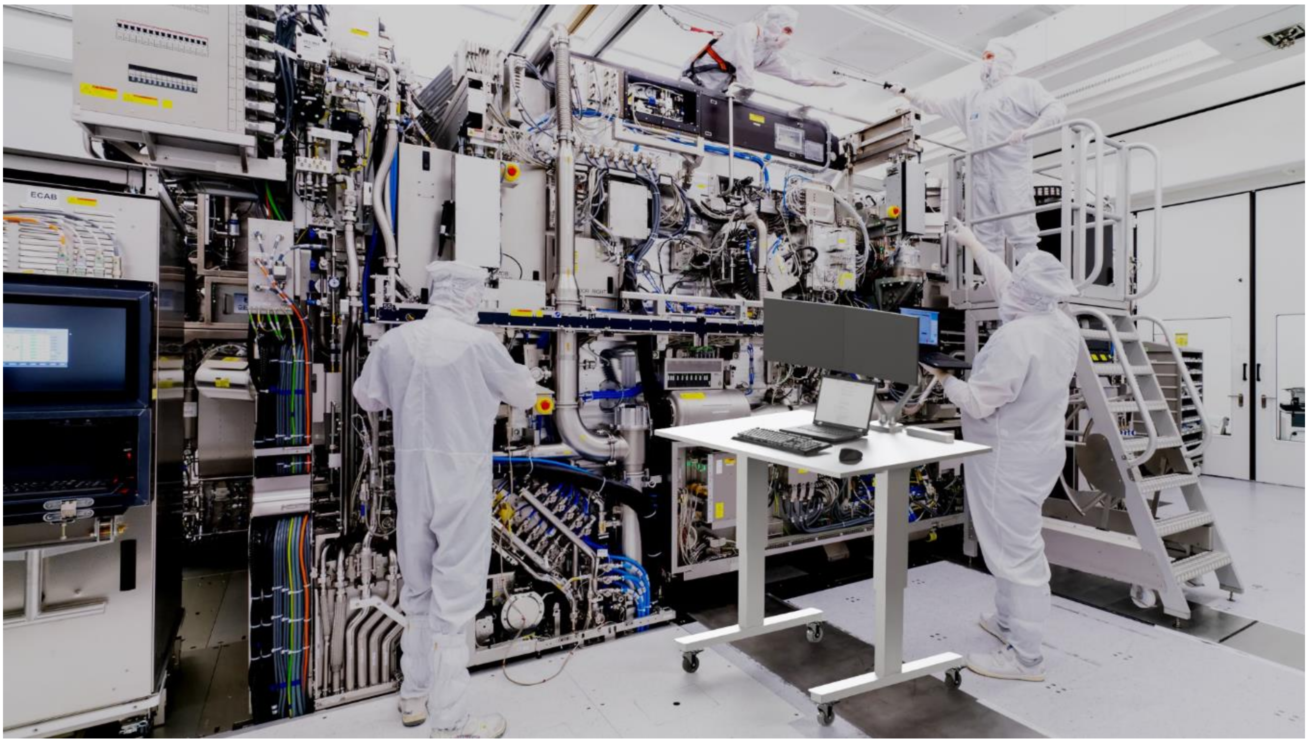


Figure 37: Impression of high mobile workspace in context – Original background image obtained from open internet source (ASML, n.d.)

Displaceable with Wheels

The desk wheels allow the operator to move the workstation around the system. Like the use scenario research presented in chapter 4.2, many tasks require being at different locations around the system. The mobile desk allows the user to pull/push the workspace closer to their work area. The wheels also include locking mechanisms when it is desired to be parked in a stationary position. When it needs to be displaced again, the wheels are intuitively unlocked.

Full Ergonomic Adjustability

The desk is adjustable in height with an integrated electric motor. This desk can delivered with a chair, or it can be combined with the typical office chair that is present at the majority of customer site locations, according to user interviews.

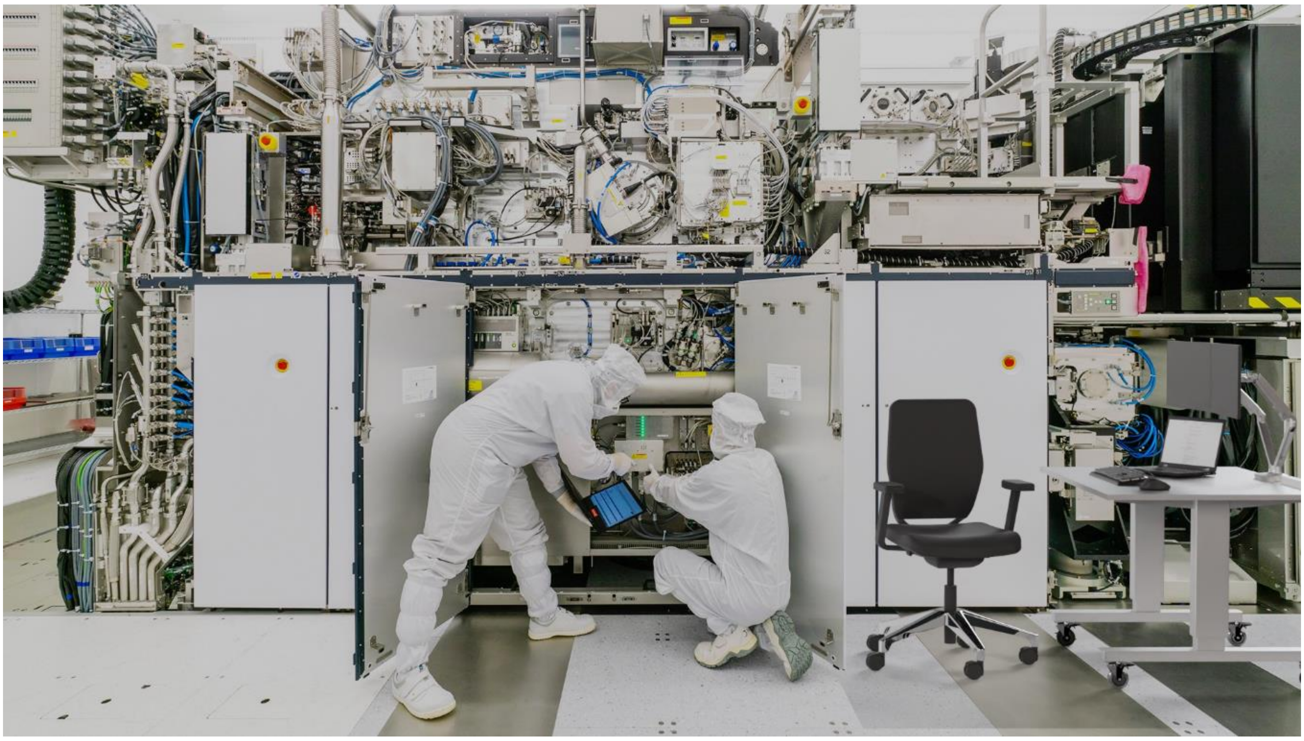


Figure 38: Impression of low mobile workspace in context – Original background image obtained from open internet source (ASML, n.d.)

Dual Monitor Setup

The display setup consists of two monitors on a frame that allows them to move up and down, as well as adjust the angular positions. By being able to see two screens at once, in addition to the laptop screen, it improves workflow and responds to requests made in chapter 3 to increase the amount of screen visible simultaneously. Both screens can be used to work on the system. Also, the second screen can be used to access your laptop to optimize the user's posture. Monitor lighting is optimized for yellow cleanroom light. Automatically adjustable lighting is not essential due to the constant lighting within cleanrooms. However, accessible adjustments are required to accommodate personal user preferences and lighting differences between cleanrooms.

Laptop Integration, Connectivity, and Power Supply

Enough desk space is available to place the laptop, and the available cables allow the users to directly connect their laptop to the desk. With these cables, they can extend their laptop screen to one of the monitors. The desk will also be connected to a power supply and will provide charging ports that are reserved specifically to charge user laptops. Additionally, laptops that are capable of being charged with USB-C will have their own reserved power cable to charge and connect at once.

Space on Desk for Optimal Mouse and Keyboard

The desk is large enough for the user to use any kind of mouse or keyboard that is allowed to enter the cleanroom. According to the results presented in chapter 3, the standard devices will be an optical mouse and a full-size mechanical keyboard with a keypad.

Figure 39: Impressions of mobile workspace

Connect to the System

The mobile desk can connect with the system at both two OIU locations, allowing long enough cable connection to work all around the machine. The desk power and monitor will be connected to a universal service outlet shown in Figure 40, that enables power and Ethernet connection. In turn, this outlet will be connected to the scanner OIU or electric cabinet in the system. Therefore, in this first version, this displacement has to be done with care because it will be connected to the system with a long cable.

Cleanroom and Industrial-grade Materials

The full workspace is constructed with materials suitable for cleanrooms and other industrial conditions. The base frame is constructed with aluminum profiles to be lightweight, durable, and to minimize contamination risks.

Figure 40: Universal Service Outlet (Power Source + RJ45 ethernet) (ASML, n.d.-b)

User scenario

Below is a user scenario of an operator who will work a full day at the system, requiring the OIU. During this shift, the first tasks will require a few hours at the OIU, so they will choose to sit. Later in the day, the OIU will be required for shorter use, but more frequently and combined with mechanical work at a specific machine part. At this moment, the user will move the mobile desk to their workspace and prefer to adapt it to a standing position.

Based on a Tested and Approved Laptop Desk Design

A desk specifically designed to use with the fabtop in the customer cleanroom environment has been developed in the past. This desk has been tested in the field, and the operators have been asked to share their insights.

Design Refinement and Implementation

It is recommended to build upon the structural layout of the desk pilot presented in Figure 41. If needed, partner with an ergonomic workspace design firm to refine the concept. Within the process refinement, maintain a user-centered approach and frequently update and assess design decisions with the user groups. Additionally, thoroughly test the suitability of all required materials on cleanroom compatibility and durability. Create working prototypes and approve them to enter the cleanroom use environment. Discuss the implementation with the customers. It is recommended to present this workspace as an ASML tool.

Figure 41: Fabtop Desk Pilot (ASML, n.d.-b)

6.3 Discussion

Importance of Early HFE Integration in Design Process at ASML

The results of this project emphasize the importance of involving the human factors engineering expertise early in the design process within ASML. It can help preventing issues that are presented in this report to occur in the future. This early involvement can improve the machine design to better meet the user needs and improve the overall design process. This way, human factors engineers can work more on the immediate improvement of the machine, and less on solving issues when they arise later on. I hope this project helps making this value apparent since a successful safety and compliance often only shows in an absence of incidents. Also, ergonomic issues can sometimes develop slowly, and the exact source of the problem can be hard to identify. The added value is not always immediately visible, though it is significant. This project can serve as a reminder that addressing human factors early in the development process, helps to ensure a safer machine.

User Involvement

Within this project, speaking to users has been crucial to validate design decisions. The users possess the most practical insight into whether a design choice will be effective when applied in the field. When implementing new solutions to improve the OIU design, I recommend a continuous feedback system to be established that allows users to easily report their experiences with the adjusted designs.
Once this feedback is collected, it should be reviewed in regular sessions (e.g. monthly or quarterly) with teams consisting of design engineers, human factors engineers, and optionally the user. Within these sessions, the raw, collected data can be transformed into actionable improvements. Then, preferably update the users on how their input has influenced changes or improvements. This process maintains transparency and ensures the users that all their input is acknowledged.

AR Headset Challenges

AR headsets offer ergonomic advantages, like a more natural body posture and hands-free operation. Also, new designs are becoming even more lightweight, and the new tasks in the design proposition aim to decrease the time in the cleanroom. However, they also introduce new ergonomic concerns. Long use could lead to physical discomfort in the eyes and neck. During long work procedures it is recommended that users take frequent breaks and receive ergonomic training. Additionally, the implementation of the headset results in security challenges. The integrated cameras could capture sensitive information, and also the wireless connectivity should be researched to ensure the customer of its safety.

Customer involvement

In future scenarios, it is increasingly important to ensure that technological advancements can effectively collaborate. To realize an effective workflow between the ASML machine, an advanced customer control room, and an ASML-provided advanced wearable (like an AR headset) it is important to communicate closely with the customers. Additionally, the approach is required to develop a potential platform that communicates between these devices. Finally, keeping track of the changes in the customer use environment improve the usability of the final design.

References

- *2019-ASML-Cleanroom-Assembly-1*. (2019). bvof.nl. https://bvof.nl/wp-content/uploads/2023/01/BvOF-2019-ASML-Cleanroom-Assembly-1.jpg
- *An ASML extreme ultraviolet lithography machine*. (2023). Bloomberg. https://www.bloomberg.com/news/articles/2023-04-19/asml-sales-outlook-beats-estimates-as-demand-remains-strong
- ASML. (2020). *CDR Generic OIU ASSY MK2-D001128826-03.* Internal report.
- ASML. (2020). *DFMEA GOIU introduction in NXE and YS_v1*. Internal training courses.
- ASML. (2021). *DFMEA GOIU in NXE, EXE and YS Design status as of: 09.09.2021.* Internal report.
- ASML. (2022). *EDS Generic OIU ASSY MK2.* Internal report.
- ASML. (2023a). *2022 Annual Report*. Retrieved from ASML Annual Report 2022 | ASML
- ASML. (2023b). *Training Courses.*
- ASML. (2023c). *Human Factors Engineering Course.*
- ASML. (2023d). *ASML Discovery Course.*
- ASML. *(2023e). Persona's*
- ASML. (n.d.-a). Reticle and Wafer Handling Training
- ASML. *(n.d.-b). Workstation Cart Pilot Result.*
- ASML. *(n.d.-c). Main Human Factors Engineering Requirements*
- *ASML-Cleanroom-Assembly-2*. (2019). bvof.nl. https://bvof.nl/wp-content/uploads/2023/01/BvOF-2019-ASML-Cleanroom-Assembly-2.jpg
- *ASML-Cleanroom-EUV-Wafer-Stage-training-2*. (2019). bvof.nl. https://bvof.nl/wp-content/uploads/2023/01/BvOF-2019-ASML-Cleanroom-EUV-Wafer-Stage-training-2.jpg
- *European Agency for Safety and Health at Work, Occupational safety and health in Europe: state and trends, 2023*
- Fink, R., Hill, D. R., & O'Hara, J. M. (2004). Human Factors Guidance for Control Room and Digital Human-System Interface design and Modification, Guidelines for planning
- *Intel Newsroom. (2022). Behind this Door: Learn about EUV, Intel's Most Precise, Complex Machine [Video]. Intel Oregon.*
- Kirwan, B., & Ainsworth, L. K. (1992). *A guide to task analysis*. Taylor & Francis.
- Kokken, J. van Veen, M. Toeter, L. (2023). *Non-Compliance case 2206: NXE3800_OIU_SEMI S8 ergonomic height requirements.* Internal ASML report.
- Milos Blagojevic, Mark van Veen, Perry Egelmeers, Raf Verbist. (2021). *DFMEA GOIU in NXE, EXE and YS.* Internal ASML report.
- Muijters, E. (2022). *OIU Customer Journey Map.*
- Roozenburg, N. F. M., & Eekels, J. (1995). Product design: fundamentals and methods. Chichester, UK; John Wiley & Son Ltd.
- Sauro, J., & Lewis, J. R. (2016). *Quantifying the User Experience, Second edition: Practical Statistics for User research. In Morgan Kaufmann Publishers Inc. eBooks.* http://dl.acm.org/citation.cfm?id=3044726
- SEMI. (2018). Semi S8-0218 Safety Guideline for Ergonomics Engineering of Semiconductor Manufacturing Equipment
- Stanton, N. A., & Young, M. S. (1999). *Guide to Methodology in Ergonomics: Designing for Human Use.*
- Van Bakel, K. Delvaux, D. n.d. *NXE:4000 GOIU SEMI-S8*
- van Veen, M. (n.d.). *PSA NXE-3800 OIU Height Regulatory Board intake slides.*
- Vivek Jaiswal. (2021). *EPS Generic OIU ASSY Mk2.*
- Wickens, C. D. (1997). *An introduction to human factors engineering.* http://ci.nii.ac.jp/ncid/BA6489643X

Appendix

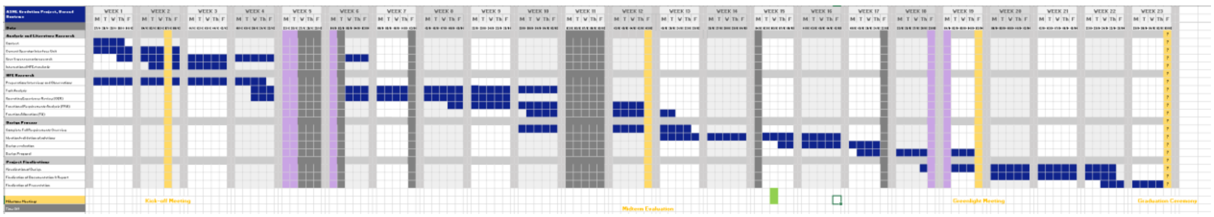
A. Personal Project Motivation

My personal goal is to improve my skill of finding concrete design solutions to address complex ergonomic challenges by integrating HFE research into my existing design expertise.
In addition to the learning objectives of the Graduation Project, my personal aspirations involve diving into the field of HFE. I want to gain practical experience in user research and HFE methods and experience in designing for systems in the industrial field.

This project presents an opportunity for me to combine my academic background, personal interests, and career aspirations. I am enthusiastic about contributing to ASML's vision while advancing my professional development goals.

B. Gantt Chart Planning

See attached Gantt Chart planning document



C. Research Methodologies

To fulfil the aim of this project, and gather all the information that is required to have an effective design phase, many different methodologies and analysis are performed. In this chapter, all approaches to these methodologies are presented and discussed, and then later in the report point will be referenced back to these methods. Findings that are relevant for certain design assessments or decisions will be referenced in that specific part of the report.

Semi-structured interviews

The semi-structured method has been chosen because it allows for flexibility in exploring the individual perspectives of each user. Unlike a structured interview, it has the room to room to encourage participants

to elaborate on their thoughts, and going off on side track stories. This provides richer data and increases the chance of discovering new topics. So, the semi-structured approach ensures that while the key topics are covered, there is room for unexpected yet relevant information to emerge, which is crucial to results in an effective design result.
Part of the aim of conducting these interviews is to ensure all crucial information will be covered in the analysis and further research, like the survey. For example, when the survey is made, all topics should be known, to ensure that no crucial data is missing and therefore leading to better design decisions in the end. Also, the user interviews aim to understand the context of certain limitations or topics of the design. For example, just finding out that operational efficiency would improve when a portable device is added to the system, leaves you wondering: why? Then, in the user interviews you have learned that sometimes and operator can work on top of the machine wearing a safety harness, and getting the harness off and on, including getting down and up again, can take much more time than simply checking a portable device.
The conversation often deliberately started with the user to openly get out their specific frustrations. This, helped for them to later focus better on the other important topics to be covered. It also helps to set off with a relaxed environment, to help the interviewee to feel comfortable. When possible, the interviews have been recorded and transcribed, and the raw data is saved.

Field Observations and Interviews

Field visits to observe and interview the user as he or she is using the OIU is crucial to get a wholistic understanding of the context. It is important to directly witness how users interact with the current design, and also experience the design myself. Being in the user-environment uncovers ergonomic issues and user behaviours that cannot be communicated in an interview setting. Observations can uncover subtle, non-verbal cue and workarounds that user have developed, which they might not think of to mention in a discussion. In addition, standing next to the OIU adds an additional layer of depth, as users directly reference and demonstrate certain aspects of the OIU during the conversation. If allowed, the visit can also result in visual materials of photos and videos, to later be used to use as a reference when presenting the results.

Expert Discussions

Topics are discussed with relevant experts in ASML for several reasons:

- Improve the interpretation of user research results.
- Get access to new technical or previously researched data.
- Get transferred to more, different OIU users.

Include commentary of expert in the research to prepare for future possible critique.
The aim of also including expert discussions within the user research phase is to think ahead of how technical limitations require certain user data. For example, if through a computer Systems expert consultation, that wireless connectivity is challenging to realize, than the user questions can be adapted according to this.
The expert discussions are also crucial to gather the right documents. At the start of the project, there was not one package provided with all relevant documents. These all had to be gathered through building a network at ASML.
Different departments are consulted. Multiple meetings are held with the computer systems department, they are the product owner of the OIU. Also multiple discussions with UX design department has helped to

get to know more about user personas and user journeys. This research was conducted while operating within the human factors engineering team at ASML. Each week Human Safety Competences and Human Factors Engineers team meeting are attended, providing many occasions to consult the experts within these groups.

OIU Incident Report Analysis

All incident reports have been requested from ASML's health and safety department that have some relation to the Operator Interface Unit (OIU), General Operator Interface Unit (GOIU), User Interface (UI), Keyboard, Mouse / Trackball, PC drawer, Screen, Touchscreen, Work environment, (e.g. light, heat or noise), Sub Rack, Laptop. These reports have been received in 12 excel files containing the lists of reports sorted by date. All of these have been read and relevant comments have been selected and used in the analysis.

Task Analysis

Task analysis is a systematic approach used in fields like design and operations to understand how people interact with systems. It is a tool that ensures that systems work well for the people who use them. It helps to create an overview of human involvement, ensuring that systems are safe and efficient. Task analysis is an effective tool for identifying safety hazards, improving productivity, and minimizing downtime (Kirwan & Ainsworth, 1992).
The methods applied in the task analysis is partly based on literature references, Kirwan & Ainsworth and Stanton & Young, also input from experienced human factors engineers at ASML. (Kirwan & Ainsworth, 1992) (Stanton & Young, 1999). This resulted in a tabular task analysis format. The primary data collection method for the task analysis consists of interviews, because the options to observe and be at the OIU is limited. Because most information comes from interviews without being able to be at the machine, it is more challenging to be correct and complete. However, when in the field, the user is observed while working, tasks are performed with questioning, users are instructed to think-aloud when working.

International HFE standards Research

There are several organizations worldwide that set ergonomic and human factors standards.
SEMI Requirements are specifically developed for the semiconductor industry. International Organization for Standardization (ISO) is one of the largest organizations to provide standards to ensure that products and services are safe, reliable, and of good quality. There is also, SAF (Product Safety Documentation) and the GID (General Information Document), which is about how to fulfill these requirements. Furthermore, SIS (Safety Information System) helps to access the safety levels of the system.

User Survey

The user survey is rounds up the user research by integrating all findings, and focussing on gathering high amounts of data. The aim of the survey is to reach research large user groups, and gather big amounts of

data. Dedicated time and effort has been invested in this survey to reach a as big and diverse user group as possible.
The survey consists of 47 questions and takes around 15-20 minutes to complete. The survey has collected 130 responses. Respondents had the option to skip a question that they could not, or preferred not, to answer. Therefore, some questions do not have a total of 130 responses. When a survey outcome is presented, the amount of responses will also be provided.

D. Field Observations

ASML Cleanroom Visit, Veldhoven, November 22, 2023

Together with a mechanical architect from the Mechanical System Layout department at ASML, a private guided tour has been organised through the cleanroom in Veldhoven. Showing around the fab locations of the NXE, EXE and DUV systems. Also, having the first up-close look at the OIU and discussing the space limitations around the OIU according to the mechanical system layout of the system.

BIC Learning Centre Visit, Eindhoven, December 21, 2023

The BIC Learning Centre is where OIU operators are instructed and trained to use the OIU. At this location, one of these instructors has been interviewed. During this visit, the software on the OIU has been demonstrated. Also, topic could be discussed like procedures, operator workflows and their responsibilities. At the end, learning documents were received that were valuable reference to write chapter 4 on the Operator Interface Unit.

Customer location Research Centre Visit, February 15, 2024

A customer field visit is crucial to form a complete understanding of the user groups and use environments. To organize this, ASML customers worldwide were contacted. However, it is challenging to organize a visit because to the sensitivity of the environment, and because the time of these operators and engineers is highly valued. Luckily, a visit at the customer location. For this visit, human factor engineering expert of ASML joined to assist.
Before this visit additional trainings had to be completed to be allowed to enter their cleanroom. The entire visit was guided by a former ASML Service Engineer.
The customer location cleanroom was visited twice. While in the cleanroom, two the customer location customer operators could be extensively interviewed while standing at the different OIUs. Also, one (former) long-time ASML service engineer and one the customer location ergonomic expert could be interviewed. During interviews, the operators could directly refer to the OIU, because we were standing right next to them. We were also able to sit/stand at the OIU and operate ourselves. Also, other the customer location customer operators could be observed while interacting with the OIU.
The customer location ergonomic expert made photographs of the OIU use environment and operator postures.

E. Design Methodologies

Morphological Chart

A morphological chart is a design tool that helps in brainstorming and organizing potential solutions for challenges. In this chart, the products functions are listed vertically, and potential solutions to these functions are presented horizontally. This method allows to brainstorm on specific sub-challenges of the system, and explore a variety of different combinations. This results in a selection of different concept designs.

Brainstorm & CO-Creation Sessions

After the conclusion of the research of the current design, the OIU functional requirements will be referred to as an interface instead of an OIU, to let go prevent being limited by the current design.
Use Affinity mapping to cluster ideas, to categories a large cluster of ideas
Use morphological chart to generate concepts from ideas
How to optimize work efficiency?
This chapter provides the information that helps to gain a better understanding of the context of the project. It begins by describing ASML as a company, covering their purpose, vision & mission, customers, products and services, and departments. Then, EUV lithography is covered in more detail. The basic functionality of the systems is explained, together with the production steps, wafers, reticles, the machine types and the current user interactions within this machine design. Concluding the chapter, human factors engineering within ASML is described, including the group in which they act within ASML, and why it is relevant for this project.

F.Work Posture Analysis Results

In the ergonomic assessment of the OIU, both forward and sideward upper arm postures present notable concerns. Firstly, 25 out of 128 users indicate that one of the most occurring angles of their upper arm surpasses 60 degrees in a forward direction, as shown in Figure 42. This posture is unacceptable according to the HFE Engineering Requirements, if it is maintained for more than 8 minutes daily (see Figure 46). Furthermore, a large majority, 100 users, frequently maintain their upper arm at a forward angle between 21 and 60 degrees, as shown in Figure 42. This is an unsuitable posture when held for longer than 24 minutes per day. Only 21 users indicate that their upper arm is frequently in the forward 0 to 20 degree range. This is insufficient, since this is the only correct position to be in for this use, according to the HFE guidelines shown in Figure 46.

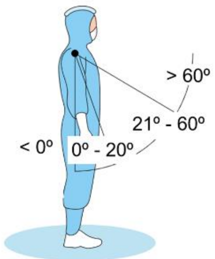


Figure 42: Upper Arm in a Forward Direction

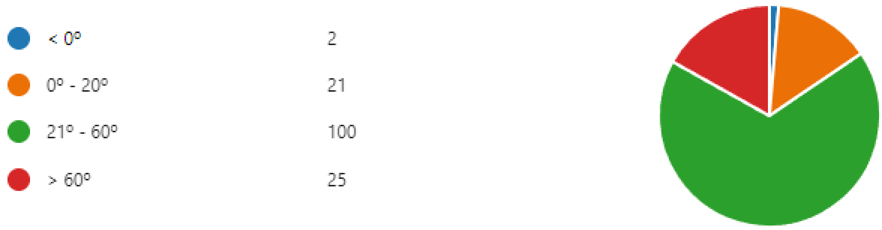


Figure 43: When working at the OIU while standing, which zone(s) would best describe the most frequently occurring angle(s) of your upper arm in a forward direction?

In addition to these findings, the analysis of the sideward motion of the arms reveals that 24 out of 128 users often move their upper arm in front of their body, depicted as <0 degrees in Figure 44. According to the HFE standards shown in Figure 46, this zone is never allowed. Also, 9 out 128 of users often extend their upper arm beyond 60 degrees. This violates the HFE requirements if maintained for more than 8 minutes daily. Finally, 45 out 128 of the users indicate one of the most occurring angles of their upper arm to be in the sideward direction of between 21 and 60 degrees. This position would be unacceptable for durations exceeding 24 minutes daily. Luckily, the majority, 64 of the users, is most frequently assumes the correct position, which is between 0 and 20 degrees.

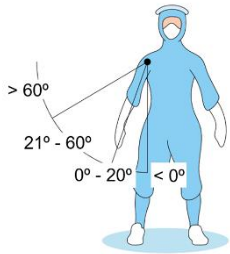


Figure 44: Upper Arm in a Sideward Direction

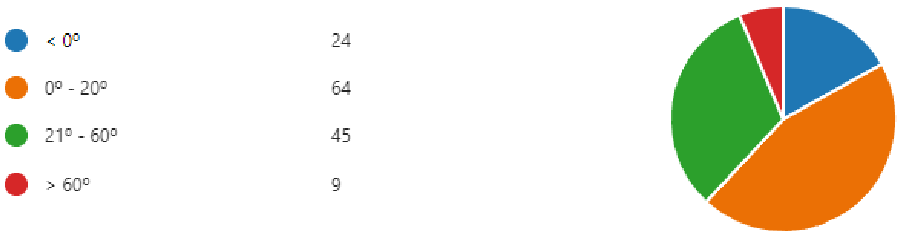


Figure 45: When working at the OIU while standing, which zone(s) would best describe the most frequently occurring angle(s) of your upper arm in a sideward direction?

Underneath, the HFE requirements of the upper arm movements are shown.

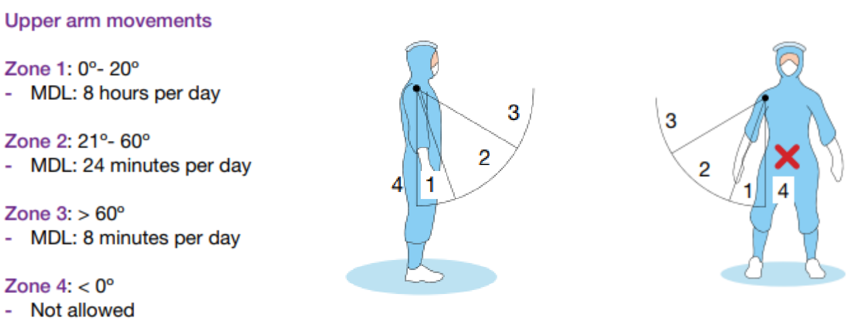


Figure 46: HFE Engineering Requirements, Working Postures with Upper Arm Movements

The inputs gathered on the angular position of the back of the user also reveals limitations of the current OIU design. 41 out of 128 responses indicate that their back is frequently positioned at an angle between 21 and 60 degrees, as illustrated in Figure 47. According to the HFE Engineering Requirements shown in Figure 49 this position is only recommended for 32 minutes per day. Also, 12 users indicate that they often lean backwards (<0 degrees), which is never allowed. 7 people respond that their back also regularly exceeds 60 degrees. According to the recommendations, this would only be acceptable for less than 8 minutes per day. Still, most users (82 people) are positioned in the 0 to 20 degrees posture most frequently, which is the preferred position to be in.

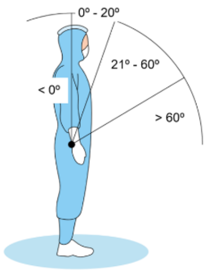


Figure 47: Angle(s) of the Movement of the Back

Figure 48: When working at the OIU while standing, which zone(s) would best describe the angle(s) of your back?

Below, the requirements related to the posture of the back are illustrated according to the HFE handbook.

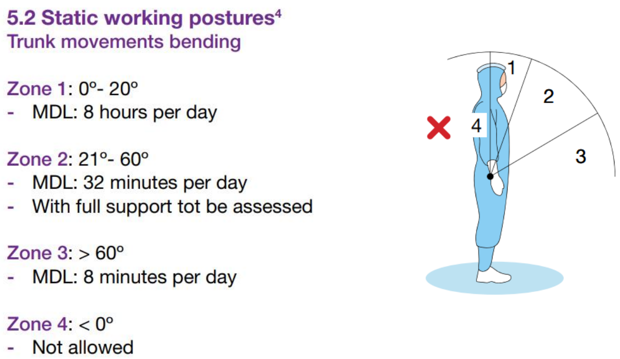


Figure 49: HFE Engineering Requirements, Working Postures of Trunk Movements Bending

The analysis of the head posture also reveals ergonomic concerns. 10 out of 128 of the users frequently move their head backwards (<0%) like shown in Figure 50. According to the HFE Engineering Requirements, it is unacceptable to be in this zone (see Figure 52). In addition, 50 users indicate that the angle of the head often exceeds the 20 degrees shown in Figure 50. According to the HFE Engineering Requirements it is unacceptable position your head in this zone for longer than 64 minutes a day.

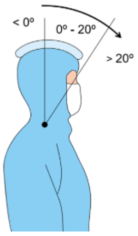


Figure 50: Angle(s) of Head Moving Forward

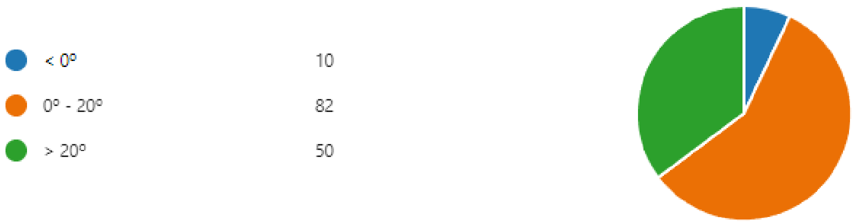


Figure 51: When working at the OIU while standing, which zone(s) would best describe the angle(s) of your head (bending forward)?

Underneath, the requirements from the ASML HFE handbook are shown.

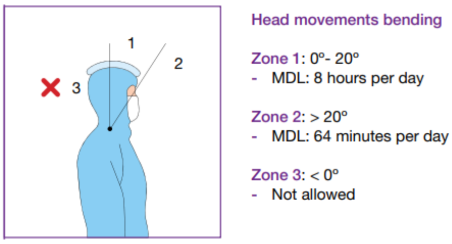


Figure 52: Figure 31: HFE Engineering Requirements, Working Postures of Head Movements Bending

G. Optimal keyboard and mouse

Mechanical Keyboard vs. Chiclet Keyboard

Mechanical keyboards have individual switches between all keys. Chiclet keyboards have low-profile keys that press more easily compared to mechanical. In user interviews, the general feedback is that the key size of the mechanical keyboards are more suitable for the double layered gloves of the operator. Compared to chiclet keyboards, mechanical keyboards, often have better tactile feedback, longer travel distance when pressed, require slightly more force to press and the keys can be place slightly further apart from each other. In interviews, users have indicated that these qualities generally improve accuracy when wearing gloves in the cleanroom environment. Therefore, based on the collective feedback, it is recommended to continue to use mechanical type keyboards.

Figure 53: Chiclet Keyboard

Figure 54: Mechanical Keyboard

KEY RESULT

A full-size mechanical keyboard is the optimal text input tool for the OIU user.

Trackball vs. Optical Mouse Preference

In the user interviews, there has not been one clear preference for either the optical or trackball mouse. Therefore, users were asked to indicate their preference in the survey, if there were not space limitations on the keyboard tray. Figure 54 shows a preference for an optical mouse.

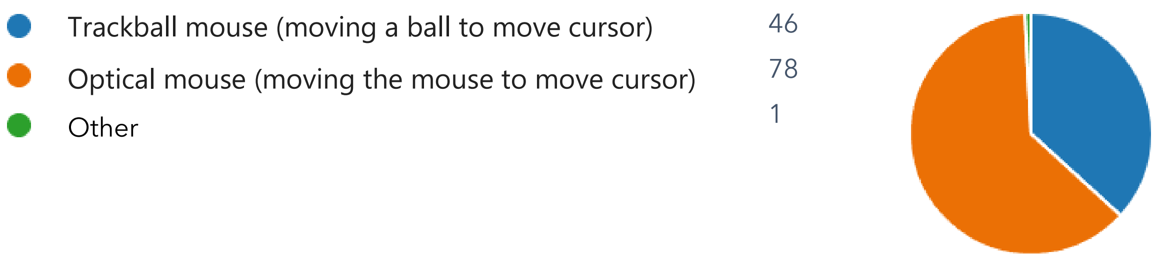


Figure 55: What is your ideal primary pointing device (mouse) if there were no space limitations on the OIU keyboard tray?

KEY RESULT

The majority of the users prefer an optical mouse over a trackball mouse.

H. ISO Selecting Keyboard

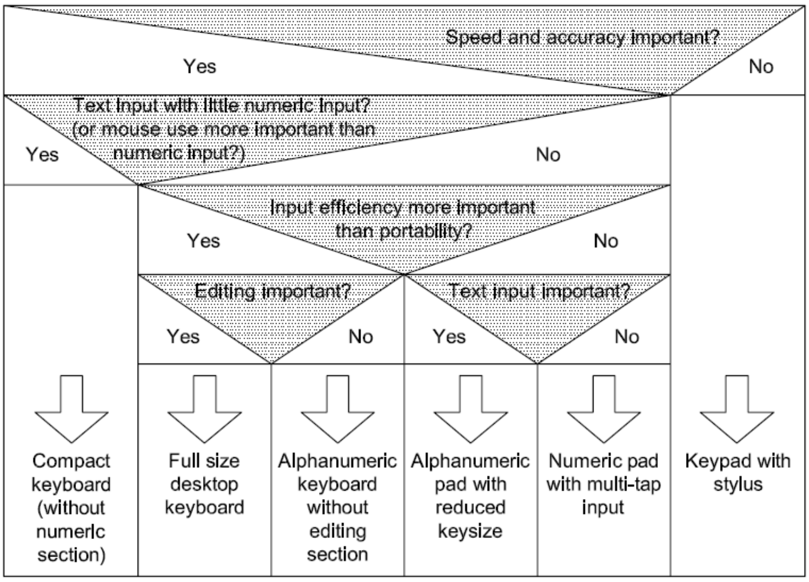
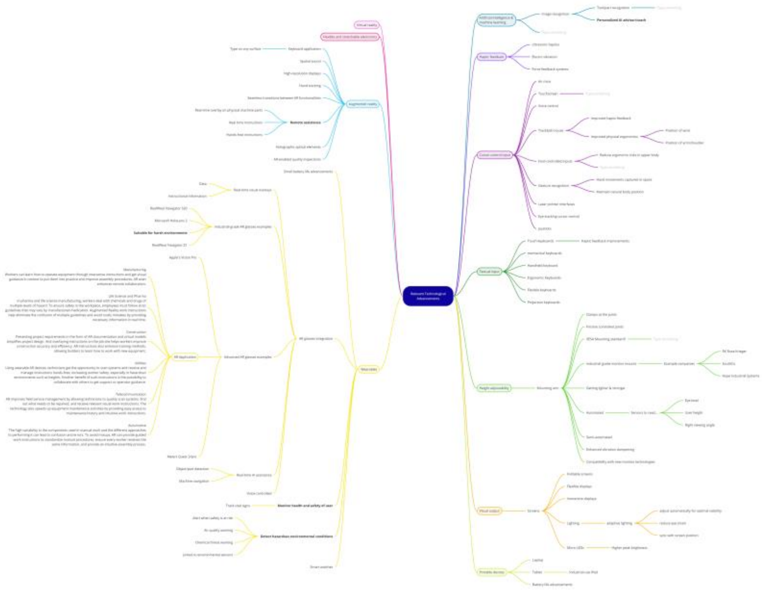
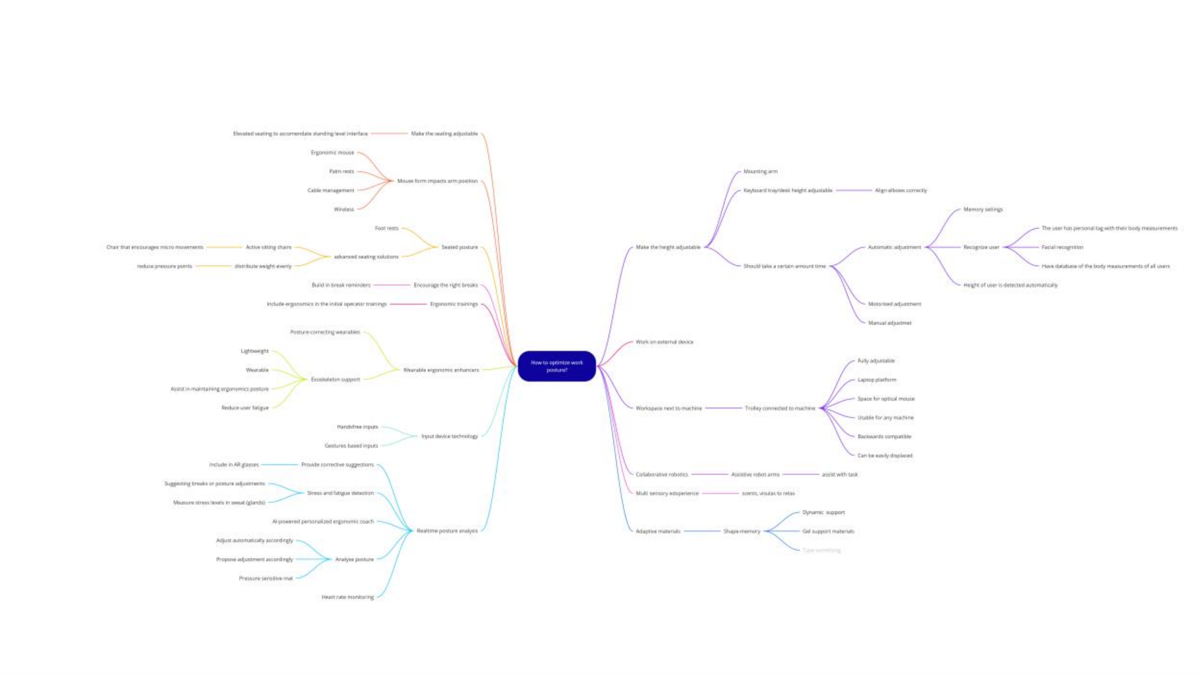


Figure 56: Guidance For Selecting Appropriate Keyboard (ISO 9241-410:2008)

I. Technological Advancements and Human-Machine Interaction research





Data Input

Machine learning applied in touchscreen to improve

- Gesture detection
- Accuracy improvement
- Input discrimination

"the machine learning applications have been…." (reference to paper)

Voice Control

- Voice to text technology allows for hands-free input, which could allow for operation on distance.
- The high noise levels described in the use environment, will be a challenge for this technology. It would require high-level noise cancellation and voice recognition. Noise-cancelling algorithms would have to be developed to filter the cleanroom noise effectively.
- The technology seems more relevant for situations where manual input is hindered when located at the interface.
- When providing input when away from the interface, the user would also need a response of the interface to know if & how their input is received.
- The microphone would have to be close to the user because of the environment noise, so it would require integration in a wearable.

Haptic Feedback

Touch keyboards

Provides tactile responses in touch-based keyboards, simulating the feel of mechanical keyboards even when wearing gloves. This could enhance the opportunity to use touch screen keyboards, that could have a more versatile application. It could even be more clean solution for the cleanroom, eliminating the physical crevices in the mechanical keyboards when contaminants that settle. The touch based keyboard could be better cleanable.

It will be a challenge if the haptic response will be user friendly enough with the context of the environment and the double layered gloves. And also, the

Types of haptic feedback

- Ultrasonic haptics
- Electro vibration
- Force feedback systems

Increased resolution of tactile feedback
Integration with AI for adaptive responses

Trackball mouses

Opportunities

- Add sense of touch when interaction with digital elements
- Enhancing controls
- Reducing need of visual confirmation

Challenges

- Not to overwhelm the senses of the user

Augmented Reality

Keyboard application

AR technology can project virtual keyboards onto surfaces to enable typing in various environments without physical hardware. This provides opportunities for use . The clarity of the AR projections could be limited due to the high brightness of the cleanroom environment.

Challenges

- Cognitive overload
- Motion sickness

Virtual Reality

AR uses a real-world setting while VR is completely virtual. +

Flexible and stretchable electronics

For applications in adaptable electronic tools.

Portable devices

Keyboard application
Portable keyboards can address the need to input text when located at any part of the machine. Likely, it is best if these keyboards, are then integrated in a device that also allows feedback to the user to confirm if and how their input is received. In addition, the keyboard should maintain suitability for the double layered gloves and industrial setting. This could be achieved by maintaining the mechanical keys, or implementing mechanical-like haptic feedback.

Artificial intelligence and machine learning

AI-powered predictive text

Predictive text could help the user with textual input efficiency or work on a distance with possible less key available. It might be challenging to tailor the AI algorithms in the right way. Ai driven error corrections can reduce mistakes in manual data entry, which might be especially useful in portable application because that might result in high error frequency.

Air Mice / Gesture Recognition

Opportunities

- Allowing cursor control through hand movements captured in space, allow for more natural hand movements.
- As an alternative to traditional mice, this can decrease risk of injury over long periods.

Challenges

- To be precise
- Accidental inputs

Advanced Touchpads

Opportunities

- Advanced touchpads can support gesturers to enable complex commands with simple movements on a mousepad.
- This would reduce the need for repetitive movements.

Challenges

- A touchpad based solution is complex to be used will with double layered gloves.
- Would require advanced haptic feedback
- Could result in accidental inputs
- Increase the time required to learn for a new operator

Foot-controlled inputs

Opportunities

- Reduce ergonomic risks in upper body
- Requires no (or less) adjustments for different types of users
- Relatively easy to maintain correct posture

Challenges

- Unusual control method might require more training.
- Challenging design it intuitively
- Maintain the balance of the user.
- Could introduce, new and different ergonomic issues\

Physical Ergonomics Tools Design Advancements

Opportunities

- Improving the responsiveness of the trackball, and therefore decreasing their required movements,
- Personal adjustability of the mouse
- Improve wrist and shoulder positioning

Challenges

- Improving the responsiveness of the trackball, and therefore decreasing their required movements, might result in an overly sensitive mouse to unintentional movements

Joysticks

Opportunities

- Joysticks that respond to varying pressure levels

Challenges

- Motion prediction

Wearables

ring controller

- Track hand gestures through finger movements
- Ensure reliable connectivity

Augmented Reality Glasses

- Could provide real time data to the operator while working at other part of machine
- Highlight important information in the
- Reduces need for physical interaction
- Easier to work with on distance

Other

- Eye-tracking cursor control
- Laser Pointer Interfaces

J. Human-Machine Interaction in Different Industries

K. Morphological Chart

Functions															
Seated and standing work position	Mounted fully adjustable	Ergonomic high chair setup	Adjustable on rails mounted on machine	Separate standing and seated workspace	Fully adjustable trolley with monitor	Slide along pilar attached to machine	Slide along pilar separate from machine	Integrate 'control pocket' in machine	Stool with screen	Hand-held terminal	Panels fold out to adjustable desk	Adjustable suspension from ceiling	Only backup/status OIU on machine & separate workspace next to machine		
Working in parallel with laptop	Laptop tray on machine	Adjustable trolley for laptop	Fixed monitor to connect laptop to	Laptop tray on mounted arm	Large enough desk space	Eliminate need for laptop	Multiple docking stations around machine	Tray to insert laptop, to connect automatically to desk setups							
Use at multiple locations	Laptop workflow optimization	Tablet	Smart watches	Rotate screens or mounts	Additional screens	Wireless control options	AR Glasses	Additional projections	On wheels	Transparent screens	Large overhead displays	Interface can move along track of the machine	Voice control/ audio feedback		
Pointing input	Optical mouse	Trackball mouse	Touchscreen	Hand gesture input	Joystick	Laser pointer interfaces	Voice control	Foot controlled	Air mice	Eye-tracking control					
Textual input	Mechanical keyboards	Ergonomic Keyboards	Handheld keyboard	Touch keyboards	Projection keyboards	Flexible keyboards	Neurolink	Voice control	Use mobile input device	AI typing assistance					
Visual output	Monitor	Ultra wide monitor	Multiple monitors	Foldable screens	Flexible screens	Rotatable monitor	Micro LED screens	Transparent micro LED	Projection on panel or floor	Adaptive lightning	AR Glasses	Smart watch	Connected tablet as screen	Enclosure panels made of LED screen	Large screen with 2-4 quadrants
Don't obstruct pathways	Foldable	Extractable	Telescopic	On wheels	On rails	Attached to the ceiling	Insert into cavity in machine	Wide enough pathways	Work-pocket in machine	Foldable within enclosure	Mobile workstation	Mobile work option all around the machine	Separate workspace for OIU		
Posture support	Palm rests	Elbow rests	Motorized adjustability	Encourage enough breaks	Monitor user health/posture	Exoskeleton support	Foot rests	Know the users' body dimensions, and adjust automatically							

L.Personal Project Brief

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT
Complete all fields, keep information clear, specific and concise

Project title Applied Design Research of the Operator Interface Unit of ASML's Extreme Ultraviolet Lithography Systems.

Please state the title of your graduation project (above). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

The project holds significant value for various stakeholders within the semiconductor manufacturing domain, particularly machine operators, ASML, ASML's customers, and ASML's Human Factors Engineering (HFE) Team.

One of ASML's main product lines are extreme ultraviolet (EUV) lithography machines. To install, operate and maintain these, human interaction is required. Therefore, an operator interface unit (OIU) is integrated in the system. However, there are several issues with the current design. The purpose of this project is to conduct an applied HFE research on the OIU to reimagine this human-machine interaction.

[redacted]

The ASML HFE team is a crucial internal stakeholder that will gain new insights and design solutions that can be applied to this OIU, and likely to other ASML products in the future.

However, the project will be limited by the existing mechanical system layout of the machine. The diversity of the users, their training and familiarity with the current design can also constrain the results. Design adjustments are expected to mostly be subject to time and regulatory constraints, but also budget constraints. Each identified limitation will be addressed by including them in the newly developed requirements.

→ *space available for images / figures on next page*

introduction (continued): space for images

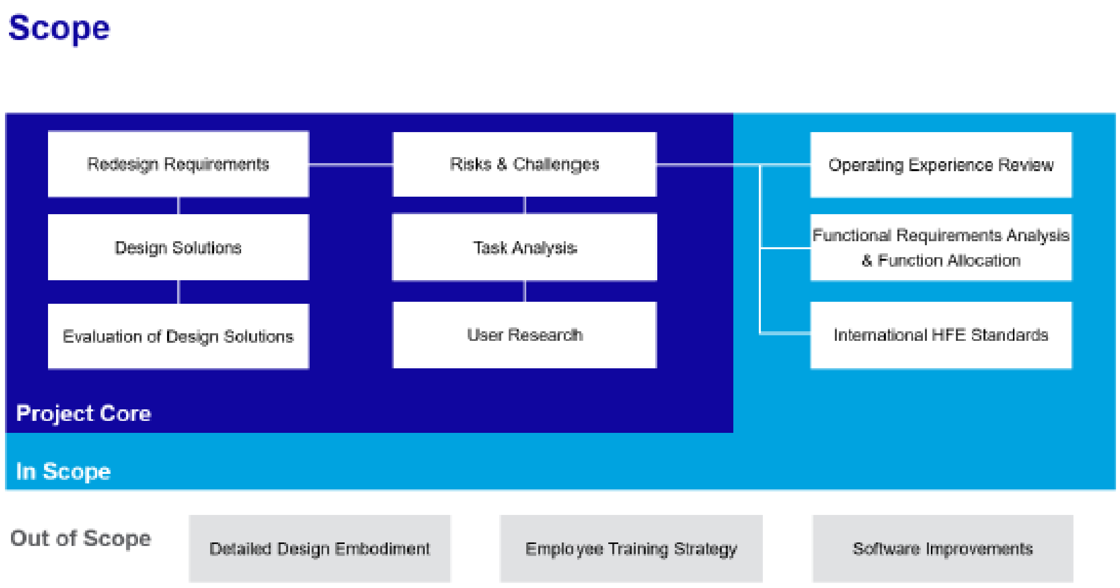


image / figure 1 Scope Visual

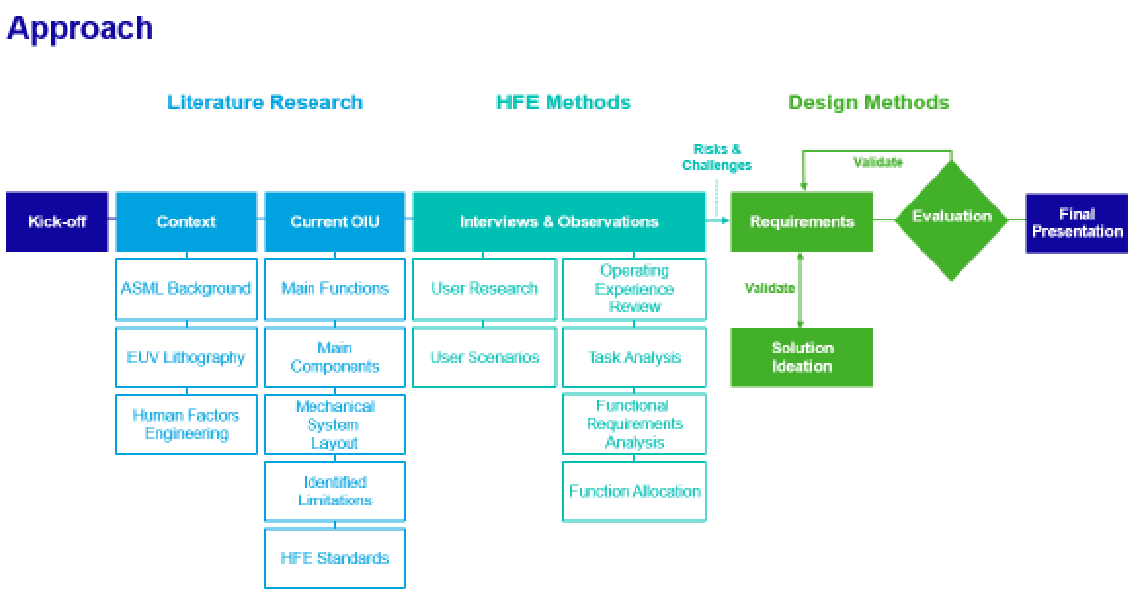


image / figure 2 Approach Visual

Personal Project Brief – IDE Master Graduation Project

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.
(max 200 words)

[redacted]

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence)
As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

Propose new design solutions based on an applied research of the operator interface unit of ASML's extreme ultraviolet lithography machines through the application of human factors engineering and design methods.

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

The project approach includes HFE research and design methods aimed at delivering risks & challenges, an overview of new requirements, and finally, design solutions.

It begins with a literature research phase, covering the context, including ASML's vision and short-term goals, EUV lithography systems, and the application of HFE. This is followed by an analysis of the current OIU, including its main functions, components, mechanical system layout, identified limitations, and relevant international HFE standards. Then, also the users and user scenarios will be researched.
Interviews and observations will be conducted based on the following HFE methodologies: user and user scenario research, task analysis, operating experience review, functional requirements analysis and function allocation.
All conducted research will provide inputs for the new requirements. Then, design methodologies will be applied to ideate and validate solutions in alignment with these requirements. This ideation phase aims to find new design solutions, while letting go of the current design. These outcomes will be evaluated, and finally, presented in the final presentation.

Project planning and key moments

*To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a **kick-off meeting, mid-term evaluation meeting, green light meeting** and **graduation ceremony**. Please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any (for instance because of holidays or parallel course activities).*

Make sure to attach the full plan to this project brief.
The four key moment dates must be filled in below

Kick off meeting	7 Dec 2023
Mid-term evaluation	16 Feb 2024
Green light meeting	5 Apr 2024
Graduation ceremony	

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	
For how many project weeks	
Number of project days per week	

Comments:

Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.
(200 words max)

My goal is to improve my skill of finding design solutions to address complex ergonomic challenges by integrating HFE research into my existing design expertise.
In addition to the learning objectives of the graduation project, my personal aspirations involve diving into the field of HFE. I aim to gain experience in user research and HFE methodologies such as task analysis, operator experience reviews, functional requirements analysis, and function allocation. Furthermore, I want to gain experience in designing for systems in the industrial field.

This project presents a unique opportunity for me to combine my academic background, personal interests, and career aspirations in a meaningful way. I am enthusiastic about contributing to ASML's vision while advancing my professional development goals.